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RESEARCH ARTICLE

Experimental studies and mathematical modeling on the effects of rapid airflow and baking temperature during baking

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ABSTRACT

Rapid airflow in oven will influence the heat transfer in baking process therefore the purpose of this study is to experimentally and numerically investigate the effects of operating conditions on the heat transfer mechanism and volume expansion during baking. Cakes are baked in an air fryer and convection oven with constant speed 5.11 m/s and 0.88 m/s respectively at 150, 160, 170 °C in different baking times. A heat transfer model was defined to describe the influence of baking temperature on internal cake temperature by Fourier's law. It was observed that the presence of rapid airflow (air fryer) and increment in oven temperature yielded an increase in volume expansion but produced a less moist product. Cakes baked in the presence of rapid airflow at 150 °C were moister but with little volume expansion in the cakes compared to convection oven-baked cakes. Significant correlation between the numerical models with experimental temperature profiles were recorded during complete cake baking process.

Keywords: Air fryer; Convection oven; Heat transfer; Oven temperature; Rapid air

INTRODUCTION

Cake baking is a processing technique that involves complex physical, chemical, and biochemical changes occurring in the productand these changes determinethe final quality of the product. A good quality cake is defined as a moist and fine-grained (cake), with an even crumb structure, a tender texture, sweet taste, and pleasant flavours and aromas (Conforti, 2014). Several factors influence the quality of a product during baking,and the major factors are operating parameters, mainly baking temperature, airflow velocity, and baking time (Chang, 2006). These parameters affect heat distribution in the oven chamber during baking.

Conventionally, heat is transmitted to the product during baking through three well-known heat mechanisms, namely thermal radiation from the heating surfaces, heat convection from the high-temperature air in the oven, and heat conduction from baking trays to the product's lower and lateral surfaces (Gundu et al., 2012). The combination of heat transfer modes in non-homogenous heating conditions of the oven is able to cause a degradation in product quality resulting in irregular crumb structure, darker top crust, and under-baked cakes (Conforti, 2014). In correspondence, previous studies suggested that operating the oven with an airflow mode is a good option to accomplish a uniform heating process (Therdthai et al., 2004; Xue and Walker, 2003).

Presence of rapid airflow in an oven chamber generally affects heat distribution by increasing the percentage of convective heat in the oven chamber (Zareifard et al., 2009). Previous investigations have been conducted on temperature distribution and airflow by experimenting on various types of baking ovens (Lostie, 2002; Ureta et al., 2016; Andresen, 2013), but there have not a clear statement of how heat mechanisms of rapid airflow and temperature control affect the cake during baking.

Mathematical modelling in a study functions to explain the baking process and to quantify the interactions between the product and the oven conditions, and the changes in the baked

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product (Sakin et al., 2007). Many studies have reported the effects of oven conditions on the product quality, especially on bread quality (Chhanwal et al., 2012; Sakin et al., 2007; Mondal and Datta, 2010; Therdthai et al., 2004), however, the modelling of cake baking is still lacking due to various types of cakes that can be studied. Sakin-Yilmazer et al. (2012) examine the heat and mass transfer during the baking of convective ring cake batter using an implicit finite differences method. They found that the model was validated when compared with the experimental data. Andresen (2013) and Ferrari et al. (2012) simulated biscuit baking process using a finite elements and 2D geometry, and the models produced accurate predictions of the thermal profiles. Another study by Marc et al. (2020) concerns a new design of transient heat flux during the baking of cereal batter by contact heating. The Inverse Heat Conduction Problem (IHCP) was used to estimate the transient heat flux transferred from a hot metallic surface to a product. The value of total energy supplied to the dough deduced from the time integration of the estimated heat flux. Purlis (2019) predicted very well the critical time of bread for a wide and common range of operating conditions by using three simple methods (two heat transfer models and one regression equation).

Based on the previous study, the some of the mathematical models can be used to study the heat transfer mechanisms during baking under rapid airflow such as air fryers. The air fryer has a rapid heating rate which involves expansion during baking, changing from a fluid state to a porous solid state, and the occurrence of a structural transformation. Therefore, the aim of this study is to experimentally and numerically investigate the effects of operating conditions on the heat transfer mechanism and volume during baking towards the moisture content of the cake. Heat transfer was represented using Fourier's law and physical properties adapted from previous studies. This investigation is conducted to correlate the heat transfer model with the experimental that describe the influence of baking temperature on internal cake temperature during baking.

MATERIALS AND METHODS

Cake preparation

A modified chocolate moist cake recipe was used. The following ingredients were weighed using a digital balance (Excell, ALH3, Japan): cake flour (7.0%), cocoa powder (6.3%), castor sugar (12.5%), evaporated milk (20.3%), condensed milk (24.6%), baking powder (0.2%), soda bicarbonate (0.3%), vegetable oil (16.8%), eggs (11.3%) and vanilla essence (0.5%). All ingredients were purchased from Harmoni Ingredients Supply, Serdang, Malaysia. The batter was prepared according to a standard creaming method using a hand mixer (Panasonic, MK-GBI, Taiwan). After mixing, the batter was poured into a round stainless steel baking pan with a diameter of 6 inches.

