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

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Abstract

The aim of this work was to monitor the fermentation phase of bread-making using a 3D vision system based on Structured Light (SL). The evolution of the dough was studied employing 10 wheat flours with non-physicochemical and rheological differences. However, differences in dough behaviours 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 are directly related to the fermentation capacity. Specifically, a lower number of peaks, during the main fermentation time (100 minutes), are 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 behaviour.

Keywords: Structured light, monitoring, fermentation, bread, behaviour.

1. Introduction

Several important factors affect productivity in the bread industry due to the modifications of wheat flour properties and behaviour during the bread-making process. Some of them are: the cultivation method, wheat variety, phytohealth products, environmental factors, climatic conditions, plagues, store kernel alterations and milling, etc., all of which result in changes in flour composition (Cocchia *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 the skeleton of wheat dough which combines the remaining ingredients and additives within the dough (Barak *et al*., 2013). The oxidation of cysteine amino acids from gluten proteins (gliadines and glutenines) by tiol 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 the cell size and the 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 have been used to characterize the different phases of the bread-making process (Dobraszczyk & Morgenstern, 2003), the majority of them based on destructive analysis. In particular, the fermentation phase has been extensively studied from different points of view by various non-destructive techniques (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 behaviour will have an important influence on the quality of the final product.

Image analysis is an important tool in 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 on multiple principles have been used to acquire and analyse images obtained during the process. Some examples are: Confocal laser scanning microscopy (Jekle *et al*., 2011, Upadhyay et al. 2012), magnetic resonance (Franci & Serša., 2011) 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 a 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 & methods

2.1 . Dough preparation and fermentation process

Ten different doughs were made employing the following percentages: 56% wheat flour, 35% water, 2% sunflower oil, 2% commercial pressed yeast (*Saccharomyces cerevisiae*), 4% white sugar and 1.5% NaCl. All doughs were made using the same procedure but employing ten different batches of wheat flours which were obtained from a local factory. Wheat flour

moisture, gluten, falling number and rheological parameters were determined according to the methods of the International Association for Cereal Science and Technology (ICC) and protein content by the Kjeldahl Method.Table 1 lists the average and standard deviation of the parameters valuated.

Table 1. Average and standard deviation of protein, alveograph parameters (P=maximum pressure (mm), L=extensibility (mm); W=strength (J^{-4}), falling number, moisture, gluten and dry-gluten for the 10 batches of wheat flour employed.

P	97	± 2
L	104	± 3
W	373	± 12
P/L	0,93	± 0,03
Falling number	413	± 6
Moisture (%)	14,28	± 0,24
Wet Gluten (%)	31,23	± 0,25
Dry gluten (%)	13,51	± 0,11

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, liquid components (water and oil), sugar and NaCl were mixed for 4 minutes at 37 °C. The pressed yeast was added in the next step and mixed at the same temperature for 30 seconds. Finally, the flour was added and mixed with the rest of the ingredients using a special bread dough mixing program which provides homogeneous dough. Then, 450 g of dough was placed in the metal mould (8x8x30cm) 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 % of RH. The samples were fermented until the dough lost its stability and size, when growth depletion occurred. For each dough, four replicates were used.

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

2.3. A 3D vision system was designed specifically to monitor fermentation. 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 the network graycamera, with index protection of 67 (IP67), for the image acquisition (In-Sight 5100, Cognex, Boston, Massachusetts (USA)), both of them were installed inside 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 (640x480) 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 of 0.08m in the Z axis.

The camera worked with an acquisition rate of 1 fps due to the long period of time for the test performed (around 2 hours) but it can work at up to 60fps.

Calibration of the equipment was realized 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).

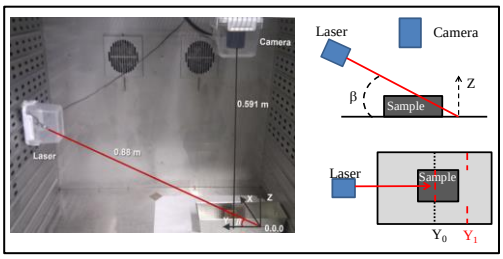

Figure 1. Developed 3D vision system installed in the fermentation chamber and schematic 3D vision system.

2.4. 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 (Otsu *et al.*, 1979), then the image was filtered removing non connected pixels with an area lower than 100px 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 to apply a rotation matrix to them 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 are 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).

3. Results & discussion

Dough volume expansion, in which CO_2 production is associated with yeast activity (Bajd & Serša, 2011), was characterized from data obtained employing the structured line method. Data were expressed as transversal area (*A*), the maximum height (*H*) at each time and the relationship between both (*A/H*). Figure 2, as an example, shows the evolution of the dough transversal area with the fermentation time. The X axis expresses the thickness of the bread, the Y axis the fermentation time and the Z axis the height.

