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Application of novel acoustic measurement techniques for texture analysis of co-extruded snacks

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ABSTRACT

The aim of this work was to analyse the complex texture of co-extruded cereal products with different fillings (toffee, milk, coconut and chocolate creams, fruit jelly). Measurement of selected physical and mechanical properties and recording of audible sounds and acoustic emission accompanying deformation of materials were the scope of this study. Acoustic emission of products and sounds transmitted via air were recorded during the puncture test using a texture analyser. Sensory analysis of filled extrudate was carried out for hardness, crispness as well as sound attributes of texture. All analysed snacks with cream filling were products with a crispy texture that emitted sounds with a significant intensity. A higher number of force and sound peaks and a higher number of acoustic events were recorded for extruded products with milk cream. The sensory analysis showed that extrudates with a fruit jelly filling were perceived as less crispy and more rubbery than snacks with creams. Application of force-deformation measurement together with acoustic methods can be a sensitive technique to control texture of co-extrudates.

1. Introduction

Texture is one of the most important quality features of extruded products. Peleg (2006) defined texture as the assortment of mechanical-structural-acoustic properties that humans perceive as food's distinctive physical characteristics. Research during the past years has focused on developing an instrumental method to measure texture and express it in objective numerical descriptors (Chen & Opara, 2013; Rojo & Vincent, 2009; Saeleaw & Schleining, 2011; Taniwaki, Sakurai, & Kato, 2010). The texture of extruded foods is one of the key parameters driving consumer preference. Among the texture attributes of food products, crispness is one of the most important and desirable textural attributes in quality evaluation of extruded products (Saeleaw & Schleining, 2011).

Acoustic emission generated during deformation of cereal products constitutes a significant factor of features described as crispness and crunchiness (Luyten, Plijter, & van Vliet, 2004). The acoustic emission method has now found wide application in testing of food properties (Lewicki, Marzec, & Ranachowski, 2009). The acoustic signal generated during deformation of different food products has been registered by microphone probe (Primo-Martín, Sözer, Hamer, & van Vliet, 2009; Saeleaw, Dürrschmid, & Schleining, 2012) or using a piezoelectric contact sensor (Chanvrier, Jakubczyk, Gondek, & Gumy, 2014; Herremans et al., 2013; Wiktor et al., 2016; Zdunek, Konopacka, & Jesionkowska, 2010). The application of mechanical tests as well as acoustic measurement can provide better characteristics of texture attributes than using those methods alone (Saeleaw & Schleining, 2011).

Extrusion processing is an important technology used for producing a variety of cereal foods such as expanded snacks, breakfast cereal, baby foods, as well as pasta and pet foods (de Cindio, Gabriele, Pollini, Peressini, & Sensidoni, 2002). A co-extrusion process is a technique where two materials (different in nature) are combined in an extrusion die. The materials can come from two extruders or from an extruder and a pump. This process gives the manufacturer the ability to create a product with two different textures or two flavours (Moore, 1994). Filled extruded snacks represent products with unique sensory attributes that make them popular among consumers. Filled snacks made by the co-extrusion cooking method are composed of an external dry cereal shell and an inner filling such as fruit jam, ketchup, lemon cream or cheese cream (Peressini et al., 2002). The filling process is the important step in filled snack production because of its great influence on the

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sensory properties of the final product (de Cindio et al., 2002). Filler materials range from solid, creamy to gel-like consistency, which can have a significant impact on the texture of these dual-phase snacks. Inherent differences in the physical states and compositions of the two phases provide interesting textural variation of co-extrudates to the consumer (Samuel, Dogan, McGrane, & Kokini, 2007).

Texture evaluation of crispy foods is a complex issue, and because of that a combination of techniques involving sensory analysis, the acoustic method and instrumental analysis has been applied (Altamirano-Fortoul, Hernando, & Rosell, 2013). A trained or laboratory sensory panel is usually applied to evaluate crispness, crackliness and hardness of extruded snack foods (Anton & Luciano, 2007). Many studies have shown that results of the instrumental analysis of texture were closely related to sensory analysis of cereal products (Jakubczyk et al., 2015; Saeleaw et al., 2012). Combining instrumental techniques with sensory evaluations may increase the efficiency and accuracy of food texture measurement (Chen & Opara, 2013). The textural contrasts that may occur within a complex product such as a layered cake are highly acceptable by the consumers. The most pleasant combinations require strong differentiation such as crispy and creamy (Szczesniak, 2002).

There have been many studies describing extruded products, but very few of them concerning co-extrudates. The objective of this work was to compare selected textural attributes of extruded cereal products with different fillings. The method proposed in this study provides two acoustic systems applied during deformation of samples: a novel contact system for capturing and analysing vibrations and a non-contact system with a microphone for recording sounds transmitted via air. Our objective was also to assess the relationships between the textural attributes determined using both sensory analysis and instrumental techniques.

