UNIVERSITI PUTRA MALAYSIA

COLOR AND FLAVOR DEVELOPMENT OF ROASTED JACKFRUIT
(Artocarpus hetrophyllus L.) SEEDS

SHAKIRAH OMOTOKE AZEEZ

FSTM 2015 20
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By

SHAKIRAH OMOTOKE AZEEZ

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfillment of the Requirement for the Degree of Master of Science

December 2015
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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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\((Artocarpus heterophyllus\ L.\) SEEDS

By

SHAKIRAH OMOTOKE AZEEZ

December 2015

Chairman : Associate Professor Lasekan Olusegun Olaniyi, PhD
Faculty : Food Science and Technology

Jackfruit \((Artocarpus heterophyllus\) seed is known to be an underutilized seed. It has many potentials and applications in food, cosmetics, pharmaceuticals and bio-nanotechnology industries. Most studies on jackfruit seed (JFS) have been focused on the chemical, functional, and nutritive values of both raw and processed (cooked) jackfruit seed flour. The increasing demand for under-utilized seeds as alternative cheap source of nutritious food snack is making JFS gain more attention in the recent years. The aim of this research therefore was to investigate the flavor and color development in JFS during roasting, through; chemical analysis, sugar profiling and amino acid profiling of both raw and roasted JFS; color development analysis using response surface methodology (RSM); effect of roasting condition on the structural changes of the starch granules using scanning electron microscopy (SEM) and Fourier Transform Infrared spectroscopy (FTIR); and lastly flavor development analysis using gas chromatography-olfactometry (GC-O) and gas chromatography-mass spectrometry (GC-MS) coupled with aroma extract dilution analysis (AEDA) for the identification of key odorants. For chemical analysis of the three cultivars of jackfruit seed analyzed, results showed that the starchy seeds were very high in moisture (53.16-62.41%) and starch (15.95-32.04%), moderately high in protein (7.62-8.46%), dietary fiber (2.80-7.19%), ash content (3.19-3.70%), but low in fat (1.09-1.48%). Analyses of the color and flavor precursors (amino acids, sugar and fatty acids) of JFS cultivars showed that cultivar J31 had the highest contents of amino acids such as methionine, leucine, alanine and threonine. Fatty acids linoleic and linolenic were also the highest. Although, the sugar contents were low, fructose and sucrose were significantly higher in cultivar J31. The effect of roasting conditions on the color development \((L^*, a^*, b^*\) and browning intensity) and fracturability (measured using Universal Texture Analyzer) using a three factor central composite rotatable design (CCRD) gave R square of 0.81, 0.96, 0.93, 0.92, and 0.74, respectively. The optimum roasting conditions were found to be at temperature of 153.4 °C, time 34.4 minutes, pH 6.34 and a composite desirability of 0.95. The micro-structural studies of both raw and roasted JFS at different roasting levels showed a B-type category of starch granules with semi-oval to round/bell shapes (5-9µm in diameter), which became flattened as the roasting temperature and time increased. The IR spectra was in the 4000-1000 cm\(^{-1}\) region and it was described by five main modes; O-H, C-H stretching, C=O, C-H bending and C-O. The major functional group with the highest intensity in both raw and roasted JFS was
the C-O bond stretch of esters. A total of 95 compounds were identified using the gas chromatography-olfactometry (GC-O) on a diphenyl dimethyl polysiloxane (DB-5) and free fatty acid phase (FFAP) columns. The major classes of aroma compounds include aldehyde, esters, alcohols, alkanes, monoterpenes and ketones. Application of aroma extract dilution analysis (AEDA) to the flavor extract from both raw and roasted JFS revealed 16 and 26 odor-active compounds respectively in the flavor dilution (FD) range of 16-32. Aromas perceived on the GC-O were dominated by Flowery, green, pungent-sulfurous, and sweet-caramel and woody aromas, which were more persistent in the roasted seed. Roasted jackfruit seeds can be used as an alternative healthy snack product due to its good source of dietary nutrients. Also, the most needed literature on the optimum roasting conditions for color and flavor development can be exploited by researchers and food industries at large.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PEMBANGUNAN WARNA DAN PERISA BIJI NANGKA (Artocarpus hetrophyllus L.) SEMASA PEMANGGANGAN