Moist cake baking

Baking tests were carried out in two different electric cooking ovens: an air fryer (Philips, HD9220, China) and a convection oven (CEO-TS42L, US). The air fryer has dimensions of 0.38 m x 0.29 m x 0.32 m (*L* x *W* x *H*) and a fan at the top of the heating element which forces air at a constant speed of 5.11 m/s (this value was measured by Vane anemometer, TESTO 416, TESTO, UK). The convection oven has dimensions of 0.6 m x 0.42 m x 0.44 m, a heating element rod at the top and bottom and a fan at the right side of its chamber with a fixed air velocity of 0.88 m/s. Two series of experimental runs were conducted for both ovens with nominal oven temperature set at 150°C, 160°C and 170°C, respectively. In each of the temperature test, the oven was preheated for several minutes until the temperature set for each condition was reached.

Temperature measurement

The moist cake temperature profile and oven temperature were recorded during the baking process using K-type thermocouples connected to a data logger to measure the air temperature inside the oven and the internal temperature of the cake. The oven temperature was recorded by placing a thermocouple at the side of the mould. Four thermocouples were inserted inside the batter in a vertical position to measure the cake internal temperature profile. The placement positions of the four thermocouples were pointed according to the observation during preliminary experiment, in which it was noted that when the baking process starts the initial center of the batter does not show the lowest temperature point. Thus, four thermocouples were inserted inside the mould during the whole experiment at different positions. Therefore, the thermocouples were positioned at the axial axis of the sample ($r = 0$) at 0.035 m (T1) and 0.015 m (T2), $r = 0.03$ m at 0.015 m (T3), and the fourth thermocouple (T4) was positioned near the mould wall ($r = 0.05$ m), 0.03 m from the bottom of the mould as shown in Fig. 1. Each baking condition was replicated twice.

Volume expansion measurement

Volume expansion was measured during the baking test. The height measurement was measured at 5 points along the radius of the cake. During the baking process, the height of each of the point on the cake was measured at 5 minute intervals from the left side to the right side point as shown in Fig. 2. The cake height measurement was carried out using Vernier calipers.

Moisture content measurement

The initial and final moisture contents of the cake were measured using a moisture analyser (Infrared moisture

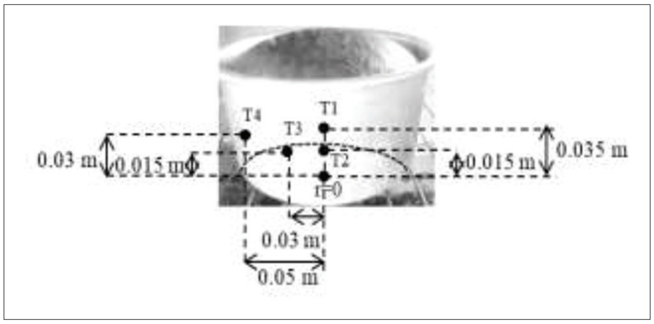

Fig 1. Measurement of cake temperature of moist cake.

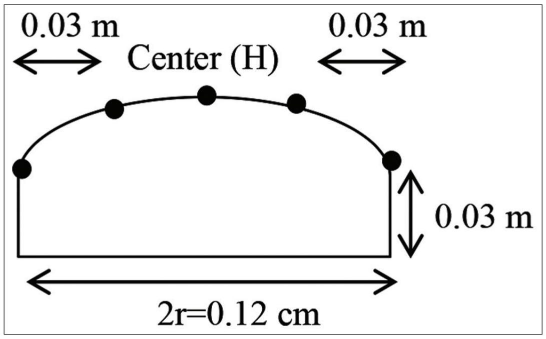

Fig 2. Measurement of volume expansion of moist cake.

balance, MX-50, A&D Weighing, Adelaide) under standard drying conditions. The results obtained by this instrument were certified under the standard oven method for total solids and moisture in baked products, in overnight drying at 105 °C (AOAC, method no. 934.06, 2000) The initial moisture content in the batter was measured by pouring 2 g of the batter sample on an aluminium dish and heating the sample.

The final moisture content in the cake was analysed using a baked cake that was formerly cooled at room temperature for 1 h. The cake was then cut into halves and a 2-cm sample was cut out from the centre of the cake crumb as shown in Fig. 3. The samples were placed in a sealed bag to prevent moisture loss. The weight needed for the test was 2 g for each sample. Two identical experiments were conducted for each baking condition. The data of moisture content were based on wet sample mass. The moisture content in all samples was recorded.

Mathematical model description

The numerical heat transfer mechanism in a moist cake during baking can be described by the two-dimensional (in *r* and *z* directions) unsteady state heat transfer equation with appropriate boundary conditions.

Fourier's equation is used for unsteady state heat conduction with constant thermophysical properties (Ureta et al., 2016). The energy balance in the system can be expressed in a cylindrical coordinate from theEq. (1):

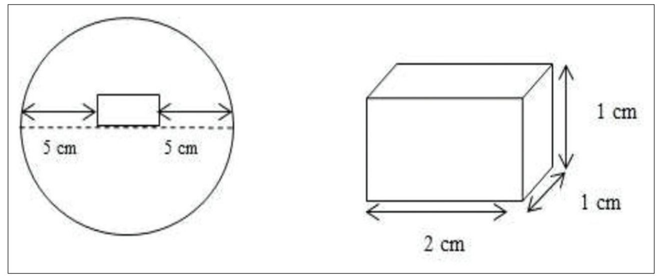

Fig 3. Sample of baked cake for moisture content measurement.