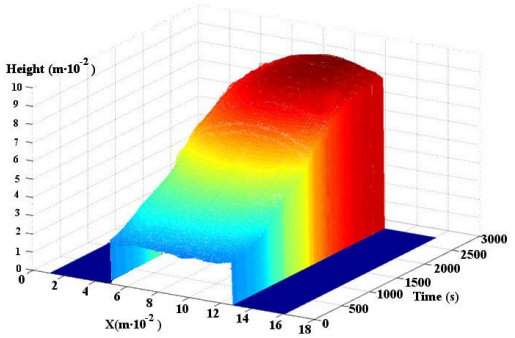

Figure 2. 3D representation of dough transversal area evolution with fermentation time.

Figure 3 shows the evolution of the transversal area, for the 10 doughs tested, with each fermentation time (until growth depletion occurred). Although the physicochemical analysis of the wheat flours used for making the doughs did not show any significant difference (Table 1), the times to reach the maximum transversal area were different for the doughs tested (Fig. 3). The maximum area value was 1758.7 ± 189.2 mm^2, employing 187 minutes (dough number 10) and the lowest was 1027.2±53.7 mm^2 employing 108 minutes (dough number 1) (Table 2). Similar behaviour was obtained when the maximum height at each fermentation time was compared (Table 2). When the data about area and height at 100 min were compared, statistical differences were observed (Table 2). The time of 100 min was the shortest time for a dough to reach its final fermentation and was similar to that employed by other authors as a fermentation time (Keskin *et al.*, 2004; Bajd & Serša, 2011; Rizzello *et al.*, 2012). Differences between doughs could be related to the level of starch damage, the influence of gluten proteins and the number of bubbles and their size (Faridi, 1990; Barrera *et al.*. 2013; Mills *et al.*, 2003; Boyaci *et al.* 2004). The fraction of starch damage is a consequence of the kind and time of milling the wheat-kernels. It has an influence on the rheological and functional properties of dough (Faridi, 1990) since it is able to modify flow regimes, processing variables and swelling proprieties (Barrera *et al.*, 2007). Excessive starch damage could overly hydrate the dough and permit

accelerated enzymatic action (Boyaci*et al.* 2004), thus it produces differences in the availability of yeast substrates and dough stability with time. On the other hand, climatic fluctuations (Daniel &Triboi, 2000) and levels of several fertilizer compounds such as nitrogen, sulphur and phosphorus (Altenbach *et al.*, 2002) may affect the enzyme activity kinetics during wheat growth, thus disturbing an optimal ratio generation of subfractions of gluten proteins (gliadin and glutenin). Higher glutenin levels make the dough more elastic, thus giving the dough its property of resistance to extension, while higher gliadin content increases the extensibility of the dough (Barak *et al.*, 2013). This ratio has a strong influence on the quality and technological proprieties of wheat flour (Radovanovic *et al.*, 2002). However, the analysis of starch damage or gluten protein composition requires specific techniques and devices that are not easy to carry out on a daily basis in the industry.

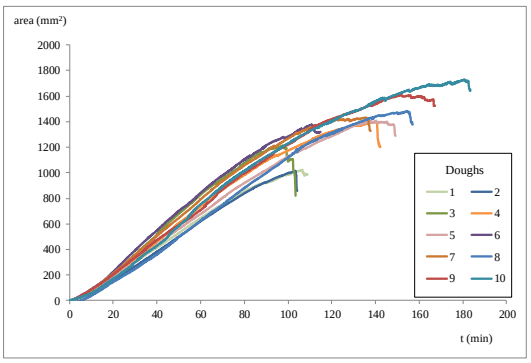

Figure 3. Evolution of the dough's transversal area with fermentation time (until growth depletion occurred).

Table 2. Transversal area and the maximum height of the tested doughs, at the end of each fermentation time (until no increase is observed) and at 100 minutes (time required for the dough which reached its final fermentation first).

