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EFFECTS OF DIFFERENT OPERATING CONDITIONS OF AIR FRYER AND CONVECTION OVEN ON THE QUALITY OF MOIST CHOCOLATE CAKE

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By

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Processing parameters in different operating conditions play important roles for producing a good-quality cake. Baking temperature, airflow velocity, and baking time are among the important processing parameters that influence heat transfer mechanisms in the operating conditions during baking process. The purpose of this study is to investigate the effect of processing parameters in different operating conditions of air fryer and convection oven on the quality of moist chocolate cake. The operating conditions: airflow rate (air fryer = 5.11 m/s and convection oven = 0.88 m/s), baking temperature (150 - 170 °C), and baking time (40 - 50 min). Oven temperature, cake temperature, and volume expansion were measured during the baking process. The optimum baking temperature and baking time were determined by using response surface methodology (RSM). Relative height, moisture content, texture, color, and overall acceptability of the cakes were analyzed. Fourier's law model was used to describe the influence of baking temperature and baking time on the internal cake temperature during the baking process. The results showed that higher airflow rate significantly accelerated (p<0.05) the heating process, thus increased the convective heat transfer during baking. An increase in baking temperature with higher airflow produced higher surface cake temperature, internal cake temperature and higher expansion rate, (0.35 to 0.46 cm/min) during baking as compared to the convection oven-baked cake. During high baking temperature, the moisture content reduced by 14.3% using the air fryer and 14.5% using the convection oven. The optimum air fryer-baked cake at 150 °C for 25 min had higher relative height (37.19%), higher moisture content (28.80%), and lower crumb firmness and chewiness (5.05 N and 1.42 N, respectively), lower total color change (ΔE) (6.2) and most preferable in overall acceptance as compared to the convection oven-baked cake. The model of heat transfer on the internal cake temperature for the air fryer had an excellent

correlation with the experimental data (R>0.9) and the maximum errors were less than 10%. Oven temperature profile, cake temperature profile, and volume expansion significantly influenced the baking process, which consequently affected the final cake quality. The use of the air fryer for baking cakes effectively reduced baking time by 40% as compared to the convection oven.

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

KESAN PERUBAHAN KEADAAN PENGOPERASIAN DI DALAM PENGGORENG UDARA DAN KETUHAR TERHADAP KUALITI KEK COKLAT LEMBAB

Oleh

MAZIDAH MIOR ZAKUAN AZMI

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ABSTRAK

Pengerusi : Farah Saleena Taip, PhD
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Parameter pemprosesan bagi keadaan operasi yang berbeza memainkan peranan penting untuk menghasilkan kualiti kek yang baik. Suhu pembakaran, halaju aliran udara, dan masa pembakaran adalah antara parameter pemprosesan penting yang mempengaruhi mekanisme pemindahan haba bagi keadaan operasi semasa proses pembakaran. Oleh itu, tujuan kajian ini adalah untuk mengkaji kesan parameter pemprosesan pada operasi berbeza penggoreng udara dan ketuhar perolakan terhadap kualitikek coklat lembap. Keadaan operasi yang berbeza: kadar aliran udara (penggoreng udara = 5.11 m/s dan ketuhar perolakan = 0.88 m/s), suhu pembakaran (150 - 170 °C), dan masa pembakaran (40 - 50 minit). Suhu ketuhar, suhu kek, dan pengembangan isi padu telah diukur semasa proses pembakaran. Suhu pembakar optimum dan masa pembakaran ditentukan dengan menggunakan kaedah permukaan tindak balas (RSM). Ketinggian relatif, kandungan kelembapan, tekstur, warna, dan penerimaan keseluruhan kek telah dianalisis. *Fourier's law* model digunakan untuk menggambarkan pengaruh suhu pembakaran dan masa pembakaran terhadap suhu dalaman kek semasa proses pembakaran. Keputusan menunjukkan bahawa kadar aliran udara yang lebih tinggi telah mempercepatkan proses pemanasan (p<0.05), dengan itu meningkatkan pemindahan haba olakan semasa pembakaran. Peningkatan suhu pembakaran dengan aliran udara yang lebih tinggi menghasilkan suhu permukaan kek,suhu dalaman kek yang lebih tinggi dan kadar pengembangan yang lebih tinggi (0.35 hingga 0.46 cm/minit) semasa pembakaran berbanding ketuhar perolakan (0.10 - 0.23 cm/minit). Pada suhu pembakaran yang tinggi, kandungan kelembapan berkurang sebanyak 14.3% menggunakan penggoreng udara dan 14.5% menggunakan ketuhar perolakan. Kek yang dibakar menggunakan penggoreng udara pada suhu 150 °C selama 25 minit mempunyai ketinggian relatif tinggi (37.19%), kandungan kelembapan yang lebih tinggi (28.80%), dan kekerasan dan kekenyalan yang rendah (masing-masing 5.05 N dan 1.42 N), jumlah perubahan warna (ΔE) yang rendah (6.2) dan paling disukai dalam penerimaan keseluruhan berbanding dengan kek