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\left(\frac{1}{r} + \left(\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r_2}\right) + \frac{\partial^2 T}{\partial r^2}\right) \quad (1)$$

where T (°C) is the temperature inside the product, r is the distance in the radial direction (m), z is the distance in the upward direction (m) and ρ, Cp and k are the product density (kg m-3), the specific heat (J/kg°C) and the thermal conductivity (W/m°C), respectively. A uniform initial temperature distribution throughout the cake batter was assumed as $t = 0$, $T = T_i - T_{oven}$, where T_i is the initial batter temperature (°C) and T_{oven} is the temperature inside the oven chamber (°C).

The boundary conditions on the product surface that considers convection heat transfer are written as Eq. (2):

$$K\frac{\partial T}{\partial t} = h(T_{oven} - T) \quad (2)$$

where h is the convective surface heat transfer coefficient (W m^{-2}°C^{-1}).The heat transfer coefficient, h was estimated as suggested by Carson et al., (2006) and is written as Eq. (3);

$$h = \frac{m_w \lambda}{A(T_{oven} - Ts)t} \quad (3)$$

where m is the total moisture evaporated (kg) during complete baking, λ is the latent heat of vaporization of water (J/kg), A is the total heat transfer area (m^2), T_s is the surface temperature (°C), and t is the baking time (min) of 25 min for the air fryer and 35 min for the convection oven.

Thermophysical properties

Thermophysical properties in cakes such as density, specific heat and thermal conductivity are assumed to be constant and are given as functions of internal temperature. To avoid the discontinuity produced by phase change, internal temperature is assumed to be 100 °C in the expression of thermophysical properties. Density, specific heat, and thermal conductivity of the product were measured independently following well-established methods adopted by Ureta et al. (2016). The thermophysical properties are briefly presented as Eq. (4-8):

Density, ρ:

$$\rho = \begin{cases} 1013 - 6.13 & T < 100 \\ 400 & T \geq 100 \end{cases} \tag{4}$$

Specific heat Cp:

$$C_p = C_{p\,sen} + C_{p\,lat} \tag{5}$$

$$C_{p\,sen} = \sum \chi_i C_{pi} \tag{6}$$

$$C_{p.lat} = \frac{\Delta Hevamwater}{\Delta T} \tag{7}$$

Sensible heat was calculated based on the initial batter composition, where x_i is the component i mass fraction; $C_{p,water}$ = 4178.3, $C_{p,protein}$ = 2031.9, $C_{p,CHO}$ = 1585.7, $C_{p,fat}$ = 2011.0, and $C_{p,ash}$ = 1128.9 are constant values expressed in J/kg·°C. ΔH_{eva} is the water vaporization enthalpy (J/kg), m_w is the amount of water evaporated (kg), and ΔT is the temperature interval (assumed for the phase change of 5 °C).

Thermal conductivity, k :

$$K = \begin{cases} K_o + 0.18x10^{-0}T & T < 100 \\ 0.2 & T \geq 100 \end{cases} \tag{8}$$

where k_0 is considered as the thermal conductivity of the product's initial water content.

Numerical solution

From the predictive model (Eq. 1-8), the heat transfer problem was defined by partial differential equations. In this work, a two-dimensional interpolation function in a cylindrical coordinate method was applied. The data interpolation and statistical analysis were performed using Microsoft Excel 2007 (Microsoft Corporation, USA). The first-order ordinary differential equation (ODE) was used to solve a non-homogeneous equation (i.e., time equation).

Validatio

In order to verify the model, the experimental data (V_{exp}) was compared with the predicted values (V_{pred}), and the absolute relative error (ε, %) between them was estimated (Eq. 9):

$$\varepsilon = \frac{1}{n} \sum_{i=0}^{n} \left(\frac{V_{exp} - V_{pred}}{V_{exp}} \right) x100 \tag{9}$$

RESULTS AND DISCUSSION

Oven temperature profile

The oven temperature profile was built to compare the baking process using an air fryer and a convection oven. The oven temperature profiles for the air fryer and convection oven at 150 °C, 160 °C, and 170 °C during baking are shown in Fig. 4(a) and (b). The results show that the oven temperature during baking presents a periodic behaviour. It is noticeable that the amplitude of oscillation was also greater when baking with an air fryer. Higher airflow velocity in a small space cooking chamber at different baking temperatures produced larger amplitude oscillations, thus a shorter baking time is required. The usage of an air fryer also significantly accelerated the heating process (p< 0.05) which is caused by increased convective heat transfer, hence affecting the temperature profile (Zareifard et al., 2009). Baking process using a convection oven caused a slow increment in the oven temperature during baking. This might be due to] the airflow circulated slowly, which decreases heat transfer rate in the oven chamber.

