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Review

Approaches to analysis and modeling texture in fresh and processed foods – A review

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ABSTRACT

Texture analysis and modeling are important techniques in food and postharvest research and industrial practice. A wide range of methods have been used to evaluate instrumental results, which provide time-series data of product deformation, thereby allowing a wide range of texture attributes to be calculated from force–time or force–displacement data. Several indices of texture such as the firmness index, crunchiness index and texture index based on "vibration energy density" have been reported, but these are not widely used to quantify food texture. Some modeling and statistical approaches have been adopted to analyze food texture data, including chemical reaction kinetics and the Michaelis–Menton type decay function, mechanistic autocatalytic models based on logistic equation, and the finite element method. However, increasing demand for comprehensive approaches to texture profile analysis, generalized texture indices and fundamental texture models still remain challenges in the food research and industry.

Contents

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1. Introduction

Texture is a key quality attribute used in the fresh and processed food industry to assess product quality and acceptability. Among the texture characteristics, hardness (firmness) is one of the most important parameters of fruit and vegetables, which is often used to determine the freshness of food (Konopacka and Plocharski, 2004). Crispness is the key trait of cellular, brittle and crunchy food (Taniwaki and Kohyama, 2012). Given gelled products such as muscle food, springiness, cohesiveness, adhesiveness and gumminess are significant properties for the texture evaluation (Akwetey and Knipe, 2012; Stejskal et al., 2011). Textural quality attributes of food may be evaluated by descriptive sensory or instrumental analyses. The combination of time and high cost associated with sensory perception has motivated the development and widespread use of empirical mechanical tests which correlate with sensory perceptions of food texture (Costa et al., 2011; Kim et al., 2012; Wang et al., 2007). Over the years, a wide range of instrumental tests have been used in both research and industry to assess food texture, and a great deal of effort has been expended in improving the instruments and measurement techniques for meaningful estimation of textural properties (Oraguzie et al., 2009; Zdunek et al., 2010a, b). Different texture measurement methods may give different results, some expressed as single values such as fruit firmness measured by hand held penetrometer (Ioannides et al., 2007), while others provide more in depth information on the history of deformation, such as time-series data on texture measurement (Derington et al., 2011; Taniwaki et al., 2010). These developments have enabled researchers to further analyze food texture data to provide better understanding of the mechanisms of texture and relevance to sensory perception.

The objective of this article is to provide a review of recent developments in texture analysis and modeling of fresh and processed foods, including approaches to texture profile analysis of instrumental measurements. Various texture indices employed in food analysis and models to predict texture changes during food handling and processing are also discussed.

2. Texture profile analysis

Texture profiles are curves which monitor and record the spatial or temporal characteristic events of samples during food texture measurements. Analysis of the profiles of mechanical and acoustic measurements is an important aspect of food texture research. Texture profile analysis (TPA) sets up a 'bridge' from objective measurement to subjective sensation and makes food texture characteristics more predictable.

The history of food texture measurement and texture profile analysis (TPA) dates back to the late 19th and early 20th centuries when the analysis was based primarily on simple sensory evaluations to detect and eliminate defects (Bourne, 1982). It was during the past 60 years which coincided with boom in food processing that texture measurement and analyses emerged as a subject of research and learning in tertiary education, particularly in food science and technology (Szczesniak, 2002). Given its fundamental importance on food science, several authors have discussed the meaning and historical context of TPA (Bourne 1982, 1978; Brandt et al., 1963). The his seminal textbook on food texture and viscosity Bourne (1982) chronicled the early history of texture measurement and analysis and credited Dr. Alina S. Szczesniak for pioneering our current understanding of the multidimensional nature of texture and its importance to the consumer and for developing the principles of texture profile analysis for both instrumental and sensory methods. Bourne (1982) provides an excellent detailed description of the principle of the TPA, with illustrations of the compression required for TPA test, typical TPA curves generated with specific instruments and a generalized texture profile analysis curve obtained from Instron Universal Testing Machine. With respect to food products, these reviews agree that texture profiling involves compressing the product at least twice and quantifying the mechanical parameters from the recorded force–deformation curves (Szczesniak, 2002) as illustrated in Fig. 2. In this section of the review, we discuss the applications of TPA to the two main of types of tests (mechanical and acoustic) used to measure food texture.

2.1. Profile analysis of mechanical measurements

Mechanical measurements of food texture can be categorized as destructive and non-destructive methods. For example, destructive group includes three-point bending test, single-edge notched bend (SENB) test, puncture and penetration tests and cutting "tooth method" which used an incisor blade (Jiang et al., 2008). This group of methods may link with the micro-structural and molecular mechanisms and imitate the mastication process, but they are destructive and there are no clear relationships with mouth feel. The methods of quasi-static force–deformation (Ruiz-Altisent et al., 2010), impact response (Herrero-Langreo et al., 2012; Molina-Delgado et al., 2009; Ragni et al., 2010), "finger" compression (Jiang et al., 2008), and bioyield detection (Lu and Tipper, 2009; Mendoza et al., 2012) are named as non-destructive measurement as usually no visible damage is found and possible to be applied on line. However, the main disadvantages of mechanical non-destructive methods are that they are still destructive in micro-scale and the information obtained from experiments is not comprehensive.

In both of destructive and non-destructive measurements, force is the key parameter. Therefore, typical texture profiles are force versus time/distance (displacement)/deformation (Chaunier et al., 2007; Farris et al., 2008; Greve et al., 2010; Ragni et al., 2010; Sasikala et al., 2011). De Roeck et al. (2010) compressed carrot cylinder to 70% of its original thickness to obtain the maximum force as the hardness; Sila et al. (2006) described hardness as compression force at 30% strain. In a penetration test, the steep initial slope was treated as the character of stiffness (Nguyen et al., 2010). Takahashi et al. (2009) measured texture properties of cookies and raw radish by puncture test, which showed many peaks and formed a zigzag pattern in the force–strain curves indicating the crispy characteristic. Varela et al. (2008a) compared the texture properties of roasted and raw almonds, which indicated that roasted almond was clearly brittle and crisp with significantly lower first force breakdown (force at first peak) and lower deformation at the point. The probe tensile separation method has been applied for quantitative characterization of the stickiness of fluid foods. During the tensile separation test, the probe is slowly brought downwards to squeeze the fluid sample till the final pre-set gap between the two plates is reached and subsequently pulled back at a set speed (Fig. 1). The force needed for separation is recorded. The maximum tensile force and the work till the maximum force were found to be useful parameters for stickiness prediction (Chen et al., 2008). Tsukakoshi et al. (2007) studied the force–deformation curves recorded by two different testing machines and the results showed that the number of changes in the curves depended on the testing machine. Thus, it is difficult to compare the results by using different instruments.

Warner–Bratzler shear force (WBSF) test is a useful technique that has been used since the 1930s as standard mechanical measurement to estimate the toughness (or tenderness) of raw and cooked meat (Girard et al., 2012; Lorenzen et al., 2010) such as pork (Cai et al., 2011), beef (Destefanis et al., 2008) and rabbit meat (Combes et al., 2004). The profile shows either force exerted over time or force exerted versus the distance that the blade has