UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF NATURAL PEANUT BUTTER PRODUCED BY ONE-STAGE FINE GRINDING METHOD USING ULTRA-HIGH SPEED GRINDER

NORAZATUL HANIM BINTI MOHD ROZALLI

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By

NORAZATUL HANIM BINTI MOHD ROZALLI

Thesis Submitted to the school of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2015
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To my beloved husband Muzaidi
and my wonderful kids Muaz & Mus’ab....
Thank you for your loving support.
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By

NORAZATUL HANIM BINTI MOHD ROZALLI

May 2015

Chairman : Assoc. Prof. Ir. Chin Nyuk Ling, PhD
Faculty : Engineering

Peanut butter is a major product of peanuts (Arachis hypogaea L.) consumed worldwide. The concerns with additives in food products attract the demands for alternative natural peanut butter in market. It is common in peanut butter production that two stages of size reduction are required to transform the peanuts into paste form. Little attempts had been made to minimize the grinding stage and producing natural peanut butter as well. This study focuses on producing natural peanut butter by single 1-stage fine grinding method using ultra-high speed grinder. An extensive study on interrelation of particle size and natural peanut butter properties were conducted. Comparisons were made with commercial peanut butter in quality aspects. The qualities of roasted peanuts were optimized in roasting process. The effect of hot-air roasting temperatures and time on quality attributes of two different types of peanuts (Virginia and Spanish variety) were investigated using response surface methodology (RSM). The optimum roasting parameters for the Virginia and Spanish peanuts was 152°C-60 minutes and 158°C-45 minutes, respectively. Roasted peanuts were ground in a commercial ultra-high speed grinder operated at 20000 rpm for 2.0-5.0 minutes for natural peanut butter production. Grinding characteristics of both peanuts were evaluated in terms of specific energy consumption, \( E_{sc} \) with respect to its grinding time and mean particle size. The specific energy consumption modeled to the size reduction ratio of Virgina and Spanish peanuts was predicted more accurately using a linear and exponential model respectively compared to the classical models by Bond, Rittinger and Kick. Bond’s working index, \( W_i \), the ultra-high speed grinder is said to be more energy efficient than other comminutors in terms of its capability to produce finer particle size in shorter time than the rest. The peanut butter was successfully produced by 1-stage fine grinding method using the ultra-high speed grinder. Particle size analysis of natural peanut butter exhibited statistically significant difference between the analyzed parameters \( (d_{0.1}, d_{0.5}, d_{0.9}) \). Multimodal particle size distribution (PSD) was observed for all the samples. Particle size distribution is an inverse function of grinding time. All peanut butter samples exhibited elastic properties, adequately fitted to the Casson model and behaved as non-Newtonian shear-thinning food suspension with apparent yield stress. The storage modulus (\( G' \)) is a decreasing
function of grinding time and temperature. Grinding time and temperature show significant effect on all the responses ($p \leq 0.05$) while peanut origins only had impact on the particle size distribution. Identical trend was observed on all tests between natural peanut butter of Virginia and Spanish peanuts. The storage stability of natural peanut butter was evaluated for changes in physicochemical quality, microbiological properties, oxidative stability and textural quality. For storage study conducted over 16 weeks at 10, 25 and 35°C, products stored at 10°C exhibited similar textural quality with commercial product without appreciable loss in oxidative stability until the 12th whereas it was within 4 weeks for 25°C and 35°C storage. Storage temperature and time have more significant impact than other factors on quality changes of natural peanut butter during storage.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN MENTEGA KACANG SEMULAJADI DIHASILKAN OLEH SATU PERINGKAT KAEDAH PENGISARAN HALUS MENGGUNAKAN PENGISAR BERKELAJUAN ULTRA TINGGI

Oleh

NORAZATUL HANIM BINTI MOHD ROZALLI

May 2015

Pengerusi : Professor Madya Ir. Chin Nyuk Ling, PhD
Fakulti : Kejuruteraan

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I certify that a Thesis Examination Committee has met on 29 May 2015 to conduct the final examination of Norazatul Hanim binti Mohd Rozalli on her thesis entitled "Characterization of Natural Peanut Butter Produced by One-Stage Fine Grinding Method using Ultra-High Speed Grinder" 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 Doctor of Philosophy.

