Journal of Food Engineering 130 (2014) 8–13

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Continuous monitoring of bread dough fermentation using a 3D vision Structured Light technique

Eugenio Ivorra [b], Samuel Verdú Amat [a,*], Antonio J. Sánchez [b], José M. Barat [a], Raúl Grau [a]

[a] Departamento de Tecnología de Alimentos, Universidad Politècnica De València, Spain
[b] Departamento de Ingeniería de Sistemas y Automática, Universidad Politècnica De València, Spain

ARTICLE INFO

Article history:
Received 23 September 2013
Received in revised form 19 December 2013
Accepted 30 December 2013
Available online 14 January 2014

Keywords:
Structured Light
Monitoring
Fermentation
Bread
Behavior

ABSTRACT

Fermentation of the dough is an important phase in the bread-making process which is affected by several important factors related to raw materials and processing. Changes in fermentation affect parameters in the final product, such as texture, palatability and general quality. For this reason, it is important to develop dynamic methods to study this phase. In this work, a 3D vision system based on Structured Light (SL) was used to monitor the fermentation phase. The evolution of the dough was studied employing 10 wheat flours with non-physicochemical and rheological differences. However, differences in dough behaviors during fermentation were found based on SL method parameters. When the variation of the total transversal area was related to the maximum height at each fermentation time a set of peaks and valleys appeared. These sets were directly related to the fermentation capacity. Specifically, a lower number of peaks during the main fermentation time (100 min) is related to wheat flours with high fermentation capacity. Consequently, the proposed SL Technique could be used as a method to check the fermentation capacity of wheat flours according to their fermentation behavior.

1. Introduction

Several important factors affect productivity in the bread industry due to changes in the properties and behavior of wheat flour during the bread-making process. Some of these are: the cultivation method, the variety of wheat, phytohealth products, environmental factors, climatic conditions, pests, stored kernel alterations and milling, all of which result in changes in the composition of the flour (Cocchi et al., 2005). Therefore, it is important to develop methods to study wheat flour properties and process phases to decide the best use for each batch of raw materials, and in turn to modify the process parameters when necessary. Fermentation of the dough is an important phase in the bread-making process which affects parameters in the final product, such as texture, palatability and general quality. This is an important temperature-dependent phase, in which the metabolism of yeasts transforms assimilable carbohydrates and amino acids into carbon dioxide and ethyl alcohol as the principal end products (Birch et al., 2013). Gluten plays a crucial role in creating the dough structure and baking the bread. It affects the stability of the dough and bread volume by forming a skeleton which combines the remaining ingredients and additives (Barak et al., 2013). The oxidation of cysteine amino acids from gluten proteins (gliadines and glutenines) by thiol groups generates a viscoelastic network which is capable of retaining carbon dioxide from which the gas cells develop. The growth of gas cells depends on cell size and dough composition (flour, water and other ingredients). Several compounds are known to exert a stabilizing influence and retard unwanted phenomena such as coalescence (Gan et al., 1995). As a result, dough composition and yeast activity are manifested in dough bubble sizes and dough volume expansion.

Recently, empirical and physicochemical techniques (the majority of them based on destructive analysis) have been used to characterize the different phases of the bread-making process (Dobraszczyk and Morgenstern, 2003). In particular, the fermentation phase has been extensively studied from various points of view (many of them non-destructive) (Lassoued et al., 2007). All of them are aimed at obtaining information about the implicated fermentation and baking parameters, thereby explaining the process phenomena and improving knowledge as well as control over the final product. The evolution of parameters such as dough volume, density and gas cell sizes are important control variables, since their behavior has an important influence on the quality of the final product.

Image analysis is an important tool for the characterization of the bread-making process which has been demonstrated to be an important research and industrial application (Calderón-Domínguez et al., 2008). Different techniques and methods based

* Corresponding author. Address: Departamento de Tecnología de Alimentos, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain. Tel.: +34 646264839.
E-mail address: saveram@upvnet.upv.es (S.V. Amat).

0260-8774/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jfoodeng.2013.12.031

on multiple principles have been used to acquire and analyze images obtained during the process. Some examples are: Confocal laser scanning microscopy (Jekle and Becker, 2011; Upadhyay et al., 2012), magnetic resonance and methods based on 2D (Pour-Damanab et al., 2011).

The structured-light method is another imaging technique. 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. Accordingly, the aim of this work was to monitor bread dough fermentation of different wheat flour samples with developed computer vision based on Structured Light, in order to obtain useful information about the process and characterize the response of the raw material.

