



**DEVELOPMENT OF SUGAR CRAVING ASSESSMENT  
TOOL AND THE APPLICATION OF LOW CALORIC  
SWEETENER IN APPETITE REGULATION AND  
EATING BEHAVIOUR**

**BY**

**WAN FATHIN FARIZA BINTI WAN MAHMOOD**

**A thesis submitted in fulfilment of the requirement for the  
degree of Doctor of Philosophy in Health Sciences  
(Nutrition Sciences)**

**Kulliyyah of Allied Health Sciences  
International Islamic University Malaysia**

**September 2017**

# TABLE OF CONTENTS

Abstract .....	vi
Abstract in Arabic .....	vii
Abstract in Bahasa Malaysia.....	viii
Approval Page.....	ix
Declaration .....	x
Dedication .....	xiv
Acknowledgements .....	xv
List of Tables .....	xvi
List of Figures .....	xviii
Abbreviations .....	xxi
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>1</b>
1.1 Background of The Study .....	1
1.2 Research Objectives .....	3
1.3 Research Questions .....	4
1.4 Theoretical Framework .....	4
1.5 Research Hypotheses .....	5
<b>CHAPTER 2: SUGAR: SWEETNESS AND CRAVING .....</b>	<b>7</b>
2.1 Sugar as Simple Carbohydrate .....	7
2.1.1 Carbohydrate.....	7
2.2 Sugars.....	10
2.2.1 Fructose: Sucrose and High-Fructose Corn Syrup (HFCS).....	11
2.2.2 Definition and Classification of Sugars .....	13
2.2.3 Recommendation of Sugar Intake .....	15
2.2.4 Local and Global Trend of Sugar Intake .....	17
2.3 The Health Burden of Sugar Intake .....	20
2.3.1 Diabetes Mellitus .....	20
2.3.2 Obesity .....	21
2.3.3 Metabolic Syndrome and Cardiovascular Diseases.....	22
2.3.4 Dental Caries .....	24
2.3.5 Other Health Concerns .....	24
2.4 Low Calorie Sweetener as Sugar Substitute .....	25
2.4.1 Aspartame .....	27
2.4.2 Stevia .....	28
2.5 Sweet Taste .....	29
2.6 Sugar Craving .....	31
<b>CHAPTER 3: APPETITE REGULATION AND EATING BEHAVIOUR .....</b>	<b>33</b>
3.1 Fundamental of Appetite Regulation .....	33
3.1.1 Definition of Terms .....	33
3.2 Satiety Cascade .....	35
3.3 Hormonal Regulation of Appetite.....	37
3.3.1 Central and Peripheral Control of Appetite Regulation .....	37

3.3.2 Tonic and Episodic Mechanism of Appetite Control .....	39
3.3.3 Ghrelin .....	40
3.3.4 Insulin .....	41
3.3.5 Leptin .....	42
3.4 Factors Affecting Satiety .....	44
3.4.1 Body Composition .....	44
3.4.2 Meal Texture.....	44
3.4.3 Physical Activity.....	45
3.4.4 Eating Behaviour .....	46
3.5 How Palatable Foods Affect Appetite Response? .....	47
<b>CHAPTER 4: MATERIALS AND METHODS: GENERAL .....</b>	<b>49</b>
4.1 Anthropometric Measurement .....	49
4.2 Measuring sugar craving.....	50
4.2.1 Existing method .....	50
4.2.2 Local Method.....	52
4.3 Measuring Sweetness Perception and Acceptance of Sugar and LCS.....	53
4.3.1 Food Sample Preparation.....	53
4.3.2 Visual Analogue Scale (VAS) – subjective rating of sweetness perception .....	54
4.3.3 Sweetness Acceptance Rating .....	56
4.4 Assessment of eating behaviour.....	56
4.4.1 Dutch Eating Behaviour Questionnaire (DEBQ) .....	56
4.4.2 DEBQ Malay-translated version.....	58
4.5 Preload-to-test meal paradigm .....	58
4.5.1 Preloads.....	59
4.5.2 Test meals .....	61
4.5.3 Food intake and energy compensation .....	62
4.6 Measuring appetite response .....	63
4.6.1 Visual analogue scale (VAS) – hunger, fullness and sugar craving rating .....	63
4.7 Appetite regulating hormones.....	64
4.7.1 Blood Sample Collection.....	64
4.7.2 Serum Preparation .....	65
4.7.3 Analysis of Hormones .....	65
4.7.4 Human Insulin ELISA Kit.....	66
4.7.5 Human Leptin ELISA Kit.....	66
4.7.6 Human Ghrelin ELISA Kit.....	67
4.8 Statistical analysis .....	68
<b>CHAPTER 5: DEVELOPMENT OF SUGAR CRAVING ASSESSMENT TOOL FOR MALAYSIAN (MySCAT) .....</b>	<b>69</b>
5.1 Introduction.....	69
5.1.1 Sugar craving .....	70
5.1.2 Methods assessing food craving .....	70
5.1.3 Objectives .....	71
5.2 Materials and method.....	71
5.2.1 Study design and participants .....	71
5.2.2 Participants .....	71