Variations in the amplitude of oscillation has been recorded (in a former step) and each baking condition is characterised with an effective temperature] [T_{eff}, *full lines*, Fig. 4 (a) and (b)]. T_{eff} is calculated as the average temperature values recorded in the chamber of each baking temperatureand the value was found to be close to the nominal baking temperature ($T_{nominal}$). It was found that average T_{eff} in air fryer at 150°C was higher than the convection oven which values 154.5 °C. While at 160 °C and 170 °C being slightly less than set temperature in the convection oven. This result was hypothesised to be caused by uncontrolled environmental temperature in the cooking chamber.

It was also observed that a smaller cooking chamber induced a higher effective temperature, since it is more efficient as less energy is used than in the larger ones. A bigger oven with a rectangular shape has more tendency to lead to a natural rise and fall in the heat level caused by uneven temperatures inside the chamber (Carrasco, 2016). Ureta et al. (2016) found that electric domestic oven resulted in lower effective temperatures due to the usage of natural convection (no airflow) during baking, which is in good agreement with the results of the present study.

Effects of baking temperature and airflow on the internal cake temperature

The temperature profiles of an air fryer-baked cake and a convection oven-baked cake at different thermocouple

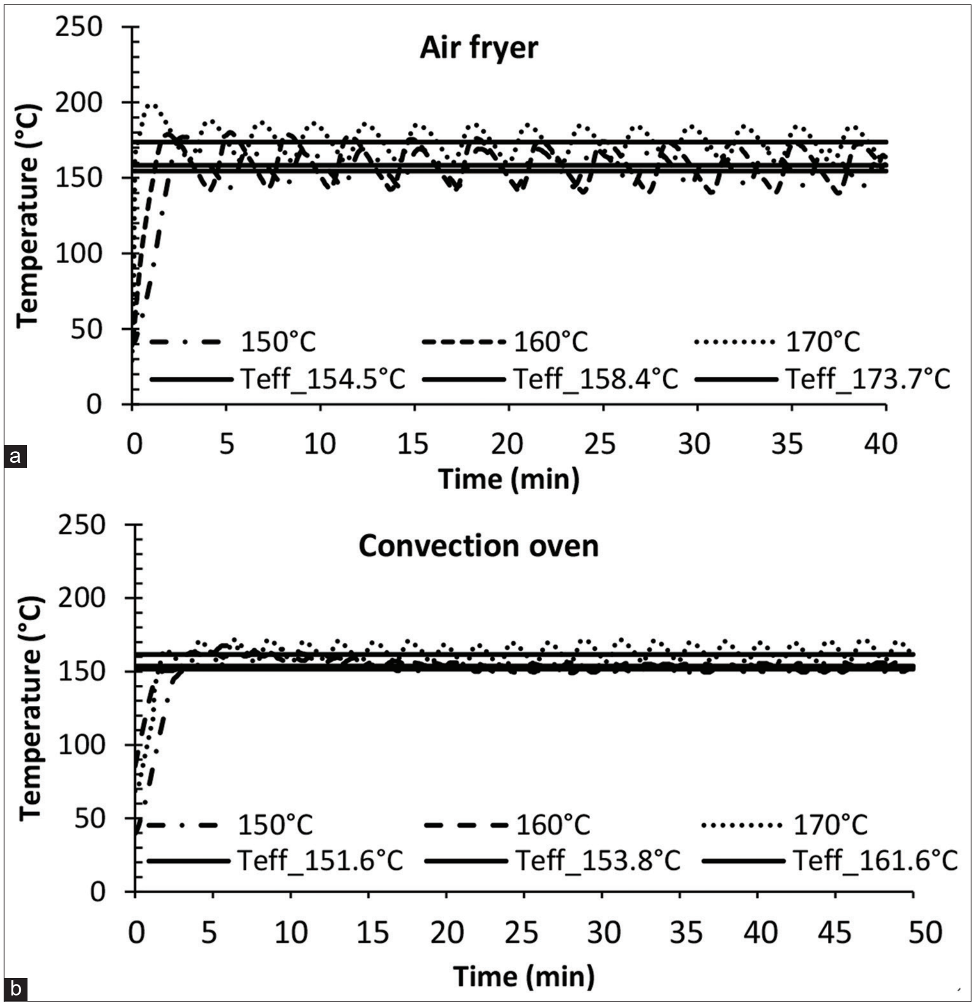

Fig 4. Temperature profile of oven chamber and effective oven temperature (T_{eff}, *full lines*) during cake baking in a) an air fryer and b) convection oven at baking temperatures 150 °C, 160 °C and 170 °C (*dashed lines*).

positions (T1, T2, T3 and T4) are shown in Fig. 5. Initially, both baking modes showed rapidly increasing temperatures at T1 with values of over 60 °C. This is due to the exposure to radiant heat from heating element while convection heat is moving in a strong airflow through the open bottom of the oven chamber yielded this observation.

