MONITORING PHYSICOCHEMICAL PROPERTIES IN LASAGNA PASTA USING CONTACTLESS ULTRASOUND

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ABSTRACT

In recent years, the market of ready to serve meals has experienced significant growth, leading to the development of new products and innovations. Furthermore, the concept of Industry 4.0 represents a great challenge for the food industry, requiring the development of automated and non-invasive sensors capable of accurately estimating food quality parameters. In this context, contactless ultrasound has emerged as an advanced characterization technique that enables real-time and on-line measurements.

Moisture adsorption and dehydration is widely recognized as one of the most critical factors influencing the shelf life of cereal-based products. This study aims to assess the feasibility of contactless ultrasound as an innovative and non-invasive technique for monitoring the physicochemical properties of lasagna, including moisture content, water activity, and texture, which are influenced by moisture adsorption. Lasagna samples were subjected to different relative humidities storage conditions (10 and 40 %) for 14 days at 30 °C to induce changes in their physicochemical properties. The results demonstrated the sensitivity of ultrasound in detecting the physicochemical changes associated with moisture adsorption in lasagna.

Keywords—ultrasound, contactless, lasagna, moisture desorption.

1. INTRODUCTION

Ultrasound (US) is a technique applied in many research fields; however, it is still relatively undiscovered by the food industry as a non-destructive testing (NDT) method [1]. The considerable growth of the food industry, coupled with the trend toward automating industrial processes (Industry 4.0), has led to the development of sensors for controlling and monitoring food transformation and quality parameters [2].

High-frequency ultrasound has, therefore, been introduced into the food industry as a versatile and valuable tool for characterizing and potentially predicting parameters such as density, moisture content, and textural properties [3,4]. Ultrasonic waves are strongly influenced by the physical properties of the food matrix through which they travel, leading to modifications in ultrasonic parameters such as the ultrasonic velocity or attenuation [5]. For instance, Garcia-Perez et al. [6] monitored the salting process of ham using pulse-echo US measurements (1 MHz) and correlated the salting evolution with changes in the time-of-flight (ΔTOF).

Dried pasta products, including lasagna sheets, represents examples of foods that could significantly benefit from the application of US as quality control technique. The main challenge faced by these products during production and storage is small variation on the moisture content caused by formulation or drying operations, which may cause noticeable modifications on its technological properties, such as texture [7]. Consequently, texture analysis has become a critical control point in the production line. However, instrumental texture analysis is a destructive method that generates food waste, is time-consuming, and requires trained professionals [2]. Therefore, the incorporation of smart sensors into lasagna processing lines could provide a rapid and cost-effective method for quality evaluation.

Air-coupled ultrasound presents a significant potential for in-line applications due to its contactless character in contrast to conventional ultrasound, which requires physical contact between product and sensor or the use of couplants. Contactless US, in this regard, is considered a sensor that offers numerous advantages at an industrial level, including improved product quality at a low installation cost, non-invasive analysis, and ease of use. These advantages have recently been documented in the literature. Thus, Kerhervé et al. [5] who studied the feasibility of on-line ultrasound

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measurements for industrial quality control of noodle dough. They established correlations between ultrasonic velocity and attenuation, and moisture content and dough sheets thickness. Therefore, the aim of this study was to assess the viability of using air-coupled ultrasound as a quality evaluation technique for dried lasagna. This evaluation is based on the modification of its textural properties due to slight variations in moisture content.

2. MATERIALS AND METHODS

2.1. Raw sample and storage conditions

Lasagna dried sheets were purchased from a local market (Valencia, Spain). The commercial lasagna had square dimensions (80×80 mm) and an averaged thickness of 1.17 mm. The samples were stored at room temperature (22 ± 1°C) until the analysis.

Different storage conditions were carried out in hermetic containers with controlled relative humidities (H.R.) of 10 and 40 % in order to cause slight changes on the moisture content. For this purpose, lasagna sheets were placed in closed containers with saturated salt solutions (LiCl, 10 % and K_2CO_3, 40 %) at 30 ± 1 °C until equilibrium was reached. The adsorption experiments were performed in triplicate using 10 lasagna sheets per test.

2.2. Contactless ultrasound measurements

Contactless ultrasound measurements were performed in through-transmission mode, as shown in Figure 1. A pair of unfocused piezoelectric transducers with a central frequency of 0.3 MHz of a peak sensitivity of −25 dB, and 20 mm diameter (ITEFI-CSIC, Spain) were used [8]. A pulser/receiver (5077 PR, Olympus, USA) was used to drive a 400 V impulse tuned at 0.3 MHz to the transmitter transducer. Afterwards, the received signal was amplified by 59 dB, and the resulting signal was digitalized (NI 6501, National Instruments, USA). The digitalization rate was 100 MS/s and 128 samples were averaged to minimize the random electrical noise.