5.2.3 Procedure .....	72
5.2.4 Development of MySCAT.....	72
5.2.5 Face and content validation .....	73
5.2.6 Validation against reference method. ....	73
5.2.7 Statistical analysis.....	74
5.3 Results.....	74
5.3.1 Subjects.....	74
5.3.2 Sugar Craving .....	74
5.3.3 Sugar Intake .....	75
5.3.4 Internal Consistency of MySCAT .....	77
5.3.5 Linear Regression Model.....	78
5.4 Discussion.....	79
5.4.1 The MySCAT Construct.....	79
5.4.2 Sugar Craving, BMI and Sugar Intake .....	79
5.4.3 Practical Benefits of Screening for Sugar Craving.....	80
5.4.4 Limitation of the Study and Direction for Future Research .....	81
5.5 Conclusion .....	82

**CHAPTER 6: SWEETNESS PERCEPTION OF SUGAR AND LOW CALORIE SWEETENERS. .... 83**

6.1 Introduction.....	83
6.1.1 Sweetness Perception and Acceptance of Sugar and LCS .....	84
6.1.2 Sweet Tooth and Perception of Sweetness .....	84
6.1.3 Study Aim and Objectives .....	85
6.2 Methodology .....	85
6.2.1 Study Design.....	85
6.2.2 Participants .....	85
6.2.3 Procedures.....	86
6.3 Results.....	86
6.3.1 Subject Background.....	86
6.3.2 Sweetness Perception.....	87
6.3.3 Sweetness Acceptance .....	89
6.3.4 Relationships of Sweetness Perception and Acceptance with Sex, Age and Anthropometric Measurements .....	90
6.3.5 Associations between Sweetness Perception and Acceptance of Sugar and LCS .....	93
6.3.6 Eating Behaviour .....	93
6.3.7 Eating Behaviour and Sweetness Perception: The Association. ....	97
6.4 Discussion .....	100
6.4.1 Factors Affecting Sweetness Perception .....	100
6.4.2 Implication of High Sweetness Liking on Health.....	103
6.4.3 Eating Behaviour: How Does It Influence Sweetness Perception? .....	104
6.4.4 The Potential Benefits of Substituting Sugar with LCS in Managing Sweetness Perception.....	106
6.5 Conclusion .....	106

**CHAPTER 7: ASSOCIATIONS BETWEEN SUGAR CRAVING AND SWEETNESS PERCEPTION AND EATING BEHAVIOUR. .... 108**

7.1 Introduction.....	108
-----------------------	-----

7.1.1 How Does Sugar Craving Associate with Liking for Sweetness?.....	108
7.1.2 Sugar Craving and Eating Behaviour .....	108
7.1.3 Study Aim and Research Questions .....	109
7.2 Methodology .....	110
7.2.1 Study design .....	110
7.2.2 Participants .....	110
7.2.3 Procedures.....	110
7.3 Results.....	111
7.3.1 Subjects' Background.....	111
7.3.2 Sweetness Perception.....	112
7.3.3 Sugar craving .....	113
7.3.4 Association between Sweetness Perception and Sugar Craving .....	113
7.3.5 Sugar Craving and Eating Behaviour .....	113
7.4 Discussion .....	116
7.4.1 Sugar Craving and Its Influence on Sweetness Perception in Adults....	116
7.4.2 Sugar Craving and Risks of Overeating Measured by Eating Behaviour Influences.....	117
7.5 Conclusion .....	119

**CHAPTER 8: STEVIA AS SUGAR SUBSTITUTE: ASSOCIATIONS WITH  
FOOD INTAKE, APPETITE REGULATION AND SUGAR CRAVING ..... 121**

