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Miniature bread baking as a timesaving research approach and mathematical modeling of browning kinetics

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ABSTRACT

Miniature bread baking is presented as an economical and timesaving laboratory approach to study the baking process in the present work. Results indicate that the miniature bread baking is essentially analogical to the baking process of regular-sized bread: quality-related properties of miniature breads, such as crumb formation, crust thickness, crust color and moisture content, behaved similarly to regular-sized breads (380 g) during baking, albeit at a different time scale. This was explained as analogous for large breads, initially baking is externally limited and only later internal limitations play a dominant role with the crust being formed. After initial development of the crust, the lightness and the total color difference were found linearly correlated with the crust thickness. Moreover, the S-REA (spatial reaction engineering approach) was used here to model the moisture content and temperature during miniature bread baking whose results were implemented to describe the browning kinetics. The results indicate that the S-REA accurately models the browning kinetics during miniature bread baking.

1. Introduction

Bread making is a complex process involving dough mixing, proofing, baking and cooling. Among these processes, baking is of great importance. During baking, many quality- related properties of bread, such as color, texture and flavor, are developed by transformations that depend on the development of the temperature and moisture content. Those transformations are due to simultaneous heat and mass transfer phenomena and mechanical deformation of the bread (Therdthai and Zhou, 2003; Thorvaldsson and Janestad, 1999; Zhang and Datta, 2006). However, prediction of the bread quality properties according to baking conditions is relatively difficult since the mechanisms of the baking process are not fully understood (Mondal and Datta, 2008). For instance, the color change on the crust of bread, which is a result of Maillard reactions and caramelization, is complicated to predict due to the influence of water activity, heat transfer mode, temperature and air velocity (Mundt and Wedzicha, 2007). Therefore, more detailed understanding of the baking process is necessary, especially when the quality of the final products need to be optimized or when bread recipes need to be modified.

In previous studies on the quality prediction of bread in terms of crust formation, crust browning, moisture content of the final products, regular-sized bread were used. Mohd Jusoh et al. (2009) presented a strong positive correlation between crust thickness and the total

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Nomenclature

A	Surface area of samples (m^2)
A_{in}	Internal surface area (m^2)
C_p	Specific heat of sample ($J\,kg^{-1}\,K^{-1}$)
C_s	Solid concentration ($kg\,m^{-3}$)
C_v	Water vapor concentration ($kg\,m^{-3}$)
$C_{v,s}$	Internal–surface vapor concentration ($kg\,m^{-3}$)
$C_{v,sat}$	Internal–saturated vapor concentration ($kg\,m^{-3}$)
D_v	Effective water vapor diffusivity ($m^2\,s^{-1}$)
$D_{v,o}$	Water vapor diffusivity ($m^2\,s^{-1}$)
D_w	Liquid diffusivity ($m^2\,s^{-1}$)
h	Heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_m	Mass transfer coefficient ($m\,s^{-1}$)
$h_{m,in}$	Internal mass transfer coefficient ($m\,s^{-1}$)
$\dot{I}$	Local evaporation rate ($kg\,m^{-3}\,s^{-1}$)
k	First order kinetic constant (s^{-1})
k	Thermal conductivity of sample ($W\,m^{-1}\,K^{-1}$)
M	Initial weight of dough (kg)
n	Constant
r	Radial position (m)
RH_b	Relative humidity of drying air
R_s	Sample radius (m)
R_{WL}	Rate of total weight loss (s^{-1})
T	Sample temperature (K)
T_{oven}	Oven temperature (K)
T_s	Surface sample temperature (K)
t	Time (s)
T_b	Drying air temperature (K)
W	Weight of sample (kg)
X	Moisture content on dry basis ($kg\,kg^{-1}$)
$\bar{X}$	Average moisture content on dry basis ($kg\,kg^{-1}$)
X_b	Equilibrium moisture content on dry basis ($kg\,kg^{-1}$)
X_o	Initial moisture content ($kg\,kg^{-1}$)
X_s	Moisture content at the surface of sample ($kg\,kg^{-1}$)
ΔE_v	Spparent activation energy ($J\,mol^{-1}$)
$\Delta E_{v,b}$	'Equilibrium' activation energy ($J\,mol^{-1}$)
ΔE	Surface color at particular time
ΔE_∞	Surface color at infinite time
Δt	Time interval (s^{-1})
ΔH_{ev}	Latent heat of evaporation ($kJ\,kg^{-1}$)
ΔH_v	Vaporization heat of water ($J\,kg^{-1}$)
ε_w	Fraction by liquid water
ε_v	Fraction by water vapor
ρ	Sample density ($kg\,m^{-3}$)
ρ_s	Density of solids ($kg\,m^{-3}$)
$\rho_{v,b}$	Vapor concentration in drying medium ($kg\,m^{-3}$)
$\rho_{v,s}$	Surface vapor concentration ($kg\,m^{-3}$)
$\rho_{v,sat}$	Saturated vapor concentration ($kg\,m^{-3}$)
ρ_w	Density of water ($kg\,m^{-3}$)