Oleh

SHAKIRAH OMOTOKE AZEEZ

Disember 2015

Pengerusi : Profesor Madya Lasekan Olusegun, PhD
Fakulti : Sains dan Teknologi Makanan

Biji nangka (Artocarpus hetrophyllus) ialah tanaman yang kurang digunakan dan diperhatikan. Ia mempunyai banyak potensi dan aplikasi dalam bidang makanan, kosmetik, farmaseutikal dan industri nano bioteknologi. Kebanyakan kajian yang mengenai biji nangka (JFS) telah memberi tumpuan kepada fiziko - kimia, fungsi, dan nilai-nilai pemakanan untuk kedua-dua biji nangka sebelum dan selepas proses (telah masak) dalam bentuk tepung. Permintaan daripada konsumer yang semakin meningkat membolehkan biji nangka yang kurang digunakan ini dijadikan sebagai sumber alternatif makanan snek yang murah dan berkhasiat, oleh itu, JFS telah mendapat lebih tumpuan pada tahun-tahun kebelakangan ini. Tujuan kajian ini adalah untuk mengkaji pembangunan rasa dan warna dalam JFS semasa pemanggangan melalui analisis kimia, profil gula dan profil asid amino bagi kedua-dua JFS sempel sebelum dan selepas pemanggangan; analisis pembangunan warna menggunakan kaedah permukaan respons (RSM); kesan pemanggangan kepada perubahan struktur granul kanji dengan menggunakan mikroskop imbasan elektron (SEM) dan Fourier Transform spektroskopii inframerah (FTIR); dan akhir sekali analisis pembangunan rasa menggunakan gas kromatografi - olfaktometri (GC-O) dan gas kromatografi - spektrometri jisim (GC-MS) bersama dengan analisis pencairan ekstrak aroma (AEDA) untuk mengenal pasti komponen yang utama. Bagi analisis kimia daripada tiga jenis kultivar biji nangka, keputusan menunjukkan bahawa biji nangka menganjurkan kelembapan (53.16 - 62.41%) dan kandungan kanji (15.95-32.04%), yang amat tinggi (7.62 - 8.46%), serat (2.80 - 7.19%), kandungan abu (3.19 - 3.70%), tetapi rendah dalam kandungan lemak (1.09 - 1.48%).

Analisis warna dan rasa prekursor (asid amino, gula dan asid lemak) untuk kultivar JFS menunjukkan bahawa kultivar J31 mempunyai kandungan tertinggi dalam asid amino seperti methionin, leusin, alanin dan threonin. Asid lemak linoleik dan linolenik juga didapati paling tinggi. Walaupun kandungan gula adalah rendah, tetapi fruktosa dan sukrosa adalah tinggi dalam kultivar J31. Kesalahan pemanggangan untuk pembangunan warna (L *, a * b * dan intensiti pemerangan) dan kerangupan dengan menggunakan tiga faktor utama reka bentuk putaran komposit (CCRD) telah menunjukkan R kuasa dua adalah bernilai 0.81, 0.96, 0.93, 0.92 dan 0.74 masing-masing. Keadaan pemanggangan yang paling optimum didapati adalah pada suhu 153.4°C untuk 34.4 minit dengan pH 6.34 dan komposit penerimaan bernilai 0.95.

