Impact of Baking Bed and Baking Temperature on Staling of Sangak Bread

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ABSTRACT

The mode of heat and mass transfer during baking of bakery products is an important factor determining the quality of the final product. The heating rate could alter the starch properties during gelatinization and affect the quality of products after baking and during aging. Sangak is a kind of Iranian flat bread baked on the hot pebble gravels. The aim of this study was to evaluate the impacts of baking beds (gravel and metal beds) and baking temperatures (280, 310 and 340°C) on staling of Sangak bread during storage at 20°C. The mean value of the measured heating rate of bread baked on gravel bed was higher than that in bread baked on metal bed. In the case of baking on gravel bed, unlike baking on the metal bed, the increase of baking temperature had no significant effect on all quality parameters (moisture content, firmness and freezable water of breads, etc). Recrystallization of amylopectin seemed not to be related to the baking condition. During aging, the firmness of bread baked on gravel bed was significantly lower than that for bread baked on the metal bed and baking at higher temperature and shorter time resulted in the increment of moisture content and the decrease of firmness. As a consequence, baking on gravels and higher baking temperature increased the heating rate, which led to reduction of the staling kinetic of Sangak bread.

Keywords: Amylopectin retrogradation, Bread Firmness, Freezable water, Heating rate, Unfreezable water.

INRODUCTION

Sangak is one of the most traditional Iranian flat breads with a very good flavor and a high nutritional value. Its name is derived from the way it is baked on a bed of hot tiny pebble gravels in the oven. This bread is prepared from whole wheat flour in a triangular shape with 0.5-1 cm thickness. In traditional Sangak baking ovens, temperature range is 250-350°C in different parts of oven and baking time is only a few minutes. Recently, several semi-industrial ovens have been designed for Sangak baking on the metal beds, but the bread quality baked in these ovens is not acceptable to some consumers. It seems that the quality difference between bread baked in traditional oven with semi-industrial oven can be only related to the distinction in their baking beds and conditions.

There are different factors in baking oven that affect the quality of the final product in baking stage. They include the rate and amount of heating, the humidity level in the baking chamber, baking time, etc (Therdthai *et al.*, 2002). Heat and mass transfer phenomena are taking place simultaneously during bread baking, causing physical, chemical, and structural transformation such as evaporation of water, formation of porous structure, volume expansion, protein denaturation, starch gelatinization, and crust formation (Sablani *et al.*, 1998; Mondal and

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Datta, 2008). These transformations largely determine the structure and texture of the final product. Radiation was found to be the predominant mode of heat transfer (between 50 and 80% of total heat) while convection was the least important mode in conventional baking ovens. The ratio of the convection to the conduction mode of heat transfer in industrial baking ovens changes bakery products quality and energy consumption (Dostie, 2002; Zareifard et al., 2009). Temperature is the dominating factor in various physicochemical changes during baking. Baking temperature and baking duration influence the degree of gelatinization, thereby affecting staling rate (Le Bail et al., 2009). Higher oven temperature and heat transfer coefficient result in more rapid heating rate. When oven temperature and heat transfer coefficient are increased, baking time decreases with an exponential trend due to the relationship between internal and external resistance to heat transfer. With the increase of heat transfer coefficient, the external resistance to heat transfer becomes negligible and heating rate will be controlled by low thermal conductivity of the product. Heating rate affects the extent of starch granule hydration, swelling, dispersion, and the extent of re-association (Mondal and Datta, 2008). Denaturation of protein takes place during bread baking and protein solubility decreases with the time of baking due to aggregation or cross-linking. Protein denaturation and starch gelatinization cause releasing and absorbing water respectively, and affect the diffusion of water (Mondal and Datta, 2008). The location of the loaves in the oven and baking bed can also induce a difference between baked breads. Indeed, the loaves that are placed close to the wall of the oven may heat up at a different rate than the bread placed at the center of the oven (Borczak et al., 2008).

During storage of the bread, gelatinized starch (amorphous structure) tends to be transformed to the crystalline structure. Amylose association increases as the concentration of soluble amylose increases (Morris, 1990). Faster heating rate resulted in a larger amount of leached amylose (Patel et al., 2005) and a higher amount of leached amylose could be observed for the prolonged baking (Langton and Hermansson, 1989). Therefore, the thermal history of the crumb during baking affects starch properties and also the staling kinetics (Faridi and Rubenthaler, 1984; Therdthai et al., 2002; Patel et al., 2005; Schirmer et al., 2011; Le Bail et al., 2009, 2012).

