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EFFECTS OF TEMPERATURE AND AIRFLOW ON VOLUME DEVELOPMENT DURING BAKING AND ITS INFLUENCE ON QUALITY OF CAKE

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Abstract

Volume and texture of cake are among the important parameters in measuring the quality of cake. The processing conditions play important roles in producing cakes of good quality. Recent studies focused more on the formulation and the manipulation of baking temperature, humidity and time instead of airflow condition. The objective of this study was to evaluate the effects of baking temperature and airflow on the volume development of cake and final cake quality such as volume development, firmness, springiness and moisture content. The cake was baked at three different temperatures (160°C, 170°C, and 180°C), and two different airflow conditions. Baking time, height changes of batter, texture and moisture content of cake were compared to identify the differences or similarities on the final product as the process conditions varied. Results showed that, airflow has more significant effects towards the product quality compared to baking temperature especially on baking time which was 25.58 - 45.16%, and the rate of height changes which was 0.7 mm/min. However, different baking temperatures had more significant effects towards volume expansion which was 2.86 – 8.37% and the springiness of cake which was 3.44% compared to airflow conditions.

Keywords: Temperature, Airflow, Volume expansion, Texture, Baking process.

1. Introduction

Baking is a complicated process and optimum conditions vary with the type of food being prepared and even with specific formulae within the food type [1]. Baik et al. mentioned that final product properties are not only affected by the formulation (choice and quantity of ingredients) but also by processing conditions

[2]. Basically, processing conditions affect starch and protein properties and hence the food's quality. It resulted from the heat that is being transferred into the food causing changes in protein denaturation and starch gelatinization both within the product and its surface [3].

Traditionally, baking process in an oven is controlled by manipulating the time and temperature. However, in this study, by having some modifications on the convection oven, the airflow can be manipulated. The presence of airflow creates forced convection process that resembles the convection oven while the absence of airflow creates natural convection process that resembles the conventional oven or static oven. Presence of airflow affects the temperature distribution by evenly distributing the hot air inside the oven chamber rather than without airflow. Hence, the setting temperature can be reduced to get the same food quality because the heat flux in the oven chamber is larger [4].

As normal practices in baking processes, too high baking temperature will cause high crust colour, lack of volume with peaked tops, close or irregular crumb, and probably all the faults due to under-baking. However, too low baking temperature will cause pale crust colour, large volume and poor crumb texture. A good quality cake should have large volume with a fine uniform moist crumb besides having a good colour and sheen, a good flavour, and the general appearance should be attractive, with a good eye appeal [4-5]. During baking, volume expansion, enzymatic activities, protein coagulation and partial gelatinization of starch in batter are the most apparent interactions and affect the final product quality such as firmness, springiness and moisture content of crumb [6].

There have been numerous studies on the effects of process conditions such as baking temperature, types of oven used and baking time to the final product quality such as volume expansion, texture and moisture content in cakes [7, 8], bread [9, 10] and biscuits. Other than that, many researchers have studied the effects of product formulation such as type of flour used, types of resistant starch, etc., towards the final product quality [7, 11]. However, only a few studies concentrated on comparing product qualities by manipulating baking temperature and airflow mode. The comparison is important to identify the differences or similarities of product qualities as the process conditions vary. Hence, the objective of this present study is to compare the effect of baking temperature and airflow towards baking time and the quality of cake such as volume expansion, texture and moisture content of cake.

2. Experimental Procedure

2.1. Cake preparation

A standard butter cake recipe was used and weighed by using digital balancer (Scientch, JB3002-GA-F): superfine flour (146g, 38.12%), castor sugar (135g, 35.25%), butter (102g, 26.63%), fresh milk (90g, 23.50%), eggs (98g, 25.59%), baking powder (2.99g, 0.78%) and vanilla essence (0.61g, 2.35%). All ingredients were purchased from the Yummi Bakery Store, Bandar Baru Bangi, Malaysia. The batter was prepared according to standard and mixed using a Panasonic mixer (Panasonic, MK-GB1, Taiwan). A Modified stainless steel baking pan with a dimension of 15cm x 15cm x 7.5 cm wide with transparent glass on the front side was used to determine the height of cake during volume development.

