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Relationship between fermentation behavior, measured with a 3D vision Structured Light technique, and the internal structure of bread

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ABSTRACT

The bread-making process is a set of operations where could be relevant to use monitoring methods. Specifically, the fermentation phase is a crucial step in which the quality of the product can be affected. Several methods have been developed to monitor this stage based on different technologies. The aim of this study was to analyze and obtain information about the internal structure of bread dough during the fermentation process using a 3D vision system based on Structured Light (SL). The differences about fermentation behavior of two wheat flours classified as "high strength flour" by company providing were studied. The parameters of the internal structure of the baked product (final bubble size and their population density) were analyzed with 2D image segmentation. An important correlation ($r = 0.865$) was observed between the 3D and 2D information, specifically between the transversal area and height (3D), and final bubble size and number of bubbles (2D). Although at the end of the dough fermentation process (Tf) the area (A) and maximum height (H) were different, the relationship between both parameters were similar, reaching a similar bubble size as a consequence of coalescence phenomena, independent of the bubble growth rate. This could be a base for the development of prediction models and devices to monitor the fermentation phase of the bread-making process.

1. Introduction

The preservation and improvement of product quality and properties is of utmost importance in the food industry. This must be as constant as possible to maintain competitiveness as well as to satisfy the expectations of consumers (Miralbes, 2004). Therefore, obtaining detailed information about the factors which influence the different phases in their processes is one of the main issues in the food industry. The present study is focused on this context, specifically the industrial bread-making process. Several factors affect productivity in the bread industry due to the modifications of wheat flour properties and hence their behavior during processing (Bajd and Serša, 2011; Wang et al., 2011). In particular, chemical composition and rheological properties may seriously affect both the dynamics of the process and the final homogeneity of products (Barak et al., 2013; Cocchi et al., 2005). Process variables (time, temperature, humidity, proportions of ingredients, etc.) and relevant quality attributes (texture, palatability, aroma profile) could be affected by these modifications (Le-Bail et al., 2009; Novotni et al., 2011). Specifically, one of the most influential phases, dough fermentation, is an easily alterable phase due to small changes in the characteristics of the raw materials, which thereby brings out significant modifications in the usual development of production.

During fermentation, the gas produced by yeast activity expands the air bubbles previously incorporated into the dough system in the mixing phase (Ktenioudaki et al., 2009), therefore anything that modifies this phase could alter the final attributes of the product. These alterations occur because the variability in the gas phase distribution in the dough system plays a crucial role in crumb structure formation, since the stability and the growth of gas bubbles generated will determine the final volume of the loaf as well as the texture of the baked product (He and Hosene, 1991). Thus, variables such as the volume and density of the dough, to control the fermentation process, as well as their relationship with the properties of the gas phase have been widely studied.

To improve the knowledge about the fermentation phase, many studies have been carried out using different points of view and techniques. Among them, there are static controls of variables like volume, density and bubble size (Pérez-Nieto et al., 2010;

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Upadhyay et al., 2012). There are also studies addressing the development of applications to dynamically monitor the same variables (Falcone et al., 2005; Zuñiga and Le-Bail, 2009; Lucas et al., 2010) based on ultrasound, MRI, 2D and 3D imaging analysis. Although 2D image analysis, in which segmentation images have been applied, is usually employed as a static control for checking the bubble size or bread crumb grain (Lassoued et al., 2007; Gonzalez-Barrón and Butler, 2008; Scanlon and Zghal, 2001; Pérez-Nieto et al., 2010), in order to be related to different recipes or processing, mainly baking.

There are various techniques used to obtain 3D imaging, one of them based on Structured Light (Verdú et al., 2013). It is based on the projection of a pattern of light on a sample and the calculation of 3D dimensions from the deformation of the pattern using a camera (Verdú et al., 2013). This technique permits the monitoring of continuous processes and could be applied on-line. In a previous study (Ivorra et al., 2014), ten wheat flours, without physicochemical and rheological differences, were monitored and analyzed during their fermentation evolution, employing the Structured Light method. Results showed differences in their fermentation behavior (peaks and valleys that take place during fermentation, when the variation of the total transversal area is related to the maximum height) which were related with the fermentation capacity.

Thus, the objective of this work is to focus on that study, relating the fermentation behavior, measured with a 3D vision Structured Light technique, to the evolution of the internal structure of bread, measured with 2D image analysis.

2. Material and methods

2.1. Physicochemical characterization of flours

A battery of physicochemical analyses was carried out to obtain information about the general characteristics of the samples. Each analysis was realized according to the standard methods of the International Association for Cereal Science and Technology (ICC). The analyses performed were: moisture (ICC standard No. 110/1), percentage of gluten (ICC standard No. 106/2), falling number (ICC standard No. 107/1, FN 1500, Perten, Sweden) and rheological parameters (ICC standard No. 121, Alveograph®, Chopin Technologies). All analyses were carried out in triplicate. Table 1 lists the average and standard deviation of the evaluated parameters.