As mentioned above, the mode of heat transfer at the bread boundaries and external conditions such as hot air temperature in oven affect the bread heating rate during baking and, consequently, quality characteristic of the final product. One of the most important factors which affects the bread heating mode in oven is the baking bed. The effects of various baking conditions such as temperature and duration of baking on bakery products quality were studied extensively (Smith et al., 1983; Leuschner et al., 1999; Faridi and Rubenthaler, 1984). However, to our knowledge, there is no published research on the impact of baking bed on the bread quality, especially on the staling of the flat breads produced from dough with high water proportion such as Sangak.

This research was part of a study on the Sangak bread to provide a better understanding of the involved phenomena in its baking process. The aim of the present study was to investigate the effect of baking on a bed of hot tiny pebble gravels compared to a metal bed at different temperatures (280, 310 and 340°C) on quality properties of Sangak bread during storage at room temperature.

MATERIALS AND METHODS

Raw Materials

The wheat flour used (local milling plant, Isfahan, Iran) had the chemical composition of 1.01% ash, 13.7% proteins, 2.02% lipids, and 13.2% moisture on a wet basis. Other

flour properties were 27.8% wet gluten, 9.5% dry gluten, 50.5% gluten index and 63.5% water absorption obtained from Farinograph test (AACC, 2000). The recipe for Sangak dough preparation was as follows: 100 g of flour, 100 g of water, 1 g of compressed yeast (Fariman Co., Iran), and 1 g of salt (Esco, Levallois-Perret, France).

Sample Preparation

Mixing of ingredients was performed in a spiral mixer (VMI, Montaigu, France) for 7 minutes in low speed and followed by 8 minutes rapid mixing. After 45 minutes fermentation at 30°C and 75-85% relative humidity in a proofing cabinet, dough layers with a thickness of 3.5 mm were prepared and frozen at -30°C. After 24 hours storage at -20°C, the Sangak dough sheets of 15×15 cm were prepared. Baking was done in the oven (MIWE-Germany) at 280, 310, and 340°C for 8, 5.5 and 4 minutes, respectively; on two different baking beds (a bed of hot tiny pebble gravels and a metal bed). The tiny river stones were placed in the steel container with 10 cm depth. Their surface was flattened by wooden paddle and put in the oven for at least one hour before baking. Cooling of breads was done at room temperature and considered as completed when the temperature at the bread crumb reached 20°C. Then, the baked bread was packed in sealed impermeable films and stored at 20°C for 4 days (sampling intervals were 0, 1, 2, and 4 days). Two different approaches were adopted for measuring the degree of staling: thermal and rheological analysis. Thermal analysis was conducted by differential scanning calorimetry to study amylopectin retrogradation and the changes in the amount of freezable water. In rheological analysis, firmness and hardness were evaluated using compression test and Kramer shear cell test, respectively, during the storage. Tests were done in triplicate with samples taken from 3 different parts of bread for each test.

Time-Temperature Profile Measurement

The dough temperature was logged during baking with K type thermocouples connected to a data logger (SA 32–AOIP–France). Heating rates during baking were calculated from the ascending part of time-temperature histories (from the initial temperature of 20 to 98°C, which is the highest temperature in bread crumb).

Calorimetry

Samples (80-90 mg) were taken from the central section of the crumb and hermetically closed in aluminum pans. Calorimetric tests were carried out by a scanning calorimeter (DSC Q100, TA Instruments, USA) with the following program: after equilibration of samples at 20°C for 2 minutes; they were cooled down to -50°C at a rate of 10°C min^{-1} and maintained at this temperature for 2 minutes and, finally, were heated to 120°C at a heating rate of 10°C min^{-1}. An empty pan was used as the reference. The scans were used to determine the thermal properties (onset temperature (T_o), initial temperature (T_i), peak temperature (T_p), conclusion temperature (T_c), enthalpy of fusion (ΔH_f, J g_{dm}^{-1}) and melting enthalpy of amylopectin (ΔH_r, J g_{dm}^{-1}). The amount of freezable water (FW, $g_{H2O} g_{dm}^{-1}$) was obtained by dividing the enthalpy of fusion by the latent heat of melting of pure water (Ribotta and Le-Bail, 2007; Le-Bail *et al*., 2009). The moisture content of samples was determined in triplicate by drying 5-6 g of sample in a forced convection oven at 105°C for 24 hours.