2.2. Baking conditions and oven

A modified electrical convection oven (Brio-Inox, Milano, Italy) was used. Cake was baked at three different baking temperatures (160°C, 170°C and 180°C) with two airflow conditions (with airflow, i.e., 1.88 m/s and without airflow). Process conditions were varied simultaneously for a total of 6 experimental conditions. Experiments were performed in three replicates. The thermocouple which was placed at centre of pan was used to record the internal temperature of batter. Once the internal temperature of batter reached within 101-102 °C, the baking process was stopped.

2.3. Volume expansion measurement

Changes in contour and volume during baking were measured by methods described by HadiNezhad and Butler [7]. Five dowels were attached to the pan (p1, p2, p3, p4, p5) and the distance between each point was 2.5 cm (Fig. 1). Height of batter was measured at every 4 minutes intervals during baking.

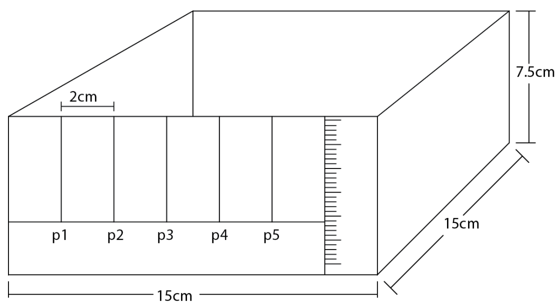
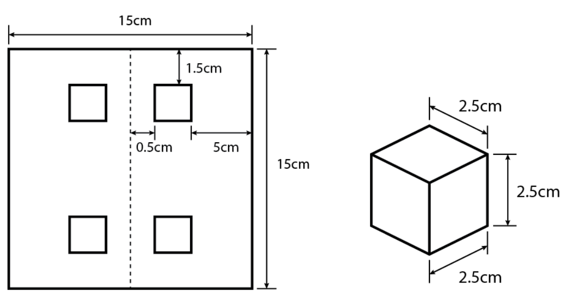


Fig. 1. Dowels Attached at Baking Pan.

2.4. Cake texture measurement

Cake firmness and springiness was measured according to AACC Approved Method (74-09) [12] using TA-XT plus Texture Analyser using Texture Exponent software version 2.0.7.0. , (Stable Microsystems, Godalming, UK). Four square blocks with the dimension of 2.5×2.5×2.5 cm were taken from the centre of crumb at 4 different points after 2 hours of baking (Fig. 2). The test speed was 1mm/s with 50% strain of the original cube height. A trigger force of 5 g was selected. The compression was performed with 32 mm diameter round plunger (P/32). The results were averaged.



(a) Top View of the **(b) Size of Each Sample.**

Fig. 2. Cake Texture Measurement.

2.5. Moisture content measurement

The moisture content of cake was determined by measuring the weight difference of the cake before baking and 1 hour after baking. This method involved drying the sample overnight at 105±3°C in vacuum oven. The sample was weighed out 1-5 grams to the nearest 0.1mg into the dish. The cake was cut into half and 2 different points of samples of the first half were taken (Fig. 3). Then, the crumb was sliced at 3 cm height and the results were averaged.

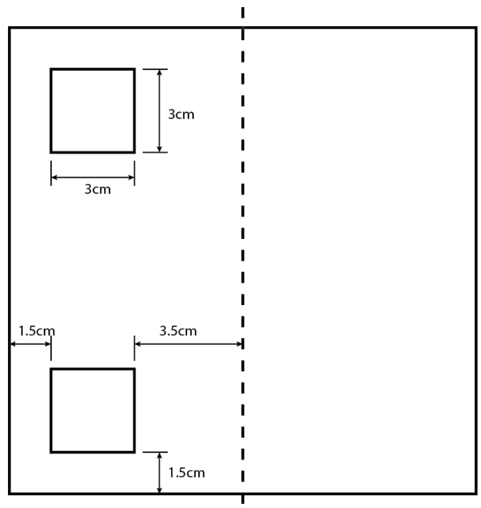


Fig. 3. Moisture Content Measurement (Top View of the Cake).

2.6. Statistical analysis

Data were analysed using a two-way analysis of variance (Graphpad Software, California, USA) with baking temperature and airflow as the main parameter. The significant difference between baking temperature and airflow with regards to quality was analysed. The interaction between baking temperature and airflow was also analysed.