During the second stage of baking with the air fryer, all the temperature points start to increase rapidly reaching approximately 93 °C. The temperature slowly increased to the 95-98 °C range, and then at final stage of baking cake reached to the final stabilisation of plateau temperature close to about 98-100 °C. In contrast, convection oven required 1.4 times longer than air fryer to reach 95 °C. This means that the temperature of the cakes baked using the air fryer was significantly ($p < 0.05$) higher than those baked using convection oven. The baking process is considered complete when the final temperature reaches 100 °C during the third stage. At this baking stage, the product has transformed into a stiffening structure with the formation of a dry crust layer (Ousegui et al., 2012). Baking process was completed in a 30-35 min range for air fryer-baked cakes and 45 min for convection oven-baked cakes. Increments in baking temperatures (above 170 °C), faster heating rate and baking time are resulting in a harder cake crumb, over-cooking and burnt cakes (Patel, Waniska and Seetharaman, 2005). Notice that at higher heating rates (air fryer, effective oven temperature 173.7°C) during the third stage of baking process, the crumb just below might not have complete crumb development even when the crust had reached plateau temperature (Fig. 6). During the continuous increment of the internal temperature (2nd stage), the rate of heating of the product can be estimated. In the air fryer, average internal heating rate of the cake (T1, T2, T3 and T4) presented values within the range of 4.8 - 5.6 °C/min for baking temperatures between 150 °C to 170 °C. In contrast, the rate of heat penetration was lower (2.9 - 3.2 °C/min) when convection oven was utilised. A high heat penetration rate was found (10.8 °C/min) in the second stage of baking of sponge cake in an electric oven with the presence of a 1.6 m/s

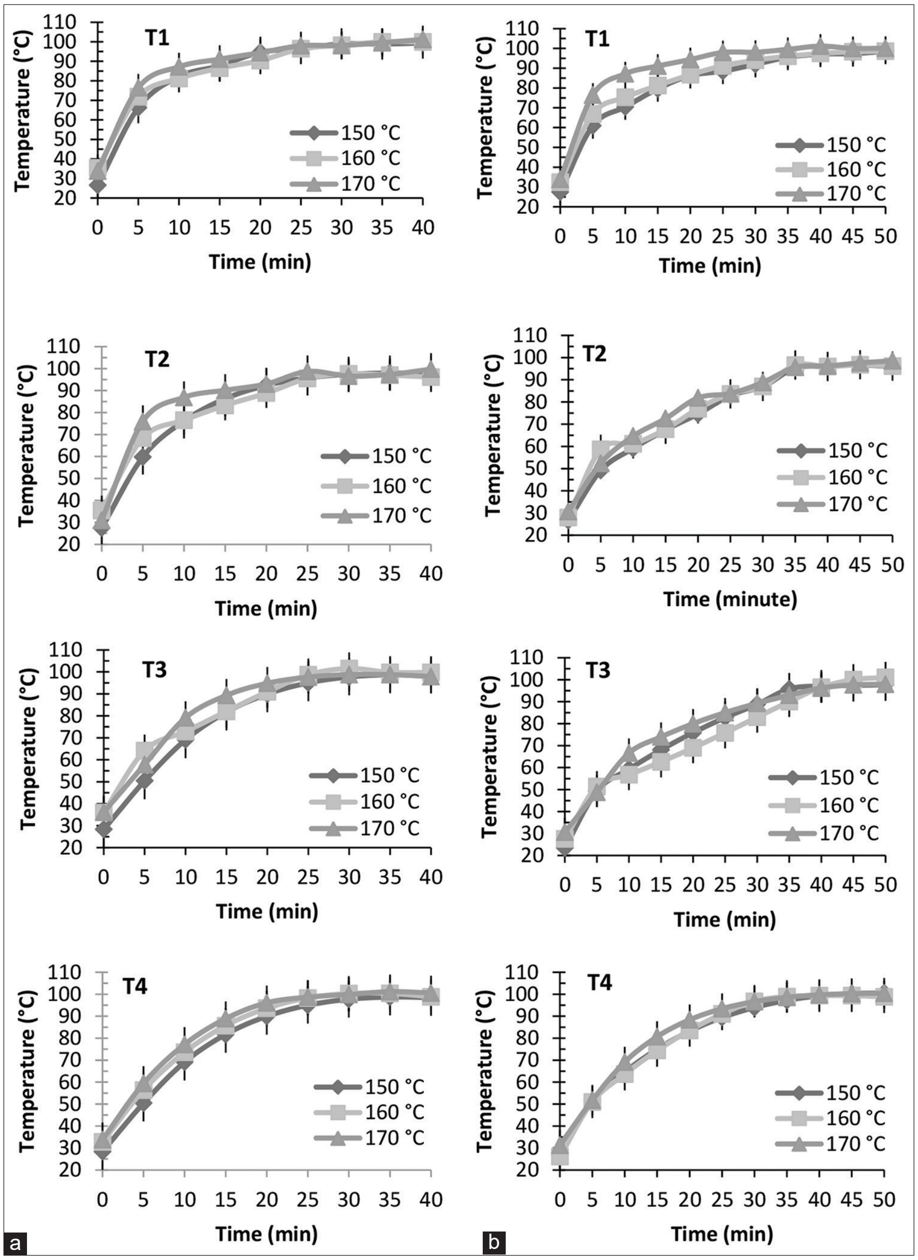

Fig 5. Temperature profile of cake baked in a) air fryer and b) convection oven condition at different position.