8.1 Introduction.....	121
8.1.1 Objectives .....	121
8.2 Methodology .....	122
8.2.1 Study design .....	122
8.2.2 Participants .....	122
8.2.3 Study protocol.....	123
8.2.4 Preloads and Test Meal.....	124
8.2.5 Blood Sample Analysis .....	125
8.2.6 Data Analysis.....	126
8.3 Results.....	126
8.3.1 Background Data .....	126
8.3.2 Energy and Macronutrients Intake.....	127
8.3.3 Sugar Craving .....	131
8.3.4 Eating Behaviour .....	133
8.3.5 Hunger, Fullness and Sugar Craving Rating .....	133
8.3.6 Appetite-Regulating Hormones .....	136
8.3.7 Associations between Food Intake and Appetite-Regulating Hormones .....	142
8.4 Discussion .....	143
8.4.1 Energy Intake and Compensation.....	143
8.4.2 Subjective Appetitive Responses (Hunger and Fullness) and Relationships with Sweeteners .....	145
8.4.3 Effects of LCS and Energy Compensation on Appetite-Regulating Hormones.....	147
8.4.4 Strategy for Weight Reduction and Maintenance: Reduction of Sugar- Sweetened Beverages Consumption.....	150
8.4.5 Limitation of the Study and Direction for Future Research .....	152
8.5 Conclusion .....	153

<b>CHAPTER 9: SUMMARY AND CONCLUSION.....</b>	<b>155</b>
9.1 Summary of relationships between sugars, energy intake and appetite regulation from this study .....	155
9.2 The practicality of screening for sugar craving and eating behaviour traits in clinical setting .....	157
9.3 Recommendation to use Stevia as sweetener in daily diet.....	158
9.4 The Conflicting Evidence of Benefits of LCS towards health.....	158
9.5 Conclusion .....	159
<b>REFERENCES.....</b>	<b>161</b>
Appendix A: Sugar Craving Assessment Tool for Malaysian (Myscat) .....	<b>183</b>
Appendix B: Food Frequency Questionnaire for sugar (FFQ Sugar).....	<b>186</b>
Appendix C: Dutch Eating Behaviour Questionnaire (Malay translated) .....	<b>194</b>
Appendix D: Standard Recipe for Food Samples .....	<b>199</b>
Appendix E: Energy and nutrient content of food samples .....	<b>200</b>
Appendix F: Visual Analogue Scale (VAS) for Sweetness Perception and Sweetness Acceptance Scale .....	<b>201</b>
Appendix G: Results of Sugar Craving Rating in Chapter 4 .....	<b>202</b>
Appendix H: Result for Sugar Craving Rating in Chapter 6 .....	<b>203</b>
Appendix I: Information to Subjects and Consent Form .....	<b>204</b>
Appendix J: Standard Recipe for Preloads .....	<b>208</b>
Appendix K: Energy and macronutrient content of preload and test meal.....	<b>210</b>
Appendix L: Weighed Food Record Form .....	<b>211</b>
Appendix M: Visual Analogue Scale (VAS) for Appetite Response .....	<b>212</b>
Appendix N: Energy Intake and Compensation Index (COMPX) in Test Meals.....	<b>213</b>
Appendix O: Human Insulin ELISA Kit Assay Procedure.....	<b>214</b>
Appendix P: Human Leptin ELISA Kit Assay Procedure.....	<b>215</b>
Appendix Q: Human Ghrelin ELISA Kit Assay Procedure .....	<b>216</b>