Kajian mikro-struktur bagi kedua-dua JFS sebelum dan selepas pemanggangan di bawah tahap pemanggangan yang berbeza menunjukkan jenis kategori B granul
berkanji adalah berbentuk separa bujur hingga bulat/loceng (5-9 μm diameter), yang menjadi leper semasa suhu dan masa pemanggangan meningkat. Spektrum IR adalah di antara bahagian 4000-1000 cm⁻¹ dan ia telah dihuraikan dengan lima model utama iaitu O-H, C-H regangan, C = C, C-H lentur dan C-O. Kumpulan fungsian yang utama dengan intensiti tertinggi dalam kedua-dua sampel JFS sebelum dan selepas pemanggangan adalah ikatan C-O ester. Sebanyak 95 kompaun telah dikenal pastikan menggunakan gas kromatografi-olfaktometri (GC-O) DB-5 dan FFAP. Kelas-kelas utama bagi kompaun aroma termasuk aldehid, ester, alkohol, alkana, monoterpenes dan keton. Penggunaan analisis pencairan ekstrak aroma (AEDA) untuk ekstrak perisa daripada kedua-dua JFS sebelum dan selepas pemanggangan telah mendedahkan 16 dan 26 sebatian bau-aktif masing-masing dalam nilai pencairan rasa (FD) di antara 16-32. Aroma yang berjaya dikesan dengan GC-O diutamakan oleh bunga, hijau, pedas-sulforous, dan gula-karamel dan aroma berkayu, yang berterusan dalam biji nangka selepas proses pemanggangan. Biji nangka telah dipanggang boleh digunakan sebagai sumber alternatif bagi menghasilkan produk makanan ringan yang sihat kerana ia ialah sumber nutrien makanan yang baik. Oleh itu, kajian ini adalah penting untuk mengkaji keadaan optimum proses pemanggangan bagi pembangunan warna dan rasa boleh dieksploitasi oleh para penyelidik dan pihak industri makanan.
ACKNOWLEDGEMENTS

I give all glory, honor and adoration to Almighty ALLAH S.W.T and Prophet Mohammed S.W.A for the successful completion of this program. I will forever be thankful for the love and guidance.

First and foremost, I would like to express my deepest and sincere appreciation to my supervisor, Assoc. Prof. Dr. Lasekan Olusegun, for your fatherly advice and mentoring throughout this project. Thank you for instilling in me a good professional academic trait. I will also like to thank my co-supervisors, Prof Jinap Selamat and Dr. Rabiha Sulaiman, for useful suggestions and invaluable advice in accomplishing this project.

Secondly, I would like to use this medium to appreciate my ever loving husband, Rasheed Durojaiye Azeez, for your sacrifice and support both financially and morally in allowing me pursue my dream. I will forever be grateful to you my love and bestie. To my daughter, Amal Niniola Azeez (my side kick), for your love and company in Malaysia. My sincere appreciation also goes to my wonderful parents, Mr. and Mrs. M.O. Salami for bringing me into this world and giving me a loving background. I acknowledge my siblings for your love and support throughout this program. The tie that binds will never cut. And to my family both nuclear and extended, I appreciate your love.

Lastly, I would like to appreciate my mentor, Dr Chinma for your constant assistance and advice. To the lecturers of the faculty and the staffs of biochemistry laboratory, for your kind assistance during my laboratory work. To Mrs. Fausat Kolawole (Granma), for your motherly advice and friendship. To my Flavor Gang, you guys have made my stay in the faculty a memorable one, especially Somayeh, Siew and Teo (Ogami and Otami). I appreciate you all.
I certify that a Thesis Examination Committee has met on 4 December 2015 to conduct the final examination of Shakirah Omotoke Azeez on her thesis entitled "Color and Flavor Development of Roasted Jackfruit (Artocarpus heterophyllus L.) Seeds" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

**Azizah binti Abdul Hamid, PhD**
Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Chairman)

**Sharifah Kharidah binti Syed Muhammad, PhD**
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Internal Examiner)

**Nym Kar Lin, PhD**
Assistant Professor
UCSI University Kuala Lumpur
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 January 2016
This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science.