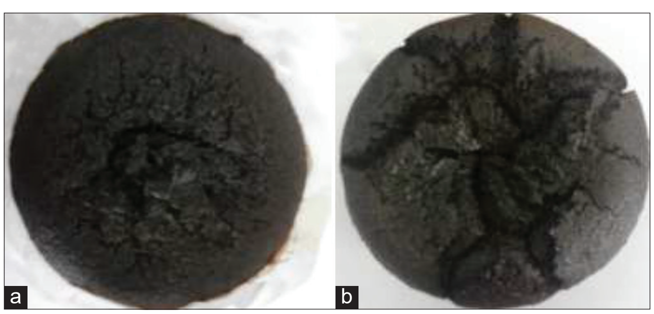

Fig 6. Top surface cake at different temperature during final stages, air fryer condition, effective oven temperature a) 154.5 °C and b) 173.7 °C.

airflow velocity at a temperature of 200 °C (Baik and Marcotte, 2002).

Effects of baking temperature and airflow on cake expansion

Internal cake temperature affects the expansion of the cake during baking as the increment in batter temperature during baking process causes the thermal expansion of vapour and raises the saturation pressure of water within the batter, which leads to a local expansion (Mondal & Datta, 2008). Fig. 7 presents the percentage of relative heights of the air fryer-baked cake and convection oven-baked cake, which reflects volume expansion of the cakes. During the first stage of baking, different baking temperatures and airflow in the ovens did not cause significant differences ($p > 0.05$) in the changes of cake height. The occurrence was observed because heat has

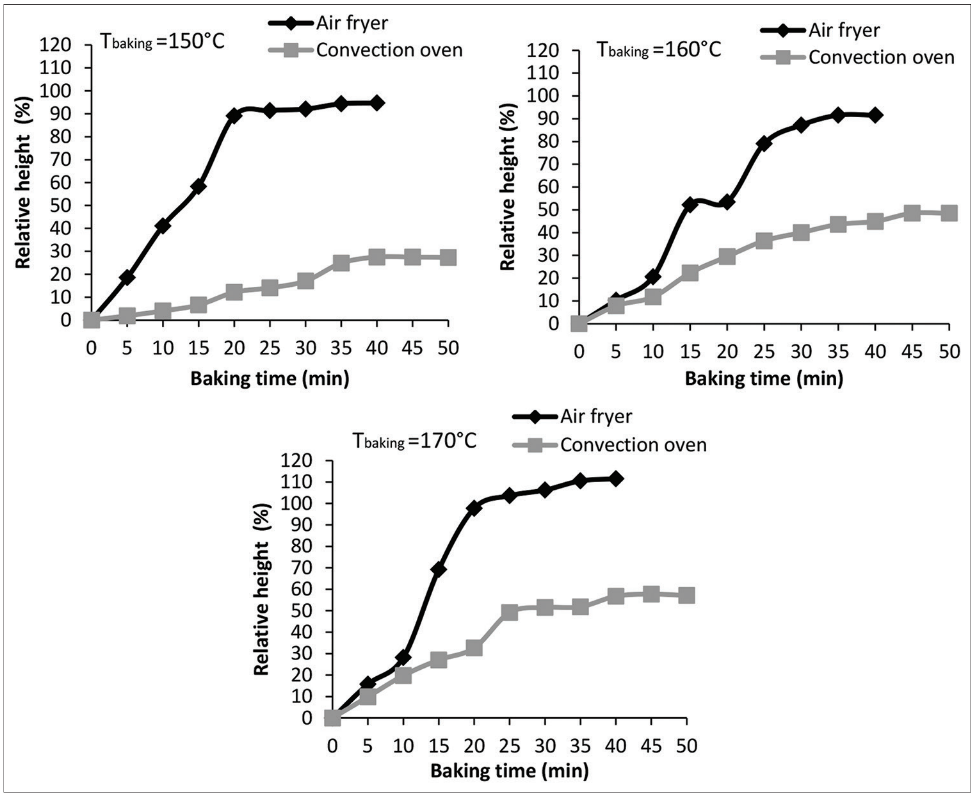

Fig 7. Percentage of relative height baked in an air fryer and a convection oven.

just started to slowly penetrate into the batter and caused only a little expansion.

In this study, the air fryer-baked cake showed a higher percentage of cake height increment, which ranged from 94.7% to 110% during the second stage of baking process. Increment of internal cake temperature produces greater volume expansion of the cake during baking. In an air fryer, the presence of rapid air flow increases convective heat transfer due to rapid heating and leads to the increment in volume expansion. The results also showed that the air fryer-baked cake had a higher rate of expansion at the centre of the cake, which ranged from 0.35 to 0.46 cm/min during the second stage of the baking process. In contrast, the convection oven-baked cake had lower expansion rates of 0.10, 0.19, and 0.23 cm/min at baking temperatures of 150, 160, and 170 °C, respectively, during the second stage of baking process. The expansion rate at the centre of the cake was 0.20 cm/min at 175 °C and 0.27 cm/min at 205 °C as reported by HadiNezhad and Butler (2010).

The investigation on baking temperatures showed that a high baking temperature produced a greater cake volume increment than cakes baked at a low temperature. This experimental behaviour was previously reported by Lara et al. (2011) who studied the specific volume of corn biscuitsunder a natural convection oven (190, 210, 230 and 250 °C). They found that at higher temperatures, baked biscuits showed a higher volume expansion and the surface dried crust showed when the expansion period has ended. The maximum relative height of the cake increases along with the increment of baking temperature and a more rapid airflow rate of the oven. The result was a drier crust and a less moist cake.