crust color difference (ΔE) which allows prediction of crust thickness from the brown surface color of baked bread. The original weight of the dough used in this study before baking was 380 g and the baking time was up to 35 min. Purlis and Salvadori (2007) explained that the browning at bread surface during baking depends on weight loss and oven temperature: linear trend was found between total color change and weight loss of 100 g breads. Moreover, a strong positive correlation between crust thickness and the bread moisture ratio was found by Soleimani Pour-Damanab et al. (2012), which allows prediction of bread quality. However, the influence of the sample size on the baking behavior of bread has rarely been addressed. To gain insight into the possible effects of dough size on the bread baking process, we propose here a miniature bread baking approach, which was inspired by a kind of Chinese biscuit (Fig. 1a). This approach offers the opportunity to easily generate larger data sets in a shorter baking time (Fig. 1b) which may be used to study physical and chemical reactions during baking and validate mathematical models of baking processes.

The aim of this work is therefore to study the bread baking process by using a miniature bread making approach and to model the browning kinetics of miniature bread during baking using S-REA. For this, miniature breads (0.5 g and 1.0 g dough) were made according to a traditional process of bread baking at three different baking temperatures (175, 205 and 235 °C) with a baking time of 8 min. Physical properties of miniature breads, such as temperature profiles, moisture content, crust color, and crust thickness, were monitored to gain insight into the baking behavior of miniature breads. To make sure that miniature bread baking is essentially analogical to larger bread baking process, a comparison between the data gained from the miniature baking experiment and the data of regular-sized bread from the literature was made. In addition, the applicability of S-REA to model the temperature and moisture content profiles during miniature bread baking was evaluated. The accuracy of the S-REA to describe the color change of the crust was assessed.

2. Materials and methods

2.1. *Preparation of miniature bread*

Bread dough was made following a recipe in Wang and Zhou (2004) with slight modification: bread flour (75 g), sugar (7.5 g), fine salt (1.25 g), butter (2.25 g), instant yeast (0.75 g), and UHT skim milk (50 g). Dough was first made in a mixer (Twinbird, Japan) and then leavened for 45 min at ambient temperature. After proofing, small pieces of dough (0.5 g and 1.0 g) were shaped into a ball before proceeding to baking at 175, 205 and 235 °C in an electric oven (Changdi, China) for 8 min. The baking dish was placed in the central zone of the oven (Fig. 2).

2.2. *Physical properties*

2.2.1. *Weight loss and moisture content*

Weight loss and moisture content analyses were carried out immediately after each sampling, and were calculated according to Eqs. (1) and (2), respectively.

$$\text{Weight loss} = \frac{W_1 - W_2}{W_1} \times 100\% \tag{1}$$

$$\text{Moisture content} = \frac{W_2 - W_3}{W_2} \times 100\% \tag{2}$$

where, W_1 and W_2 are the weights of the dough prior and after baking for a certain time; and W_3 is the weight of the baked bread after dehydration at 105 °C for 24 h.

2.2.2. *Crust color and crust thickness*

Crust color and crust thickness analyses were conducted after cooling down the baked breads to room temperature. The crust color was measured by a spectrocolorimeter (Konica Minolta sensing, Japan). The crust thickness was determined according to the method described in Mohd Jusoh et al. (2009) with little differences in implementation. Several measures of each sample were recorded and an average value was obtained for each baking time. All tests were done by triplicate at least with the oven under steady condition. All data were presented as