The members of the Supervisory Committee were as follows:

**Lasekan Olusegun Olaniyi, PhD**  
Associate Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Chairman)

**Selamat Jinap, PhD**  
Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Member)

**Rabiha Suliaman, PhD**  
Senior Lecturer  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BIN KIM HUAT, PhD**  
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Signature: ________________________________
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Signature: ________________________________
Name of Member of Supervisory Committee: Selamat Jinap, PhD

Signature: ________________________________
Name of Member of Supervisory Committee: Rabiha Suliaman, PhD
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
</tr>
<tr>
<td>ABSTRAK</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
</tr>
<tr>
<td>APPROVAL</td>
</tr>
<tr>
<td>DECLARATION</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
</tr>
</tbody>
</table>

## CHAPTER

1 **INTRODUCTION**

2 **LITERATURE REVIEW**

2.1 Importance of fruits, origin and history  
2.2 Importance of seeds  
2.3 Jackfruit  
2.4 Jackfruit seed and its components  
2.4.1 Phytonutrients in jackfruit seed  
2.4.2 Functional properties of jackfruit seed  
2.4.3 Health- benefits and value-added products of jackfruit seeds  
2.5 Roasting process  
2.5.1 Concept/principle of roasting  
2.6 Effect of roasting on chemical components of nuts/seeds  
2.7 Flavor  
2.8 Color  
2.9 Effect of roasting on flavor and color development of seeds  
2.10 Factors influencing Maillard reaction  
2.10.1 Temperature and heating time  
2.10.2 pH  
2.10.3 Use of buffer/salt  
2.10.4 Reactant type  
2.10.5 Water activity  
2.11 Measurement of flavor  
2.11.1 Gas chromatography-olfactometry (GC-O)  
2.11.2 Gas chromatography-mass spectrometry (GC-MS)

3 **DETERMINATION OF THE CHEMICAL COMPONENTS, THE COLOR AND FLAVOR PRECURSORS OF THREE CULTIVARS OF JACKFRUIT SEEDS (JFS)**

3.1 Introduction  
3.2 Materials and reagents  
3.2.1 Materials  
3.2.2 Reagents and apparatus  
3.3 Methodology  
3.3.1 Preparation of seeds
3.3.2 Proximate analysis (carbohydrate by difference, protein, moisture, ash and dietary fiber) 22
3.3.3 Sugar determination 23
3.3.3.1 Analytical procedure 23
3.3.3.2 HPLC equipments and conditions 23
3.3.4 Amino acid profile determination 24
3.3.4.1 Analytical procedure 24
3.3.4.2 HPLC equipments and conditions 24
3.3.5 Fatty acid analysis 24
3.3.6 Anti-nutritional content determination 25
3.3.6.1 Determination of phytic acid 25
3.3.6.2 Determination of tannin 25
3.3.6.3 Determination of trypsin inhibitor 25
3.3.7 Statistical analysis 25
3.4 Results and discussion 26
3.4.1 Proximate analysis of jackfruit seeds 26
3.4.2 Flavor and color precursors of jackfruit seeds 27
3.4.2.1 Amino acid composition of jackfruit seeds 27
3.4.2.2 Sugar composition of jackfruit seeds 28
3.4.2.3 Fatty acid composition of jackfruit seeds 29
3.4.3 Anti-nutritional factors of jackfruit seeds 29
3.4.4 Conclusion 30

4 DETERMINATION OF THE EFFECT OF ROASTING CONDITIONS ON COLOUR DEVELOPMENT USING RESPONSE SURFACE METHODOLOGY AND STRUCTURAL CHANGES IN JACKFRUIT (Artocarpus heterophyllus) SEEDS 31

4.1 Introduction 31
4.2 Materials and methods 32
4.2.1 Materials 32
4.3 Methodology 32
4.3.1 Soaking 32
4.3.2 Experimental design and data analysis 32
4.3.3 Statistical analysis 32
4.3.4 Optimization procedure and model verification 33
4.3.5 Color measurement of roasted jackfruit seed 33
4.3.6 Textural studies of roasted jackfruit seed 33
4.3.7 Microstructure analysis of JFS starches using scanning electron microscopic analysis (SEM) 34
4.3.8 Functional group determination using Fourier transform infrared (FTIR) analysis 34
4.4 Results and discussion 34
4.4.1 Model fitting and optimization of roasting conditions 34
4.4.2 Effect of roasting process variables on color (L*, a*, b*) attributes of JFS 41
4.4.3 Effect of roasting process variables on browning index (BI) of JFS 43
4.4.4 Effect of roasting process variables on fracturability of JFS 44
4.4.5 Optimization and model verification of models 44
4.4.6 Mid-infrared spectra of raw and roasted JFS 44
4.4.7 Microstructure analysis of raw and roasted JFS 50
4.5 Conclusion