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Associate Professor Ir.  
Faculty of Engineering  
Universiti Putra Malaysia  
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Mohd Shamsul bin Anuar, PhD  
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Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

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Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

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**Chin Nyuk Ling, PhD**  
Associate Professor. Ir.  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

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

**Nor Ainy Mahyudin, PhD**  
Associate Professor  
Faculty of Food Science and Technology  
Universiti Putra Malaysia  
(Member)

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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>AOAC</td>
<td>Association of Analytical Chemists</td>
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<tr>
<td>CCD</td>
<td>Central composite design</td>
</tr>
<tr>
<td>d.b.</td>
<td>Dry basis</td>
</tr>
<tr>
<td>DSC</td>
<td>Differential scanning colorimeter</td>
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<tr>
<td>FDA</td>
<td>Food and Drug Administration</td>
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<tr>
<td>HVO</td>
<td>Hydrogenated vegetable oil</td>
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<td>LVR</td>
<td>Linear viscoelastic region</td>
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<td>MC</td>
<td>Moisture content</td>
</tr>
<tr>
<td>MSE</td>
<td>Mean squared error</td>
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<tr>
<td>N</td>
<td>Newton</td>
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<tr>
<td>Pa</td>
<td>Pascal</td>
</tr>
<tr>
<td>PCA</td>
<td>Plate count agar</td>
</tr>
<tr>
<td>PV</td>
<td>Peroxide value</td>
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<td>PSD</td>
<td>Particle size distribution</td>
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<td>pf</td>
<td>Power factor</td>
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<td>RSM</td>
<td>Response surface methodology</td>
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<td>SAOS</td>
<td>Small amplitude oscillatory stress</td>
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<td>Sdn. Bhd.</td>
<td>Sendirian Berhad</td>
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<td>SEM</td>
<td>Scanning electron microscope</td>
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<td>TFA</td>
<td>Trans fatty acid</td>
</tr>
<tr>
<td>TSA</td>
<td>Tryptic soy agar</td>
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<td>USDA</td>
<td>United States Department of Agricultural</td>
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NOMENCLATURE

A  Current (ampere)
$a_w$  Water activity
$d_1$  Initial particle size diameter (mm)
$d_2$  Final particle size diameter (mm)
$d_{0.1}$  Particle size at which 10% of the particle size distribution fall below
$d_{0.5}$  Particle size at which 50% of the particle size distribution fall below
$d_{0.9}$  Particle size at which 90% of the particle size distribution fall below
$E$  Energy (kJ)
$E_{sc}$  Specific energy consumption (kJ/kg)
$G'$  Storage modulus (Pa)
$G''$  Loss modulus (Pa)
$K_k$  Kick’s law constant (kJ/kg)
$K_R$  Bond’s law constant (kJ/kg)
$K_R$  Rittinger’s law constant (kJ/kg.m)
$M_{H_2O}$  Weight of sample loss after drying (g)
$M_{solids}$  Weight of sample before drying (g)
$P$  Power (kWatt)
$R^2$  Correlation coefficient
$t$  Grinding time (second)
$V$  Voltage
$W_i$  Bond’s working index (kJ/kg)
CHAPTER 1

INTRODUCTION

1.1 Introduction

Peanut butter is one of the most important products prepared from peanuts (*Arachis hypogaea* L.) where in the U.S. alone as example over 50% of the peanuts produced are processed into peanut butter (Suchoszek-XNDQLXN et al., 2011). Its high protein (27-30%) and polyunsaturated fatty acid content (45-50%) makes it an excellent source of energy (581 kCal/kg) (Woodroof, 1983). Peanut butter is a household staple and is usually consumed as spread on bread or cracker. It is also widely used in the food industry for flavour variety especially in confectionery and dessert products. The principal quality parameters for consumer acceptance of peanut butter are the appearance, flavour and aroma, as well as the spreadability and texture, which are dependent on the processing conditions during the production of peanut butter.

