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Influence of bread structure on human oral processing

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ABSTRACT

The strong interconnection between food structure and its resistance to breakdown is the rationale behind designing bread structure to control its digestion, starting from the oral phase. Three types of bread, i.e. baguette, baked bread and steamed bread, with distinct cellular structures and textures were prepared by only varying the processing conditions. Baguette with thick and dry curst required a larger chewing force and a longer chewing time than steamed bread which has a moist and soft skin. Greater chewing effort resulted in more saliva impregnated and smaller particle size in baguette bolus which might elevate starch digestion and glycaemic response. The impact of crumb structure on oral processing was more complicated which involved both the mechanical strength of the crumb and the textural perception it elicited. Strong correlation was found among bread structure, texture, and oral processing behavior. Our study demonstrated that two important factors, grain feature of bread crumb and the relative portion of bread crust, should be considered when designing bread structure.

1. Introduction

There is an increasing awareness of the relationship between food structure and human digestion. The understanding of food structure and its breakdown is critical to the design of new food for controlling the release of both macronutrients and micronutrients and increasing the satiety (Norton et al., 2007). Unfortunately, most food products are structurally complex. Their structure and mechanical properties are not well understood or easily engineered. Bread, one of the most commonly consumed staple foods, is a good example of food products with complex microstructure and a high glycaemic index (GI) in general. Physical structure of the bread was identified as one of the most important factors determining the postprandial glycaemic response (Fardet et al., 2006). However, most of the attention has been focused on reformulations using low GI ingredients (Bharath and Prabhasankar, 2014; Burton et al., 2011). Manipulating bread structure as one of the options to control bread digestion has rarely been attempted so far.

Oral processing is the first key stage of human digestion process, where food is broken down and moistened to form a bolus for safe swallowing. The level of chewing determines the degree of food disintegration which was shown to influence the glucose uptake into the blood stream. Studies on rice showed that the degree of particle size breakdown during mastication influenced both the *in vitro* digestibility and *in vivo* glycaemic response of human subjects (Ranawana et al., 2014, 2010). Similarly, Zhu et al. (2013) found that a greater number of masticatory cycle was associated with a higher postprandial plasma glucose level after eating pizza, even though it also increased satiety.

The highly porous structure of bread crumb is identified as a major contributor to its high GI value (Mishra et al., 2012). Such porous structure is developed through a series of aeration during the stage of mixing, proofing and thermal setting (Zhou and Hui, 2014). The final morphologies of bread crumb, i.e. the size, shape and distribution of cells and the thickness of cell wall, strongly influence its mechanical strength (Gibson and Ashby, 1997) and texture perception in mouth (Panouillé et al., 2014). Scanlon and Zghal (2001) provided a comprehensive review of the relationship between the cellular structure (relative density) and mechanical properties of bread crumb based on the scaling law developed by Gibson and Ashby (1997). A few studies reported the kinetics of bread destruction during oral processing in terms of saliva incorporation, particle size reduction and textural properties (Hoebler et al., 1998; Le Bleis et al., 2013; Tournier et al., 2012); however, little is known about the interconnection among bread structure, the level of oral processing required and its digestibility.

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The cellular structure of bread crumb has been characterized using 2D image analysis and 3D micro-tomography (μCT) technique (Besbes et al., 2013; Lassoued et al., 2007; Van Dyck et al., 2014). But to characterize the changes in bread structure throughout the chewing process is a challenging task. For this purpose, the adaption of chewing physiology provides us some insights on the transformation of food structure. Surface electromyography (sEMG), which measures the electric activities of jaw-closing muscles is one of the few techniques that are able to characterize the *in vivo* chewing behavior (Chen and Espinosa, 2012). Studies have reported the link between EMG results and food texture, especially the hardness and dryness of solid food, such as Melba toast, breakfast cake, and peanut (Pereira et al., 2006; Woda et al., 2006).

This study investigated the impact of bread structure on people's chewing behavior and resulting bolus properties. Variations in bread structure were created by manipulating only the processing conditions while keeping bread formulation the same. During the first stage of study, a group of panellists masticated a normal serving of bread sample that consisted of both crust and crumb. Then a single panellist was selected to participate in the second stage of study, in which bread crumb was separated from crust. This design allowed us to obtain a clear idea on the average behavior of oral processing as well as the isolated effect of bread crumb and crust. Results of this study would shed some light on the design of bread structure that could lead to prescribed levels of oral processing and digestibility.

