# CHANGES THAT OCCUR DURING BAKING ON THE STRUCTURE OF CHEMICALLY LEAVENED DOUGH

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REVIEW ARTICLE

**Abstract**

*The baking of the thin dough was carried out in a pilot oven under various conditions, allowing the study of macroscopic changes in relation to physical and biochemical changes during the baking process.*
*The influence of baking parameters (temperature, humidity and air velocity) on macroscopic and microscopic changes was investigated, together with variations (temperature and humidity levels,heating and drying rates) of product variables. The main changes observed during the baking of the biscuits were: the development of a partially open porous structure, associated with a reduction in density, drying and surface colouring. The structural changes were due to the evaporation of water and gas bubbles produced by the decomposition of the chemical leavening agents used. The expansion stopped due to theexhaustion of the chemical leavening agents and the percolation of water vapour at appropriate temperatures. The setting of the biscuit structure was not related to thermal aggregation of proteins (which started at 85 °C) or to limited damage to starch granules at temperatures below 100 °C. The setting apparently occurred during the cooling period, when the molten sugars undergo a glass transition. The colouring of the biscuit surface and a subsequent decrease in brightness were correlated with reduced sugar consumption in Maillard reactions.*

**Keywords**: biscuit, coloring, expansion, temperature.

## INTRODUCTION

Shortcrust pastry is generally composed of three main ingredients (flour, sugar and fat) and contains only a small amount of water (<20% g.a.). The biochemical and physicochemical reactions in biscuit dough during baking are very complex, involving protein denaturation, loss of starch granular structure, fat melting, Maillard reactions and browning, dough expansion by water evaporation and the production and thermal expansion of gases. Expansion, a relevant event in texture formation, is limited by the rheological properties of the dough, which depend on the behavior and interactions of its components, and on the solubility of gas in the continuous phase. Two main mechanisms have been proposed, which may be complementary depending on the dough composition. The first, based on calorimetric studies (Cadough differential scanning calorimetry, DSC), considers that dough properties are essentially governed by the phase transition of a gluten network. The second suggests that the viscoelastic properties of tender dough are due to a co-continuous process, which includes a dispersed or continuous fat system, a fat-free phase and the suspension of flour particles in a sucrose solution. In both cases, the study of interactions between all dough components is relevant. Various studies have considered the structural changes that occur in starch (the main component of dough) over a wide range of water contents3–5. DSC has been used to determine the behavior of starch and the influence of ingredients or other components of flour in excess water or with a water content above 60% (c.a.)6–9. However, few results have addressed the influence of ingredients with a water content below 60% (c.a.), typical of biscuit dough.

Although it is commonly assumed that starch is not gelatinized after short dough baking (due to water limitation), intermediate states of damaged starch, either swollen granules or amylase leaching, can affect dough rheological properties as well as starch granule interactions with other components during baking. The role of proteins has often been investigated due to the gluten network in thin dough. In fact, the apparent viscosity of dough is reduced after the glass transition of gluten polymers, rather than increasing by their aggregation. This may be due to the high aggregation temperature (above 80 °C at 20% moisture content) or the influence of sugars on the gluten Tg. The process is also made more complex by fat melting, which occurs between 15 and 40 °C, depending on the fat polymorphism and the proportion of solid fat. Finally, for reasons of simplicity, studies on biscuit baking modeling actually focus on predicting volumetric characteristics (volume, color) and often neglect the physicochemical changes of the dough by limiting the baking step to heat transfer in a homogeneous material. Therefore, the structural changes of the dough must be studied during baking to consider their relationship with macroscopic changes.

The aim of the present study was to determine the changes that occur during baking in terms of size, surface color and moisture, in relation to the concomitant physicochemical changes of the dough components (starch, protein, sugar, water).

The baking experiments were carried out with a large-scale pilot oven, in a range covering the typical conditions of the bakery industry. The dough recipe used for this study produced a typical French biscuit, the most significant characteristics of which were thickness and color. This cookie is clearly different from sugar cookies, where the spread is essential.

