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ULTRASOUND-AIDED MIXING OF SPONGE CAKE BATTER

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ULTRASOUND-AIDED MIXING OF SPONGE CAKE BATTER

By

TAN MEI CHING

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

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To my father and mother…

Thank you for your loving support.

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

ULTRASOUND-AIDED MIXING OF SPONGE CAKE BATTER

By

TAN MEI CHING

August 2011

Chairman : Chin Nyuk Ling, PhD, Ir

Faculty : Engineering

The effect of ultrasound-assisted mixing of cake batter and its effect on baked cakes were studied. The Box-Behnken design was used to optimize the experimental condition of cake batter mixing. This involved three factors, *i.e.* mixing time, mixing speed and cake loading before conducting experiments with ultrasound application using a commercial mixer. The batter mixing time ranged from 6 to 20 minutes with speed from 90 to 120 rpm, and cake loading from 3 to 5 cakes were chosen for this purpose. A total of 15 runs of experiments with three levels, each attributing to high, central and low, and with additional three replicated center points were conducted. Based on goal settings of minimum batter density, cake density, hardness, gumminess and chewiness; and maximum springiness, cohesiveness and resilience, the optimum and feasible batter mixing required 9 minutes of mixing time at 90 rpm for the loading of 3 cakes.

The high power ultrasound bath system was then set up to be used as a processing

aid during mixing. The bowl of the existing mixer system is located at the center of the ultrasonic bath tank filled with water. The power ultrasound of 1 kW, 1.5 kW or 2.5 kW can take effect for the entire or partial mixing period. It is generated by two generators, and five units of flange type piezoelectric transducers mounted on the stainless steel tank. The electric field of energy received in each transducer is contracted by the piezoelectric ceramics in the transducer, expands and leads to pressure waves transmitting through water in the tank to the batter in mixer bowl.

The optimum experimental condition determined earlier was then used for mixing of sponge cake batter with different combinations of ultrasound power exposure ranging from 1 to 2.5 kW, and for duration ranging from 3 to 9 minutes. Ultrasound-aided mixing for 9 minutes at 1 kW produced lower batter density (0.9%), cake hardness (5.2%) and springiness (0.4%); higher batter viscosity (9.7%), consistency index (10%), overrun (3%), and cake volume (4.1%). At 2.5 kW, it produced lower batter density (2.3%) and cake hardness (11.5%); higher batter viscosity (6.9%), consistency index (7.3%), overrun (7.6%), cake volume (1.4%), and springiness (0.3%). However, at 1.5 kW, the lower batter density (0.63%), viscosity (4.1%), consistency index (4.4%) had produced higher batter overrun (0.02%), cake volume (1.8%), and springiness (0.2%) resulting in lower cake hardness (8%). These findings indicate that more air is being incorporated into the food system with the aid of ultrasound application during mixing, and it has directly enhanced the volume and textural properties of cakes. The two-way ANOVA showed that ultrasound duration has the most significant effect on cake volume ($P < 0.001$), followed by batter density and overrun ($P < 0.1$), and viscosity ($P < 0.5$). For cake textural attributes, ultrasound duration and power showed similar significant effects on hardness and springiness at $P < 0.5$. The ultrasound power and duration showed more significant effects on cake properties than batter properties. In conclusion, ultrasound-aided mixing was able to enhance cake batter mixing process through the improved textural properties of cakes.

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

PENGGAULAN BERBANTUKAN ULTRABUNYI BAGI ADUNAN KEK SPAN

Oleh

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Kesan penggaulan berbantukan ultrabunyi bagi adunan kek dan kesannya terhadap kek yang dibakar telah dikaji. Reka bentuk Box-Behnken digunakan untuk mengoptimumkan keadaan eksperimen penggaulan adunan kek. Ini melibatkan tiga faktor, iaitu tempoh penggaulan, kelajuan penggaulan dan muatan kek sebelum melaksanakan eksperimen dengan aplikasi ultrabunyi menggunakan alat pengadun komersil. Masa penggaulan adunan berjulat dari 6 hingga 20 minit dengan kelajuan penggaulan dari 90 hingga 120 rpm, dan muatan kek daripada 3 hingga 5 biji kek telah dipilih untuk mencapai tujuan ini. Sebanyak 15 eksperimen telah dijalankan di mana 3 peringkat seperti peringkat tinggi, tengah dan rendah diatributkan kepada setiap faktor dengan tambahan 3 titik tengah ulangan. Dengan berdasarkan kepada tujuan untuk mendapatkan ketumpatan adunan, ketumpatan kek, kekerasan, keperekatan dan kekenyalan kek yang minimum; dan keanjalan, keutuhan dan ketahanan kek yang maksimum, penggaulan adunan yang optimum dan munasabah memerlukan

masa penggaulan selama 9 minit pada kelajuan 90 rpm untuk muatan 3 biji kek.