5 INVESTIGATION OF THE CHANGES IN FLAVOR PRECURSORS AND THEIR EFFECT ON CHARACTERISTIC FLAVOR OF ROASTED JACKFRUIT SEEDS, AND IDENTIFICATION OF THE FLAVOR COMPOUNDS

5.1 Introduction

5.2 Materials and methodology
  5.2.1 Sample preparation
  5.2.2 Chemicals standards and reagents
  5.2.3 Methodology
    5.2.3.1 Chemical analysis of roasted optimized JFS
    5.2.3.2 Statistical analysis
    5.2.3.3 Extraction of flavour volatiles
    5.2.3.4 Gas chromatography-mass spectrometry
    5.2.3.5 Gas chromatography-olfactometry
    5.2.3.6 Identification and quantification of compounds
    5.2.3.7 Aroma extracts dilution analysis (AEDA)
    5.2.3.8 Aroma profile analysis

5.3 Results and discussion
  5.3.1 Proximate Analysis
  5.3.2 Amino Acid Composition
  5.3.3 Fatty acid composition
  5.3.4 Anti-nutritional factors
  5.3.5 Volatile flavors in jackfruit seed

5.4 Conclusion

6 GENERAL CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

REFERENCES
APPENDICES
BIODATA OF STUDENT
LIST OF PUBLICATIONS
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Taxonomy of jackfruit</td>
</tr>
<tr>
<td>2.2</td>
<td>Common names of jackfruit in different countries</td>
</tr>
<tr>
<td>2.3</td>
<td>Proximate composition and nutritive value of jackfruit</td>
</tr>
<tr>
<td>2.4</td>
<td>Dietary and medicinal uses of jackfruit plant parts</td>
</tr>
<tr>
<td>2.5</td>
<td>Summary of pharmacological findings of jackfruit seed</td>
</tr>
<tr>
<td>3.1</td>
<td>Proximate, starch, sugar, and pH of jackfruit seed cultivars</td>
</tr>
<tr>
<td>3.2</td>
<td>Amino acid composition (mg/100 g) of jackfruit seed cultivars</td>
</tr>
<tr>
<td>3.3</td>
<td>Fatty acid composition and anti-nutritional factors of Jackfruit seed cultivars</td>
</tr>
<tr>
<td>4.1</td>
<td>Levels of independent variables established according to the central composite design (CCD) for jackfruit seed slices roasting conditions</td>
</tr>
<tr>
<td>4.2</td>
<td>Central composite design (CCD) with independent variables</td>
</tr>
<tr>
<td>4.3</td>
<td>The matrix of central composite design (CCD) and experimental data obtained for the response variables studied (Y1-Y5) (mean ± SD)</td>
</tr>
<tr>
<td>4.4</td>
<td>Adjusted models, R sq, R sq (adjusted), probability value, and lack of fit for response variables studied</td>
</tr>
<tr>
<td>4.5</td>
<td>ANOVA and regression coefficient of the first- and second-degree polynomial regression models</td>
</tr>
<tr>
<td>4.6</td>
<td>Experimental and predicted values of the response variables studied (Y1-Y5)</td>
</tr>
<tr>
<td>4.7</td>
<td>Representative FT-IR spectra (cm-1) of raw and roasted jackfruit seeds</td>
</tr>
<tr>
<td>5.1</td>
<td>Proximate, starch, sugar, and pH of raw and roasted jackfruit seed</td>
</tr>
<tr>
<td>5.2</td>
<td>Amino acid composition (mg/100 g) of raw and roasted jackfruit seed</td>
</tr>
<tr>
<td>5.3</td>
<td>Fatty acid composition and anti-nutritional factors of raw and roasted jackfruit seed</td>
</tr>
<tr>
<td>5.4</td>
<td>Characteristics of the calibration curves</td>
</tr>
<tr>
<td>5.5</td>
<td>Odor qualities, retention index of the odorants and the FD values of raw and roasted jackfruit seed on DB-5 and FFAP columns</td>
</tr>
<tr>
<td>5.6</td>
<td>Odor perceived on GC-O and concentration of the odorants with FD value &gt;8 in raw and roasted jackfruit seed</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Jackfruit tree with fruits</td>