Analysis of Bread Texture

The evaluation of the textural properties of Sangak bread samples during storage was performed by two different rheological tests, compression test and Kramer shear cell test.

Compression Test

A dynamic mechanical analyzer (Q800 Dynamic Mechanical Analyzer, TA Instruments, New Castle, USA) was used to do compression test. The compression was done with a compression rate of 8% min^{-1} until 30% strain on the cylindrical bread samples (14 mm diameter) in a parallel plate system. The static force (N) was measured at 30% strain and reported as firmness. Four replications were performed for each experiment.

Kramer Shear Cell Test

A texture Analyzer (Lloyd Instruments, LR5K, UK) with a Kramer shear cell (ten blades) at a rate of 60 mm min^{-1} and a 5 kN load cell was used to cut the bread samples (55×55 mm). From the curves obtained, one parameter (maximum force) was used for comparing the textural properties. The hardness curves (force _vs._ distance) were plotted. The maximum force (N) required to cut a sample was considered as a measure of bread hardness. The experiment was performed in three replications.

Statistical Analysis

SAS 9.0 software was used for statistical analysis of the data. Least significant difference test (LSD) was performed to determine the impact of baking bed, baking temperature, and storage time on thermal and textural properties of Sangak bread ($P<$ 0.05).

RESULTS AND DISCUSSION

The thermal profile at the center of crumb during baking can be divided into three distinct phases: slow temperature increase, rapid increase of temperature, and asymptotic increase of temperature (Patel _et al._, 2005). In this study, the first phase was

negligible and the increasing rate of temperature in the second phase was very fast due to low thickness and high ratio of surface area to volume of the Sangak dough. Figure 1 represents the time- temperature history of Sangak bread during baking at 280°C on gravel and metal beds at three different locations. Evaluation of time-temperature profiles showed that heating rate of bread baked on metal bed was almost constant in the center of the crumb, but in the case of baking on gravel bed, because of different heat transfer conditions in different parts of bread and also the change of dough thickness, it was varied. Heating rate in bread crumb baked at 280°C on metal bed was 27.7°C min^{-1}, while in the case of baking on gravel bed, the rate depended on location and varied from 26.6 to 40°C min^{-1}.
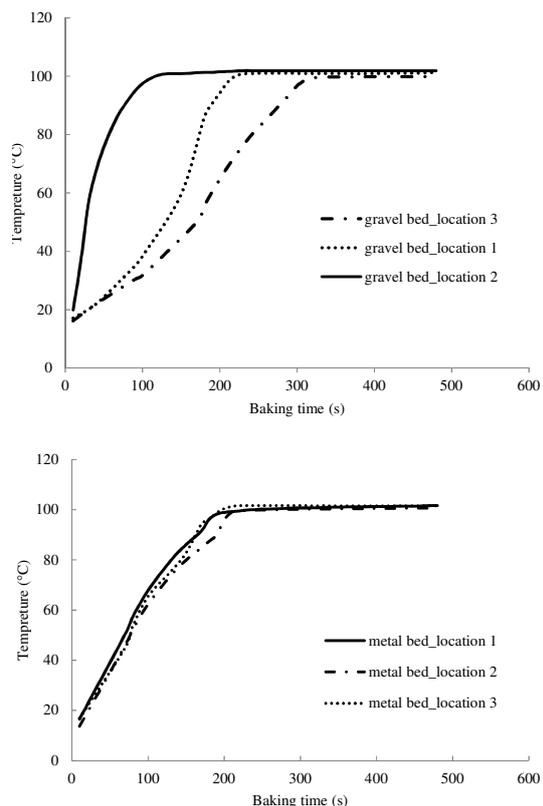
As shown in Figure 2, the increase in

