Food Structure 9 (2016) 13–21

Contents lists available at ScienceDirect

Food Structure

journal homepage: www.elsevier.com/locate/foostr

Structure and irregularities of surface of fried batters studied by fractal dimension and lacunarity analysis

Jamshid Rahimi, Michael O. Ngadi*

Department of Bioresource Engineering, McGill University, Ste-Anne-de-Bellevue, Quebec, H9X 3V9, Canada

ARTICLE INFO

Article history:
Received 6 November 2015
Received in revised form 29 June 2016
Accepted 1 July 2016
Available online 2 July 2016

Keywords:
Batter frying
surface irregularities
fractal dimension
lacunarity

ABSTRACT

Fractal dimension and lacunarity were applied to study the structure and irregularities of fried batters. Using scanning electron microscopy, images of batter surfaces were captured, and analyzed via ImageJ software. Fractal dimension (FD) ranged between 1.79 and 1.81. Higher amount of wheat flour in batter preparation resulted in higher FD values compared to batters with higher amount of rice flour. FD significantly ($P < 0.05$) increased during frying. There was a high positive correlation between FD and fat uptake for all batter formulations ($|r| = 0.91$-0.99) that means that surface roughness is an important factor affecting the amount of fat remaining on the surface of batters. Lacunarity, as a measure of degree of heterogeneity of batter ruptures, ranged between 1.19 and 1.25. The lacunarity results showed that the size and shape of ruptures generated on the surface of batters during frying was approximately uniform.

1. Introduction

Surface topography, i.e., structure, morphology, or texture, is an essential physical feature of solid foods impacting not only their sensorial and optical feature, but also their behavior during processing and storage. Different food processing operations cause new surfaces with new characteristics. Roughness, as a surface characteristic, is entirely scale sensitive, which means a surface that normally looks smooth and flat to the naked eye may be rough when examined using advanced microscopic techniques. These microscopy techniques provide high quality digital images for further processing. In a digital image of a surface, data is stored as an array of pixels with different intensity or gray scale. Therefore, the local deviation of brightness from one pixel to another pixel or within a small area is defined texture. The texture of images is a useful method applied for pattern identification to characterize the arrangement of basic constituent of a material in a surface (Quevedo, Carlos, Aguilera, & Cadoche, 2002).

Conventionally and based on Euclidean geometry, the dimension of an object is expressed as an integer number. However, the dimension of some patterns such as contours of biological cells, fractals and some other natural objects is very difficult to describe based on Euclidean geometry, but can be quantitatively evaluated using measures of complexity. Fractal geometry is considered as an extension of Euclidean geometry. The word fractal was first coined by Mandelbrot (1982) from the Latin adjective “fractus”, which corresponds to the Latin verb “frangere” meaning “to break”, or “to create irregular fragments”. Fractals have been used to describe and measure irregular fragments or complex shapes of materials such as mountains, shorelines, clouds, stars, plants, brain cells, and gold colloids (Kerdpiboon, Kerr, & Devahastin, 2006; Mandelbrot., 1982). Many foods, like many other natural objects, show a number of specific properties such as complexity and inhomogeneity in their structure. Study of complexity and inhomogeneity of food surfaces using some measures such as fractal dimension (FD) and lacunarity (λ) can become a great interest for many scientists and provide useful information for food processors (Smith Jr., Lange, & Marks, 1996).

Fractal dimension is a very important parameter for topographical measurement of various materials (Chen, 2007). It is used in several applications, such as, measurement of irregularities in an image, texture segmentation, surface roughness estimation and many other functions (Biswas, Ghose, Guha, & Biswas, 1998). It has also found vast applications in fields ranging from material science, power technology, computer vision, and micro-electrons. Fractal analysis’s practice in food industry dates back from early

* Corresponding author.
E-mail addresses: jamshid.rahimi@mail.mcghill.ca (J. Rahimi), michael.ngadi@mcgill.ca (M.O. Ngadi).

http://dx.doi.org/10.1016/j.foostr.2016.07.002
2213-3291/

years of applications of fractality concepts. Liao, Cavalieri, and Pitts (1990) used Haussdorf fractal dimension to characterize the surface of fruits using gray-level images. Barrett, Normand, Peleg, and Ross (1992) used Fast Fourier Transform technique to assess the jaggedness of the stress-strain relationship of puffed extrudes. They used the Blanket algorithm to evaluate the fractal dimension. Fractal values were extracted from the digital images captured from the agglomerates of instant coffee and instant skim milk (Barletta and Barbosa-Cánovas, 1993). The morphological characteristics of a fractal remain the same regardless of the scale of observation and the level of magnification (Quevedo et al., 2002). Fractal functions can provide suitable information and model for explaining rough surfaces. Different methods have been used in the literature to estimate fractal dimension (Biswas et al., 1998; Quevedo et al., 2002; Zheng, Sun, & Zheng, 2006). These methods include differential fractal Brownian motion (FBM) method, ε-blanket method, variation method, two-dimensional variation method, differential box counting (DBC) method and frequency domain method.