3. Results and Discussion

3.1. Effect of baking temperature and airflow on baking time

For a bakery product to be considered baked it must have specified surface colour and defined crumb structure [13]. To ensure that cake has finished its baking, the internal cake temperature was monitored to reach within 101-102°C. Once the internal cake temperature achieved this temperature, the baking process was stopped and baking time was recorded. Figure 4 shows the time needed to complete the baking process at different temperatures and airflows. As can be observed from the figure, baking time was shorter with the presence of airflow 45.16%, 29.17% and 25.58% for 160°C, 170°C, and 180°C, respectively. This was due to better temperature distribution in the oven caused by the presence of airflow. The air flow helped to enhance the baking process and reduce baking time. Increase in baking temperatures resulted in smaller differences of baking time between cakes baked with and without airflow. However, with the same airflow condition, increase in baking temperature resulted in shorter baking time for both with and without airflow by 6.25% and 44.20%, respectively. Increase in baking temperature automatically increased heat transfer inside the oven chamber. Higher heat transfer resulted in the increase of internal cake temperature which resulting in shorter baking time. From the result, the lower baking temperature of 160°C with the presence of airflow is more efficient in terms of reducing cooking time and energy consumption. However, cake baked at 160°C with airflow produced smaller volume expansion with high firmness, springiness and moisture content as compared to cake baked at different temperatures with no airflow. A two-way analysis of variance showed that for all cakes baked at different temperatures and airflows, the baking times have significant differences. Moreover, there are significant differences ($p < 0.05$), interaction between the baking temperature and airflow towards the baking time. Different letters in the Fig. 4 indicate statistical difference with a confident level of 95%, ($p < 0.05$).

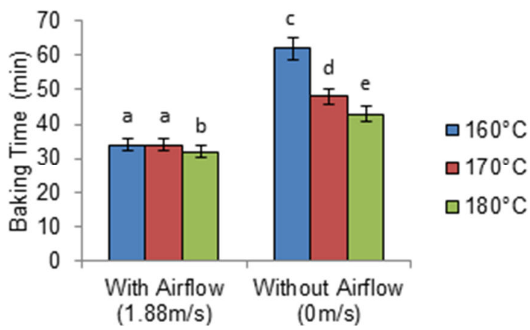


Fig. 4. Baking Time at Different Baking Temperature and Airflow.

3.2. Effects of baking temperature and airflow on volume development

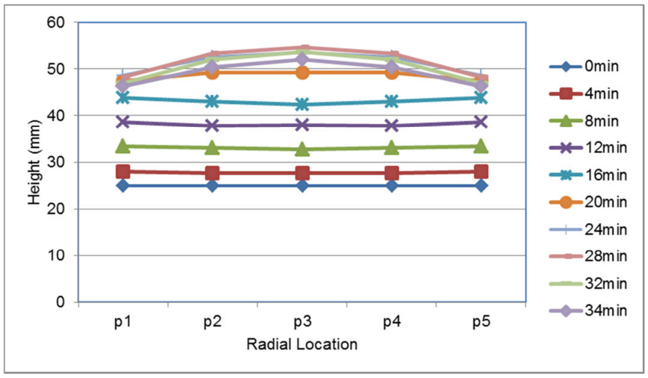
Chang [14] mentioned that the first step of heating in baking process starts with the increase of temperature of outer crumb layers. The rise in temperature of the product will initiate the chemical reactions and thus rapidly increases the carbon dioxide gas production and keep expanding the product volume. Volume is an important characteristic in the evaluation of cake and cake quality [7]. Volume development can be judged during baking process by using height profile method [7]. Similar trend in the shape and development of the top contour during baking for all six different process conditions can be seen from this study. Figure 5 shows the profile development during baking at five pin locations for both cakes baked with and without airflow at 170°C (data at low and high temperatures are not shown). A typical increase was observed to reach a maximum volume. Then the cake volume decreased slightly at the end of baking. A similar trend can be seen for all volume expansion of cake at different process conditions.