<td>5</td>
</tr>
<tr>
<td>2.2</td>
<td>Jackfruit pulp</td>
<td>5</td>
</tr>
<tr>
<td>2.3</td>
<td>Jackfruit seed with seed coat</td>
<td>8</td>
</tr>
<tr>
<td>2.4</td>
<td>Jackfruit seed without brown endosperm</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>Schematic diagram of gas chromatography-mass spectrometry instrument</td>
<td>20</td>
</tr>
<tr>
<td>4.1</td>
<td>Response surface plot for effect of roasting conditions (roasting temperature, roasting time and pH) on the color L*</td>
<td>41</td>
</tr>
<tr>
<td>4.2</td>
<td>Response surface plot for effect of roasting conditions (roasting temperature, roasting time and pH) on color a*</td>
<td>42</td>
</tr>
<tr>
<td>4.3</td>
<td>Response surface plot for effect of roasting conditions (roasting temperature, roasting time and pH) on the color b*</td>
<td>42</td>
</tr>
<tr>
<td>4.4</td>
<td>Response surface plot for effect of roasting conditions (roasting temperature, roasting time and pH) on the browning index (BI)</td>
<td>43</td>
</tr>
<tr>
<td>4.5</td>
<td>FT-IR spectra for raw jackfruit seed</td>
<td>45</td>
</tr>
<tr>
<td>4.6</td>
<td>FT-IR spectra for low level roasted jackfruit seed at 130 °C for 30 minutes</td>
<td>46</td>
</tr>
<tr>
<td>4.7</td>
<td>FT-IR spectra for medium level roasted jackfruit seed at 140°C for 45 minutes</td>
<td>47</td>
</tr>
<tr>
<td>4.8</td>
<td>FT-IR spectra for high level roasted jackfruit seed at 150°C for 60 minutes</td>
<td>47</td>
</tr>
<tr>
<td>4.9(A&amp;B)</td>
<td>Scanning electron micrograph of raw jackfruit seed without A&amp;B heat treatment at magnification of x500 and x1000</td>
<td>51</td>
</tr>
<tr>
<td>4.9(C&amp;D)</td>
<td>Scanning electron micrograph of low level (130 °C for 30 minutes) C&amp;D roasted jackfruit seed at magnification of x500 and x1000</td>
<td>52</td>
</tr>
<tr>
<td>4.9(E&amp;F)</td>
<td>Scanning electron micrograph of medium level (140 °C for 45 minutes) E&amp;F roasted jackfruit seed at magnification of x500 and x1000</td>
<td>53</td>
</tr>
<tr>
<td>4.9(G&amp;H)</td>
<td>Scanning electron micrograph of high level (150 °C for 60 minutes) G&amp;H roasted jackfruit seed at magnification of x500 and x1000</td>
<td>54</td>
</tr>
<tr>
<td>5.1</td>
<td>Comparative aroma profiles of raw and roasted jackfruit seeds</td>
<td>71</td>
</tr>
</tbody>
</table>
**LIST OF ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>Centimeter</td>
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CHAPTER 1

INTRODUCTION

Nowadays, there is increasing search for cheap and under-utilized tropical fruits which have high nutritional benefits. Tropical fruits such as mango, papaya, durian, rambutan, jackfruit, longan, chempedak, passion fruit, sour soup, citrus and banana are now majorly grown in Asian countries. They are popularly known for their large scale commercial cultivation (Araro & Rao, 1995). They are also called exotic fruits owing to their unique flavor and aroma. Generally, when these fruits are consumed, their seeds are usually discarded. However, several investigations in the past have shown their potential application in food products due to their high nutritive value (Shuangliet al. 2014; Singh et al. 2013; Okolie et al. 2012; Zaini et al. 2009).

