Impact of Humidified Baking on Crust and Crumb Properties of Open Bread during Storage

Y.M. MOHD JUSOH1,3, N.L. CHIN1*, Y.A. YUSOF1 and R.A. RAHMAN1,2

1 Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
2 Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
3 Department of Bioprocess Engineering, Faculty of Chemical Engineering and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310, UTM, Skudai, Johor, Malaysia

Received July 24, 2012; Accepted October 14, 2012

Humidified baking was investigated in the light of producing breads envisaged to have better quality and freshness. Open bread loaves were prepared using the straight dough method where baking was performed with or without humidity at three levels of temperatures of 185, 195 and 205°C, and baking times of 25, 30 and 35 min. Baked breads were evaluated by measuring its crust color and thickness, and bread crumb moisture content and firmness. Humidified baking has no significant effect in enlightening bread crust color (P > 0.05) but significantly reduced the crust thickness (P < 0.001) and increased the initial moisture content (IMC) of bread crumb. The higher IMC of bread crumb led to a higher final moisture content (FMC) of bread during storage and these helped to reduce the firming rate of bread during a 96 h storage especially for the lower baking temperatures and times. Significant differences (P < 0.001) were observed on crust color and thickness, and bread crumb moisture content and firmness as effect of baking temperature and time.

Keywords: bread, humidified baking, crust, crumb

Introduction

Baking is an eminent step in a breadmaking process as it highly contributes to the setting and changes of bread’s organoleptic and physico-chemical properties. With simultaneous heat and mass transfer processes occurring during baking, dough experiences changes which lead to the transformation of raw dough to bread through a series of physical, chemical and structural transformations which include starch gelatinization, protein denaturation and coagulation, volume expansion, and browning reactions (Mohd. Jusoh et al., 2009; Zanoni et al., 1993).

Apart from transforming inedible raw dough to soft, moist and palatable porous bread structure, baking process is also responsible in controlling the moisture content in bread. In conventional baking, the relationship of moisture content is reciprocal to the baking temperature and time (Wagner et al., 2007; Baik and Marcotte, 2002; Faridi and Rubenthaler, 1984). An appropriate amount of moisture content is required in bread to prolong its shelf-life. Higher moisture content is proven to assist in slowing down the rate of crust firming (Baik and Chinachoti, 2002; Faridi and Rubenthaler, 1984). Crumb firming is the condition which the crumb becomes dry and crumbly resulting in gradual reduction of bread eating properties, or more commonly described as bread staling. The common causes for bread staling are starch retrogradation, proteins and protein-starch interactions and moisture migration (Gomes-Ruffi et al., 2012; Gray and Bemille, 2003). Crumb firming is unavoidable, however it can be slowed down by adding bread emulsifiers, enzymes or hydrocolloids in the bread recipe. Complex interaction between bread emulsifiers and enzymes with the flour components improves bread quality and assists in retarding crumb firming (Gomes-Ruffi et al., 2012; Purhagen et al., 2011).

*To whom correspondence should be addressed. E-mail: chinnl@eng.upm.edu.my
Hydrocolloids, which are known for its high water retention capacity, prevent crumb dehydration which subsequently reduces crumb hardening in bread during storage (Guarda et al., 2004).

Apart from controlling moisture content, Patel et al. (2005) also demonstrated that different baking method with different heating rate influenced the extent of starch granule hydration, swelling, dispersion and re-association which leads to different quality of bread produced. New technologies for example microwave, microwave plus infrared (MIR), microwave plus jet-impingement (MJET), jet-impingement (JET) and halogen lamp microwave have been studied in the light of producing breads of better texture and longer shelf-life through a faster and less energy consuming process (Sumnu et al., 2007; Patel et al., 2005; Demirekler et al., 2004). One disadvantage of these methods is the requirement for bread ingredients modification to make the final bread product comparable to the conventional baked breads. On contrary, the method we investigated in this study, humidified baking, does not require ingredients modification.

Humidified baking is not a new technique in the bakery industry. In fact, it is a common baking technique in the production of cheese cakes and crusty French breads. In the production of these specific bakery products, additional humidity or steam is provided during the baking process via automated steam injection, water bath or more conventionally by inserting and allowing small amount of water to evaporate in the oven during the start-up of baking. The amount, method and duration of humidity or steam to be supplied depend highly on the characteristics and quality of bakery products to be produced. This is a rare technique because the process is complex, adds cost and on top of that, it produces products with specific characteristics (i.e. lighter surface color, higher moisture content, glossy and crusty crust) which are different compared to regular baked products. In conventional baking, temperature and time are known to have direct relationship with the crust color and moisture content thus the application of humidified baking is anticipated to suppress the original effect of these thermal processing parameters on the products. Earlier work by Marston and Wannon (1976) showed that humidity application during baking interrupted the heat and mass transfer processes during baking and caused some differences on the baked products. Xue and Walker (2003) and Xue et al. (2004) shared the similar result showing that the application of humidified baking significantly affected the final quality of baked product by lightening the crust color, increasing volume and final moisture content of the product.