At the beginning of baking process, a uniform increase in height can be seen at the first 4 minutes of baking at170°C for both with and without airflow. This lies within the first stage of baking process. The first stage of baking process took

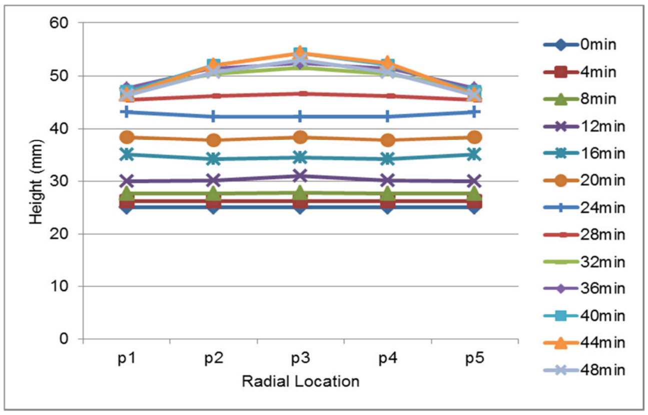
25% of total baking time and rapid expansion occurred during this stage [15]. This is due to high heat absorption occurring at the beginning when the product is at room temperature and is exposed to high temperature of the oven. From the Fig. 5, cakes baked with airflow have a higher rate of height changes compared to cakes baked without airflow with the rate of 0.7 mm/min and 0.29 mm/min, respectively. This might be due to evenly distributed hot air inside the oven chamber. No temperature difference was observed near the surrounding of the pan. A two-way analysis of variance showed that for both cakes baked with and without airflow at 170°C, a significant difference of height changes can be seen between both airflow at first stage ($p < 0.05$). A similar trend was also observed for the cakes baked at 160°C and 180°C for both with and without airflow. A two-way analysis of variance showed that there are significant differences of height changes for cakes baked at different temperature and airflow ($p < 0.05$). However, airflow has higher significant effect towards height changes as compared to baking temperature. There are also significant differences in interaction between baking temperature and airflow ($p < 0.05$) resulting in few discernable patterns.

During the second stage of baking process, the volume expansion continued to maximum volume with further increment of crumb temperature. At this stage, all reaction was maximized including moisture evaporation, starch gelatinization and protein coagulation [15]. This was because heat continued to penetrate inside the batter which caused successive expansion. It resulted from the expansion of bubbles from the increase in vapor pressure of water and air in the bubbles. From Fig. 5, different heights of batter between the center radial (p3) and the edges radial (p1, p5) of the cake at 8-16 minutes of baking at 170°C for both cakes baked with and without airflow can be seen. The height of cake at the edges (p1, p5) was higher than the center of cake (p3). A similar trend was observed to cake baked at all different process conditions. This was due to heat transfer which started during the first few minutes of the baking process. Two-way analysis of variance showed both airflow and baking temperature have significant differences in height changes between the center and edges of cake ($p < 0.05$). However, airflow had higher significant effect on the height changes between center and edges of cake. On the contrary, as the center part of the cake is being cooked, it expanded the most, resulting in dome like shape [16]. This was because the edges section were set, leaving the center part to expand in upward direction only. This occurred after 16 minutes of baking until 32 minutes of baking for both cakes baked with and without airflow.

At the final stage, further increase of temperature caused strengthening of the cake structure and the batter released gas in the form of bubbles which resulted in slight cake shrinkage at 30-34 minutes for cakes baked with airflow and 40-44 minutes for cake baked without airflow at 170°C. This took 25% of the total baking time to the end of baking [8]. From Fig. 5, maximum shrinkage occurred for cakes baked with airflow of 1.17% compared to 0.90% for cakes baked without airflow at 170°C. However, at different temperature with airflow, the maximum cake shrinkage occurred in the cake baked at lower temperature, i.e., 160°C was 2.32%. In no airflow condition, the maximum shrinkage occurred in cake baked at higher temperature, i.e., 180°C was 2.24%. Two-way analysis of variance showed there were significant differences ($p < 0.05$), interaction between baking temperature and airflow towards the cake shrinkage. However, airflow has higher significant effect as compared to baking temperature towards cake shrinkage.



(a) Baking Temperature of 170°C with Airflow.



(b) Baking Temperature of 170°C without Airflow.