Sistem ultrabunyi rendaman yang berkuasa tinggi telah dipasang untuk digunakan sebagai alat bantu pemprosesan semasa penggaulan. Mangkuk bagi sistem penggaul yang sedia ada diletakkan di tengah tangki ultrasonik rendaman yang diisi dengan air. Kuasa ultrabunyi 1 kW, 1.5 kW dan 2.5 kW boleh berfungsi untuk tempoh sepanjang penggaulan atau pada tempoh tertentu sahaja. Ultrabunyi dihasilkan daripada dua penjana kuasa dan lima unit transduser piezoelektrik jenis berbibir yang dipasang pada tangki keluli tahan karat. Medan elektrik daripada tenaga yang diterima dalam setiap transduser akan diperkembangkan dan dikecutkan oleh seramik piezoelektrik di dalam transduser dan menyebabkan gelombang tekanan dihantar melalui air di dalam tangki rendaman kepada adunan di dalam mangkuk pengadun.

Keadaan eksperimen optimum yang telah ditentukan sebelum ini seterusnya digunakan untuk penggaulan adunan kek span dengan pelbagai kombinasi kuasa ultrabunyi yang berjulat dari 1 hingga 2.5 kW dan jangka waktu penggaulan dari 3 hingga 9 minit. Penggaulan berbantukan ultrabunyi selama 9 minit pada 1 kW menghasilkan ketumpatan adunan (0.9%), kekerasan kek (5.2%) dan keanjalan (0.4%) yang rendah; kelekatan adunan (9.7%), indeks konsistensi (10%), *overrun* (3%) dan isipadu kek (4.1%) yang tinggi. Pada 2.5 kW, ketumpatan adunan (2.3%) dan kekerasan kek (11.5%) yang rendah; kelekatan adunan (6.9%), indeks konsistensi (7.3%), *overrun* (7.6%), isipadu kek (1.4%) dan keanjalan (0.3%) yang tinggi dihasilkan. Walau bagaimanapun, pada 1.5 kW, ketumpatan adunan (0.63%), kelekatan (4.1%) dan indeks konsistensi (4.4%) yang rendah telah menghasilkan *overrun* adunan (0.02%), isipadu kek (1.8%) dan keanjalan (0.2%) yang tinggi lalu menghasilkan kekerasan kek yang rendah (8%). Keputusan ini tersebut menunjukkan bahawa lebih banyak udara dimasukkan ke dalam sistem makanan dengan bantuan aplikasi ultrabunyi semasa penggaulan, dan secara langsung telah menambah baik isipadu dan tekstur kek. ANOVA dua hala menunjukkan tempoh ultrabunyi memberi kesan paling ketara terhadap isipadu kek ($P < 0.001$), diikuti oleh ketumpatan dan *overrun* adunan ($P < 0.1$), dan kelekatan ($P < 0.5$). Untuk tekstur kek, tempoh dan kuasa ultrabunyi menunjukkan kesan yang sama atas kekerasan dan keanjalan pada $P < 0.5$. Tempoh dan kuasa ultrabunyi menunjukkan kesan yang lebih ketara terhadap ciri kek berbanding adunannya. Secara kesimpulannya, penggaulan berbantukan ultrabunyi telah mampu menambah baik proses penggaulan adunan kek dengan menambah baik ciri tekstur kek yang dikehendaki.

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LIST OF ABBREVIATIONS

OR	Overrun
FASS	Flame atomic absorption spectometry
GRG2	Generalised Reducted Gradient 2
SSE	Sum of square errors
SST	Total corrected sum of square
TPA	Texture profile analysis
ANOVA	Analysis of variance

NOMENCLATURE

R^2	Goodness of fit
K	Consistency coefficients
n	Flow behavior index
m_{cake}	Mass of cake
m_{seeds}	Mass of seeds
v_{cake}	Volume of cake
$v_{container}$	Volume of container
v_{seeds}	Volume of seeds
C	Regression coefficient
C_o	Constant regression coefficient
C_1	Linear regression coefficient of first factor
C_2	Linear regression coefficient of second factor
C_3	Linear regression coefficient of third factor
C_{12}	Interaction regression coefficient of first and second factor
C_{13}	Interaction regression coefficient of first and third factor
C_{23}	Interaction regression coefficient of second and third factor
C_{11}	Quadratic regression coefficient of first factor
C_{22}	Quadratic regression coefficient of second factor
C_{33}	Quadratic regression coefficient of third factor
p	Probability
X_T	Mixing time

X_S	Mixing speed
X_C	Cake loading
Y1	Batter density
Y2	Cake density
Y3	Hardness
Y4	Springiness
Y5	Cohesiveness
Y6	Gumminess
Y7	Chewiness
Y8	Resilience
ρ_{batter}	Batter density
ρ_{cake}	Cake density
ρ_{seeds}	Seeds density
ρ_o	Density of non-aerated batter
ρ_a	Density of aerated batter
τ	Shear stress
η	Viscosity
$\dot{\gamma}$	Shear rate

CHAPTER 1

INTRODUCTION

Mixing is an important stage in food processing to modify the feeds materials into the final desired food products (Lindley, 1991), where it stands for 70% of all food operation (Campbell, 1999). In general for bakery, mixing process is the first main stage to be controlled by the baker in order to yield an optimum batter structure and properties for further baking into the final product so as to obtain a high quality of it. The mixing process is conducted using a domestic, commercial or industrial mixer. With the same formulation and a same piece of machinery mixer, one can yield a different product at the end by changing the mixing process parameters, such as mixing time, speed and incorporation mode.

