UNIVERSITI PUTRA MALAYSIA

POWER ULTRASONIC ASSISTED MIXING AND PROOFING DURING BREAD MAKING PROCESS

NASRUL FIKRY CHE PA

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By

NASRUL FIKRY CHE PA

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

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DEDICATION

To my beloved parents,
Che Pa Hashim and Noripah Md. Shah;
Family members and friends who makes the journey worth travelling
Thank you for your encouragement, patience and loving support.

The following poem, 'The road not taken' by Robert Frost is dedicated to all…

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveller, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;

Then took the other, as just as fair
And having perhaps the better claim,
Because it was grassy and wanted wear;
Through as for that, the passing there
Had worn them really about the same,

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept first for another day!
Yet knowing how way leads on to way,
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
two roads diverged in a wood, and I - -
I took the one less travelled by,
And that has made all the difference.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

POWER ULTRASONIC ASSISTED MIXING AND PROOFING DURING BREAD MAKING PROCESS

By

NASRUL FIKRY CHE PA

April 2014

Chairman : Ir. Chin Nyuk Ling, PhD

Faculty : Engineering

Power ultrasonic assisted mixing and proofing processes were investigated in parallel by varying the ultrasonic duration and power level factors in both processes. The effects of power ultrasonic during both mixing and proofing processes on the physical and textural properties of bread such as volume, mass, density and firmness, and also on the crumb structure of bread such as void fraction, mean cell area, average cell diameter, crumb fineness, mean cells per area and cell uniformity were studied. Both studies required the design and fabrication of an ultrasonic bath system at a frequency of 25 kHz and with a temperature controller and timer. Power levels of 1.00, 1.50, 2.05 and 2.50 kW and durations of 10, 20, 30, and 40 minutes (for mixing); 15, 30, 45, 60 minutes (for proofing) were used. A simplified algorithm using Vision Assistant 2009 (National Instruments) imaging software was developed to assist in crumb structure analysis of bread.

A preliminary study using the dough dynamic density method in the mixing study gave convincing results of the effects of ultrasonic exposure as a significant reduction in dough density was demonstrated. Power ultrasonic assisted mixing significantly altered the physical and textural properties with the bread volume increasing by 19.0 %, while bread mass, density and firmness were reduced by 2.1 %, 17.0 %, 34.1 %, respectively using the maximum ultrasonic power of 2.50 kW with the longest ultrasonic duration exposure of 40 minutes. Examination of the crumb structural characteristics showed a significant increase of void fraction, mean cell area and average cell diameter of 47.3 %, 41.7 % and 12.4 %, respectively with the maximum ultrasonic power level and exposure albeit the value can go up to 51.6 % and 15.6 % each for mean cell area and average cell diameter with reduced power level of 1.50 kW and 30 minutes of exposure. The results suggested that power ultrasonic increased bread aeration when applied during the mixing process with both ultrasonic duration and power level giving significant impact at minimally $P < 0.05$. Similarly, ultrasonic assisted proofing enhanced bread aeration with the majority of the maximum values in the tests at 1.50 kW. Bread volume, void fraction, mean cell area and average cell diameter showed an increase of 17.1 %, 20.8 %, 20.9 %, 6.7 %, while reductions were shown for bread mass, density and firmness at 2.5 %, 16.7 %, 24.1 % respectively with the overall $P < 0.001$. Based on the findings shown, it is suggested that bread aeration is significantly improved under prolonged duration of ultrasonic proofing, particularly above 45 minutes of exposure with ultrasonic duration governing the changes. However, detrimental effects prevailed when power levels exceeded 1.50 kW. Yeast injuries were suspected as the major reason for the detrimental effects shown based on a literature study. Overall, power ultrasonic was proven to impose significant changes in both the physical and textural properties of the bread and also the crumb structures when employed during the mixing and proofing processes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PROSES PEMBUATAN ROTI DENGAN BANTUAN ULTRASONIK KUASA SEMASA PROSES PENGGAULAN DAN PENAPAIAN