Fig. 5. Profile of Height Changes during Baking of Cake.

Similar trends of volume development were reported by Therdthai et al. and Lostie et al. [15, 16]. However, HadiNezhad et al. [7] and Whitaker et al. [17] reported different results at the first and second stage of baking. During the first stage of baking, a little expansion occurred followed by the second stage which was a period of rapid expansion to the maximum volume.

Figure 6 shows volume expansion of cake at different temperatures and airflow at the end of baking. As can be seen from Fig. 6, volume expansion of cakes baked with airflow increased with the increase of baking temperature and showed slightly larger volume than cakes baked without airflow which was between the ranges of 2.86 – 8.37%. Two-way analysis of variance showed there are significant differences between baking temperature and airflow towards the volume expansion ($p < 0.05$). However, baking temperature has higher significant effect on the volume expansion compared to airflow. For cakes baked with airflow, increased baking temperature increased the volume expansion by 9.72% compared to 5.86% without airflow. However, at the highest temperature, i.e., 180°C, volume expansion reduced by 1.63% than for 170°C. This might be due to longer baking time required which resulted in higher shrinkage and reducing the volume at the end of baking process. From the analysis, there are significant differences ($p < 0.05$) in the interaction between baking temperature and airflow. Changing in the baking temperature and airflow modes produced different volume expansion at the end of the baking process. Different letters in the Fig. 6 indicate statistical difference with a confident level of 95% ($p < 0.05$).

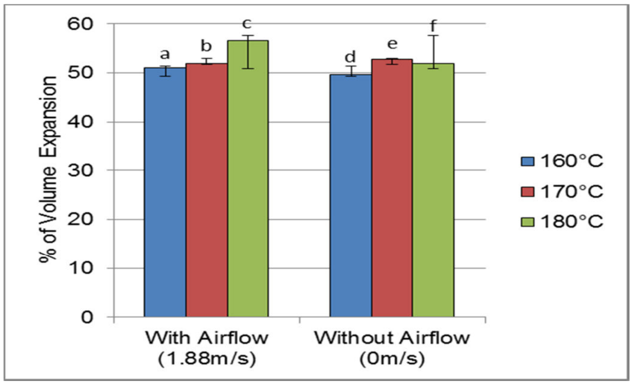


Fig. 6. Volume Expansion at different Baking Temperature and Airflow Condition.

3.3. Effect of baking temperature and airflow on cake's texture

Figures 7 and 8 show the results of firmness and springiness of cake, respectively. From Fig. 7, increasing the temperature resulted in an increase of the firmness of cake both with and without airflow with exception made for cake baked at 160°. At 160°C with airflow, the cake shows slightly higher firmness which was 518.84 g as compared to 170°C and 180°C with 514.77 g and 518.66 g, respectively. However, cake baked without airflow at 160°C shows lower firmness which was 435.48 g compared to cake baked at 170°C and 180°C without airflow which were 522.13 g and 523.68 g, respectively. However, two-way analysis of variance showed that there are no significant differences (same letter in the Fig. 7) between baking temperature and airflow towards the firmness of cake ($p < 0.05$).

The springiness of the product is shown in Fig. 8, which shows that increasing temperature at both airflows resulted in the decrease of the springiness of cake. However, at 180°C for cake baked with airflow, the springiness of the cake slightly increased by 0.57%. While the springiness of cake baked at 180°C without airflow showed lower springiness compared to cake baked at 160°C and 170°C which was 57.36% reducing 3.44% from the springiness of 170°C. From the observation, baking temperature had more significant effect towards the springiness of cakes as compared to airflow. This can be proved by two-way analysis of variance. It showed only baking temperature has significant differences towards the springiness of cake. Different letters in Fig. 8 indicate statistical difference with a confident level of 95%, ($p < 0.05$). However, there were significant differences ($p < 0.05$); interaction between baking temperature and airflow resulted in different springiness of cake baked at different conditions. Volume expansion has negative relationship with firmness. Larger volume expansion resulted in lower firmness of cake. Meanwhile, firmness of cake should have negative relationship with the springiness of cake. Higher firmness resulted in lower springiness of cakes. This has been reported by Cauvain et al. [18]. From this study, only cake baked without airflow showed negative relationship between firmness and springiness. Meanwhile, cake baked with airflow showed positive relationship between firmness and springiness. Higher firmness resulted in higher springiness of the cake as reported by Hadinezhad and Butler [7]. As for volume and firmness, none of the cake samples followed negative relationship as reported by Cuavain et al. [18].