	Until the end of fermentation time			At 100 min	
Dough	***Final time (Ft) (min)***	***Transversal area (A) (mm^2)***	***MaximumHeight (H) (mm)***	***Transversal area (A) (mm^2)***	***MaximumHeight (H) (mm)***
1	108 ± 2 ^{a}	1027.2 ± 53.7 ^{a}	44.5 ± 0.1 ^{a}	921.5 ± 46.7 ^{a}	46.3 ± 0.1 ^{a}
2	106 ± 4 ^{a}	1055.6 ± 75.5 ^{ab}	46.2 ± 0.1 ^{a}	924.2 ± 12.9 ^{a}	40.9 ± 0.2 ^{a}
3	100 ± 4 ^{a}	1228.7 ± 32.3 ^{bc}	56.1 ± 0.2 ^{b}	1171.1 ± 47.7 ^{bc}	52.9 ± 0.2 ^{cd}
4	138 ± 3 ^{c}	1402.7 ± 68.4 ^{bc}	61.8 ± 0.1 ^{bc}	1106.9 ± 74.0 ^{abc}	47.9 ± 0.1 ^{bcd}
5	142 ± 5 ^{cd}	1420.5 ± 147.8 ^{bc}	62.6 ± 0.5 ^{bc}	1021.3 ± 142.1 ^{abc}	46.7 ± 0.5 ^{abc}
6	123 ± 17 ^{bc}	1432.5 ± 133.7 ^{bc}	64.0 ± 0.1 ^{bc}	1214.9 ± 74.8 ^{c}	54.3 ± 0.1 ^{d}
7	133 ± 4 ^{b}	1439.0 ± 83.2 ^{c}	62.6 ± 0.2 ^{bc}	1167.9 ± 85.9 ^{bc}	51.7 ± 0.2 ^{bcd}
8	155 ± 1 ^{de}	1498.8 ± 190.8 ^{cd}	67.0 ± 0.8 ^{cd}	999.6 ± 109.1 ^{ab}	46.0 ± 0.5 ^{ab}
9	159 ± 3 ^{e}	1629.6 ± 45.8 ^{d}	72.8 ± 0.2 ^{d}	1107.3 ± 95.0 ^{abc}	51.6 ± 0.2 ^{bcd}
10	187 ± 8 ^{f}	1758.7 ± 189.2	74.7 ± 0.7 ^{d}	1129.4 ± 131.1 ^{bc}	50.5 ± 0.5 ^{bcd}

When the ratio between total transversal area and maximum height increase ($\Delta A/\Delta H$) at each fermentation time was calculated, no stable evolution was observed (Fig. 4). The instability was related with the different velocity that *A* and *H* had. In order to check this instability, the correlation between the arc described by the laser light when it is projected onto the dough surface (Fig. 4) and the theoretical arc was used. As it is possible to observe in figure 4, an example of two doughs (left dough 2 and right dough 9), in which the evolution of the ratio $\Delta A/\Delta H$ and R^2 of Pearson are drawn, peaks and valleys could be identified (between broken lines). Peaks were considered when data from R^2 change their derivative sign from positive to negative (derivative cero value) and the function value is equal or higher than the previous peak. R^2 of Pearson and $\Delta A/\Delta H$ had an inverse tendency with time. When $\Delta A/\Delta H$ decreased, because the higher

velocity of *H changes*, R^2 increased, evolving the shape of the dough surface to a theoretical arc. Inverse behaviour could be obtained when the *A* velocity was higher.

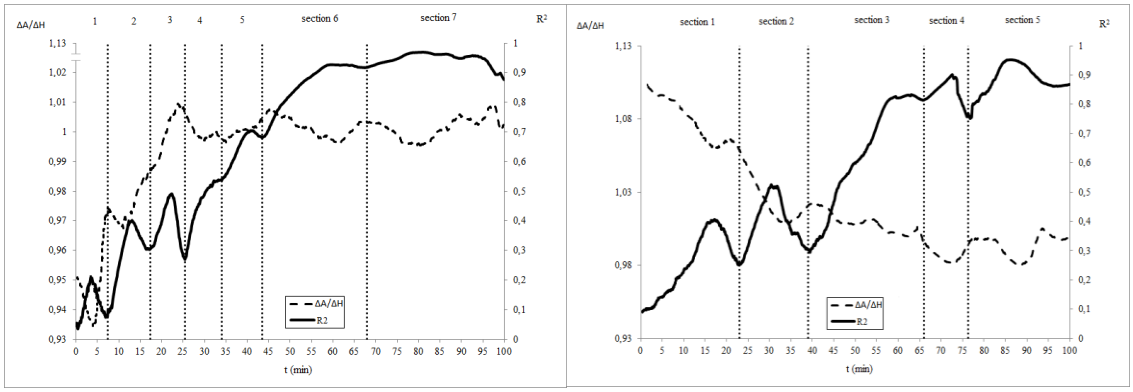

Figure 4. Evolution with fermentation time (100 minutes) of the ratio between transversal area (A) and the height (H) increase ($\Delta A/\Delta H$) (broken line) and the arc correlation (continuous line) for dough number 9 (right) and 2 (left).

