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Multifractal breakage pattern of tortilla chips as related to moisture content

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ABSTRACT

Quality of brittle foods depends on their composition and handling. Moisture content and water activity (Aw) influence the resistance to fracture and the resulting breakage patterns are frequently associated to fractal geometries. The aim of this work was to characterise the morphology of the breakage pattern of tortilla chips subjected to breakage by means of fractal, multifractal and lacunarity evaluations within the range 1–7% wb moisture contents. The morphologies of breaking patterns line and transversal section were evaluated by digital image analysis (DIA). Results showed that low moisture contents were associated to long-tortuous breaking lines described by four different multifractal morphologies and the contrary was observed at higher moistures. Two main multifractal behaviours were observed for the breakage pattern and the elasticity modulus before and after the shifting moisture content (SMC) which had a value of 5% (Aw = 0.36) that was close to GAB monolayer value (4.3% moisture content) which has been associated to quality of foodstuffs.

1. Introduction

In the United States and many other countries, one of the most popular snack products is tortilla chips (Kawas and Moreira, 2001) which are corn dough-based foods, baked and fried, so giving place to a crispy commodity susceptible to fracture and may suffer changes in moisture content during transport and storage. The texture of the tortilla chips is a quality attribute that contributes to their organoleptic acceptability and is usually measured through mechanical properties, such as resistance to fracture (Abhyankar et al., 2011), which mainly depends on structural elements of the food material (Aguilera, 2005). The determination of textural properties, for instance crispness and firmness of the bread crust, has been related to mechanical parameters (peak force, force–deformation and Young's modulus) (Altamirano-Fortoul et al., 2013). Also, the microstructure of food materials is a major factor that contributes to the modification of their textural properties and overall quality of the products (Herremans et al., 2013; Nunes et al., 2008).

In addition, moisture content affects mechanical properties of foods (Fontanet et al., 1997) and has an influence on the resistance to fracture and strain (Peleg, 1997). High water contents have an influence on structural elements which frequently originates a ductile behaviour and resistance to cracking (Łysiak, 2007). Primo-Martín et al. (2009) found that bread crust stored at high relative humidity did not show the characteristic acoustic pattern of the breakage of a crispy food. The degree of brittleness of a structure and its deformation pattern are strongly influenced by water content (Peleg, 1997). It has been reported that it is important to study the nature of the breakage pattern in brittle foods (such as tortilla chips) in relation to their moisture content (Łysiak, 2007). Breakage pattern of these materials may form part of the quality control scheme of the product.

Novel tools such as digital image analysis (DIA) have been used to obtain information on the structure of the material and allowed to understand the relationships among structure, process and functionality (Chanona-Pérez et al., 2009). In this regard, Zenoozian et al. (2007) developed image analysis tools to predict physical changes in pumpkin after an osmotic dehydration process. Also, quality control schemes have been improved by using DIA for assessing parameters such as colour and spotting of tortillas and structure of dough during baking (Mery et al., 2010;

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Pérez-Nieto et al., 2010). Matiacevich et al. (2011) evaluated and predicted mechanical properties of corn and tortilla chips such as maximum breaking force, hardness and toughness by using features extracted from DIA. Besides, breaking has been analysed by means of DIA at the post-failure stage in different varieties of cucumber, showing specific zones in a two dimensional map within the conditions at which fruits were expected to break during transportation (Dan et al., 2006). One of the steps in DIA is the image segmentation which extracts (crops) the object of interest from the rest of the image and is based on the selection of a threshold interval considering the grey level histogram of the image (Gonzales-Barron and Butler, 2006) from which allows to determine the correct dispersion of pixel intensity.

An important parameter obtained by DIA is fractal dimension which provides a numerical descriptor of morphology and irregularity of complex materials and food processes (Farrera-Rebollo et al., 2011). The breakage pattern in solid foods presents rough surfaces that have been associated to crack propagation following an irregular, tortuous path due to the effect of several factors such as their composition and physical structure (Altamirano-Fortoul et al., 2013). This roughness is apparently a random-controlled characteristic which possesses certain levels of determinism (Balankin, 1996). A fractal figure is an irregular set with specific and scale-dependant properties (Mandelbrot, 1977). Fractal dimension has been used as an index of the irregularity of food's the morphology before, during or after processing. During different drying processes, this parameter was related to moisture migration to the surface of the material (Kerdpiboon and Devahastin, 2007). Yiotis et al. (2010) performed a numerical simulation of drying patterns (measured as pores in a gas phase) using fractal dimension evaluation. It has been reported (García-Armenta et al., 2014) that the breakage pattern of maltodextrin agglomerates analysed by DIA showed a multifractal behaviour.