Figure 1. Time-temperature profile at 3 different locations in Sangak bread during baking at 280°C on: (a) The gravel bed and (b) The metal
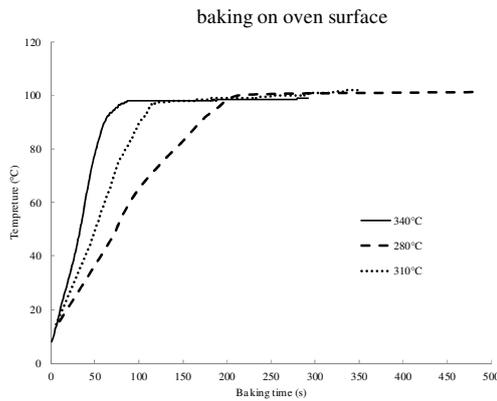
Figure 2. Temperature profile of Sangak crumb core during baking on the metal bed in oven at 280, 310, and 340°C.

baking temperature resulted in the increase of heating rate and it was 27.7, 40.2, and 58°C min^{-1} for baking on metal bed at 280, 310, and 340°C, respectively. The measured heating rates in this study were rather higher than the reported amounts by some authors (Le Bail *et al*. 2009; Patel *et al*., 2005). This could be because of the higher baking temperature, the higher surface area to volume ratio of Sangak bread, and the higher water content of Sangak dough. The high proportion of water in Sangak dough significantly affected physical characteristics of the bread and resulted in the increase of heating rate. The higher water content increased the thermal transfer into the crumb as a result of the higher heat transmission coefficient of water and water vapor compared with air (Schirmer *et al*., 2011).

Table 1 shows quality parameters of the bread baked at three different temperatures on both gravel and metal beds right after baking. In the case of baking on gravels, baking temperature had no significant effect on all quality parameters. It means that the changes of moisture content, firmness, and freezable water of the bread baked on gravels with the increase in baking temperature were lower than those for the bread baked on metal bed; therefore, there were no significant differences between the bread baked at 280, 310, and 340°C on

Table 1. The effect of baking bed (metal bed and gravel bed) on the moisture content, hardness, firmness, enthalpy of fusion, freezable and unfreezable water, and T_o, T_i, T_p, T_c of Sangak bread baked at three different temperatures after baking (before storage).[a]

Baking bed	Oven temp.	Moisture content (g g$_{dm}$$^{-1}$)	Hardness (N)	Firmness (N)	ΔH$_f$ (J g$_{dm}$$^{-1}$)	FW (g g$_{dm}$$^{-1}$)	UFW (g g$_{dm}$$^{-1}$)	T_o (°C)	T_i (°C)	T_p (°C)	T_c (°C)	T_c-T_i (°C)
MB	280°C	0.619b	1126.1a	0.385a	157.12b	0.470b	0.192a	-12.95a	-7.51a	3.73a	36.45a	43.96a
	310°C	0.712a	913.8b	0.285a	198.12a	0.593a	0.105b	-12.9a	-5.38a	5.38a	40.7a	46.08a
	340°C	0.758a	902.7b	0.257a	208.46a	0.624a	0.102b	-12.5a	-5.28a	6.77a	41.98a	47.26a
GB	280°C	0.605a	1430.2a	0.560a	153.20b	0.458a	0.148a	-13a	-6.89a	4.25a	37.35a	44.25a
	310°C	0.653a	1269.6a	0.509a	182.73a	0.547a	0.099a	-12.9a	-6.01a	5.93a	38.15a	44.25a
	340°C	0.690a	1175.8a	0.383a	187.47a	0.561a	0.061a	-12.75a	-5.41a	5.99a	39.83a	45.24a

[a] Means within columns followed by the same letter are not significantly different (P< 0.05)

gravel bed. The average moisture content of the bread baked on gravel bed was 37.7, 39.5, and 40.8% (wet basis) at 280, 310, and 340°C respectively; but for baking on metal beds, it was 38.2, 41.6, and 43.1%. The increase in baking temperature led to the higher range of moisture content of the bread baked on metal bed (4.9% on a wet basis) than the bread baked on gravel bed (3.1%) and the differences could be due to the different heat and mass transfer in the two types of baking beds. In baking on gravels, moisture could also be transferred from the back surface of the bread and the space between gravels, in addition to the upper surface (crust). This could be a reason for the lower average moisture content of the bread baked on gravel bed than the bread baked on the metal bed. In the case of heat transfer, in addition to the different heat transfer coefficient, the amounts of heat transfer surface area and boundary condition differed in the two baking beds. In baking on gravel bed, when the Sangak dough was transferred onto the hot gravels, some parts of dough penetrated into the space between gravels and, although some points of dough were not in contact with the gravels, the increase of heat transfer from the back surface area caused the increment of heat transfer rate. Although the dough prepared for the two baking methods had the same thickness, the average thickness (measured

by DMA) of bread samples baked on gravels (7.1 mm) was lower than those baked on the metal bed(9.16 mm) and this difference could be due to the increase of the back surface area of the bread baked on gravels.