Oleh

NASRUL FIKRY CHE PA

April 2014

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Proses penggaulan dan penapaian dibantu ultrasonik kuasa telah dikaji bersama dengan perubahan tempoh pendedahan dan tahap kuasa ultrasonik yang digunakan bagi kedua-dua proses. Kesan penggunaan ultrasonik kuasa pada kedua-dua proses terhadap sifat-sifat fizikal dan tekstur roti seperti isipadu, jisim, ketumpatan dan kekenyalan dan juga struktur isi roti seperti peratusan rongga dalam roti, purata saiz sel, purata diameter sel, kehalusan isi roti, purata sel dalam setiap ruang dan kesatuan sel telah dikaji. Kajian tentang kedua-dua proses ini memerlukan rekaan dan fabrikasi sebuah sistem takungan ultrasonik dengan frekuensi 25 kHz dan dilengkapi alat kawalan suhu dan masa. Tahap kuasa ultrasonik yang digunakan ialah 1.00, 1.50, 2.05 dan 2.50 kW; manakala tempoh pendedahan ultrasonik pula ialah 10, 20, 30, 40 minit bagi proses penggaulan dan 15, 30, 45, 60 minit bagi proses penapaian. Satu algoritma yang dipermudahkan telah dibangunkan melalui perisian pengimejan Vision Assistant 2009 (National Instruments) bagi membantu analisis struktur isi roti.

Kajian awal tentang kesan ultrasonik kuasa ketika proses penggaulan terhadap ketumpatan dinamik doh telah menunjukkan hasil yang meyakinkan dalam menurunkan ketumpatan doh. Proses penggaulan dibantu ultrasonik kuasa telah menunjukkan perubahan ketara pada sifat fizikal dan tekstur roti di mana isipadu roti telah meningkat sehingga 19.0 %, manakala berat, ketumpatan dan kekenyalan roti telah berkurangan masing-masing sehingga 2.1 %, 17.0 %, 34.1 %, akibat penggunaan maksimum ultrasonik kuasa dengan tahap kuasa 2.50 kW dengan tempoh pendedahan maksimum selama 40 minit. Selain itu, analisis terhadap struktur isi roti telah menunjukkan perubahan ketara pada peratusan rongga dalam roti, purata saiz sel dan purata diameter sel dalam roti masing-masing dengan peningkatan sebanyak 47.3 %, 41.7 %, dan 12.4 % dengan penggunaan maksimum ultrasonik kuasa. Walaubagaimanapun purata saiz sel dan purata diameter sel masing-masing boleh meningkat sehingga 51.6 % dan 15.6 % dengan hanya menggunakan tahap kuasa 1.50 kW selama 30 minit. Dapatan kajian ini menunjukkan bahawa penggunaan ultrasonik kuasa ketika proses penggaulan merupakan penyebab kepada peningkatkan pengudaraan dalam roti dimana tempoh pendedahan dan tahap kuasa

ultrasonik memberikan kesan yang signifikan dengan nilai minimum $P < 0.05$ dalam mempengaruhi perubahan tersebut. Proses penapaian dibantu ultrasonik kuasa turut menunjukkan peningkatan dalam pengudaraan roti dengan nilai perubahan maksimum berlaku pada tahap penggunaan kuasa ultrasonik 1.50 kW. Isipadu roti, peratusan rongga dalam roti, purata saiz sel dan purata diameter sel dalam roti telah meningkat masing-masing pada 17.1 %, 20.8 %, 20.9 %, 6.7 %, manakala penurunan telah ditunjukkan oleh berat, ketumpatan dan kekenyalan roti masing-masing pada 2.5 %, 16.7 %, 24.1 % dengan nilai keseluruhan $P < 0.001$. Dapatan kajian ini mencadangkan bahawa pengudaraan dalam roti telah meningkat dengan pertambahan tempoh pendedahan ultrasonik ketika proses penapaian terutamanya melebihi 45 minit dengan tempoh pendedahan merupakan faktor dominan perubahan. Walaubagaimanapun, kesan penyusutan perubahan ditunjukkan bilamana penggunaan tahap kuasa ultrasonik melebihi 1.50 kW. Kajian literatur mencadangkan penyusutan perubahan ini adalah disebabkan oleh pengurangan aktiviti penapaian akibat kecederaan berterusan membran yis sebagai implikasi penggunaan lampau tinggi tahap kuasa ultrasonik. Secara keseluruhannya, ultrasonik kuasa telah terbukti dalam memberi kesan perubahan yang ketara pada sifat fizikal dan tekstur roti dan juga pada struktur isi roti bilamana ia digunakan ketika proses penggaulan dan penapaian.