The sample measurement was carried out using a holding plate with a hollow (25 mm diameter) where the samples were located. Five ultrasonic measurements were acquired along the lasagna sheets. Prior to the measurements, the reference signal was taken without the sample, and the sample's thickness was measured using a laser sensor (OXH7-Z050.HI06660.VI, Baumer). Temperature and H.R. were monitored during the measurements.

The ultrasonic signals were analysed using the energy threshold method [9] to obtain the time-of-flight (TOF).

Figure 1. Contactless ultrasound set-up.

Afterwards, the propagation velocity was computed using equation (1), considering ΔTOF as the difference between the TOF from the sample and the reference.

$$v = \frac{L}{\left(L/v_0\right) + \Delta TOF} \quad (1)$$

Where v is the ultrasonic wave velocity (m/s), L is the sample thickness (m) and v_o is the velocity of sound in the air (343 m/s at 22 °C and 1 bar).

2.3. Texture analysis

The mechanical properties of the lasagna sheets were determined through a three-point bending test using a texture analyser (TA. XT2i, Stable Micro Systems, UK). The lasagna sheets were positioned over two support points separated by a defined distance (40 mm) (HDP/3PB). A flexion deformation was applied to each sample at a test speed of 3 mm/s and a travel distance of 5 mm. Finally, the stiffness (N/mm) of the lasagna sheets was computed as the slope of the force-time profile. The analysis was performed in triplicate for each sample condition.

2.4. Moisture and water activity analysis

The moisture content (%, wet basis) and water activity (a_w) of the samples were determined. The moisture content was determined using a gravimetric method, involving the drying of the samples in a convection oven (105 °C) until constant weight. Water activity was measured using a dew-point hygrometer (25 °C) (Waterlab, Steroglass, Italy). The analysis were carried out in triplicate for each sample condition.

2.5. Statistical analysis

The analysis of variance (ANOVA) was applied in order to determine if the mean values of the stiffness and ultrasonic velocity were significantly affected by the moisture content of the lasagna sheets. Comparison of the means was performed using Fisher Least Significant Differences (LSD) test with 95 % confidence interval. Statistical analysis was carried out using Statgraphics Centurion XVII (Statgraphics Technologies Inc., VA, USA).

3. RESULTS AND DISCUSSION

3.1. Modification of moisture and water activity

The different storage conditions (H.R., %) lead to modifications in the moisture content and a_w of the lasagna sheets once equilibrium was reached. Table 1 shows the reduction in a_w for samples stored at 10 and 40 % (0.223 and 0.470, respectively) compared to the commercial samples (0.561). Due to water activity of commercial lasagna was higher than relative humidity during storage, lasagna suffer small dehydration from 10.58 % (Commercial) to 3.29 % (10 % H.R.) of moisture content. The effect of the H. R. (%) conditions on the composition and quality properties in cereal products has been studied by numerous authors such as Guiné et al. [10] for biscuits and Lewicki and Jakubczyk [11] for bread crackers. Cereal-based products such as lasagna are hygroscopic and fragile products, which generates great interest in understanding the influence of small variations in moisture content on their textural properties.

Table 1. Moisture content, water activity (a_w) and thickness measurement.

Sample	a_w	Moisture [%, w.b.]	Thickness [mm]
Commercial	0.561±0.016	10.58±0.21	1.17±0.02
10 % H.R.	0.223±0.013	3.29±0.13	1.12±0.02
40 % H.R.	0.470±0.006	8.48±0.12	1.15±0.02

±standard deviation

3.2. Influence of moisture content on ultrasonic velocity

Figure 2 illustrates the increment of ultrasonic velocity due to the reduction of the moisture content. This relationship is further depicted in Figure 3 where the TOF of the three samples is visualized.

The increase of ultrasonic velocity in the samples with low moisture content could be attributed, among other factors, to the sample thickness reduction (Table 1). The possible densification of the samples with lowest moisture content could improve the wave transmission [12]. This phenomenon has been documented in different food matrices, such as dry-cured ham [13] or dried potato snacks [14]. Thus, these result shows the great influence of the moisture content variation to the lasagna structural and mechanical properties.

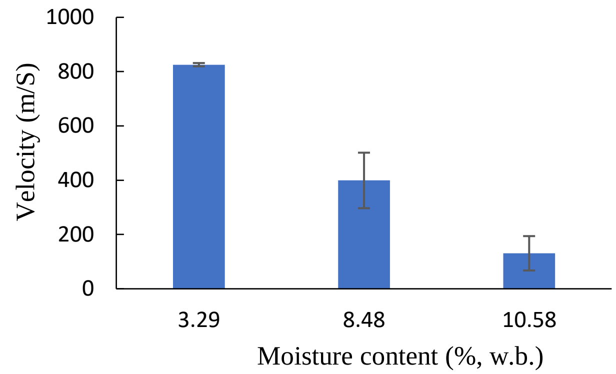

Figure 2. Ultrasonic velocity of lasagna at different moisture content. Error bars show standard deviation (SD).