Evolution of the melting enthalpy of amylopectin for Sangak bread baked at different conditions during storage is shown in Figure 3. It can be seen that the melting enthalpy of amylopectin crystallites increased during storage. The amylopectin retrogradation of bread baked on gravel bed at different temperatures were very close to each other, while in the case of baking on metal bed, a slight difference was observed between them. However, baking condition had no statistically significant effect ($P< 0.05$) on melting enthalpy of amylopectin of Sangak bread stored at room temperature as shown by Le Bail _et al_. (2012). It seems that the starch was recrystallized irrespective of the baking condition even though a slight increase in the amount of recrystallized amylopectin was observed for the shorter baking time at higher temperature and at the end of storage for baking on metal bed. Due to the high moisture content and short shelf life of Sangak bread, the maintenance of bread at room temperature was not possible for more than four days because of mold growth. But it seems that the increase of amylopectin crystallization over time followed a sigmoidal kinetic, as shown by
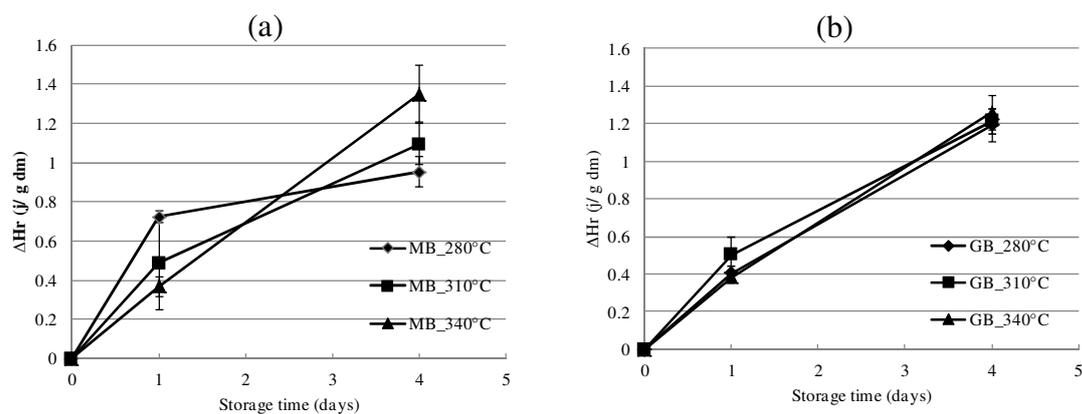

Figure 3. Evolution of melting enthalpy of amylopectin for Sangak bread baked on: (a) The metal bed (MB), and (b) Gravel bed (GB) at 280, 310, and 340°C during storage at 20°C.

some authors (Barcenas *et al*., 2003; Ribotta and Le Bail, 2007; Le Bail *et al*., 2009, 2012). The amounts of amylopectin retrogradation enthalpy of aged bread reported in literature are very different. Some authors have reported the maximum values of 1-2 J g_{dm}^{-1} for melting enthalpy of amylopectin as obtained in this study (Le Bail *et al*., 2009, 2012) and some have mentioned the higher maximum values of 5-10 J g_{dm}^{-1} (Barcenas *et al*., 2003, 2006; Patel *et al*., 2005; Ribotta and Le Bail, 2007; Ronda *et al*., 2011) and a few others have reported very large quantities (220 J g^{-1} reported by Bhatt and Nagaraju, 2009; 142.12 cal g^{-1} reported by Shaikh *et al*., 2007). In the latter case, seemingly, starch gelatinization during baking of the desired breads was not completed. These differences in the reported melting enthalpy of amylopectin could be because of different ingredients used in bread formulation, different bread baking processes, and different bread storage conditions.