yang dibakar di dalam ketuhar perolakan. Model pemindahan haba pada suhu dalaman kek bagi penggoreng udara mempunyai hubungan yang sangat baik dengan data eksperimen (R>0.9) dan ralat maksimum kurang daripada 10%. Profil suhu ketuhar, profil suhu kek, dan pengembangan kek sangat mempengaruhi proses pembakaran yang seterusnya mempengaruhi kualiti terakhir kek. Kek yang dibakar menggunakan penggoreng udara berkesan dengan mengurangkan masa pembakaran sebanyak 40% berbanding dengan ketuhar perolakan.

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Declaration by Graduate Student

I hereby confirm that:

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LIST OF SYMBOLS

T_s	Surface temperature at the center
T_{oven}	Oven temperature
T_{eff}	Effective temperature
T1, T2, T3, T4	Internal cake temperature at different positions
X_1, X_2	Independent variable
Y	Desired value of response
b_0	Constant value
b_1, b_2	Linear coefficient
$b_{1,2}$	Interaction coefficient
b^2_3, b^2_4	Quadratic coefficient
ΔE	Total colour change
*L**	Lightness value
*a**	Redness value
*b**	Yellowness value
p	Significant value
R	Correlation coefficient
R^2	Coefficient of determination
r	Radius of the cake
z	Height of cake from bottom to the top
k	Thermal conductivity
ρ	Density of the cake
h	Heat transfer coefficient
C_p	Specific heat
$C_{p\ sen}$	Sensible specific heat
$C_{p\ lat}$	Latent specific heat
ε	Absolute relative error
T_i	Initial batter temperature
x_i	Mass fraction
ΔH_{eva}	Water vaporization enthalpy
ΔT	Temperature interval
m_w	Total moisture evaporated
λ	Latent heat of vaporization of water
A	Total heat transfer area
t	Baking time
P	Power appliance
Q	Unit quantity appliance
λ_{nm}	Eigenvalue of the zeros of the Bessel function
H_{mn}	Internal cake temperature of the experimental data
A_{mn}	Constant value

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
AACC	American Association of Cereal Chemist
DOE	Design of Experiment
ODE	Ordinary Differential Equations
RSM	Response Surface Methodology
CIE	Internaltional Commission on Ilumintation
SPSS	Statistical Package for the Social Sciences
EC	Energy consumption
L	Length
H	Height
W	Width

CHAPTER 1

INTRODUCTION

1.1 Research Background

Cake baking is involve complex physical, chemical, and biochemical changes during processing. During the baking process of cake, a semi-fluid batter is transformed into a light, porous, readily-digestible, and flavourful product under the influence of heat (Chhanwal et al., 2012). A good-quality cake should be moist and fine-grained, with an even crumb structure, a tender texture, sweet taste, and pleasant flavours and aromas (Conforti, 2014). A proper selection of the ingredients used prior to mixing, as well as processing parameters, are desirable to produce a high-quality cake.