## MATERIAL AND METHOD

Dough preparation and baking:

All ingredients were supplied by LU (La Haye-Fouassière, France). The flour was a mixture containing 8•8% protein (d.b.) and 14•8% water (total weight). The doughs were mixed in a HOBART mixer for 5 minutes. After standing for 30 minutes in a room at 20 °C and then for 30 minutes in a room at 26 °C, the dough was rolled out in a sheeter and two sheeters (R-Tech, Wigan) to obtain a sheet with a thickness of 2 mm. The dough pieces were cut with a dough cutter (68•8×55•4 mm).

The experiments were carried out in a static oven (Sasib bakery, Verona, Italy) with forced convection of hot and humid air. Fourteen pieces of dough were placed on a circular wire mesh baking tray, which was rotated to improve baking homogeneity (size, color, and moisture). Since the last two parameters were set and controlled within the air conditioning system, the values were approximate for the air velocity and humidity near the dough pieces. The chosen conditions were based on a full experimental design of 23 degrees, with a central point, taking into account the spread of thermal kinetics between the extreme curves.

Real-time measurements

The temperature of the dough was measured with type K thermocouples placed inside two of the 14 dough pieces in the baking tray. These were positioned 2 mm above the top surface of the tray and recorded every 5 seconds. The reported value is the average temperature for both dough pieces during two experiments, with a maximum standard deviation of 4 °C. The variations in dough dimensions were monitored by a color video camera (CCD SONY 711 XP, focal length 100 mm, extension lens 15 mm) positioned in front of the oven door, approximately 60 cm from the baking plate. A 300 W halogen spot was placed directly above the camera, and a reflective screen was positioned behind the dough piece to enhance the contrast between the sample and the surroundings. The camera allowed monitoring the growth of the sample during baking, and the digitized images were stored at a rate of 5 seconds. Since the calibration and conversion of the digitized images resulted in variations in sample thickness over time, the thickness was calculated as the average of 10 measurements per biscuit. Thickness was not measured during the 15 seconds required to place the baking tray and chamber in front of the oven. The colour and browning of the biscuit surface were determined with the CIE L∗a∗b∗ colorimetric system (Chroma Meter CR-300 Tristimulus colorimeter, Minolta, Carriere sur Seine, France). The luminance value (L∗), which includes lightness, and chroma [defined by (a∗2+b∗2)1/2] including hue, were indicative of the colour of the biscuit surface. Measurements at 0, 1, 1•5, 2, 3, 4 and 5 minutes were made at three locations on the surface of four partially baked biscuits. The values reported are the mean of the 12 measurement points (standard deviation 3•0).

## RESULTS AND DISCUSSIONS

The variations of biscuit temperature and moisture content as a function of baking time are shown in Fig. 1 for the different baking conditions. Three stages can be identified in these curves. The first (0–60 s) is characterized by a rapid temperature increase, with a maximum rate at the inflection point, varying between 37 °C/min (condition no. 1) and 150

°C/min (condition no. 4) at higher humidity (400 g water/kg dry air). The higher value obtained in this case can be attributed to the heat generated by the condensation of water vapor on the cold dough pieces at the beginning of baking, which modified the heat transport. The second stage corresponds to a slower, more linear increase in temperature between 6 and 16 °C/min. Starting at 95 s, the temperature of the biscuits increases according to the air temperature, regardless of other aerodynamic conditions. For lower temperature conditions (#1 and 2), this stage lasts until the end of baking, but ends at approximately 170 s for higher temperature conditions (#3 and 4). During the second stage, the considerable heat is 4). During the second stage, the considerable heat is the heat of evaporation of water is high.

The third stage occurs after 170 s, when almost all the water has evaporated. The temperature increase becomes higher for higher temperature conditions (300 °C): 22 °C/min and 43 °C/min for #3 and #4, respectively. The higher heating rate, under higher humidity conditions (#4), can be attributed to variations in water content. The higher the oven temperature, the faster the decrease in water content. For a low temperature (#1), the moisture content decreases almost linearly (2•6%/min). Under other conditions, the classical shape of the drying curve is obtained, with a final water content of approximately 1%.