In relation to moisture content and bread staling, Patel et al. (2005), Baik and Chinachoti (2002), Gil et al. (1997), He and Hoseney (1990) and Faridi and Rubenthaler (1984) had all demonstrated that bread with high moisture content in crumb had lower firmness value during storage. Bread firming or staling is a complex phenomena which is not completely understood, however studies demonstrated that moisture content retained in bread after baking may contribute to it. Stauffer (2000) showed that an increase of bread moisture content of 2% will increase its shelf life by one day. Thus, it is highly plausible that bread baked in a humid environment and that having higher moisture contents will experience a slower rate of staling than the conventionally baked bread. The present work investigated the use of humidified baking to control crust properties which gives advantages in providing higher moisture content bread crumbs thus helps in reducing the staling process during storage. The effects of baking temperature and time are also presented.

Materials and Methods

Dough preparation A commercial breadmaking flour milled from strong wheat (Red Horse Brand, Interflour Sdn. Bhd., Malaysia) was used for preparing bread samples with other ingredients including filtered water, instant dried yeast (Lasaffe, France), salt (Flying Swallow, Malaysia), sugar (CSR, Malaysia) and bread shortening (Marina Blue, Malaysia). The bread formulation is given in Table 1.

The straight dough method was used to make open loaf bread samples. All the ingredients were mixed in a vertical mixer (SPN25053, Lian Huat, Malaysia), for a total of 16 min, i.e. 4 min at low speed and 12 min at high speed. The whole dough was let to rest for 5 min after mixing. The dough was weighed and divided into 380 g dough balls, then rounded and let to rest again for another 5 min before proceeding to the automatic moulding machine (CM750, Lian Huat, Malaysia). The moulded doughs were put into stainless steel baking tins with dimension of 10 cm × 19 cm × 10.5 cm and stored in the retarded proofer (LRP36052, Lian Huat, Malaysia) for 1 ½ h at 28°C and 85% relative humidity.

Humidified and non-humidified baking tests The proofed doughs were baked in a twin-deck oven (EO3050C5, Laser, Malaysia). The bread formulation is given in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Bread formulation based on 3000 g flour loading.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredients</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Flour</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td>Sugar</td>
</tr>
<tr>
<td>Salt</td>
</tr>
<tr>
<td>Yeast</td>
</tr>
<tr>
<td>Shortening</td>
</tr>
</tbody>
</table>

* maximum temperature of 2°C.
Lian Huat, Malaysia) at 185°C, 195°C or 205°C for 25, 30 or 35 min without baking lid. For humidified baking, two trays of water (1 liter each) were placed in oven while water spray was injected at every five minutes’ interval on the top crust, to ensure that the baking process has a continuous humidity supply with assumption of maximal water vapor in the baking oven chamber. This method was adapted and improvised from Xue and Walker (2003). No additional water (tray or spray) was used in the oven during the baking process of non-humidified baking or commonly known as conventional baking. The measured humidity was RH 31.3 ± 5.4, 21.8 ± 4.5 and 20.8 ± 3.8 for 185°C, 195°C or 205°C, respectively versus the average RH of 6.9 ± 2.5 of the empty oven. These RH measurements were made despite sources indicating that the relative humidity scale is essentially useless or misleading at temperatures above 100°C as water vapor above 100°C at atmospheric pressure is in the super heated state and published accuracy of RH instrument is +/-5% at 150°C, +/-10% at 175°C, +/-17% at 200°C, and useless at 370°C (Anon, 2009). Fig. 1 illustrates the technique of humidified baking. Baked bread samples were stored unwrapped on cooling racks for 96 h in ambient condition of 28°C and 75% relative humidity where the crust and crumb properties were measured during this storage period.

**Crust and crumb color measurement**  Bread crust and crumb colors were measured using Minolta Chroma Meter (CR-410, Konica Minolta, Japan). The readings were given in L a b color system. The L value represents the lightness, while the a and b value represents the redness and yellowness components of surface measured, respectively. The crust color was measured by placing the chromameter probe directly on the top crust region of unsliced bread loaves. For crumb color, the full intact bread was sliced uniformly into 125 mm bread slice using the bread slicer. Crumb color was measured by placing the probe on the surface of crumb region of the bread slice. The color for crust and crumb was measured at three different locations in triplicates.

**Crust thickness measurement**  The thickness of crust was measured via digital imaging method as described in Mohd. Jusoh et al. (2009). The definition of crust and crumb region was solely based on color where bread crust was defined as bread region having L values ranging from 29.41 to 70.50 while the crumb region has L values in the range of 70.50 to 79.00.