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I certify that a Thesis Examination Committee has met on **08 April 2014** to conduct the final examination of Nasrul Fikry Che Pa on his thesis entitled "Power ultrasonic assisted mixing and proofing during bread making process" 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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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DECLARATION

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LIST OF ABBREVIATIONS

°C	Degree Celsius
DPI	Dots per inch
FOV	Field of view
GB	Gigabyte
kHz	Kilohertz
kW	kilowatt
RDCC	Research Development Commercialization Centre
RGB	Red, green and blue
RH	Relative humidity
RPM	Revolutions per minutes
SI	International system units
TIFF	Tagged image file format

CHAPTER I

INTRODUCTION

1.1 Research Background

A wide range of baked products are consumed in our society every day and among these, the most popular and common is bread. Bread is a healthy food as it provides a balanced and a complete human diet. Over the past two decades, bread has been increasingly seen as a staple food alongside traditional Asian favourites such as rice and noodles. In terms of consumption patterns, it has evolved from being perceived as a breakfast food to food for many occasions, such as sandwiches for lunch or canapés for high tea. Due to the evolving world economic situation which demands a fast paced lifestyle, bread is a favourite item for convenience and as a tasty and healthy product for consumers.

Bread has progressively evolved by adopting a wide range of attributes across different continents of the world depending on the local favourites, traditions as well as access to material availability. Generally it represents a food made from dough and based on flour traditionally derived from cereal wheat. Wheat flour is preferable when compared to other types of flour as it is the only cereal from which highly leavened bread can be made as it has the unique viscoelastic rheology gluten proteins which enable the expansion of bubbles and retention of gas in the bread dough during the proofing process (He and Hoseney, 1991). The quality of the baked product depends on the protein content, loaf volume, crumb grain quality and texture of bread (Upadhyay et al., 2012).

The typical bread making process consists of three compulsory stages, namely mixing, proofing and baking. While these stages may vary according to bread type and local customs, nonetheless the presence of these three stages in sequence is compulsory. Since the beginning of documentation of bread, literature on bread making studies has mainly empirically demonstrated the effects of mixing speed and intensity on the rheology and its relationship with bread making performance. Such studies also include the effects of different ingredient materials as well as functional groups on bread properties to increase bread quality, and the various measurement techniques related to bread properties and crumb structures (Che Pa et al., 2013; Chin, 2003; Haraszi et al., 2008; He and Hoseney, 1991; Mohd Jusoh et al., 2009; Suchy et al., 2000; Wooding et al., 1999). Only a few research attempts have been made to improvise bread making processes via unconventional routes during the last two decades and this includes improver technology to produce pre-proofed frozen dough which was introduced in the late 90's (Mondal and Datta, 2008), microwave baking (Patel et al., 2005), high pressure processing (Bárcenas et al., 2010) and the most recent is yeast free bread by supercritical fluid extrusion and vacuum baking (Ruttarattanamongkol et al., 2011). Therefore, there are vast opportunities to improvise and improve the bread making processes besides typical conventional techniques where bread with high quality characteristics, better crumb structures and textures which are also efficient in terms of processing are produced.

Power ultrasonic is considered to be an emerging and promising technology for the food processing industry (Mason et al., 2005). It is normally used to initiate changes or to alter the properties of a material through the chemical, mechanical and/or biochemical effects it causes on the process of products or upon the medium of propagation. The effects of power ultrasonic highly depend on the nature of the medium of propagation as different effects are observed for different mediums. It has been vigorously explored to capitalize on its applications in various aspects, especially those involving industrial processing. Power ultrasonic is known to alter food structures and textures. The properties of food so altered are mostly achieved though the generation of immense pressure, shear and temperature gradients in the medium of propagation (Dolatowski et al., 2007). Power ultrasonic has been used in a broad range of industrial food applications including degassing and foaming of liquid foods, induction of oxidation/reduction reactions, viscosity alteration, drying processes, homogenization and particle size reduction, extraction of enzymes and proteins, activation and inactivation of enzymes, sterilization and pasteurization, and the induction of nucleation for crystallization (Chandrapala et al., 2012; Gallego-Juarez, 2010; Patist and Bates, 2011; Villamiel and de Jong, 2000).

Power ultrasonic assisted processing which utilizes an intensified level of acoustic energy and the approach of wave propagation might prove to be useful for the industrial bread making process particularly in the mixing and proofing stages. The introduction of this technology could possibly lead to the development of an enhanced bread making process with superior bread quality and characteristics, a reduction in the processing time, increasing process efficiency and improvements in the overall operating condition. Therefore, this thesis is concerned with exploring the possibility of combining the effects of power ultrasonic assisted processing in bread making processes, particularly during the mixing and proofing stages. In this thesis, ‘bread’ refers to the Western yeast leavened white sandwich loaf; ‘bread making’ refers to the process of manufacturing such bread and ‘mixing and proofing’ refers to two of the most important stages in the bread making. ‘Power ultrasonic’ and ‘high intensity ultrasonic’ are used interchangeably throughout this thesis.