2. Materials and methods

2.1. Bread preparation

Three types of bread were prepared using the same formulation: 1000 g flour (11.7% protein), 600 g water, 40 g sugar, 30 g vegetable shortening (Radman, Singapore), 20 g salt, and 10 g instant dry yeast (Algict Bruggeman N.V., Belgium). Bread loaves were prepared using the no-time dough method reported previously (Ananingsih et al., 2013; Wang et al., 2007) with slight modifications. The details of processing conditions are shown in Table 1.

2.2. Bread characterization

2.2.1. 2D image acquisition and analysis

Two central vertical slices (~1 cm thickness) were cut from each bread loaf using a mechanical bread slicer (Rhino CM-36, Taiwan). Each slice was scanned on both sides using a flatbed scanner (CanoScan 9000F Mark II, Canon, USA) at a resolution of 600 dpi and saved as a black and white image. A field of view (FOV) of 40 mm × 30 mm was cropped from the center of the baked and steamed bread images while a FOV of 35 mm × 30 mm was cropped from the baguette images. The cropped images were converted into binary images using Otsu thresholding method in Image J (1.46r, National Institute of Health, USA) and exported to Image Pro Plus (version 7, Media Cybernetics, UK) to quantify the porosity and mean cell size of bread. In total, 32 bread slices were analyzed for each type of bread.

2.2.2. 3D X-ray microtomography (μCT)

A cube of 1 cm × 1 cm × 1 cm was cut from the center of bread and placed in a polypropylene tube of 16 mm internal diameter. Images were obtained using a Quantum FX microCT imaging system (PerkinElmer, Hopkinton, MA) which scanned at 90 kV of peak voltage and 120 μA of current. The sample was rotated 360° which took 3 min to obtain 512 slides of 2D radiographs. The FOV was 10 mm × 10 mm which gave a resolution of 20 μm. Images were exported in DICOM format and reconstructed using Imaris (version 7.7.2, Bitpalne, Zurich, Switzerland). A volume of interest (VOI) of 6.38 mm × 6.38 mm × 6.38 mm was cropped from the center of the image to avoid the edges. CT-Analyser software (version 1.4.1, Bruker microCT, Knotich, Belgium) was used to quantify the total porosity, open porosity, mean cell diameter, cell wall thickness and the distribution of cell diameter and wall thickness. A total of 18 samples were analyzed for each type of bread.

2.2.3. Physical characterization

Specific volumes of bread were measured using a Volscan Profiler (VSP 600, Stable Micro System Ltd., Surrey, U.K.). Bread crust or skin was manually separated from the crumb and weighted to determine the ratio of crust or skin to crumb of the serving portion. Moisture contents of bread crumb and crust or skin were determined separately by drying samples of 4 g in an oven at 105 °C for 24 h.

The texture profile analysis (TPA) of the bread crumb was carried out using a TA-XT2i Texture Analyzer (Stable Micro System, Surry, UK) with a 20 mm diameter cylindrical probe. A 2 cm thick slice was cut from the center of the bread and was subjected to a double compression at 2 mm/s to 40% of its thickness. The hardness, springiness, cohesiveness and chewiness of bread crumb were quantified (Bourne, 2002). The hardness of the bread crust/skin was evaluated using a puncture test (Altamirano-Fortoul et al., 2013). The whole bread was punctured with a 2 mm diameter cylindrical probe at a speed of 40 mm/s at 5–6 different locations. This speed was chosen to simulate the biting with the front teeth (Primo-Martín et al., 2008). The peak force during the penetration was quantified as the hardness.

2.3. Masticatory performance

2.3.1. Subject selection

Fourteen healthy adults (7 females and 7 males, 22–26 years old, mean age 23.1 ± 1.5) were recruited to form a panel. The panellists were selected based on the following criteria: (i) having complete permanent dentition (excluding third molar and wisdom teeth) and normal occlusion; (ii) not having any gum or periodontal disease and major dental treatment within 6 months prior to the experiment; and (iii) not having pain or sound in their temporomandibular joints during chewing. This study had been approved by the NUS Institutional Review Board. All panellists gave informed consent to participate.

Table 1
Processing conditions of three types of bread.

	Baked bread	Steamed bread	Baguette
Mixing conditions	1 min at 45 rpm & 5 min at 100 rpm	1 min at 45 rpm & 5 min at 65 rpm	1 min at 45 rpm & 5 min at 100 rpm
Resting time (min)	15	15	15
Dough piece weight (g)	55	50	100
Proofing conditions	40 °C, 85% Relative humidity		
Proofing time (min)	70	40	90
Thermal setting	Baked at 200 °C for 10 min	Steamed at 100 °C for 10 min	Baked at 160 °C for 25 min