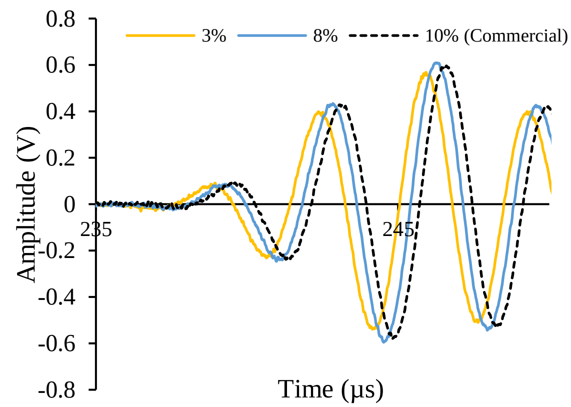

Figure 3. Ultrasonic signals in lasagna with different moisture content (% w.b.).

3.3. Influence of moisture content on textural properties

Even small changes in moisture content led to modifications in the mechanical properties of lasagna. Stiffness, or resistance to deformation, is a parameter that can be related to Young`s modulus [15]. Figure 4 shows an increment in stiffness from 19.03 ± 1.48 N/mm (at 10.58 % moisture content) to 26.44 ± 1.92 N/s (at 3.29 % moisture content) according with the moisture content, due to the different H.R. of storage. If commercial and stored at 40 % H.R. samples are compared, a noticeable change of stiffness is observed despite the relatively small increase in moisture content (from 8.45 to 10.58 %). These results show the significant effect of moisture content on the textural properties of this type of product. Similar findings were observed during the drying of potato slices by Sanchez-Jimenez et al. [14], who reported an increase in the elastic modulus due to the reduction in moisture content, ranging from 4.44 (at 3.80 kg water/kg d.m) to 6.34 MPa (at 0.11 kg water/kg d.m).

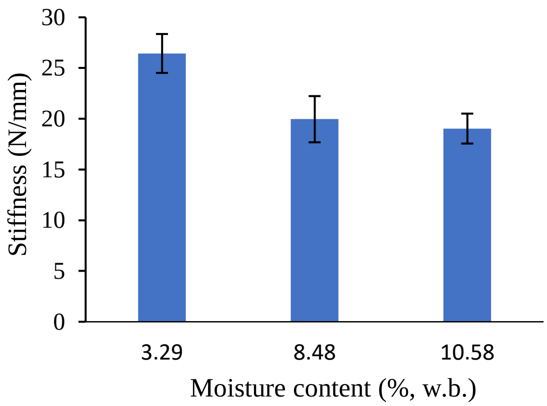

Figure 4. Stiffness of lasagna at different moisture content. Error bars show standard deviation (SD).

3.4. Relationship between ultrasonic and textural parameters

The relationship between stiffness and ultrasonic velocity is illustrated in Figure 5. It could observe a higher propagation velocity in samples with the highest stiffness (26.44 N/mm) than in the lowest stiffness samples (19.03 N/mm), with velocity values of 826 m/s and 131 m/s, respectively. In fact, Figure 5 demonstrates that even a slight increase in stiffness (from 19.03 to 26.44) leads to a significant change in ultrasonic velocity (from 130.80 to 825.60).

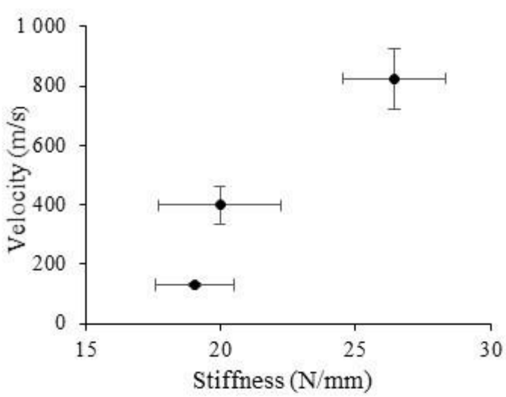

Figure 5. Relationship between ultrasonic velocity and stiffness in lasagna sheets. Error bars show standard deviation (SD).

The influence of textural properties modification on ultrasonic propagation velocity is explained by equation (2). Thus, the increase in material elastic modulus at low moisture content, leads to a faster wave propagation [1].

$$v = \sqrt{\frac{E}{\rho}} \qquad (2)$$

Where ρ is the density (kg/m^3) and E is the elastic modulus (E, Pa).

The results obtained are in concordance with those obtained by Sanchez-Jimenez et al. [14] and Kim et al. [16] when relating the elastic properties of potato slices and apple with ultrasonic velocity.

4. CONCLUSIONS

The feasibility of the contactless ultrasound technique for the estimation of the textural properties of dried lasagna with different moisture content was illustrated. The modification of the mechanical properties of lasagna by small changes of the moisture content was adequately described by the ultrasonic velocity. This application presents significant prospects for improving the texture analysis of this type of product at industrial level.

5. ACKNOWLEDGMENTS

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