Effects of baking temperature and airflow on cake moisture content

Baking with rapid airflow resulted in faster volume development and produced a higher increment of cake expansion at high baking temperatures, however it also changed other physical characteristics of the cake such as moisture content. As the internal temperature of the cake increases along with the baking temperature, the moisture content of the cake also decreases when baked at high temperatures in the air fryer. Table 1 represents the percentages of moisture content in the cakes taken as the internal temperature approached 100 °C. The percentages of moisture content in the air fryer baked-cake and convection oven-baked cake was found within the range of 26% to 28% on a wet basis while the initial moisture content of the batter was 31.03 ± 1.12%. Similar with previous study by Shahapuzi et al. (2015) found that when baking with and without airflow, the moisture content of cake batter ranged from 25.27% to 33%. Although different process conditions, the moisture contents of cakes baked

Table 1: Percentage of moisture content in wet basis of cake at different baking temperatures

	Air fryer-baked cake			Convection oven-baked cake		
Moisture content (%)	150°C	160°C	170°C	150°C	160°C	170°C
	28.19±0.06	26.92±0.47	26.56±0.24	27.26±0.04	26.57±0.02	26.52±0.06

still lies within the range of accepted moisture content of moist cakes which is 25-30% (Cauvain and Young, 2010).

At 170 °C and 160ºC, the air fryer–baked cake and the convection oven-baked cake showed a lower moisture content compared to the lower baking temperature of 150 °C. Results obtained were caused by excessive water evaporation due to increased baking temperature causing the cake to become dry, thus the taste and the quality of the product has been reduced. Cakes baked at 160 °C usingair fryer showed higher value of standard deviation at 0.47%. There were no significant effects ($p > 0.05$) of interaction between different modes of airflow and baking temperatures. The result of the moisture content was 26.52 - 28.19%, which still lies within the range of accepted moisture content of 25-30% for moist cakes (Cauvain and Young, 2010).

Numerical results

Experimental results show that the presence of airflow influenced operative conditions (oven temperature and air flow) and transfer mechanisms from the oven chamber to the product during baking. Therefore, this study's purpose is to describe the influence of operative conditions on the internal cake temperature during baking through a mathematical model. The development of the internal cake temperature profile model at four different positions [T1 (0, 0.035); T2 (0, 0.015); T3 (0.03, 0.015); T4 (0.05, 0.03)] was calibrated only by experiments at 150°C for air fryer-baked cakes and convection oven-baked cakes. Other baking temperatures were not presented since they produced moist cakes of insufficient quality.

By considering the variable thermophysical properties and all boundary conditions aspect, the mathematical model described by Equations 1 to 3 is solved to simulate heat transfer during baking. The constant density,specific heat and thermal conductivity values of the cake were given as functions of internal temperature as the cake was considered as a solid product. Heat transfer coefficient (h) calculated under these process conditions were observed as 49.8 W/m^2°C and 35.16 W/m^2°C for air fryer-baked cakes and convection oven-baked cakes, respectively. These coefficients are close to the 20-50 W/m^2°C for natural convection oven heating (Demirkol et al., 2006).

Fig. 8 shows the experimentally observed and numerically predicted internal cake temperature profiles (dashed lines) at T1, T2, T3, and T4 using the estimated parameters for baking in the air fryer and convection ovens. In general terms, the numerical internal cake temperature profile was in good agreement with the experimental temperature profiles of air fryer-baked cakes and convection oven-baked cakes at T1, T2, T3 and T4 during the first stage of baking. During the second and third stages of the baking process in the air fryer, the numerical profiles of the internal cake temperature (T1_num, T2_num and T3_num) increased rapidly to the plateau temperature (98 °C – 100 °C). On the contrary, T4 shows increased slows down to the final stabilizers near 100 °C, given that T4 is close to the pan. As expected, the presence of rapid airflow heating in the air fryer enhances water evaporation from cake surface to the core and results in a faster rise in the internal cake temperature compared with convection oven conditions. The agreement between model and experiment is consistent with the results reported in previous studies (Lostie et al., 2002; Sakin et al., 2007).

In a previous work of the authors (Ureta et al., 2016), sponge cake baking process in three operating conditions (natural and forced convection and steam addition) was studied experimentally in terms of temperature and volume expansion within the product. The process was modeled mathematically using finite elements, using a deformable grid. The numerical results were compared with the experimental temperature and volume expansion where acceptable agreement was observed. They stated that the last region to achieve a correct degree of baking is the one near the crust around the axial axis which is at the center of the cake. Consequently, their minimal baking time was defined once the internal cake temperature had reached 95-98 °C. Baking time was also strongly affected by the effective oven temperature. It was suggested that the model is a useful tool to calculate in a different process.