## ABSTRACT

Excessive sugar intake has been widely associated with the increased prevalence of obesity and diabetes due to its potential in instigating positive energy balance. Sugar craving, an issue which has yet been explored in our local community, is also postulated to relate to erratic eating behavior, impulsive food intake and binge eating. The initial part of this research aimed to develop and validate a sugar craving assessment tool suitable for Malaysians. Eventually, the Sugar Craving Assessment Tool for Malaysian (MySCAT) was created that has good internal consistency ( $\alpha = 0.866$ ) and the score was significantly correlated with sugar intake measured via FFQ Sugar ( $r = 0.332$ ,  $p < 0.01$ ). As opposed to high energy density and palatability of sugar in foods, the low calorie sweeteners (LCS) has been suggested as alternative to sweeten foods but without markedly excessive calories. Stevia has recently been popular as sugar substitute and it is from plant source, hence deemed more acceptable to be consumed by lay person, relative to artificial sweetener like aspartame. Further, we compared the sweetness perception and acceptance of solid and liquid foods containing either sugar, stevia or aspartame. Healthy adults perceived sugar sweeter than both LCS. The replacement of sugar with LCS was acceptable among the subjects. In the subsequent study using different group of subjects, we investigated the association between sugar craving and sweetness perception as well as eating behavior (restraint, emotional and external traits). Results indicate that female, overweight/obese individuals and restraint eaters possessed higher sweetness perception than their counterparts. The final part of this research aimed to compare the effects of sugar, stevia and aspartame consumption on energy compensation, appetite responses (satiety, fullness and desire to eat sweet) and appetite hormones changes (insulin, leptin and ghrelin). The “preload paradigm” method has been used, whereby 3 types of preloads (sugar, stevia and aspartame) were given prior to test meal served as lunch buffet with *ad-libitum* intake. We found that following LCS preloads, energy intake during test meal was higher (COMPX 45.6% for stevia and 54.1% for aspartame) but total energy intake (preloads + test meal) was significantly higher with LCS consumption. Sugar preload significantly increased leptin the most compared to LCS after 2 hours. There was no significant relationship recorded between sweeteners and their impact on appetitive responses. Conclusively, we had successfully develop a novel method to measure sugar craving among Malaysian and it is useful in the assessment of the risk of excessive sugar intake. In the effort of reducing energy density of food and sugar content, replacement of sugar with stevia, a natural sweetener, is recommended as it proven to reduce total energy intake while maintaining the normal hormonal changes and do not interfere with appetitive responses.

## ABSTRACT IN ARABIC

### مُلخَص البَحْث

أرتبط استهلاك السكر المفرط على نطاق واسع مع زيادة انتشار السمنة ومرض السكري بسبب تحفيز توازن الطاقة الإيجابية. التوق إلى السكر. هي القضية التي لم يتم التحري عنها بعد في مجتمعنا، وإيضاً يفترض أن ترتبط بسلوك الأكل غير المنتظم والتسرع واضطراب نهم الطعام. الجزء الأول من هذا البحث يهدف إلى التطوير والتحقق من ملائمة استخدام أداة استبيان التوق إلى السكر. في نهاية المطاف، تم إنشاء أداة لتقييم التوق إلى السكر (MySCAT) الأداة تحتوي على تناسق داخلي جيد ( $\alpha = 0.866$ ) والنتيجة كانت مرتبطة بشكل واضح مع كمية السكر التي قيست باستخدام أداة استبيان تكرار الطعام (FFQ) للسكر ( $r=0.332, p<0.01$ ). بما أنه ارتفعت السرعات الحرارية للطعام وزيادة استساعة السكر في الأطعمة ولهذا اقترحنا استخدام السكر قليل السرعات الحرارية (سكرين) كبديل لتحلية الأطعمة. ولكن بدون السرعات الحرارية الزائدة بشكل ملحوظ. مؤخراً زادت شعبية استخدام السكر قليل السرعات الحرارية (ستييفيا)، وهو من مصدر نباتي. وبالتالي تُعتبر أكثر قبولاً للاستهلاك من قبل الشخص العادي نسبة إلى المحليات الاصطناعية مثل الأسبارتام. علاوة على ذلك، قارنا توقعات قبول حلوة الأطعمة والسوائل التي تحتوي على السكر أو ستييفيا أو الأسبارتام. الأشخاص الأصحاء البالغين يعتقدون السكر احلى من السكريات قليلة السرعات الحرارية (ستييفيا والأسبارتام). كان استبدال السكر مع السكريات قليلة السرعات الحرارية مقبولاً من قبل المشاركين في البحث. في الدراسة اللاحقة استخدمنا مجموعة مختلفة من المشاركين في البحث. فمنا بالتحقيق في العلاقة بين التوق إلى السكر والفكرة السائدة عن الحلوة وكذلك سلوكيات الأكل (ضبط النفس، الصفات العاطفية والخارجية). لقد أشارت النتائج إلى أن الفكرة السائدة عن الحلوة أعلى عند كل من الإناث، ذوي الوزن الزائد أو البدناء والمقيدين بالاكل نسبة إلى نظائرهم و الجزء الأخير من هذا البحث يهدف إلى المقارنة بين تأثير استهلاك السكر أو ستييفيا والأسبارتام على استهلاك الطاقة وربطها بالشهية من خلال (الجوع، الشبع، الرغبة في تناول السكريات) وتغيير هرمونات الشهية (الانسولين، هرمون الليبتين وجريلين). وقد تم استخدام طريقة التحميل الثلاثي، بحيث اعطينا ثلاثة انواع من المواد التالية (السكر، ستييفيا واسبارتام) للاختبار التي أعطيت قبل وجبة الغداء المفتوحة. لقد وجدنا احتمالية السكريات قليلة السرعات الحرارية واستهلاك الطاقة خلال الوجبة كان عالياً بنسبة (COMPX 45.6%) لستييفيا وأما نسبة الاسبارتام (54.1%) ولكن اجمالي استهلاك الطاقة (التحميل + اختبار الوجبة) كان اعلى بشكل ملحوظ مع استهلاك السكر قليل السرعات الحرارية. التحميل المسبق للسكر زاد من الليبتين بنسبة اكبر مقارنة بالسكر قليل السرعات الحرارية. لم تكن هناك علاقة مسجلة ذات دلالة احصائية بين السكريات قليلة السرعات الحرارية وتأثيرها على استجابة الشهية. لقد نجحنا حصرياً باستحداث طريقة جديدة لقياس التوق إلى السكر بين المالبزيين، وهي طريقة مفيدة لتقييم خطورة تناول السكر الزائد. في محاولة الحد أو التقليل من المواد الغذائية ذات السرعات الحرارية العالية والسكر، نحن نوصي باستبدال السكر مع ستييفيا والمحليات الطبيعية، وذلك لأن هذه المواد وجد ان لها قدرة على الحد أو التقليل من الطاقة الكلية المتناولة من الطعام مع الحفاظ على التغييرات الطبيعية للهرمونات. واثبت أيضاً انها لا تتدخل مع استجابة تغييرات الشهية.