**Moisture content measurement**  The moisture content measurement was performed following the one-stage procedure of AACC 14-5A using only the crumb portion. The crumb sample was grinded using a blender (IT013, Itronic, Malaysia). 3 g of sample was dried in an oven (HA1350, Hanabishi, Malaysia) at 103°C for 60 min. After drying, the dried sample was stored in a dessicator for 60 min. The moisture content in percentage was calculated using the following equation:

$$\text{Moisture Content (\%)} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \times 100 \quad \text{Eq. 1}$$

The moisture content was measured at three storage periods, i.e. after 2, 48, and 96 h of baking, each labeled as the initial (IMC), intermediate (INTMC) and final (FMC) moisture contents.

**Crumb firmness measurement**  Bread crumb firmness was measured using a texture analyzer (TA.XT2, Exponent Micro Stable Systems, USA) following the standard procedure provided by the American Institute of Baking (AIB). The force and height calibrations were performed to ensure that the measuring system was uniform for all trials and produces reliable measurements. The firmness value was obtained by pressing the 36-R cylindrical probe with applied load of 5000 g on two slices of bread with total of 25 mm thickness placed on the platform. During the measuring process, the cylindrical probe which was approximately

![Fig. 1. Experimental set-up of humidified baking in chamber of oven by using two trays of water.](image-url)
30 mm above the bread moved at 30 mm/s towards the bread surface. The probe penetrates into the bread until the maximum compressible point then moves back upward. The force needed to penetrate into bread crumb until 25% and 40% compression was shown in the computer. For this experiment, the firmness value was taken at 25% compression. This test was also performed at the three storage periods, as the initial, intermediate and final firming stage and were labeled as the ICF, INTCF and FCF.

**Statistical analysis**  The JMP software (Version 8, SAS Institute Inc., USA) was used to design a 3x3x2 factorial experiments for this study. The three factors investigated in this study were baking temperature, time and humidity. Baking temperatures and times both were having three levels which were 185°C, 195°C, 205°C and 25 min, 30 min and 35 min, respectively. Baking was conducted under two humidity conditions, which were under the presence or absence of humidity. Each treatment was repeated three times. Analysis of variance (ANOVA) was used to analyze the simultaneous effect of baking temperature, time and humidity on crust color, crust thickness, crumb moisture content and crumb firming. The percentage values in the figures show the numerical difference between humidified and non-humidified baking and were calculated following this equation:

\[
\text{Difference} \% = \frac{\text{Data}_{\text{humidified}} - \text{Data}_{\text{non-humidified}}}{\text{Data}_{\text{humidified}}} \times 100
\]

**Results and Discussion**

**Crust color**  Figs. 2, 3 and 4 show the measured color of bread crust as \(L\), \(a\) and \(b\) values respectively. Baking temperature and time both have significant impact on \(L\) value \((P < 0.001)\). There was no significant difference observed between humidified baking and non-humidified baking on \(L\) value \((P > 0.05)\). The values in percentage denote the numerical difference between the humidified and non-humidified values.

![Fig. 2. \(L\) value of crusts of breads baked in humidified (■) and non-humidified (□) oven chamber at (a) 185°C, (b) 195°C and (c) 205°C. Baking temperature and time both have significant impact on \(L\) value \((P < 0.001)\). There was no significant difference observed between humidified baking and non-humidified baking on \(L\) value \((P > 0.05)\). The values in percentage denote the numerical difference between the humidified and non-humidified values.](image)

![Fig. 3. \(a\) value of crusts of breads baked in humidified (■) and non-humidified (□) oven chamber at (a) 185°C, (b) 195°C and (c) 205°C. Baking temperature and time both have significant impact on \(a\) value \((P < 0.001)\). There was no significant difference observed between humidified baking and non-humidified baking on \(a\) value \((P > 0.05)\). The values in percentage denote the numerical difference between the humidified and non-humidified values.](image)
baking caused 8.90% and 19.70% increase in L and b values but a decrease of 6.55% for the a value. Study performed by Mondal and Datta (2010) on water spray effect during bread baking also showed that extra humidity during baking can lighten crust color. Despite the insignificant differences, humidity supplied to the baking system managed to alter the crust color of baked breads in a consistent manner.