2. Materials and methods

2.1. Materials

The materials of this work were cereal extruded snacks supplied by the local manufacturer. The products were made by the co-extrusion cooking method in the form of cereal “pillows” with a different filling in the centre of the extrudate (milk, toffee, coconut, chocolate creams and fruit jelly). The cereal part of the co-extrudate (60%) contained wheat flour, wheat graham flour, corn grits, wheat bran, rice flour, sugar, salt and water. To the blend of flours cacao was added during extrusion of products with milk, chocolate and coconut cream. The co-extrusion was performed using a BC45 cooking extruder (Clextral, Firminy, France) under the following processing conditions: barrel temperature 150–180 °C, pressure 120 bar, screw speed 180 rpm, feeding rate 38 rpm. Dual-phase extrudates (a pillow-shaped product with a length of 25 mm, width of 20 mm and maximal height of 12 mm) were packed in multilayers bags with high barrier properties against water vapour. Co-extrudates were investigated directly after delivery from the manufacturer.

2.2. Selected physical properties

The following selected physical properties of extruded snacks were analysed: water content, water activity, bulk density, particle density and open porosity. The water content of the samples was determined using the vacuum drying method. The water activity was measured with a HigroLab apparatus (Rotronic AG, Bassersdorf, Switzerland) with an accuracy of ±0.001 at a temperature of 23 ± 1 °C. The open porosity was calculated based on the bulk density determined according to the displacement method with glass beads of Hwang and Yakawa (1980) and the particle density obtained using a helium stereopycnometer (Quantachrome Instruments, Boynton Beach, USA). Three replicates for all samples were performed for water content, water activity and both bulk and particle density measurements.

2.3. Mechanical properties

The force-deformation test was carried out using a TA-HD plus texture analyser equipped with a 5-kg load cell (Stable Micro Systems, Surrey, UK). Samples were collected directly from the package and subjected to a puncture test using a cylindrical flat probe (P/5) with diameter of 5 mm. The deformation tests were carried out at a constant speed of 1 mm s^{-1}. The deformation level was appropriately selected to ensure complete penetration of the probe through the co-extrudate. Force versus deformation data were recorded and some mechanical parameters were determined using Exponent software (Stable Micro Systems, Surrey, UK): force (N) and distance (mm) at fracture of upper and bottom extrudate shells (Force 1, Distance 1 and Force 2, Distance 2), number of force peaks (recorded as drop in force higher than 1 N), and area under force-deformation curve (N mm). Twenty replicates of puncture test for each kind of co-extrudate were performed.

2.4. Acoustic properties

The texture characteristics of extruded products were also analysed based on acoustic signals generated during deformation tests carried out using a texture analyser. The sound emitted by tested samples was recorded in a non-contact way with an Acoustic Envelope Detector (AED-Stable Micro Systems Godalming, Surrey, UK) with a free-field microphone 4188-A-021 (Brüel & Kjær, Naerum, Denmark) positioned at 3 cm distance from the sample. The angle between the load cell probe and the microphone was set at 45°. The microphone was calibrated using the acoustic calibrator type 4231 (94 and 114 dB SPL, 1000 Hz). Results were recorded at AED detector gain of 6 dB and a frequency of sound and force sampling reaching 500 Hz. Texture Exponent software (Stable Micro Systems Godalming, UK) enabled the following AED parameters to be determined from the sound signal: mean of sound peaks AED (the sum of the peak values divided by the number of peaks, dB), number of sound peaks AED (drop in sound pressure level larger than 10 dB), the maximum of sound peaks AED (maximum value of sound pressure level, dB).

The acoustic emission (AE) generated during puncture of the sample was also registered in the contact way using a piezoelectric accelerometer (4507B, Brüel & Kjær Naerum, Denmark). This piezoelectric sensor was installed between the load cell of the Texture Analyser and a penetrating probe. The sensor registered vibrations emitted by the deformed material and converted them into alternating voltage. The contact acoustic tests were performed and analysed according to the procedure described by Gondek et al. (2013) for extruded bread. The acoustic emission (AE) signal was recorded at a sampling frequency of 44.1 kHz using an analogue-digital processing card type 9112 (Adlink Technology Inc., New Taipei City, Taiwan). The selected acoustic descriptors obtained by the contact (AE) method were extracted at a discrimination level of 1000 mV: total acoustic energy AE (arbitrary unit – a.u.), total number of AE events. Additionally, average distribution of number of acoustic events in relation to acoustic energy for all co-extrudates was analysed. The acoustic signal was also analysed in a frequency domain which enabled the power spectrum characteristic to be obtained. The detailed description of measurement, calculation and definition of acoustic descriptors were presented by Gondek, Lewicki, and Ranachowski (2006). Twenty acoustic