Baking bed and baking temperature had a significant effect on the enthalpy of fusion of fresh bread, but they had no significant effect on temperature range of ice fusion, T_o, T_i, T_p, T_c and T_c-T_i, as shown in Table 1. The bread baked at the higher temperature had the higher ice melting enthalpy because of the higher moisture content and the increase in baking temperature resulted in the slight increase of T_o, T_i, T_p, T_c and T_c-T_i due to the

decrease of solute concentration in aqueous phase (Ribotta and Le Bail, 2007); however, these changes were not statistically significant.

The evolution of the amount of freezable water in Sangak bread baked at different baking conditions showed that there was a trend to have a higher amount of freezable water for baking at higher temperature and shorter duration (340°C for 4 minutes) due to more moisture content as shown in Table1. The amount of freezable water of all samples decreased with increasing storage time as observed by Le-Bail *et al*. (2009). The impact of baking temperature on the amount of freezable water seemed to be more sensible in the case of baking on metal bed than baking on gravels; this could be related to the higher moisture content of bread baked on the metal bed. Evolution of the mean values of freezable water and unfreezable water for Sangak bread baked on the metal and gravel beds at 3 different temperatures during storage at 20°C is shown in Figure 4. It can be seen that parallel to the decrease of freezable water, the amount of unfreezable water increased with increasing storage time, because the free water was trapped by recrystallized amylopectin (Gray and Bemiller, 2003). In bread baked on the metal bed, the decrease of freezable water and the simultaneous increment of unfreezable water mainly took place rapidly during one day storage. Then,
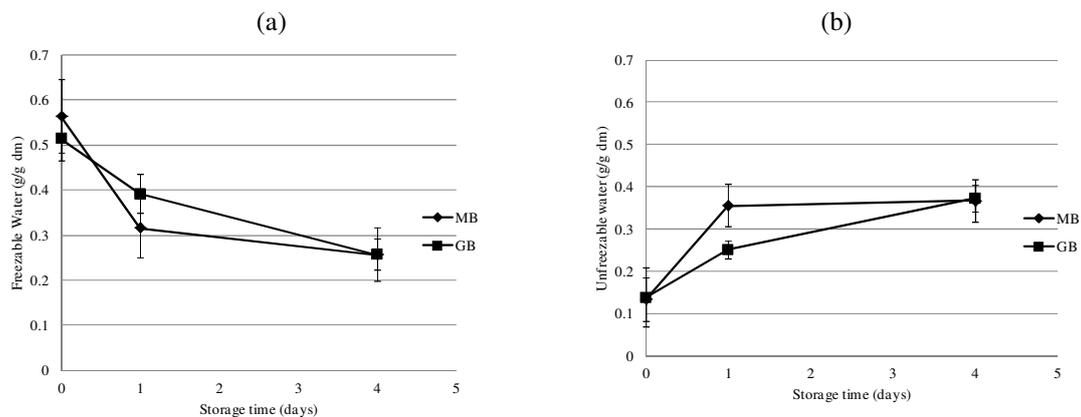

Figure 4. Evolution of freezable water (a) and unfreezable water (b) of Sangak bread baked on the metal bed (MB) and on gravel bed (GB) during storage at 20°C (data are the average of 3 baking temperatures).

the rate of changes was reduced and no statistically significant differences were found between one and four days; but, for bread baked on gravels surface, the decrement rate of freezable water and the increasing rate of unfreezable water were lower and there were significant differences between one and four days. At the end of storage time (4 days), the amounts of freezable water and, also, unfreezable water of bread baked on both baking surfaces were the same.

Figure 5 shows the firmness evolution of bread baked at different conditions during storage. The moisture content and amylopectin retrogradation could affect the texture of bread. The firmness increased significantly ($P< 0.05$) in bread during storage as the other authors mentioned (Majzoobi *et al.*, 2011; Le Bail *et al.*, 2009, 2012). In addition, the bread baked at the higher baking temperature with the shorter time had softer texture and lower firmness than that baked at lower temperatures with longer durations due to its lower moisture content and the plasticizing role of water (Gray and Bemiller, 2003; Barcenas *et al.*, 2006). Also, it was found that despite the lower moisture content of bread baked on gravel bed, the firmness was significantly lower than that for bread baked on the metal bed in two and four days and the amounts of firmness were similar for both kinds of