2.2. . Dough preparation and fermentation process

The wheat flours employed were obtained from two different batches produced by Molí del Picó-Harinas Segura S.L (Valencia–Spain). Both batches, without physicochemical and rheological differences (Table 1), were selected from the previous study (Ivorra et al., 2014).One had the lowest fermentation capacity (F1) and the other the maximum (F2). In addition a third batch (Fm), prepared mixing F1 and F2 (50%) was also used.

Table 1
Values and standard deviation of alveograph parameters (P = maximum pressure (mm), L = extensibility (mm); W = strength (J^{-4}), moisture, dry-gluten, and falling number of the two different wheat flours employed. Different letters in rows mean significant differences at $p \leqslant 0.05$.

Parameter	F1	F2
P	98 ± 1^a	97 ± 1^a
L	106 ± 1^a	105 ± 1^a
W	378 ± 5^a	369 ± 4^a
P/L	0.92 ± 0.01^a	0.92 ± 0.01^a
%Moisture	15 ± 0.1^a	14 ± 0.1^a
Dry gluten (g/100 g)	12.9 ± 0.2^a	11.2 ± 0.4^a
Falling number	410 ± 5^a	417 ± 2^a

The ingredients and their percentages for the doughs were: 56% wheat flour, 35% water, 2% refined sunflower oil (maximum acidity 0.2°. Koipesol Semillas S.L – Spain), 2% commercial pressed yeast (*Saccharomyces cerevisiae.* Lesafre Ibérica S.A – Spain), 4% white sugar ($\geqslant$99.8% saccharose. Azucarera Ebro, S.L – Spain) and 1.5% NaCl (refined marine salt $\geqslant$97% NaCl. Salinera Española, S.A – Spain). The three doughs were made using the same procedure.

The doughs were made by combining all the ingredients in a food mixer (Thermomix® TM31, Vorwerk, Germany) according to the following procedure. At the first step, the liquid components (water and oil), sugar and NaCl were mixed for 4 min at 37 °C. Then, the pressed yeast was added and mixed at the same temperature for 30 s. Finally, the flour was added and mixed with the rest of the ingredients using a specific default program for dough mixing. At this step, the device mixes the ingredients with random turns in both directions of the mixer helix (550 revolutions/minute), in order to obtain an homogeneous dough. Then, 450 g of the dough was placed in a metal mold ($8 \times 8 \times 30$ cm) for its fermentation. This process was carried out in a chamber with controlled humidity and temperature (KBF720, Binder, Tuttlingen, Germany), where a 3D imaging Structured Light (SL) device was developed and calibrated. The conditions of the fermentation process were 37 °C and 90% Relative Humidity (RH). The samples were fermented until the dough lost its stability and size (*Tf*), specifically when growth depletion occurred. Four replicates were carried out for each dough.

2.3. Fermentation monitoring by "Structured Light" method (SL)

The objective of the 3D vision system is to obtain the 3D sample profile during fermentation. In order to accomplish this objective a 3D vision system was developed specifically to monitor fermentation. This vision system was formed of a red lineal laser (Lasiris SNF 410, Coherent Inc. Santa Clara, California (USA)) and a network graycamera (In-Sight 5100, Cognex, Boston, Massachusetts (USA)). Both of them were installed inside the fermentation chamber (Fig. 1). This was possible because the camera has an index protection of 67 (IP67) and the laser is robust enough to work safely in these conditions.

The 3D visual system developed has a resolution of $2.1 \cdot 10^{-4}$ m and $1.4 \cdot 10^{-4}$ m for the X and Z axes respectively. This resolution in derived from a laser angle β of 0.65 radians (Fig. 1) in combination with the resolution of the camera (640×480) and its distance from the sample. The working range achieved with this resolution is 0.1 m in the X axis and 0.08 m in the Z axis.

Although the camera can work at up to 60 fps, the acquisition rate was 1 fps due to the long period of time that fermentation requires (around 2 h). Calibration of the equipment was firstly performed by taking ten regularly distributed points in the laser projection plane with known coordinates (Trobina, 1995) and then using these 3D points and their correspondent points in the image to calculate an homography transformation (Zhang, 2000).

2.4. SL method image processing

In order to obtain the 3D profile of the sample, the first step is the segmentation of the laser points captured by the camera. This segmentation was performed as follows: using a Otsu's global threshold (Otsu, 1979) the laser pixels were selected. Then, these pixels were filtered removing non-connected pixels with an area lower than 100 px. Finally, exact row coordinates were calculated by weight mean for each column using the intensity value. Following this method, subpixel precision was achieved.

The second step is the transformation from image coordinates to a 3D local coordinate system. This was done using the homography transformation calculated in the calibration step. The last step