Jackfruit (Artocarpus heterophyllus Lam.) is said to have originated from the Western Ghats of India and it is been cultivated throughout the tropical countries in South and Southeast Asia (APAARI, 2012). Jackfruit is becoming a more staple tropical exotic fruit grown in Malaysia and widely grown in Bangladesh, Burma, Sri Lanka, Indonesia, Philippines, Brazil and other countries (Rahman et al. 1999; Narasimham, 1990). The tree bore its fruits on the side branches with average weight ranging from 3.5 kg to 10 kg reaching up to 25 kg sometimes (Swami et al. 2012). A recent report recorded the highest weight of 81 kg from Panrutti, India (APAARI, 2012). It is considered a poor man’s food in India owing to the numerous culinary uses for the unripe, tender fruits (immature fruit) and its abundance fruiting during summer when crops are scarce (Jagtap et al. 2010; Rahman et al. 1995; Samaddar, 1985). Jackfruit is a low calorie fruit which is rich in protein, starch, calcium, potassium and thiamine with a unique flavor (Mukprasirt & Sajjaanantakul, 2004; Burkill, 1997; Samaddar, 1985). Jackfruit can be regarded as a multi-purpose crop providing food, wood, fuel, latex, nutraceutical and industrial products (APAARI, 2012).

The seeds may be boiled, or roasted and eaten or boiled and preserved in syrup like chestnuts. Roasted jackfruit seeds are ground and used to produce composite flour blends with wheat for baking (Morton, 1987). Singh et al. (1991) reported that jackfruit seeds are fairly rich in starch. It has been reported that jackfruit seed flour contains 6.09 % moisture content, 2.70% ash and 1.27% fat contents (dry matter basis), while the protein content, fiber content and carbohydrate content were 13.50 %, 3.19 % and 79.34 %, respectively (Ocloo et al. 2010). Jackfruit seed contains phytonutrients such as lignans, isoflavones, and saponins that have health benefits ranging from anticancer, antihypertensive, antioxidant, antifungal, antibacteria, antiulcer to antiaging properties (Swami et al. 2012; Karthy et al. 2009; Trindade et al. 2006; Swoong & Barlow, 2004). Despite all these health and nutritional benefits, large quantities of jackfruit seeds are usually discarded after pulp consumption.

Roasting can be referred to as a basic unit operation that bring about important physical, chemical, structural and sensorial changes and develops the flavor and texture of food product (Pittia et al. 2001; Saklar et al. 2001; Ozdemir & Devres, 2000). The flavor, color, texture and appearance of nuts and seeds can be changed and significantly enhanced during roasting process. This increases their overall palatability and these changes are mainly related to non-enzymatic browning (Perren & Escher, 1996a, b;
Mayer, 1985; Buckholz et al. 1980). The effects of different thermal processing especially roasting on the changes in chemical composition, color and aroma of seeds and nuts have been studied (Kim et al. 2000; Shin et al. 1981). Findings showed that the changes are related to series of complex chemical reactions called Maillard reaction occurring during heat processing.

Several researches have been carried out on the jackfruit seed compositions, functional properties, flour, and other health and value-added benefits (Swami et al. 2012). Literature is however lacking in the flavor and color development mechanism of jackfruit seeds. Hence, the importance of this research will not only increase knowledge in the field of Food Science but in the longer term, the development of more nutritious and health friendly snack.

The objectives of this study therefore are;

1. To determine the chemical components, color and flavor precursors of three jackfruit seeds cultivars.
2. To determine the effect of roasting conditions on color development using response surface methodology and the structural changes of jackfruit seed.
3. To investigate the changes in flavor precursors and their effects on the characteristic flavor of roasted jackfruit seeds and the identification of the flavor compounds.
REFERENCES


84


Schwab, U; Lauritzen, L; Tholstrup, T; Haldorsson, T; Riserus, U; Uusitupa, M; Becker, W (2014). "Effect of the amount and type of dietary fat on cardiometabolic risk factors and risk of developing type 2 diabetes, cardiovascular diseases, and cancer: a systematic review.". *Food & nutrition research* 58