baking bed at the beginning of storage (0 and one day). When lower temperature and longer time were employed, the difference between firmness of bread baked on the metal bed and bread baked on gravel bed was increased. In other words, at baking temperature of 280°C, the firmness of bread baked on gravels was dramatically lower than that of bread baked on the metal bed. The changes of starch granules during baking determine crumb structure and texture (Dreese *et al.*, 1988; Patel *et al.*, 2005). The heating rate would affect the gelatinization process by altering the time available for order–disorder transitions, thereby influencing the extent of disordering of the amylopectin crystals, granule swelling and amylose leaching. Therefore, the established crumb structure and texture within the bread would be a function of heating rate (Patel *et al.*, 2005). In this study, baking on gravel bed and baking at higher temperature increased the heating rate and the firmness of bread baked at higher heating rate was significantly lower than that baked at the lower heating rate during aging. The same results were reported by Le Bail *et al.* (2012).

The hardness evolution of bread baked on gravel and metal beds during storage is shown in Figure 6. The rheological changes of bread such as elasto-plastic conversions led to significant ($P< 0.05$) decrease in
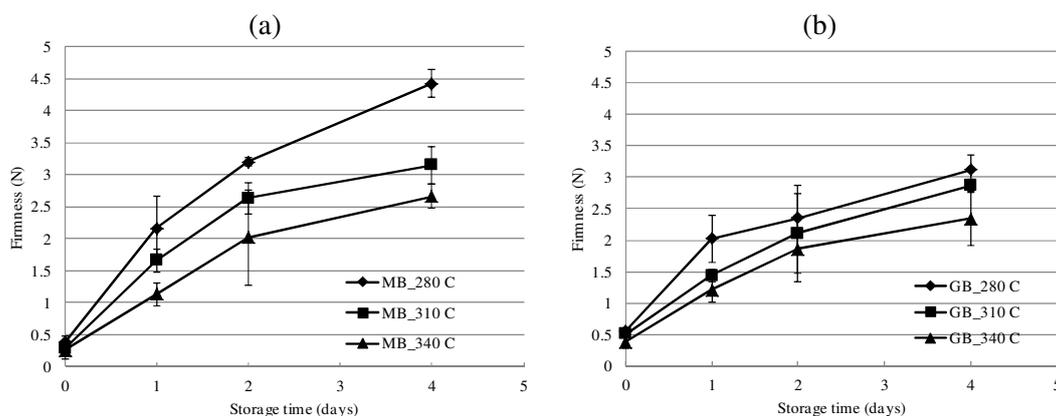

Figure 5. Evolution of firmness of Sangak bread baked on: (a) The metal bed (MB), and (b) Gravel bed (GB) at 280, 310, and 340°C during storage at 20°C.

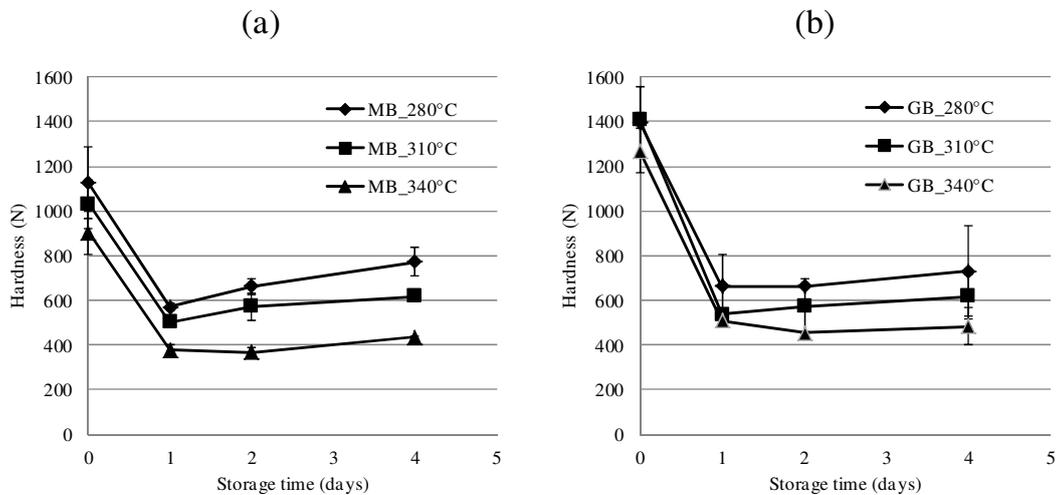(a)   (b)

Figure 6. Evolution of hardness of Sangak bread baked on the metal bed (MB) and gravel bed (GB) at 280, 310, and 340°C during storage at 20°C.

hardness during the first day of storage. Afterwards, bread hardness increased, but it was not statistically significant. Except for fresh breads, there was no significant difference between hardness of bread baked on gravels and that of bread baked on the metal bed. The hardness of fresh bread baked on gravels was significantly higher than that baked on metal bed, requiring higher forces for shearing and cutting by Kramer shear cell. This could be a consequence of the different thermal history of the bread during baking on two different baking beds.