## ABSTRACT IN BAHASA MALAYSIA

Pengambilan gula secara berlebihan adalah berkait dengan penularan prevalens obesiti dan diabetes di seluruh dunia, di mana ia boleh menyebabkan lebih kalori. 'Mengidam makanan manis' merupakan isu yang kurang diselidik dalam komuniti tempatan tetapi mempunyai kesan terhadap tingkahlaku pemakanan yang tidak sihat. Peringkat awal penyelidikan ini bertujuan untuk mencipta dan mengesahkan satu kaedah soal selidik untuk menilai tahap 'mengidam makanan manis' di kalangan rakyat Malaysia. Sehubungan itu, boring soal selidik '*Sugar Craving Assessment Tool for Malaysian (MySCAT)*' telah dibentuk dan disahkan konsisten secara statistic ( $\alpha = 0.866$ ) dan skor MySCAT didapati mempunyai kolerasi yang significant dengan jumlah pengambilan gula harian di kalangan subjek yang dinilai menggunakan soal selidik '*FFQ Sugar*' ( $r = 0.332, p < 0.01$ ). Penggunaan pemanis berkalori rendah ('*low calorie sweeteners*', LCS) menjadi satu alternatif untuk mengurangkan penggunaan gula yang berkalori tinggi. Stevia terkenal sebagai salah satu LCS yang lebih dipercayai oleh para pengguna kerana berasal dari sumber tumbuhan jika dibandingkan dengan pemanis tiruan seperti aspartame. Seterusnya, kajian dibuat untuk mengetahui hubungan antara penerimaan tahap kemanisan makanan dan minuman yang menggunakan gula, stevia aspartame. Subjek dewasa mempunyai skor penerimaan tahap kemanisan yang lebih tinggi dalam sampel gula berbanding LCS. Penggunaan LCS untuk menggantikan gula dalam sampel makanan dan minuman adalah boleh diterima di kalangan subjek. Seterusnya, subjek wanita, golongan berlebihan berat badan/ obes dan '*restraint eaters*' adalah lebih cenderung untuk mempunyai penerimaan tahap kemanisan yang lebih tinggi. Bahagian akhir kajian ini bertujuan untuk menyelidik dan membandingkan kesan pengambilan gula, stevia dan aspartame terhadap kompensasi pengambilan makanan, selera makan (rasa lapar, kenyang dan keinginan terhadap makanan manis) dan juga kesan kepada hormon yang mengawal selera (insulin, leptin dan ghrelin). Kaedah '*preload paradigm*' telah digunakan di mana 3 jenis '*preload*' yang berbeza kandungan pemanis (sama ada gula, stevia atau aspartame) telah diberikan kepada subjek sebelum hidangan kajian dihidangkan secara bufet '*ad libitum*'. Data menunjukkan pengambilan makanan selepas '*LCS preload*' adalah lebih tinggi kandungan kalori berbanding '*preload*' gula (COMPX 45.6% untuk stevia dan 54.1% aspartame). Walau bagaimanapun, jumlah pengambilan kalori adalah lebih tinggi dan signifikan bagi hidangan yang menggunakan gula berbanding kedua-dua LCS. Penggunaan gula dalam preload juga menyebabkan kenaikan paras ghrelin yang signifikan selepas 2 jam pengambilan. Namun begitu, tiada perbezaan yang ketara dari segi rasa lapar, kenyang dan keinginan terhadap makanan manis jika gula dibandingkan dengan LCS. Secara konklusi, penyelidikan ini telah berjaya menghasilkan satu kaedah soal selidik yang baru untuk menilai tahap 'mengidam makanan manis' di kalangan rakyat Malaysia; di mana ia juga berpotensi untuk mengenalpasti risiko pengambilan gula yang berlebihan. Bagi mengurangkan kepadatan kalori dalam diet, penggunaan stevia untuk menggantikan gula adalah disarankan kerana ia boleh mengurangkan jumlah pengambilan kalori di samping tidak membawa perubahan yang tidak baik terhadap kawalan hormon dan selera makan.