Baking temperature, airflow velocity, and baking time are important operation parameters that influenced on the quality of the final product (Chang, 2006). These parameters mainly involve heat distribution in the oven chamber during baking. During baking, heat is transmitted to the baking product through three heat transfer mechanisms, that are thermal radiation from the heating surfaces, heat convection from the high-temperature air in the oven, and heat conduction from trays to the product's lower and lateral surfaces (Gundu et al., 2012). The combination of heat transfer modes in the oven chamber depends on the product and types of oven used (Therdthai et al., 2004).

Although there are many studies available on the heat transfer phenomenon in industrial baking (Cernela et al., 2014; Hassan et al., 2012; Zareifard et al., 2009), hot air frying has been rarely studied for baking process. This application that uses an air fryer is of particular interest due to operational efficiencies. The air fryer's cooking chamber radiates heat from a heting element close to the food and constantly in motion to promote homogeneous contact between hot air and the product into a airfrying chamber (Arafat, M, 2014; Rahmanet al., 2016). The unique heating mechanisms of an air fryer are applied to cook food through the circulation of rapid air at high speed in a way that mimics the movement and flow of heat current in a cooking chamber to the product (Rahman et al., 2016). The biggest advantage of air fryer heating are reduce energy consumption and time savings, most widely used in home appliances, as well as can be used for various types of food products. The current challenge faced by food technologists and engineers is to improve the quality of air fryer-baked products. This is because there are no scientific publications that describe the heat mechanisms and mass transfer during baking using airfryer. Some of the studies were investigated the effect of air-frying process of fried potato strips and snack instead of bakery products (Arafat, M, 2014; Rahman et al., 2016). Therefore, a better understanding of

this operation is necessary in order to extend its application to bakery industries.

1.2 Problem Statement

In baking process, the effectiveness of oven conditions is mostly influenced by the rate and amount of heat distribution, oven temperature, airflow velocity, and baking time. The inability to properly control oven conditions and insufficient heat supplied might degrade the product quality such as irregular crumb, darker top crust, and under-baked cakes (Conforti, 2014). It can be agreed that there is a correlation between processing parameters and product quality that should be maintained and controlled (Bilgen et al., 2004; Das 2012; Flores-chávez et al., 2014; Palav and Seetharaman, 2007; Shyu et al., 2013).

Numerous studies have been conducted on efficient baking process on large-scale industrial ovens instead of small-scale ovens or household appliances (Bilgen et al., 2004; Khatir et al., 2015; Sevimli et al., 2005; Therdthai et al., 2004). Baking using an air fryer is distinctly different from a convection oven and other types of ovens due to different airflow patterns in the cooking chamber. There are several problems in a convection oven for soft-baked goods such as pastries and certain cakes (butter cake, sponge cake) because the circulated hot air is too harsh on the surfaces of the products, which may cause them to underbaked; meanwhile, for baking using an air fryer, there is no direct heat source on the product (Carrasco, 2016). However, it is not yet clearly understood how the heat mechanisms of air fryer-baked cakes are fundamentally different from those of convective baking. This is because the heat in an air fryer is transferred at very high intensity (APDS, 2016). Therefore, in order to apply air frying energy during baking, strict control over oven temperature must be maintained to avoid notable moisture loss and predictive models are needed to optimize operating parameters of air fryer-baked cakes.

Scientific works on experimental and mathematical baking modelling on various baking oven conditions can be referred (Chhanwal et al., 2012; Hadiyanto, 2013; Lostie, 2002; Lostie et al., 2002; Ploteau et al., 2012; Sakin-yilmazer et al., 2013). The variation of baking temperature, moisture loss, and surface browning during baking was predicted with a good agreement by the fundamental model in heat and moisture transport developed by (Zhang and Datta, 2006). To carefully validate the model, realistic boundary conditions need to be defined for various types of oven designs that will give temperature uniformity throughout the oven and optimized product quality (Khatir et al., 2012).