CONCLUSIONS

The heat and mass transfer during baking of bakery products are linked to the quality of the final product. The time/temperature combination imposed on the product is affected by the product and the baking apparatus (Sommier, *et al.*, 2011). The differences in qualitative properties of Sangak bread baked from the same dough with the same size were attributable to the differences in the rate of heating achieved by using different baking beds and different baking temperatures. Baking Sangak on hot

gravels changed the mode of heat and mass transfer and increased heating rate more than baking on metal bed. The heating rates and thermal profiles experienced at the crumb resulted in different moisture content and staling kinetic following the storage. The heating rate affected the gelatinization process by altering the extent of disordering of the amylopectin crystals, granule swelling, and amylose leaching. It also affected the starch recrystallization and staling kinetic after baking (Patel *et al.*, 2005). In the case of baking on gravel bed, moisture could be transferred from both the upper surface (crust) and the back surface of the bread (the space between gravels) and, as a consequence, the average moisture content of bread baked on gravel bed was lower than that of bread baked on the metal bed. Regarding heat transfer, different heat transfer coefficient, the amounts of heat transfer surface area, and different boundary condition in the two baking bed types could be the reasons for different heat flux received by the product.

Unlike breads baked on metal bed, the increase in baking temperature from 280 to 340°C resulted in no significant changes on qualitative properties of Sangak breads baked on gravel bed.

The staling kinetic of the bread baked on gravel and metal beds was different and the firmness of the bread baked on gravel bed was significantly lower than that for the bread baked on metal bed during aging, although the moisture content of the latter was higher than that baked on gravels.

ACKNOWLEDGEMENTS

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اثر نوع بستر و دمای پخت بر بیاتی نان سنگک

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چکیده

نحوه انتقال جرم و حرارت طی پخت محصولات نانوایی فاکتور مهمی در تعیین کیفیت محصول نهایی می باشد. سرعت حرارت دهی می تواند خصوصیات نشاسته را طی مرحله ژلاتینه شدن تغییر دهد و کیفیت محصولات را پس از پخت و طی نگهداری تحت تأثیر قرار دهد. سنگک نوعی از نانهای مسطح ایرانی است که بر روی سنگریزه های داغ پخت می شود. هدف از این مطالعه ارزیابی اثر بستر پخت (پخت بر روی بستر سنگریزه و بستر فلزی) و دمای پخت (۲۸۰، ۳۱۰ و ۳۴۰ °C) بر بیاتی نان سنگک در طی نگهداری در دمای ۲۰ °C می باشد. مقادیر میانگین سرعت حرارتی در نانهای پخته شده

بر روی بستر سنگریزه بالاتر از مقادیر اندازه گیری شده برای نانهای پخت شده بر روی بستر فلزی بودند. در مورد پخت بر روی بستر سنگریزه بر خلاف پخت بر روی بستر فلزی، افزایش دمای پخت اثر معنی داری بر هیچ یک از پارامترهای کیفی (مقدار رطوبت، سفتی، آب قابل انجماد و غیره) نداشت. کریستالیزاسیون مجدد آمیلوپکتین به نظر رسید که وابسته به شرایط پخت نمی باشد. میزان سفتی نانهای پخته شده بر روی بستر سنگریزه به طور معنی داری کمتر از سفتی نانهای پخته شده بر روی بستر فلزی طی دوره نگهداری بودند. پخت در دمای بالاتر و زمان کمتر باعث افزایش میزان رطوبت و کاهش سفتی نمونه ها شد. در نتیجه پخت بر روی بستر سنگریزه و افزایش دمای پخت سرعت حرارت دهی را افزایش داده و افزایش سرعت حرارت دهی منجر به کاهش سینتیک بیاتی می گردد.