## **APPROVAL PAGE**

The thesis of Wan Fathin Fariza Wan Mahmood has been approved by the following:

---

Assoc. Prof. Dr. Nik Mazlan Mamat  
Supervisor

---

Dr. Wan Azdie Mohd Abu Bakar  
Co-Supervisor

---

Assoc. Prof. Dr. M. Muzaffar Ali Khan Khattak  
Internal Examiner

---

Prof. Sakinah Harith  
External Examiner

---

Assoc. Prof. Dr. Hamid Jan Jan Mohamed  
External Examiner

---

Prof. Dr. Jamal Ahmed Bashier Badi  
Chairperson

## DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Wan Fathin Fariza binti Wan Mahmood

Signature .....

Date .....

**INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA**

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF  
FAIR USE OF UNPUBLISHED RESEARCH**

**THE EFFECTS OF STEVIA AS SUGAR SUBSTITUTE ON  
APPETITE REGULATION**

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

Copyright © 2016 Wan Fathin Fariza and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Wan Fathin Fariza

.....  
Signature

.....  
Date

**INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA**

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF  
FAIR USE OF UNPUBLISHED RESEARCH**

**THE EFFECTS OF STEVIA AS SUGAR SUBSTITUTE ON  
APPETITE REGULATION**

I declare that the copyright holder of this dissertation is International Islamic University Malaysia.

Copyright © 2016 International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Wan Fathin Fariza

.....  
Signature

.....  
Date

**INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA**

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF  
FAIR USE OF UNPUBLISHED RESEARCH**

**THE EFFECTS OF STEVIA AS SUGAR SUBSTITUTE ON  
APPETITE REGULATION**

I declare that the copyright holders of this dissertation is Wan Fathin Fariza binti  
Wan Mahmood

Copyright © 2016 Wan Fathin Fariza. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system,  
or transmitted, in any form or by any means, electronic, mechanical, photocopying,  
recording or otherwise without prior written permission of the copyright holder  
except as provided below

4. Any material contained in or derived from this unpublished research  
may be used by others in their writing with due acknowledgement.
5. IIUM or its library will have the right to make and transmit copies (print  
or electronic) for institutional and academic purposes.
6. The IIUM library will have the right to make, store in a retrieved system  
and supply copies of this unpublished research if requested by other  
universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM  
Intellectual Property Right and Commercialization policy.

Affirmed by Wan Fathin Fariza

.....  
Signature

.....  
Date

## DEDICATION

*To NH and both HNHs, with all my heart.*

*To all my sifus and gurus in academia, and in life.*

## ACKNOWLEDGEMENTS

With the materialization of this thesis, I would like to sincerely convey my gratitude and sincerely thank these people:

Assoc. Prof. Dr. Nik Mazlan Mamat, for being a very understanding and supporting supervisor throughout the years of my PhD journey. Your wisdom keeps me motivated.

My small family; my husband and daughter, for cheering me up during hard times.

My parents and siblings, for being with them keep me grounded and sane.

All my fellow colleagues and friends in KAHS; for their constant support and encouragement as well as helping hands during data collection period.

The university (IIUM) and the Ministry of Education Malaysia for the financial support through research grants and scholarship.

Also all volunteers who took part in this research and students who assist in data collection; without whom this study will not succeed.

Thank you from the bottom of my heart.



## LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
2.1	Carbohydrate categories based on the degree of polymerization	9
2.2	The timeline of high-fructose corn syrup	12
2.3	Categorization of sugars based on specific nomenclatures for the purpose of food labelling	14
2.4	Low- and high-calorie beverages based on sugar content	15
2.5	Daily added sugar recommendation for American based on sex, age and energy requirement	16
2.6	Low-calorie sweeteners and their relative sweetness	26
3.1	Central and peripheral regulation of appetite	38
4.1	Body fat ranges for standard adults	50
4.2	Content of sugar and LCS in solid and liquid food samples	54
4.3	Preloads provided in appetite study to measure the effects of sweeteners on subsequent food intake, appetitive responses and gut hormones	60
4.4	Energy and macronutrient content of preloads	60
4.5	List of menu served as test meal <i>ad-libitum</i> during lunch	62
5.1	Correlation between age, BMI and sugar intake with MySCAT score	74
5.2	Internal consistency of MySCAT construct indicated by Cronbach's alpha values	77
6.1	Subjects' age, BMI and body fat comparison between sex, BMI and fatness categories	87
6.2	Mean and SD for sweetness perception VAS (mm) according to sweetness level together with F-ratios and p values	89
6.3	Sweetness perception responses among subjects for food and beverage samples using sugar, stevia and aspartame	90

6.4	Correlation between sweetness perception of each sample with BMI, body fat and age among subjects	91
6.5	Correlation between sweetness perception rating and sweetness acceptance response among subjects	94
6.6	Association between eating behaviour and sex, BMI and body fat	96
7.1	Subjects' background data according to sex, BMI, fatness and sugar craving categories	111
7.2	Comparison of the eating behaviour types among subjects according to BMI and sugar craving categories	115
7.3	Odds ratio of eating behaviour and sugar craving	116
8.1	Summary of study protocol for each test day	124
8.2	Subjects' background data	127
8.3	Test meal, total intake and compensation index (COMPX) according to different preloads	127
8.4	Pearson's correlation ( $r$ ) between food intake and appetite-regulating hormones.	142

## LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1.1	Theoretical framework of the study of implications of LCS as sugar substitute in appetite regulation and eating behaviour.	5
2.1	Classification of carbohydrates and its postprandial metabolism	8
2.2	Molecular structures of monosaccharides (glucose, galactose and fructose) and disaccharides (lactose and sucrose)	9
2.3	The <i>Stevia rebaudiana</i> plant	28
3.1	Satiety cascade	37
3.2	Description of tonic and episodic signalling mechanism processes in brain's regulation of appetite	40
4.1	Subjective rating of sweetness perception by using 100 mm Visual Analogue Scale	55
4.2	Samples for food tasting and evaluation of sweetness perception and acceptance	55
4.3	Macronutrient distribution of preloads	61
4.4	Enzyme-linked immunosorbent assay (ELISA) sandwich technique	66
5.1	Overall mean score of sugar craving based on food items among subjects	76
5.2	Percentage of contribution of food items to daily sugar intake (from FFQ Sugar)	77
5.3	Linear regression model of sugar craving score (MySCAT) vs. sugar intake (FFQ Sugar)	78
6.1	Sweetness perception rating for liquid and solid food sample using three types of sweeteners among overall study subjects	88
6.2	Relationships between sweetness perception and BMI classification, sex and body fat categories	92
6.3	Eating behaviour traits among subjects based on the Butch Eating Behaviour Questionnaire	95

6.4	Sweetness perception rating for all samples comparing between external and non-external eaters	98
6.5	Sweetness perception rating for all samples comparing between emotional and non-emotional eaters	99
6.6	Sweetness perception rating for all samples comparing between restrained and non-restrained eaters	100
7.1	Sweetness perception rating of both liquid and solid food sample	112
7.2	Number of subjects affected by the three types of eating behaviour obtained via DEBQ (Malay version)	114
7.3	Mean sugar craving score comparing between different types of eating behaviour	115
8.1	Calorie content of test meal (lunch) and total intake following sugar, stevia and aspartame-containing preloads	128
8.2	Macronutrient distributions in weight and in proportion to energy intake in test meals following sugar, stevia and aspartame preloads	129
8.3	Energy content in lunch and total meal for different preloads comparing male and female subjects	130
8.4	Energy content in lunch and total meal for different preloads comparing between lean and overweight/ obese groups	131
8.5	Proportion of sugar cravers and non-cravers among subjects according to sex and BMI categories.	132
8.6	Total energy intake (preload and test meal) according to sugar craving categories	132
8.7	Proportion of types of eating behaviour among subjects according to sex, BMI and sugar craving categories	133
8.8	Time effects on subjective rating of hunger, satiety and sugar craving comparing the effects of sugar, stevia and aspartame	135
8.9	Insulin action following test meals preceded by sugar, stevia and aspartame preloads	137
8.10	Total Area Under Curve (AUC) for insulin action in test meals	138
8.11	Leptin concentration in test meal following sugar, stevia and aspartame preloads	139
8.12	Total AUC for leptin concentration for different sweeteners; comparison between male and female	140