2. Material and methods

2.1. Dough preparation and the fermentation process

Ten types of flour obtained from different batches produced by Molí del Picó-Harinas Segura S.L (Valencia-Spain) were used in this study. The flour was sold as "high strength flour", for bakery products, sliced bread, plum cakes, etc. The doughs were made employing the following percentages: 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% sucrose. Azucarera Ebro, S.L – Spain) and 1.5% NaCl (refined marine salt $\geqslant$97% NaCl. Salinera Española, S.A – Spain). All the doughs were made using the same procedure. The analyses of the samples were carried out according to the standard methods of the International Association for Cereal Science and Technology (ICC). Moisture was calculated based on the weight loss suffered by the sample when dried at a temperature between 130 and 133 °C. Moisture content is taken to be the loss in weight, expressed as a percentage of the weight of the original sample (ICC standard No.110/1). Wet and dry gluten were isolated from the dough of a sample of flour, prepared previously by mixing the flour with a buffer of sodium chloride. Isolated wet gluten was dried at 100 °C until constant weight to remove moisture (ICC standard No. 106/2). Falling number analysis was also carried out (FN 1500, Perten, Sweden) with the aim of evaluating alpha-amylase activity, as it affects the behavior of starch and hence the commercial value of flour (ICC standard No. 107/1). Rheological parameters were used to evaluate the resistance of the dough to stretch; its extensibility until the moment when it began to rupture was assessed based on the Chopin alveograph method (ICC standard No. 121, Alveograph®, Chopin Technologies), France. The Kjeldahl method was used to analyze the protein content. The first step was to digest the wheat flour samples in H_2SO_4 to convert the protein N to $(NH_4)_2SO_4$. Ammonia was liberated by alkaline steam distillation and finally, it was quantified with standardized acid (AOAC, 2001.11).

The doughs were made by combining all ingredients in a food mixer (Thermomix® TM31, Vorwerk, Germany) according to the following procedure. In the first step, the liquid components (water and oil), sugar and NaCl were mixed for 4 min at 37 °C. The pressed yeast was added in the next step 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. In this step, the device mixes the ingredients with random turns in both directions of the mixer helix (550 revolutions/minute), in order to obtain homogeneous dough. This process was applied for 4.5 min at 37 °C. Then, 450 g of dough was placed in the metal mould ($8 \times 8 \times 30$ cm) for fermentation. This process was carried out in a chamber with controlled humidity and temperature (KBF720, Binder, Tuttlingen, Germany), where a 3D 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, when growth depletion occurred. Four replicates were used for each dough.

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

A 3D vision system, developed in a previous study (Verdú et al., 2013) and adapted specifically to monitor fermentation, was used. This vision system was composed of Structured Light and a camera. The Structured Light was generated employing a red lineal laser (Lasiris SNF 410, Coherent Inc. Santa Clara, California (USA)), and a network graycamera, with index protection of 67 (IP67) was used for image acquisition (In-Sight 5100, Cognex, Boston, Massachusetts (USA)). Both of them were installed in the fermentation chamber (Fig. 1).

The laser had an angle β of 0.65 radians (Fig 1) which in combination with the resolution of the camera (640×480) and its distance from the sample give a Z resolution of 1.4×10^{-4} m and X resolution of 2.1×10^{-4} m. This configuration was established to achieve a working range of 0.1 m in the X axis and 0.08 m in the Z axis.

The camera worked at an acquisition rate of 1 frame per second (fps) due to the length of time for the test (around 2 h), but it can work at up to 60 fps.

Calibration of the equipment was performed by taking 10 regularly distributed points in 3D in the laser projection plane (Trobina et al., 1995). Using these points with known 3D coordinates and their correspondent points in the image, a homography transformation was calculated (Zhang et al., 2000).

2.3. SL method information extraction

The laser points projected on the image were extracted following these steps: first, the image was segmented using Otsu's global threshold, then the image was filtered removing non connected pixels with an area lower than 100 px and finally, row coordinates were calculated by weight mean. This weight mean value was calculated for each column using the intensity value in order to get subpixel precision. The 3D coordinates were then calculated using the homography from these pixel coordinates. The last step was the application of a rotation matrix in order to make the Z axis normal to the surface, as can be seen in the reference coordinate system of Fig. 1.

The sample was defined as a 3D curve composed of the 3D points which were between the known 3D points of the mould's borders. The following information about the growth of the samples during the fermentation was acquired from each image:

- Maximum height (H): The maximum Z value for the sample and its position.
- Transversal area (A): The integration of the Z values along the X direction of the sample.
- Arc correlation: A Pearson's correlation between a theoretical arc defined by two points (the two extreme sides of the sample along the X direction) and the radius (half the modulus of the vector between the two points of the arc) and the 3D curve of the sample.

Acquisition and data processing was carried out using a code developed in the Matlab computational environment (The Mathworks, Natick, Massachussets, USA).