Impact of steaming conditions on the structure and on the properties of bread crust; in the case of a crispy roll

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INTRODUCTION

Crust is an important attribute of crispy rolls such as French baguette. The quality of crust is often discussed in the literature. Besides, the precise impact of the amount of steam injected in the oven at the beginning of baking is not always very well indicated. The steam injection corresponds also to a significant amount of energy, due to the high latent heat of water vaporisation. Steam injection results in increase of the humidity in the oven. Some of the moisture condenses on the cold fermented dough pieces. The condensation plasticizes the superficial layer of the dough pieces (Zhang et al. 2007); therefore, a strong interaction is foreseen between the amount of steaming and the oven rise (loaf expansion during the first minutes of baking). This study presents an overview of recent investigations carried out in our research group.

More than any other processes, baking is concerned by energy demand as it is estimated that bread baking demands between 2 and 5 times more energy than any other food processing (Le-Bail et al. 2010). This is due to a high temperature and a low occupation ratio of the products in the oven. The energy is shared between bread dehydration (crust formation), losses to the ambiance and energy for steaming (Dinçer 1997; Fellows 1996). Values on energy demand for baking are in a wide range; (Le-Bail et al. 2010) proposed a value of 3.7 MJ/kg, whereas steaming (Dinçer 1997; Fellows 1996) proposed values in the range of 5 MJ/kg.

The moisture loss during baking is usually in the range of 10 to 20% (Vulicevic et al. 2004) which corresponds to 10 to 20% of the total baking energy. Steam injection is also representing between 10 to 20% of the baking energy (Vulicevic et al. 2004). Steaming is important for the final quality of the crust.

The expansion of the fermented dough during the first steps of baking is called the “oven rise”. The fermented dough is exposed to radiative and convective heat transfer from the oven including also condensation of the moisture contained in the air of the oven. Coupled heat and mass transfer result in an expansion of the cells contained in the fermented dough via (i) increased CO2 production by yeast (until yeast inactivation), (ii) expansion of the gas contained in the cells, (iii) vaporization of the CO2 and of the ethanol solubilized in the liquid phase of the dough and (iv) moisture vaporization as proposed by (Zhang et al. 2007). The expansion of the gas cells contained in the fermented dough stops when rupture of the wall of cell occurs (interconnection of the cells). The rupture is linked to a loss of plasticity caused by starch gelatinization and protein coagulation (crumb setting) occurring between 60°C and 90°C roughly. During oven rise, the surface of the fermented dough is exposed to an increasing tangential stress caused by the rise of the pressure in the dough. Depending on the amount of steam which condensates on the dough surface, the surface of the plasticity of the dough will be more or less pronounced. Therefore, there is a direct link between the oven rise (and subsequently final bread volume) and the amount of steaming.
The amount of literature related to steaming during baking is very limited even though some authors have taken great care in developing sophisticated models for bread during baking (Mondal and Datta 2008; Zhang and Datta 2006). In the review proposed by Mondal and Datta (2008), steaming is quoted once; the quotation was about the publication of Arhné et al. (Ahrné et al. 2007) in which the authors have done several steam injections during baking to mitigate acrylamide in the bread.

This paper presents a summary of two recent studies. Study A has been submitted in 2010 to Journal of Food Engineering (Le-Bail et al. 2011) and study B has been submitted in 2011 aiming at better understanding the impact of the amount of steaming on the structure and properties of the crust.

MATERIALS & METHODS

In Study A and study B, the effect of the amount of steam injection on selected bread characteristics were investigated using a MIWE deck oven (MIWE CO 1.1208 – Germany) equipped with a stone (1.02 m² internal surface). The amount of steam was adjusted on the control panel of the oven. A SP10 spiral mixer (VMI, Montaigu, France) was used to prepare the dough.