8.13	Ghrelin level changes following test meals	141
8.14	Ghrelin concentration and total AUC after test meals following preloads with sugar, stevia and aspartame	142
9.1	Summary of relationships between sugar craving, sweetness perception, eating behaviour and appetite regulation from this study	156

## ABBREVIATIONS

ADP	Adenosine diphosphate
ANOVA	Analysis of variance
As	Aspartame
ATP	Adenosine triphosphohate
AUC	Area Under Curve
BMI	Body Mass Index
C	Cookie
CHO	Carbohydrate
COMPX	Compensation index
DEBQ	Dutch Eating Behaviour Questionnaire
ELISA	Enzyme-linked immunosorbent assay
FCI	Food Craving Inventory
FCQ	Food Craving Questionnaire
GLUT	Glucose transporter
K	Potassium
LCS	Low calorie sweeteners
min	Minute
MySCAT	Malaysian Sugar Craving Assessment Tool
Na	Sodium
NCCFN	National Coordinating Committee on Food and Nutrition
Reb.	Rebaudioside
SSB	Sugar-sweetened beverages
St	Stevia
Su	Sugar
T	Tea
T2DM	Type 2 diabetes mellitus
USFDA	United State Food and Drug Administration
VAS	Visual analogue scale
WHO	World Health Organization

# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND OF THE STUDY

For the past few decades, there are vast interests and research works been done in studying the impacts of sugars and their connections to health consequences. Many have postulated the effects of simple sugars (mono- and disaccharides) in the etiology of nutrition-related diseases namely obesity and diabetes. The mechanism lies in the burden of high calories carried by sugars while having no other nutritive values, and at the same time provide the palatability that is irresistible to human. Hence, intake of sugar, particularly in excess compared to daily recommended intake, may disturb energy equilibrium when calorie intake is more than out (through physical activity). In Malaysia, intake of sugar has been recorded in a few studies. In 2008, the Malaysian Adult Nutrition Survey (MANS) reported sugar intake among Malaysians was 21 g/day (4.2% of total calorie intake of 2000 kcal/day) (Norimah et al., 2008), while data collected from Nik Shanita (2012) showed mean difference of 5.2 g/day of sugar intake comparing two methods: Food Frequency Questionnaire for Sugar (FFQ Sugar, 49.4 g/day, 9.8% of total calorie intake of 2000 kcal/day) and 24-hour diet recall (44.2 g/day, 8.8%).

Whilst it is still uncommon to find the study on sugar craving in Malaysia, some studies abroad have shown the associations between food craving and food intake, and when further analysis was done, craving food items which were high in sugar and fat (palatable foods) were predisposed to higher intake among adults. This is an alarming finding as craving involve particularly series of cognitive and behaviour connections

and some individuals who are resistant to this temptation may yield to the desire of consuming these calorie-dense food groups. And it has been a global knowledge that excessive intake of sugar leads to the risk of being overweight and obese, and subsequently Type 2 diabetes, hypertension and cardiovascular diseases, it become and priority for the researchers nowadays, particularly in Malaysia, to embark on this behavioural issues of sugar craving; with hope that we afterwards may relate them to the prevention of excessive sugar intake.

The efforts of reducing sugar intake include literally reducing the intake of sugar-containing foods and beverages as well as to substitute sugar with other sweetening agent, which also known as low calorie sweeteners (LCS). The LCS contribute to sweet taste but contain negligible calorie, for example stevia, aspartame, acesulfame K, sorbitol and sucralose. In Malaysia, the national guideline of dietary intake for the control of diabetes also include the usage of LCS within the recommended level for the patients. This emphasizes on the role of LCS in maintaining good glucose control especially for diabetic patients, as well as in prevention of hyperglycemia and excessive calorie intake among normal individuals.

Due to uncoupling of sweet and calorie content in LCS, there rise a theory that LCS consumption may not be in accord with the normal appetite regulation pathways compared to caloric sweetener (sugar). As deliberated by Blundell and his colleagues for almost 30 years now, satiety cascade involves sensory, cognitive, post-ingestive and post-absorptive phases. In this study, the researcher is manipulating the study design to investigate the roles of stevia in all four phases with regards to short term food intake.