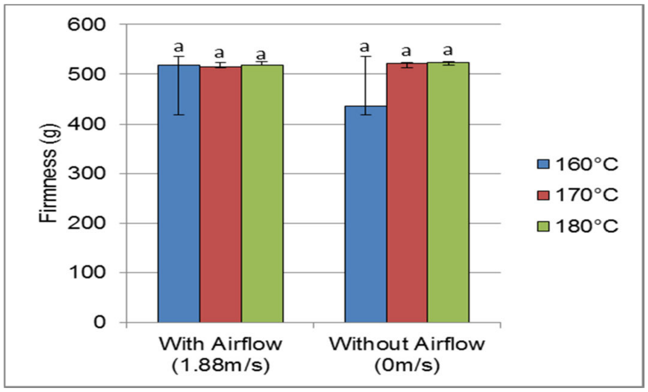


Fig. 7. Firmness of Cake at Different Baking Temperature and Airflow Condition.

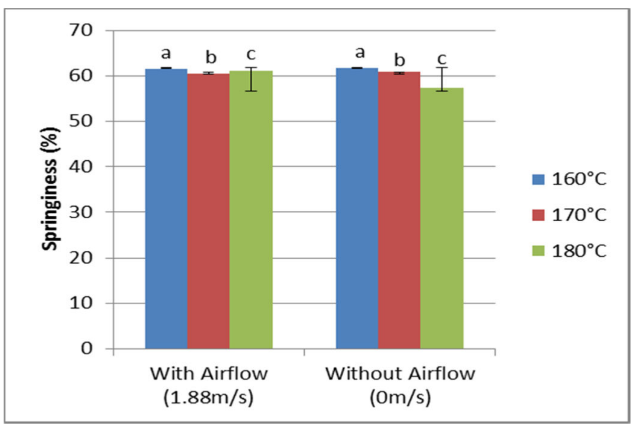


Fig. 8. Springiness of Cake at Different Baking Temperature and Airflow Condition.

3.4. Effects of baking temperature and airflow on moisture content

The final moisture content is important in determining the quality of the cake. If too much water evaporates during baking process, the cake will become dry and is not preferable. A typical cake has moisture content between 15-30%, compared to bread 35-45% and biscuits 1-5% [16]. The value for the moisture content at different baking temperature and airflow conditions are shown in Table 1. In general, the moisture content was higher for cake baked in the presence of airflow compared to cake baked without airflow. However, cake baked at middle temperature of 170°C with and without airflow showed lower moisture content compared to lower temperature and higher temperature, 160°C and 180°C respectively. Cake baked at 170°C without airflow showed higher value of standard deviation which was 1.06%. However, two-way analysis of variance showed, there are no significant differences between baking temperature and airflow towards the moisture content of cake (P>0.05). All moisture content of cake baked at different process conditions still lies within the range of accepted moisture content of cake which is 15-30%.

Table 1. Moisture Content at Different Baking Temperature and Airflow*.

Airflow Condition	**Moisture Content**		
	160°C	**170°C**	**180°C**
With Airflow (1.88 m/s)	29.53±0.87	28.04±0.62	29.20±0.54
Without Airflow (0 m/s)	28.70±0.04	27.60±1.06	28.86±0.20

* Average of three samples± SD

4. Conclusions

An observation has been made of the effects of baking temperatures and airflow conditions .The process conditions obviously influenced the quality of cake.

- Baking in the presence of airflow maintained the baking temperature to be very close to the set point temperature.
- It also reduced the baking time to 25.58 - 45.16%.
- From the observation, airflow had significant effects towards the baking time and the quality of cake in terms of height changes of batter, volume expansion of cake compared to baking temperature.
- Baking temperature had significant effect towards the springiness of cake. However, firmness and moisture content of cake was not affected by both baking temperature and airflow.
- There were interactions between baking temperature and airflow towards the height changes of batter, volume expansion and springiness of cake.

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