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A novel application of vibration technique for non-destructive evaluation of bread staling

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ABSTRACT

To develop non-destructive indices for monitoring the progression of bread staling, the changes in the free vibration responses of baguette bread were examined at different storage times (days 0, 2 and 4). The storage time considerably affected the vibration responses of the bread samples. Except for natural frequencies in the x (w_{nx}) and z (w_{nz}) directions, vibration responses were highly correlated with instrumental texture parameters during storage of the bread; that is, the breads with firmer and less springy crumbs (the stale breads) had lower damping ratios in the x (ξ_x) and z (ξ_z) directions. The lower damping capacities of the stale breads were concomitant with their higher values of root mean square for acceleration (a_{RMS_z}) and angular velocity signal (V_{RMS_x}). The results suggested that the vibration responses are reliable indices for non-destructively monitoring the progress of staling in baguette bread.

1. Introduction

Bread staling is a complex physicochemical process occurring during storage and resulting in crumb firming, crust softening and deterioration of product flavor (Curti et al., 2014). Increase in hardness of crumb is the most widely used index to measure the progress of bread staling (Gray and Bemiller, 2003). The changes in bread firmness during storage have traditionally been followed using compressibility methods, which provide data known to show good correlation with consumer acceptance (Abd Karim et al., 2000). The main disadvantage of such procedures is that bread samples may permanently be damaged during evaluation, making study of the system's viscoelastic properties difficult (Abd Karim et al., 2000). Thus, non-destructive evaluation of crumb firmness as an index of bread staling is of special importance. Recently, vibration technique has successfully been applied for non-destructive monitoring the firmness of various fruits during post-harvest ripening (Abbaszadeh et al., 2013). It has been shown that fruit responses to induced vibration change as a function of internal restructuring during ripening (Abbaszadeh et al., 2013). It is of interest to explore the potential application of vibrometry for non-destructively assessing bread staling. For this purpose, in the present study, vibration responses of bread samples at different stages of storage were compared with data obtained from instrumental texture profile analysis, the most frequently used method to measure bread staling progress.

2. Materials and methods

2.1. Samples

Thirty-six loaves of fresh and uniform baguette bread (each made using 100 g wheat flour, 60 g water, 5 g dried active yeast and 2 g salt) were specially ordered from a local bakery. The wheat flour contained approximately 12.5% protein, 0.6% ash (dry basis) and 14% moisture. The bread loaves were randomly divided into four nine-loaf groups. One group was used for vibration parameter measurements and the other groups were used for physicochemical, textural and sensorial measurements. To evaluate staling progress, bread samples were packed in polypropylene bags and stored at room temperature for four days. Samples were analyzed on days 0, 2 and 4. All measurements were carried out in three replications.

2.2. Moisture content

The moisture contents of crumb (from loaf center) and crust

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(outermost layer, 1.5 mm thick) were determined according to AACC method 44-15A (AACC, 1995). Bread samples were oven-dried at 105 °C and accurately weighed at regular time intervals until constant weight was reached. The moisture content was expressed as grams of water over grams of total weight (g/100 g).

2.3. Crumb texture

Firmness and springiness of crumb were measured using a TA.XT2i Texture Analyzer (Stable Micro Systems, Goldalming, UK) equipped with a 5 kg load cell and a cylindrical probe (diameter 36 mm). At least three slices of bread (each 2.5 cm thick) cut from the center of the loaves were compressed to 40% deformation at a speed test of 1.7 mm/s. The firmness (N) was determined as the force required to compress the slice by 40%. The springiness (%) corresponded to the compression force after 32 s holding time divided by the maximum compression force, multiplied by 100.

2.4. Vibration response spectrum

Fig. 1 presents the experimental setup to determine the vibration response spectrum of the baguette bread. The bread samples were placed on a desk and held using a clamp; the free end of each sample was attached to an accelerometer (MPU6050, InvenSense, Inc, US) using double-sided adhesive tape. The vibration was triggered using a rubber hammer to tap the free end, and the excitation signal was detected by the accelerometer attached to the sample. Since MPU6050 is a six-axis acceleration sensor, vibration in a three-axis gyroscope ($\dot{\theta}_x$, $\dot{\theta}_y$ *and* $\dot{\theta}_z$ axes) and a three-axis accelerometer (X, Y and Z axes) were measured at the same time. The vibration acceleration time histories were recorded using the accelerometer's data-acquisition program. Logarithmic decrement analysis was used to determine the damping ratio ξ of the cantilever beam from the recorded acceleration time histories according to Equation (1) (Etaati et al., 2013).

$$\xi = \frac{1}{2\pi j} \ln\left(\frac{x_i}{x_{i+j}}\right) \tag{1}$$

where x_i is the peak acceleration of the *i*th peak and x_{i+j} is the peak acceleration of the peak *j* cycles after the *i*th peak.