Crust thickness Fig. 5 shows that humidified baking is able to suppress the formation of thick crust. The significant difference in thickness as affected by the humidified and non-humidified baking conditions is supported by the ANOVA with P < 0.05. Generally, crust thickness development is caused by two eminent factors i.e. amount of moisture being evaporated and tendency of cell to rupture during baking due to heat (Wiggins, 1999; Jefferson et al., 2006 and 2007). In
normal baking condition i.e. in the non-humidified condition where the baking environment is dry, the amount of moisture evaporated is directly proportional to the amount of heat supplied to the system. When humidity is incorporated into the baking chamber, the amount of heat exposure is seen lower than the non-humidified baking thus the tendency for moisture to evaporate reduces. The different amount of heat acting on the dough via humidified and non-humidified baking is highly anticipated as the cause of the formation of a thinner crust in humidified baking. Having deduced that, results show that increasing the baking temperature and time both had caused the increase of bread crust thickness. The ANOVA results also showed that both baking temperature and time gave significant impact on crust formation and thickness with $P < 0.001$.

Crumb moisture content and firmness Fig. 6 shows that humidified baking produced breads with higher initial (IMC) and final (FMC) moisture contents. Similar results on IMC were also obtained by Xue et al. (2004) and Xue and Walker (2003). With extra water vapor supplied to the system, the oven chamber becomes more humid, and most probably, the oven humidity had reduced the temperature and moisture gradient between oven chamber and the bread, thus less water was driven out from the dough in comparison with conventional baking where to the amount of moisture evaporated from dough could be higher. Zanoni et al. (1993) showed that the heat and moisture gradient developed during baking drives moisture out from dough in conventional baking with dryer oven chamber, and this rate of evaporation correlates linearly with baking temperature and time. In addition to that, higher moisture content in bread can also be influenced by starch as starch gelatinization during baking will bind water in bread and the degree of starch gelatinization increases with baking time and temperature (Yasunaga et al., 1968).

The effect of humidified baking is more pronounced as the baking temperature increased. The IMC and FMC obtained by humidified baking at 205°C were higher than those at 185°C. This could be caused by the effect of crust thickness, in which a thicker crust prevents moisture from migrating to its surrounding or the humidity of baking environment as the capacity of air to hold water increases when temperature increases. The thick crust of bread baked at 205°C could also have prevented moisture from migrating to the surrounding during its storage of 96 h as the FMC was significantly higher. This has envisaged that bread baked in humidified conditions could keep its freshness longer as it had higher moisture contents and that contributes to slowing down the staling rate of bread. Stauffer (2000) mentioned that an increase of bread moisture content of 2% could increase its shelf life by a day. The impact of humidified baking is less prominent at lower temperature, e.g. at 185°C. Reports on crust’s role in preventing moisture migration are also found in Primo-Martin et al. (2006) and Wahlby and Skjoldebrand (2001).

Having more initial moisture content is an advantage for bread because substantial amount of moisture could probably suppress the rate of firming during storage (Kulp and Ponte, 1981; Rogers et al., 1988; He and Hoseney, 1990). Gray and Bemiller (2003) reported that the two most common factors which cause crumb firming are starch retrogradation and moisture migration. Both of these processes depend on the moisture content in bread. Starch retrogradation is the process where gelatinized starch molecules re-associate to form double helix crystalline structure (Pateras, 1999) and this process requires moisture. On the other hand, moisture migration affects crumb firming from three ways i.e. drying,

![Fig. 6. Initial (■) and final (▲) moisture content of bread crumbs baked at (a) 185°C, (b) 195°C and (c) 205°C. Humidified baking is represented by dotted line and non-humidified baking is represented by full line.](image-url)
most probably interfered its convective heat transfer process as explained by a higher relatively humidity obtained in the oven chamber of lower baking temperature which produced breads of lower crumb firmness. There is no difference in firmness value for bread baked using both methods at the highest temperature of 205°C. Excessive moisture content in bread could have lead to a faster starch retrogradation (firming) as moisture helps in mobilizing the starch to retrograde (Zeleznak and Hoseney, 1986).

Conclusions

Experimental results demonstrated that humidified baking was effective in reducing bread crust thickness \((P < 0.05)\) and increasing moisture contents of breads at its fresh form \((IMC, P < 0.001)\) and during its storage \((FMC, P < 0.001)\). The plausible reason of this observation is that the high oven humidity suppresses the impact of heat and moisture gradient that controls the crust development and moisture evaporation during baking. In normal and conventional baking using oven, the amount of moisture evaporation and crust thickness are linearly correlated to heat supplied to the system. Bread with high IMC tends to have high FMC and lower rate of firming. The effect of humidified baking is able to reduce crumb firming during storage and this is more significant for breads baked at lower temperatures of 185°C and 195°C although crumb firmness of bread kept in storage generally increased as baking time and temperature increased.

Acknowledgements

The authors would like to acknowledge the financial support from Ministry of Higher Education of Malaysia through Fundamental Research Grant Scheme (01-01-07-214FR) and thank the Research, Development and Commercialization Centre (RDCC) of Interflour Sdn. Bhd. for providing the baking facilities.
References
Zeleznak, K.J. and Hoseney, R.C. (1986). The role of water in the
Impact of Humidified Baking on Bread Storage