1.3 Objectives

The aim of the study is to investigate on the influence of processing parameters of air frying conditions on the quality of moist chocolate cake. In order to reach this aim, the specific objectives of this study are as follows:

- To investigate the effect of baking temperature and time of an air fryer and convection oven during baking towards oven temperature, cake temperature, volume expansion and moisture content of cake.
- To examine the optimum of baking temperature and time on the final products.
- To correlate the heat transfer model to describe the influence of baking parameter on the internal cake temperature in the air fryer and convection oven under different airfow.

1.4 Scope of the Research

Figure 1.1 shows the scope of this research. In this study, three phases of work were performed based on the objectives given. The first phase was done to investigate the effect of baking temperature and time of air fryer and convection oven during baking. Then a proper selection of baking parameters was done by optimize the baking parameters on the final products using Response Surface Methodology (RSM).

The final phase of this research was conducted to correlate the heat transfer model in order to describe the relationship between baking temperature and the internal cake temperature based on the data obtained from the first phases. Fourier's law was applied and the physical properties adapted from previous studies were used. The model was verified with the experimental data and accurate predictions of temperature profiles were obtained. Overall, the scope of this study is clear as the resulting outcomes can be capitalized as guidelines for bakery industries to consider the broad range of operating conditions of baking process that might be experienced by other baked products during rapid airflow heating.

1.5 Thesis Outline

The introductory chapter briefly reviews the background of studies of baking process, the influence of processing parameters, operating conditions, and how the usage of an air frying system could be applied in baked products. The problem statement and objectives of the research are given in this chapter.

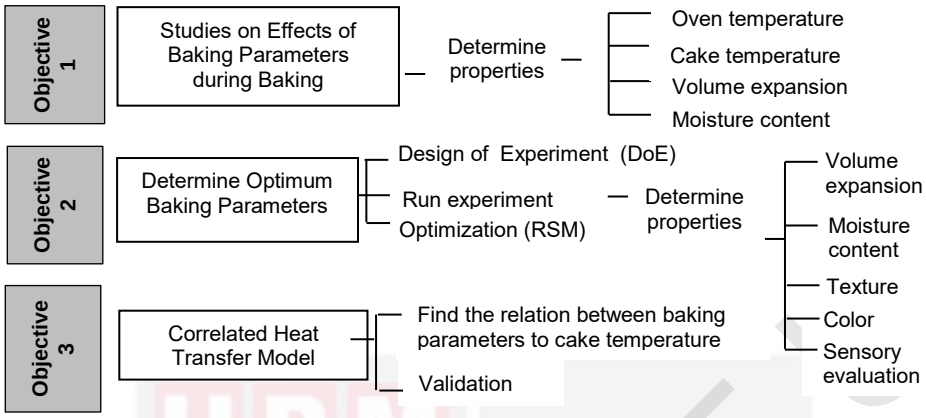

Figure 1.1: Scope of Research

Chapter 2 presents an overview on previous research works in various areas relevant to this research. The literature starts with the classification of cakes, followed by cake baking stages, and classification of baking ovens. The effect of heat and mass transfer during baking and the effect of processing parameters are also reviewed. This chapter also reviews previous findings related to the optimization of processing parameters on the quality of baked products.

Chapter 3 describes the raw materials and equipment used in performing this research. The methods of all physical characteristics including volume expansion, moisture content, texture and colour, as well as sensory evaluation are presented. Heat transfer parameters of cake baking are also identified in this research.

Chapter 4 presents the results and discussion on the effect of baking temperature, time and airflow on the temperature profile of oven temperature, cake temperature, and volume expansion during baking. In addition, this chapter also discusses the optimization of baking parameters on the quality of air fryer-baked cakes and convection oven-baked cakes in terms of relative cake height, moisture content, texture, colour, and overall acceptance. The heat transfer models for cake baking and validation of the models are also analysed and discussed in this chapter.

Chapter 5 summarizes all findings and recommendations for further works in the area.

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