In study A, Bread dough has been prepared done with soft wheat flour supplied by Moulins Soufflet Pantin - Pornic, France. The flour had the following properties: 0.53% Ash content, 10.58% protein on dry matter, falling number 402 s, Zeleny 38, alveograph parameters W = 183, Pm/L = 0.62. The composition of the dough was on a flour weight basis - for 100 g flour, 58 g water, 5 g yeast (Michard SAS - Theix, France), 2 g salt (sodium chloride - Esco, Levallois Perret, France S.A.) and 1 g improver comprising a mix of alpha-amylase, vital gluten (confidential proportion - PURATOS – Groot Bijgaarden – Belgium). The mixing duration was 2 min at 100 rpm and 7 min at 200 rpm. After 15 min rest, the dough was divided and molded (Bongard, Holtzheim, France) to obtain dough pieces of 70 g each. The dough pieces were pierced with 5 holes and were fermented for 60 min at 35 °C, 95% relative humidity (ARG68 HENGEL, France). Baking was done with dough pieces installed on aluminum trays (40 cm x 80 cm), 12 pieces being installed on each tray. Similarly to making a cut on the surface of a crispy roll, the piercing facilitates the exhaust of the moisture and of the CO2 during the first stage of baking. The dough expansion ratio versus the initial volume of the dough was of 4 at the end of fermentation. The steam injection at beginning of baking was 100, 200, 300, 400 or 500 ml, corresponding to 0.33 l/m³, 0.66 l/m³, 0.99 l/m³, 1.32 l/m³ and 1.65 l/m³, respectively.

In study B, the dough was prepared with 100 g flour, 63 g water, 2 g compressed baker’s yeast (l’Hirondelle, France), 2 g table salt (Cérebos, France). Commercial wheat flour was supplied by Paulic Minotiers SA (France). The flour had the following properties: 11.30% d.m protein, Zeleny index 33 ml, alveograph parameters W=243x10⁻⁴ J and P/L=0.95. Mixing was done for 4 min at 100 rpm and 4 min at 200 rpm. After 20 min rest, the dough was divided in 75 g portions (Bongard, Holtzheim, France) and was rolled mechanically in MB230 moulder (L’Artisanne, France). Nine dough pieces were placed on aluminium trays (size 40 cm x 60 cm) and proofed at 25 °C and 95% relative humidity in a fermentation cabinet (ARG68 HENGEL, France). A dough expansion ratio of three (versus the initial volume of the dough) was selected as the optimum time of fermentation. Baking was done at fixed oven temperature of 230 °C for 18 min. The steam injection at beginning of baking was 100, 200 or 400 ml, corresponding to 0.33 l/m³, 0.66 l/m³ and 1.0 l/m³, respectively.

After baking, breads were allowed to cool down for 1h at room temperature. In tests A, temperature in the bread was logged with K type thermocouples (Omega, USA, 0.3mm diameter) connected to a SA...
32 Data Logger (AOIP-France). The temperature was measured at centre of 3 different breads for each baking and was averaged.

Crust crumb ratio was estimated in study A. The difference between crust and crumb was done by scrapping the crumb with the fingers. Bread volume was measured with a Texvol volumeter. Structure of the crust was studied with XRay microtomography in Study B (Sky Scan 1174 - Skyscan, Belgium).

RESULTS & DISCUSSION

Study A
Study A showed that the bread volume is the largest either for low or high steaming as shown in Figure 2. Tearing of the crust was often observed for low steaming; therefore, low steaming bread were not acceptable in terms of outlook. Beside, high steam bread had a very glossy outlook. The intermediate steam breads were showing a better compromise in terms of outlook and colour.

![Figure 2](image)

**Figure 2**
Bread volume in function of the amount of steaming. Study A

For low steaming (100 and 200 ml), the heating rate was high until 55°C and slowed down for higher temperature. For higher steaming (300-400-500 ml), the heating rate was lower. This was attributed to the condensation of steam on the loaf at the beginning of baking. Indeed, the heat flux transferred from the ambiance of the oven towards the dough was divided between heat transferred to the dough as such and heat taken to vaporize the condensed steam. This permits to explain why the heat up rate of “high steam” bread was slowed down in comparison to low steam bread.

Crust Crumb ratio on a dry basis is shown in Figure 3 showing that the crust crumb ratio decreasing with increasing amount of steaming. This was attributed to a higher internal pressure in the dough for low steaming during oven rise caused by a faster drying and setting of the outer crust.