Furthermore, for the same conditions of oven temperature (300 °C) and air velocity (21 m/s), an increase in air humidity induces a faster decrease in the water content of the biscuits (conditions no. 3 and no. 4). Injecting water vapor into the oven helps to accelerate the drying rate of the biscuits. This may be due to the fact that water vapor modifies the properties of the thermophysical properties of the air, which can thus increase the external heat and mass transfer coefficients. The water vapor would then limit the formation of the crust, which could reduce the water loss from the biscuits. Finally, under high humidity conditions, condensation can occur at the beginning of baking, thus creating a larger temperature gradient between the surface and the center of the product and increasing the corresponding internal mass transfer.

Macroscopic changes

The final product in this study was characterized by volume criteria, which partially correspond to those defined by the manufacturer and which are usually measured after baking at the end of industrial production lines. These include brightness and chroma (which take into account the surface color), size and moisture. Since thickness is the most sensitive of the size variables, our study focused on this parameter. The surface color of a baked product is, together with texture and taste, a criterion for consumer acceptance. Brightness values increase from 72•7 to a maximum (80•6–82•5), which only occurs after the oven temperature is raised. The surface of the biscuits then darkens in color, the brightness decreasing in relation to the increase in oven temperature. At the same time, chroma first decreases from 25•6 to values between 17•6 and 21•9. Its subsequent behavior is complex, depending on the oven temperature level. Thus, the general staining kinetics involves two steps. First, the increase in brightness and the decrease in chroma correspond to a whitening of the biscuit surface. Two phenomena can explain this behavior often encountered during food drying: the migration of water to the biscuit surface and/or the change in the surface state due to the lifting of the sample. This stage is followed by a colouring process corresponding to blackening and the development of a more saturated shade. At 300 °C the considerable decrease in brightness and chroma is concomitant with a dark browning of the biscuit surface after 2.5 minutes, which produces a product unacceptable to consumers. These results allow the quantification of the browning of biscuits induced by biochemical reactions and activated by heat treatment (Maillard reactions, caramelization). The variation of the sample thickness as a function of the baking time reveals two stages: first, the biscuit rises rapidly (55–115 s), as the oven temperature and air velocity are high, before collapsing to higher values (4•7–5•4 mm) as the maximum thickness is reached early. The comparison of the obtained values shows that the maximum thickness occurs when the temperature is between 80 and 98 °C. This means that the temperature of the biscuits is not the only factor responsible for the variations in the thickness of the biscuits during baking. Based on these macroscopic observations, three major changes can be defined during baking: 1. an increase in the thickness of the biscuits due to the production of gases from chemical leavening agents and the evaporation of water; 2. a decrease in the weight of the product due to drying, resulting in a significant decrease in the density of the product and the development of an open porous structure; and 3. browning of the biscuit surface (low brightness, increased chroma), possibly due to non-enzymatic browning (Maillard reactions) involving the interaction of reducing sugars with proteins, but also possibly due to starch dextrinization and sugar caramelization.

## CONCLUSIONS

During baking, three major physicochemical changes occur that affect the dough components. First, there is a decrease in protein solubility, corresponding to a subsequent thermal aggregation, which starts at a temperature above 85 °C. In our study, no direct relationship could be established between the insoluble protein content and a macroscopic development, such as the end of the biscuit development phase. Second, starch destructuring occurs essentially in the first third of the baking period and is limited by the drying of the biscuits. Third, a decrease in the reducing sugar content occurs in the last two thirds of the baking period, which is correlated with the surface color. Although well known for biscuit doughs, the significant collapse following the rising stage has not been previously reported for shortcrust pastry. The assumed general rule for biscuit expansion is a linear diametrical increase (spreading) and a slow and uniform increase in thickness until the point where the size is established. In our experiments, the maximum thickness was reached in the temperature range 80–98 °C for all baking conditions.

The end of the rise stage can be attributed to a significant increase in the viscosity of the dough matrix, which prevents further expansion. This occurs in the same temperature range of 80–100 °C as that in which protein aggregation is triggered. However, the collapse stage (observed for all baking conditions) indicates that the dough matrix has not become sufficiently rigid to overcome the effect of gas loss or permeability increase. Currently, no experimental device is suitable for monitoring the permeability of thin dough with respect to the humidity and temperature dynamics representative of baking. However, in the last decade, major rheological variations have been studied in various works on the influence of phase transitions on the mechanical properties of the components. Thus, during baking of sugar-rich shortcrust pastry, the expansion period is followed by a marked collapse.

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