1.2 Problem Statement

Bread is a staple food generally characterized by well aerated structures and fluffy crumb. The conventional bread making process is recognized as time consuming, energy driven and labour intensive as for certain bread making method it takes up to eight hours to complete the whole process of bread making e.g. the sponge and dough method. Power ultrasonic assisted processing is known to be helpful in enhancing unit operations for a myriad of industrial food processing processes. High intensity ultrasonic is known to alter many food properties through various applications. The significant effects of power ultrasonic depend on the medium of propagation e.g. cavitation effects for a liquid medium, sponge effects for a solid system and micro-stirring for a gas medium. Hence, power ultrasonic is known to be versatile for various processing applications.

Previously, Jackel (1970) has invented a continuous dough developer (extruder type) assisted power ultrasonic and succeeded to improve the bread making process by reducing the mixing requirement, decreasing the operating temperature and increasing the dough throughput. His patented invention can be considered as two steps processing where an initial premixed process is required. Therefore, the intention of this study is to combine power ultrasonic assisted processing in-situ with the bread making process, particularly during the mixing and proofing stages. This is conducted to explore the possibilities of enhancing the physical and textural properties of the bread and also the bread crumb structures through the effects of power ultrasonic while concurrently studying the efficiency of bread making through this alternative route.

1.3 Aims and Scope of This Research

Power ultrasonic assisted processing is known to alter many food operations in order to develop efficient ways of producing products with enhanced quality and characteristics. Therefore the aims of this research are to investigate the effects of the power ultrasonic assisted bread making process, particularly during the mixing and proofing stages. The knowledge of how power ultrasonic assisted processing can affect the physical and textural properties of bread, also its crumb structures during both mixing and proofing processes is important to produce bread with improved quality and crumb characteristics. The ultimate aim of this research is to improve the existing knowledge on the bread making process through unconventional ways by incorporating ultrasonic technology during the mixing and proofing processes.

Hence to achieve the aim of this study, four objectives have been clearly drawn:

1. To design and fabricate an ultrasonic bath system setup to provide for both the mixing and proofing processes. The system enables the study of the effects of power ultrasonic during the mixing and proofing processes to yield changes in the physical and textural properties of bread and also its crumb structure.
2. To develop a simplified algorithm of the method of quantitative analysis of gas cell properties e.g. gas cell sizes and distribution, though imaging techniques based on commercial software.
3. To investigate the effects of the power ultrasonic assisted mixing process on the physical and textural properties of bread also its crumb structures.
4. To design and build a set-up of sonicated proofer and thereby to investigate the effects of the power ultrasonic assisted proofing process on the physical and textural properties of bread also its crumb structures.

1.4 Organization of the Thesis

The research conducted in this study into the effects of power ultrasonic assisted mixing and proofing processes is of a macroscopic approach. The effects of power ultrasonic during both the mixing and proofing processes on the physical and textural properties of bread and also its crumb structure are measured through both direct and indirect methods. The introductory chapter includes a brief review of bread, its usage, processing and a brief introduction of the applications of power ultrasonic in the food processing industry.

Chapter 2 discusses and reviews in detail the bread making processes and power ultrasonic applications in food industry. The first part of the chapter emphasizes bread and its significance, the bread making processes including common bread making ingredients, dough mixing and proofing processes and also their respective functions, a brief review of bread quality assessments and also a comprehensive review of dough aeration. The last part of the chapter focuses on power ultrasonic in food processing, its effects in different mediums of propagation including in aerated food systems, factors affecting cavitation also a general review of both power ultrasonic generation and the power ultrasonic bath system.

Chapter 3 reports the experimental procedures and set-up involved in performing this research. All the materials and methods including the design and set-up of the ultrasonic bath system and the sonicated proofer, dough dynamic density measurement, power ultrasonic assisted mixing and proofing processes and the physical and textural characteristics of bread are reported. The design of an algorithm for crumb image analysis as well as the set-up of the computerized system for crumb image processing is described. The statistical analysis performed with the respective statistical tools is explained.

Chapter 4 discusses the effects of the power ultrasonic assisted mixing process on the physical and textural properties of bread and also its crumb structures. Details of the mechanism of how power ultrasonic influences both the properties and crumb characteristics of bread during the mixing process are described accordingly.

Chapter 5 presents the results of the influence of power ultrasonic on the physical and textural properties of bread and also its crumb structures during the proofing process. Corresponding with Chapter 4, the discussion in Chapter 5 focuses on explaining the mechanisms involved during the power ultrasonic assisted proofing process in changing the physical and textural properties of bread and its crumb characteristics. Both Chapter 4 and Chapter 5 thoroughly discuss the issues and conclusions are drawn.

Chapter 6 summarises all the findings concerning the ultrasonic assisted mixing and proofing processes. Recommendations for future works are also suggested.

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