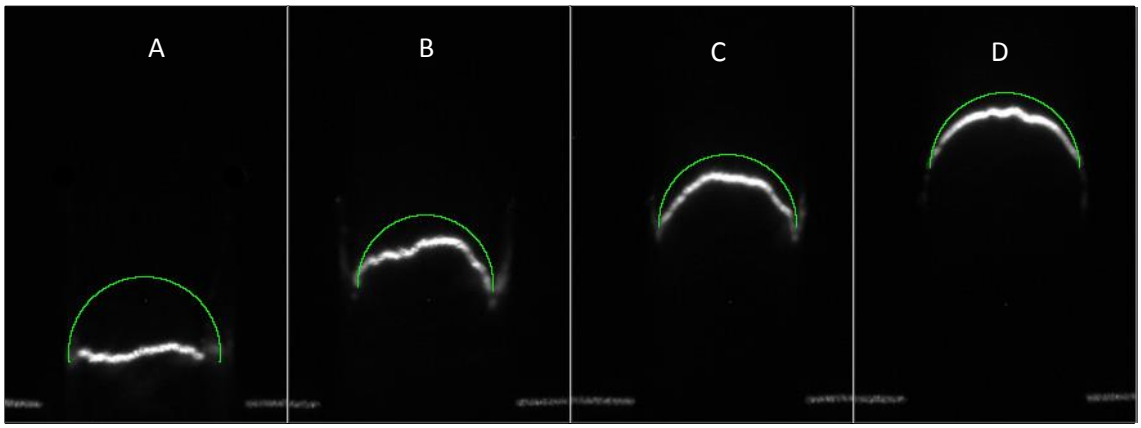

Figure 5. Laser light projected onto the dough versus fermentation time(A: 5 min, B: 30 min, C: 60 min, D : 100 min) and the theoretical arc (green line).

The recount of the number of peaks at 100 min (NP_{100}) (Table 4) showed how this number is related to dough evolution and could be used to discern the final behaviour of doughs (Fig. 6). In doughs which did not have an important variation in their transversal area between 100 min and their final fermentation time (first doughs), the number of peaks did not increased, reaching their highest number of peaks. On the other hand, doughs which increased their transversal area also increased their number of peaks (Table 4). The failure of the gluten-network films separating some bubbles has been implicated in the correct gas retention and therefore in the instability of the foam structure of bread (Gan *et al*., 1995), which could produce variations in the dough's evolution with time. Therefore, this could be the reason that a reorganization or non-uniform distribution of bubbles could lead to total or partial collapse of the dough (Wang *et al*., 2011), making changes in the shape of doughs which could be related to the peaks and valleys.

According to this result, employing SL technique it is possible to characterize the

wheat flours according to their fermentation capacity.

Table 4. Number of peaks at 100 min (NP_{100}) and at final fermentation time (NP_f)

Dough	NP_{100}				NP_f			
1	7.5	±	0	de	8	±	1	ab
2	8.5	±	1.4	e	8.5	±	1	ab
3	7	±	0.7	cd	7	±	0	a
4	6	±	0.7	bc	7.5	±	1	ab
5	6	±	0.7	bc	8	±	1	ab
6	6	±	0	bc	7.5	±	1	ab
7	6	±	0.7	bc	9.5	±	1	b
8	4.5	±	0.7	a	7	±	1	a
9	5	±	0	ab	8.5	±	1	ab
10	4.5	±	0.7	a	9	±	1	ab

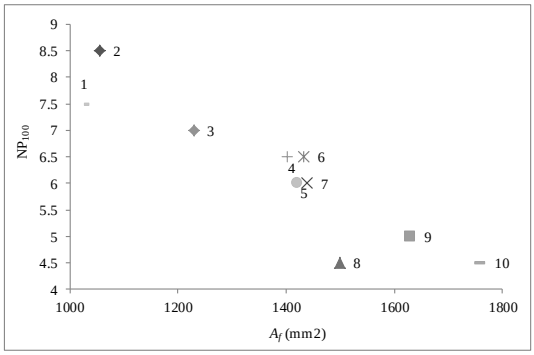

Figure 6. Ratio between the transversal area (A_{100}) and the number of peaks at 100 minutes (NP_{100}) related to the transversal area at the end of each fermentation time (A_f) for the ten doughs tested.

4. Conclusion

The study demonstrated that the Structured Light method (SL) can provide useful information about the behaviour of dough during fermentation. The monitoring of the fermentation of dough showed that wheat flours with similar moisture, protein, gluten, dry-gluten, falling number and alveograph parameters have different fermentation capacities. The peaks and valleys that take place during fermentation time, when the variation of the total transversal area is related to the maximum height or with R^2 of Pearson (obtained when the curvature described by the laser light is adjusted to a theoretical arc when it is projected onto the dough surface), are directly related with the fermentation capacity. A lower number of peaks during the main fermentation time (100 minutes) is related to wheat flours with high fermentation capacity. Hence the described technique could be used to check the fermentation capacity of wheat flours according to their fermentation behaviour.

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