Fast Fourier transformation was applied on the measured time histories to obtain the frequency spectrum of vibration. The first natural frequency of the bread sample was determined by locating

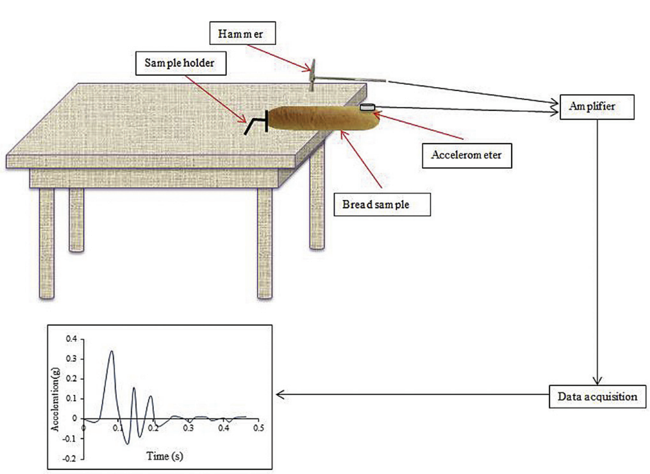

Fig. 1. Experimental setup for measurement of vibrational spectrum of baguette bread.

the first peak value in the vibration-frequency spectrum.

The values for root mean square (RMS) of acceleration and angular velocity for each treatment were calculated using Equations (2) and (3) and the time domain signal (Taghizadeh-Alisaraei et al., 2012).

$$\alpha_{RMS} = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\alpha_k^2} \tag{2}$$

$$\upsilon_{RMS} = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\upsilon_k^2} \tag{3}$$

where a_{RMS} and V_{RMS} are the values of root mean square for acceleration (m/s^2) and angular velocity signal (deg/s), respectively; a_k and v_k are the kth acceleration and angular velocity values in the time domain signal and N is the total number of acceleration values (N = 3700) for the duration of 1 s .

2.5. Sensory evaluation

A sensory panel of 40 members including students of Ramin Agricultural and Natural Resources University assessed the baguettes for staling. Panelists were asked to evaluate each sample by answering the question "Would you normally consume this product?" The answers (yes or no) were used to calculate the percentage of consumer rejection (Baixauli et al., 2008).

2.6. Statistical analysis

The data were analyzed by one-way analysis of variance (ANOVA) using SAS software version 9.3 (SAS Institute, Cary, NC). The least significant difference test (LSD) was used to determine statistically significant differences among the means. The relationships between variables were tested using Pearson's correlation coefficient test.

3. Results and discussion

During storage, the baguette breads experienced a decrease in crumb moisture and an increase in crust moisture (Table 1) as a result of macroscopic migration of water from the wetter crumb to the drier crust (Curti et al., 2014). Staling is divided into two parts: crust staling and crumb staling (Bhatt and Nagaraju, 2009). The crumb-to-crust migration of water associated with decreased crispiness of crust is believed to be the major contributor to crust staling. In contrast, crumb staling is mainly associated with structural changes of the starch matrix during storage, leading to progressive stiffness of the crumb (Bhatt and Nagaraju, 2009). The results of instrumental texture analysis revealed that it became firmer and less springy with storage time (Table 1), indicating the progress of crumb staling. As expected, the changes in the baguette breads during storage adversely affected consumer acceptance (Table 1).

Table 2 gives the vibration characteristics of baguette bread. The values for w_{nx} and w_{nz} remained statistically unchanged during the first two days of storage and decreased significantly afterwards. However, the ξ_x and ξ_z tended to decrease significantly over the entire storage time. It was also observed that V_{RMS_x} and a_{RMS_z} both increased dramatically over the four-day storage period; however, the changes in V_{RMS_x} were statistically significant only during the last two days of storage. Fig. 2 gives the free vibration time histories of the baguette bread at different stages of storage; the results show