The difference between the experimental and numerical temperature profiles is compared by absolute relative error, ε%; where values of ε% below 10% indicate a good fit between the results (Sakin-Yilmazer et al., 2012). The average values of ε% were 2.9% (T1), 3.2% (T2), 3.0% (T3), and 3.2% (T4) for air fryer-baked cake and 2.3% (T1), 3.9% (T2), 5.2% (T3), and 3.2% (T4) for convection oven-baked cake. These errors are in the range of values mentioned by other researchers during cake baking in different ovens (Ureta et al., 2016; Sakin-Yilmazer et al., 2012). The predicted internal cake temperatures were in good agreement

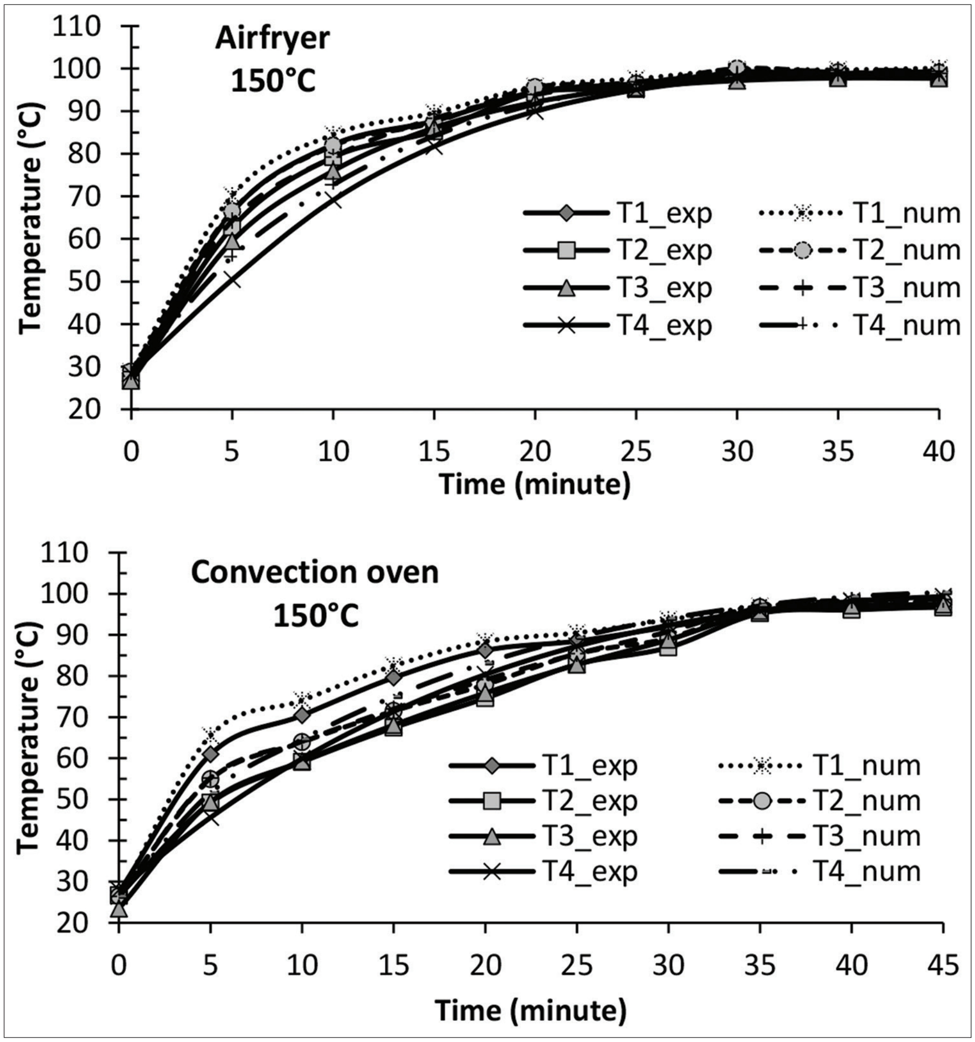

Fig 8. Experimental temperature profiles (full lines) predicted (dashed lines) during the baking of the convection oven-baked cake.

with the experimental temperatures, especially for the air fryer-baked cake at T1.

Consequently, all these observations point out that the suggested model can be used to predict the internal cake temperature of a moist cake during baking. In the future, this will allow predictions of baking time of moist cakes in different baking conditions.

CONCLUSION

In this work, the moist cake was studied by considering two different baking modes (air fryer and convection oven) and three different oven temperatures (150, 160 and 170 °C). A mathematical model was used to describe the process of heat transfer and volume expansion during baking. From the results obtained, a smaller cooking chamber (air fryer) with the presence of rapid airflow induced a higher effective temperature (T_{eff}), as it is more efficient and uses less energy in comparison with a convection oven. The high ambient temperature inside the air fryer increased the internal cake temperature of air fryer-baked cake. The rate of heat penetration into the cake is higher in air fryer than in convection oven. The volume expansion rate of air fryer-baked cake is double the convection oven-baked cake during baking. The final moisture content of the air fryer-baked cake results in a moister cake when baking at lower baking temperature compared to cakes baked in a convection oven.

The estimation of parameter values including the density, thermal conductivity and heat capacity could be considered as reliable and precise in the numerical solutions. The numerical results at all positions of the thermocouples at a lower temperature (150 °C) agreed well with the experimental results recorded during baking.

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Author's contributions

Mazidah conducted the research work, interpreted the data, and prepared the manuscript, Farah and Anvarjon provided the guidance for the experimental design and participated in the design of the modeling. Farah involved in revising the paper critically. All authors read and approved the manuscript.

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