Studies have shown that fractal dimension is not a sufficient metric for the characterization of most textures (Iqbal, Valous, Sun, & Allen, 2011; Valous, Sun, Allen, & Mendoza, 2010), since it only measures how much space is filled. Lacunarity complements fractal dimension by measuring how the data fill the space. Lacunarity is a term that is used to describe the morphology of objects (Dàvila and Parés, 2007; Dàvila, Toldrà, Saguer, Carretero, & Parés, 2007). It is accounted as the gappiness or the visual texture of an image because it explains the heterogeneity of the gaps or the degree of structural variance within an object (Smith et al., 1996). Lacuna (related to lake) is originally a Latin word for gap (Mandelbrot, 1982), and a fractal is said to be lacunar if the gaps in an object have large intervals, holes, and voids. Objects are more lacunar if gap sizes are distributed over a wider range (Dàvila et al., 2007). Lacunarity calculates the distribution of gap sizes along datasets. Heterogeneous, high-lacunarity sets cover gaps of divergent lengths while sets with even gaps are homogeneous and exhibit low lacunarity (Charisis, Hadjileontiadis, & Sergiadis, 2014). Lacunarity is a scale dependent measure of heterogeneity of texture since a heterogeneous set at small scale might be considered homogenous at larger scales and vice versa. For fried batters, these gaps refer to holes, cracks and any other ruptures on the surface, where open channels are available for water and oil to transfer. The study of gap distribution i.e. heterogeneity of the rupture, by means of lacunarity provides information about the surface microstructure of fried batter. Valous et al. (2010) computed the lacunarity of digital images to characterize the texture of pre-sliced cooked pork ham. They were able to extract important textural information from lacunarity scatter plots. Lacunarity analysis of heat-induced plasma protein gels shaowed that reduction in pH increased the heterogeneity of cavities distribution pattern that could be due to change in water holding capacity (Dàvila and Parés, 2007). In another study cane sugar crystalisation was characterised using lacunarity analysis (Velazquez-Camilo, Bolaños-Reynoso, Rodriguez, & Alvarez-Ramirez, 2010). Lacunarity has been widely studied using binarized or gray scale images. However, more recent studies showed that in the binarizing process of converting a gray level image to a black and white image many valuable information on the spatial arrangement of the interested objetcs may be lost (Sezgin and Sankur, 2004; Valous et al., 2010). For this defect through binarization process, the grayscale lacunarity could provide better results that binarized images for texture characterization.

Several factors including porosity, hydrophobic behaviour, and surface attributes determine the characteristics of a food and therefore, transport phenomena during its frying. Previous studies revealed that the surface attributes of fried foods and especially the geometrical irregularity or roughness highly influence the oil uptake kinetic (Moreno, Brown, & Bouchon, 2010; Quevedo et al., 2002; Thanatuksorn, Pradistsuwana, Jantawat, & Suzuki, 2005). Using scanning laser microscopy, Moreno, Brown et al. (2010) studied the relationship between surface roughness and oil gain in fried formulated products. Area-scale fractal analysis approach was used to measure surface topography. The surface topographic analysis showed that potato flake based products are considerably rougher than gluten based products. The authors also found that there was a good agreement between oil uptake and surface description within each product category. Quevedo et al. (2002) employed area-scale fractal analysis technique to quantify morphological changes in images acquired by microscopy for starch gelatinization during frying process and chocolate blooming during storage. In the study by Thanatuksorn et al. (2005), the correlation between changes in fractal dimension, as measure of roughness surface, due to initial moisture level and the final oil content were considered for a wheat flour and water food model.

The purpose of this study was to: measure surface topography, particularly fractal dimension as a metric of roughness of batters as affected by different combinations of wheat and rice flours during frying; assess the effect of the surface roughness on fat content; and to study the level of heterogeneity of surface ruptures using lacunarity analysis of fried batter surfaces.

2. Materials and methods

2.1. Materials

Wheat flour (Five Rose All Purpose Flour, Les Cuisines Five Roses Kitchens, QC, Canada) was purchased from a local grocery store in Montreal, Canada. Long grain rice flour, RL-100, was prepared by Rivland Partnership (Riceland Foods, Arizona, USA). Carboxylmethyl cellulose (CMC) used was supplied by TIC Gums Inc., Maryland, USA. Canola oil (Les Essentiels De La Cuisine, Richmond, BC, Canada) was supplied by Food & Dining Service, McGill University.

2.2. Batter preparation

Five different ratios of wheat and rice flours were prepared namely: 100 g wheat flour to 0 g rice flour (100W0R), 75 g wheat flour to 25 g rice flour (75W25R), 50 g wheat flour to 50 g rice flour (50W50R), 25 g wheat flour to 75 g rice flour (25W75R), and 0 g wheat flour to 100 g rice flour (0W100R). A fixed amount of salt (NaCl) and CMC were added at the amount of 2.5 and 1.5 g/100 g, respectively. Batter slurry was prepared by adding distilled water to flour mix in the ratio of 1.3:1. Then, the batter system was thoroughly mixed and poured in rectangular aluminum cells ($50 \times 25 \times 5$ mm), and transferred for frying. Aluminum pans are normally used in batter frying to direct moisture and oil transfers to only one side. It makes the study of mass transfer less complicated.

2.3. Frying

A kitchen programmable deep fat fryer (De'Longhi, America Inc., Saddle Brooke, NJ 076663, USA) was used to fry the samples at 180 ±2 °C for 1, 2, 3, and 4 min. The fryer was filled with 1.5 L fresh canola oil and preheated and maintained at 180 ±2 °C for 2 hrs before frying. To minimize the variation of oil properties due to degradation during frying, each batch of oil was used for only 30 min before it was replaced with a new batch of oil. All experiments were performed in triplicate. Excess oil on the surface was mopped off using paper towel. Fried samples were then allowed to cool under ambient conditions.