The production of peanut butter is relatively simple, consisting of roasting, blanching the peanuts followed by fine grinding. It is during the grinding stage that differentiates the textural quality among type of peanut butters. In commercial peanut butter manufacturing, peanuts have to undergo two steps of grinding in order to obtain the finest particle size of peanut butter. The initial milling reduces the peanuts into coarse or medium grind. It is then followed by second grinding in a high speed grinder operating at ~3000 rpm, to produce ultrafine particle size reaching to 2-PDQG KRPRJHQLJDWLRQ (Anyang General International Co., 2010). The peanuts have to be ground in two different grinders since the required clearance between plates of the grinder is different at each stage. The use of ultrasonification to substitute fine grinding in the second stage with do not give peanut paste particle sizes much smaller than conventional sizes (Dzurik et al., 1971). It is interesting to investigate if these two steps procedure can possibly done using single size reduction apparatus by applying the ultra high speed grinding. The implementation of single stage step grinding process in peanut butter production would be beneficial in terms of time and cost reduction. Besides it could ensure proper hygiene due to reduce chance of handling the product from one machine to another.

In commercial peanut butter production, various stabilizer and additives are added to serves various purposes. The use of hydrogenated vegetable oil (HVO) as stabilizer in peanut butter has arisen many health concern issues as it contains trans fatty acid (TFA) which associate with cardiovascular disease. Most peanut butter brands in Malaysia fell within a range of 0.02–0.67 g TFA kg⁻¹ and are LGHQWLILHG DV ORZ 7) but a range of 1.6–6.7 g TFA kg⁻¹ was reported ZKLFLVFRQVGLHUHGDVKLJK 7) (Karupaiah et al., 2014). It is suggested that TFA in peanut butter is varied between manufacturers (Karupaiah et al., 2014). Although this issue has been constantly overcame by reducing the HVO content to less than 1% or with better stabilizer and modification of hydrogenation process, it could not evade the demand for natural peanut butter. The increasing demands and consciousness among consumers suggest that fewer natural additives or no additives added in food are
preferable. 59% of the respondents in a study of peanut butter preference favour the ‘old fashioned’ peanut butter due to its flavour, aroma, texture and absence of additives (How et al., 1985). The addition of HVO in peanut butter succeed to prevent oil separation but the resulting peanut butter has the disadvantage where it is difficult to spread and tends to cling to the palate when eaten (Gills et al., 2000b). Various attempts had been made to find the suitable stabilizer which satisfies all quality attributes of peanut butter such as by replacing HVO with palm oil (Gills and Resurreccion, 2000b; Hinds et al., 1994). However, the oxidative stability of palm oil-stabilised peanut butter is less susceptible than HVO-stabilised peanut butter. Sensory analysis showed that the natural peanut butter is more preferable than the palm oil-stabilised peanut butter in texture, oiliness, spreadability and overall liking (Gills et al., 2000a).

Oil separation is the major problems in natural peanut butter production. It leads to peroxidation of oil which results in rancidity of the product. To regain the terms of natural peanut butter, it is a challenge that no stabilizer should be added. By means, the capability of ultrahigh speed grinding to improve the fine particle size would provide some useful research area in mechanically controlling the oil separation thus improve the other quality attributes. Controlling particle size distribution (PSD) was proved to be the most prominent factor to obtain a desirable product (Lima et al., 2000).

1.2 Problem statements

In conventional peanut butter processing, two steps of grinding are required to achieve the finest possible particle size to ensure a smooth spread is achievable. Therefore, it is the main focus of this research to reduce the 2-steps to a 1-step grinding process in peanut butter production. The difference between conventional and new peanut butter processing are illustrated in Figure 1.1 and 1.2, respectively. In conventional peanut butter production, stabilizers such as hydrogenated vegetable oil (HVO) and additives are added to prevent oil separation. Due to various health concerns on the usage of HVO, it is the interest of this research to produce natural peanut butter as an alternative to the current range of peanut butter. The information and literature on natural food product particularly peanut butter is scarce. Therefore, the characterization and storage study on natural peanut butter would provide knowledge in structure-rheological interrelationship particularly in plant-based food suspension and also in stability evaluation of preservative-free food products.
Figure 1.1. Flow diagram of conventional peanut butter processing

Figure 1.2. Flow diagram of new peanut butter processing
1.3 **Objectives of the study**

The main objective of this study is to evaluate the performance and capability of ultra high speed grinding in producing a reasonably stable natural peanut butter shelf life without stabilizer. Since the stability and quality of the product depends on the organoleptics, textural and microstructure properties, it is important to achieve desire characteristics to support the main objective. The study was carried out in comparison with commercial peanut butter in order to compare the quality between commercial and natural product. The specific objectives of the research were therefore:

1. To assess the influence of roasting parameters on the textural and organoleptic attributes of roasted peanuts. It is during roasting that determine the aroma, flavour and colour of final products. The determination of roasting parameters on quality parameters of roasted peanuts are reported in **Paper I**.