Generally, the main purpose of mixing is to disperse all the ingredients efficiently and to combine the ingredients into one homogeneous mass. However, without realizing, air is also being incorporated into the food system during mixing. This air inclusion process is known as aeration. This incorporated air content affects food properties including density, volume, viscosity, and texture. Hence, air can be regarded as one of the vital ingredients in highly aerated food as it is important for characterizing its quality. For example, typical air content is 60% in meringues, 35% in sponge cake and 15% in cake batter (Allais *et al*., 2006a).

1.1 Significance of this Study

In general, a consumer's liking of food is because of its flavor, while texture is the reason they dislike the foods (Bourne, 2002). Since texture of bakery product is very dependent on the air content in the product, people has worked towards achieving desired aerated properties to give a better product quality. In this research, the mixing process of a highly aerated food, sponge cake was studied by varying the mixing time, mixing speed and cake loading and optimized to yield a better aerated product.

This work also looks into ways of enhancing the stabilization of gas bubbles in the batter mixing system for cake production using ultrasound technology. When mixing stops, the air content cannot be maintained and will collapse or escape to the surrounding air due to its instabilization which appears in bubbles form in the batter system. This will affect the qualities of the final cake product as the aerated structure of the final product depends on the aerated structure of batter gained in the initial mixing stage. The application of the ultrasound system begins with the set-up of the system to an existing mixer.

Even though the application of ultrasound has been widely tried in food industry in different aspects, the application of high power ultrasound system in cake batter mixing has not yet been explored. Hence, in this research, the effect of ultrasound power and exposure time of the ultrasound assisted mixing system was investigated through the examination on the batter and cake properties.

1.2 Objectives

The general objective of this research is to investigate the mixing process of cake. The ultrasound was introduced to enhance the process to produce a better product. The specific objectives are:

i. to optimize processing parameters which include mixing time, mixing speed and cake loading of a cake batter mixing process,
ii. to set-up an ultrasound bath system which is able to function as an optional aided process during mixing,
iii. to determine the effect of ultrasound aided mixing on aerated and rheological properties of cake batters, and
iv. to evaluate the effect of ultrasound aided mixing on aerated and textural properties of final cake products.

1.3 Scope of Work and Thesis Outlines

The work conducted in this thesis focuses on mixing studies of cake batter. The properties of cake batter were evaluated in terms of density, overrun, rheology, while the baked cake was evaluated in terms of volume and texture. Chapter 2 begins by introducing the types of cake, the functions of each ingredient in cake making, introduction about mixing and aeration. The reviews of previous studies on low and high intensity ultrasound application on food, and the setup of basic components in ultrasound bath and probe system are presented. Besides, the basic theories of measurement analysis are also included and the experimental design methodologies are reviewed.

The materials and methods, equipment used and procedures for analyses conducted in the experiments are described in Chapter 3. The procedure of sponge cake production was also given. The whole research was performed in three sections. In the first section, response surface methodology was used to obtain the optimal experimental condition of batter mixing as control, in terms of mixing time, mixing speed and cake loading. The methods of modeling and surface plots of each response including batter density, cake density, cake hardness, springiness, cohesiveness, gumminess, chewiness, and resilience are presented. Then, the optimal experimental mixing condition was used in the newly set-up independent ultrasound-assisted mixing system. All experimental designs and methods of analysis are stated.

Chapter 4 discusses the first section of the study which is to determine the optimum experimental conditions of cake batter mixing. By using the Box-Behnken design in the Minitab Statistical Software Release 14, the surface regression analysis, modeling, response behavior, optimization and desirability of each response were obtained and discussed. For each response, the correlation of the predicted responses versus the observed responses, and the surface plots are presented.

In Chapter 5, which is the second section of the study, details the set-up of ultrasonic-assisted mixing system. The parts of the system are described and the operating steps of the system are illustrated in a flow diagram. The functions of each component used for the set-up which includes the holding tank, control panel, and ultrasound generator are described. The schematic diagram of the overall picture for the whole system is also provided.

The third section, Chapter 6 presents the findings of power ultrasound aided batter mixing for sponge cake batter at varies ultrasound power ranging from 1 kW to 2.5 kW and ultrasound exposure duration ranging from 3 to 9 minutes. The batter and cake properties with and without ultrasound effect were analyzed and discussed in terms of density, volume, rheology, and texture.

Finally, Chapter 7 concludes the findings on this work and recommendations are listed for further research.

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