![Figure 3](image)

**Figure 3**
Crust crumb ratio on dry and humid basis. Study A

Study B
Study B was done with crispy rolls with cut (see Figure 1). The opening of the cut and the outlook of the bread was much different in comparison with study A, in which no cut was done at the surface of
the bread. The range of steaming was lower than in study A and was 100, 200 and 400 ml. These values were chosen based on results obtained in study A. Water vapour permeability was measured by placing a piece of crust (2 cm diameter) on a flask containing water (Figure 5). The flask was weighted every day for a 4 to 5 days period. The Water vapour transmission rate (WVTR) was determined using Equation (1) according to (ASTM 1980). The slope of the rate of weight loss versus time plot was divided by the effective crust area (3.14 cm²) to obtain the WVTR.

$$\text{WVTR} = \frac{g_{\text{water}}/s}{\text{Crust Area}} \quad (1)$$

The Water vapour permeability (WVP) accommodated corrections proposed by (Bird et al. 1960; Kronchta 1992) to determine the effective vapour partial pressure P2 in the crust inner surface according to Equation (2) proposed by (McHugh et al. 1993).

$$\text{WVTR} = \frac{P * D * \text{Ln}[(P-P2)/(P-P1)]}{R * T * \Delta z} \quad (2)$$

P= Total pressure (Pa)
D= Diffusivity of water through air at 20° C (2.53 10⁻⁵ m²/s)
R= Gas law constant (8.32 Pa m³ mol⁻¹ K⁻¹)
T= Absolute temperature 293.25 K
$$\Delta z$$=Mean stagnant air gap height $$(z_{\text{original}}+z_{\text{final}})/2$$ (m)
P1= Water vapour partial pressure at solution surface (Pa)
P2= corrected water vapour partial pressure at crust inner surface in cup (Pa).

The water vapour permeability was then calculated using Equation (3), the corrected partial pressure at the inner surface of the crust being determined with Equation (2). The external partial vapour pressure was corresponding to a RH of 61% at a temperature of 20°C.

$$\text{Permeability} = \frac{\text{WVTR}}{P2-P3} * \text{Thickness(mm)} \quad \text{in g.mm.m}^{-2}.s^{-1}.Pa^{-1} \quad (3)$$

Values of permeability were of 1.88 10⁻⁶, 1.41 10⁻⁶ and 1.2 10⁻⁶ g.mm.m².s⁻¹.Pa⁻¹ at 100, 200 and 400 ml respectively. An increase of moisture permeability of the crust by 50% was thus observed by decreasing the steaming from 400 ml to 100 ml. This interesting result shows that the crust permeability can be modulated by the amount of steaming. Further cork is needed to better understand the impact of the baking duration on the crust thickness and on crispiness perception. A High steaming combined with a long baking may result in a thick crust which may be crispier. However, this thick crust may also represent a barrier for the diffusion of crumb moisture towards the ambiance; its crispiness may thus be harder to preserve during storage after baking. An intermediate amount of steam combined with an adapted baking time should result in a better compromise: a crispy crust which may keep its crispiness longer due to its capability to let the moisture escaping from the crumb travel through it. These values were supported by XRay microtomography images as shown in Figure 5, Figure 6 and Figure 7 obtained for steaming of 100, 200 and 400 ml.
CONCLUSION
The key results of the two studies presented in this paper are as follows:

**Study A**: Steaming affects the heating rate during oven rise. A higher amount of steaming yields a slower heat up rate. This was attributed to the fact that condensation occurs in the case of high steaming. The crust crumb ratio and the bread volume was higher either for low steaming or for high steaming. A higher bread volume was obtained for low and high steaming; however, for low steaming, tearing of the crust occurred and the bread was not acceptable in terms of outlook.

**Study B**: Results showed that non gelatinized starch was visible for the low steaming crust whereas evidence of starch gelatinization was visible for high steaming (not shown in this paper). This was attributed to the presence of condensed steam at the surface of the bread. The crust crumb ratio was
negatively correlated to the amount of steam. The permeability of the crust to moisture was higher for lower steaming. Water vapour permeability of crust (g mm⁻² m⁻² Pa⁻¹) was increased by 50% when decreasing vapour transmission rate from 400 to 100 ml. X-ray microtomography showed that the crust domain was thinner for low steaming than for high steaming. Steam injection during bread baking addresses important issues both in terms of energy demand (Le-Bail et al. 2009) and in terms of crust structure. Further study is needed to assess the impact of baking duration on crust crispness and the possible relation between crust permeability and crispness retention. Indeed, as shown recently by (Hirte et al. 2010), crispness and crispness retention is not just a question of water activity. The permeability of crust is also playing a very important role in crispness retention. A highly permeable crust will allow the moisture travelling from the crumb towards the external ambiance to diffuse through the crust more freely than in the case of a crust with a low permeability.

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