2. To evaluate the performance of ultra high speed grinder in terms of specific energy consumption. It is described in **Paper II**.

3. To study the influence of grinding on the textural, rheological and physicochemical properties of natural peanut butter. It is reported in **Paper III and IV**.

4. To study the behaviour and oxidative stability of peanut butter during storage at different temperatures. It is reported in **Paper V**.

1.4 **Scope of work and thesis outlines**

The work conducted in this research focused on production of natural peanut butter using ultra-high speed grinder. Quantitative characterization and evaluation were conducted on the production which are roasting and grinding as well as on the product which is natural peanut butter. Chapter 2 begins by introducing the classification of peanut butter and process flowchart of peanut butter production with detail description on roasting and grinding stage. Elaborate discussions were also presented on quality responses of peanut butter and other nut butters as well. The applications of instrumental analyses for quantitative measurements in previous studies are extensively discussed. The storage stability of peanut butter and other nut butter are also presented in terms of oxidative stability and microbial contamination.

The materials and methods, equipment used and procedures for analyses conducted in the experiments are described in Chapter 3. The works started with preparation of the peanuts for roasting process, followed by grinding process, and characterization of peanut butter, and storage study. The experimental design of roasting process is presented with aims to evaluate the effect of roasting time and temperature on four quality responses for roasted peanuts which are colour, moisture content, hardness and fracturability. This chapter also describes the experimental design of grinding process at five levels of grinding time and two levels of peanut origin where grinding
characteristics including particle size distribution, energy consumption and temperature generated were evaluated. The characterizations of natural peanut butter properties were also presented which includes physicochemical, rheological and textural properties. The properties of natural peanut butter were also compared with commercial peanut butter as benchmark of its characteristics. The effect of grinding time and storage temperature on oxidative stability, microbial count and changes in physicochemical, rheological and textural properties of natural peanut butter in comparison with commercial peanut butter are also described in this chapter.

Chapter 4 is a published paper of work on optimization of roasting process. It details the experimental design of roasting process and the application of response surface methodology (RSM) for simultaneous multiple responses modelling and optimization of peanuts roasting process in this study. The optimization was obtained by defining the goals and boundaries of each measured responses and later combined them into a single measure. The correlations between the responses are also reported.

Chapter 5 is a published paper of work on grinding process of roasted peanuts using ultra-high speed grinder. It discusses the grinding characteristics of roasted peanuts for natural peanut butter production. It covers the energy consumption and heat generated during grinding and particle size distribution obtained after grinding. The energy consumption and particle size were fitted to the three classical grinding laws and the correlations between the responses are also reported.

In Chapter 6, the preliminary study of rheological properties of natural peanut butter is presented. This chapter compared the dynamic rheological properties of natural peanut butter with commercial peanut butter at 25°C. The stress sweep test was performed in the work of this chapter. Comparisons were made between natural peanut butter produced at different grinding time and also with commercial peanut butter by comparing the linear viscoelastic region (LVR) of the products.

Chapter 7 discusses the effect of grinding time and temperature on rheological, textural, colour and density of natural peanut butter in comparison with commercial peanut butter. Dynamic rheological properties are extensively discussed which includes results from oscillatory strain sweep test, time sweep test and frequency sweep test. The flow behaviours of peanut butters are also presented in this chapter. The SEM and particle size analysis were also assessed to understand particle size and structure influence on the peanut butter properties.

Chapter 8 elaborates the storage related changes in quality changes on natural peanut butter. It reports the effects of storage temperature and time, peanut variety and grinding time on storage stability of natural peanut butter. The quality attributes monitored were moisture content, water activity, microbial count, peroxide value, oil separation and spreadability. Subsequently, comparisons of quality changes during storage were compared with those of commercial peanut butter.

Finally, Chapter 9 concludes the overall findings and contributions of the works. Recommendations are listed for further research.
REFERENCES