Frequently, simple fractal dimension does not describe properly the complex breakage pattern since it is composed by different sets with different scale properties. Multifractal analysis considers decomposing the figure on self-similar measures inside the interwoven fractal sets which are characterised by their singularity and by a generalised fractal dimension (Li et al., 2012). In addition, lacunarity is a property of fractals that complements multifractal analysis by providing information on the spatial distribution and formed gaps of real data sets (Kaye, 2008; Plotnick et al., 1996). Lacunarity measures the deviation of a geometric object, whether or not is a fractal, from translational invariance at a given scale (Plotnick et al., 1993). It describes the heterogeneity of an image in terms of the spatial distribution of the parts forming the object.

The aim of this work was to characterise the morphology of the breakage pattern line and transversal section of tortilla chips through DIA by applying fractal and multifractal analysis coupled to lacunarity evaluations as a function of the moisture content of the product.

2. Materials and methods

2.1. Sample preparation

Tortilla chips Tostitos® (Sabritas, Mexico) which were acquired from a single batch in a local supermarket in Mexico City were used in the experiments. Tortilla chips were conditioned to moisture contents ranging 1–7% by exposing samples to 75% of relative humidity and 25 °C in glass desiccators, withdrawing samples at the desired moisture contents and allowing for an even moisture distribution in the materials. The relative humidity was reached by using a supersaturated solution of NaCl, prepared by adding 233 g of NaCl into 100 mL of distilled water, according to Spiess and Wolf's methodology (Spiess and Wolf, 1986).

2.2. Proximal analysis and water activity (Aw)

Proximal composition of tortilla chips was determined according to AOAC (1995) methods; moisture was determined by the oven method (AOAC 925.09) at 100 °C for 90 min; ash content was determined at 550 °C (AOAC 923.03); protein content ($N \times 6.25$) was determined by the Kjeldahl method (AOAC 960.2); oil content determination was performed using the Soxhlet procedure (Viuda-Martos et al., 2012) and total carbohydrates were calculated by difference. Aw was measured by using an Aqualab 4TE (Decagon Devices, USA) equipment. All determinations were made in triplicate.

2.3. Sorption isotherm

Water vapour adsorption isotherm was determined gravimetrically by exposing tortilla chips at a stable relative humidity (25 °C) with Aw ranged from 0.0 to 0.9. Saturated salt solutions were used to maintaining the corresponding Aw's according to the methodology reported by Spiess and Wolf (1986).

Experimental equilibrium moisture contents within a range of Aw from 0.0 to 0.9 were fitted to the Guggenheim, Anderson and de Boer (GAB) model (Van den Berg and Bruin, 1981):

$$X = \frac{X_m CK\mathrm{Aw}}{(1 - K\mathrm{Aw})[(1 - K\mathrm{Aw}) + CK\mathrm{Aw}]} \tag{1}$$

where X is the equilibrium moisture content, X_m is the monolayer moisture content, C is a parameter related to water sorption heat of the monolayer and K is a constant related with the water sorption heat of the multilayer. These parameters were estimated by nonlinear regression fitting (Moreira et al., 2010a).

2.4. Breakage tests

Breakage tests of tortilla chips were carried out by using a universal testing machine (Instron 5565, USA) working under a compression program and using a 500 N loading cell which was coupled to a cylindrical probe (3.5 mm diameter, 0.096 cm^2 of contact area, 15 cm height) operating at 50 mm/min of vertical descending velocity. The Young's modulus was estimated from the slope of the linear section of the stress–strain (Mizuno et al., 2013).

2.5. Image acquisition and digital image analysis (DIA)

Images of the broken tortilla chips were captured by using a digital camera (Canon Powershot A2200, USA) located 15 cm above the sample on a ring stand and under natural illumination conditions. The captured images presented a 0.1 mm/pixel scale and 800×600 pixels of resolution. Images of the broken tortilla chips were analysed with the software ImageJ v.1.49p (National Institutes of Health, Bethesda, USA) in order to determine fracture length and lacunarity, as well as to perform fractal and multifractal analyses by using the Frac-Lac (2015Febb5810) tool of the software ImageJ. When several lines existed in the fragments of tortilla chips, each one of them was analysed by means of digital image analysis and the mean of generalised fractal dimension (D_0) was reported in this study.

Image processing consisted in converting the original image (RGB) to 8-bits format (grey scale). A 14.72×62.02 mm^2 section was cropped from the original image including the whole breakage pattern line of the tortilla chip. For all images (the whole batch), a semi-automated threshold (Gökmen et al., 2006) was obtained (75(max) – 255(min)) in order to obtain a binary image (Meraz-Torres et al., 2011a,b) by subtracting the grey level