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The influence of agar gel texture on sucrose release

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ABSTRACT

The relationship between sucrose release and texture of food gels was investigated by rheological measurements. Agar gels were selected as model food gel, and sucrose was used as a sweetener. Large deformation uniaxial compression tests were carried out at different compression speeds. The fracture stress increased with increasing agar concentration, while the concentration dependence of the fracture strain was different at different compression speeds. The size-distribution of fragments obtained after repeated compression-cycles was quantified using image analysis. The number and total surface area of fragments decreased with increasing agar concentration. Increasing the compression speed led to an initial increase followed by a monotonous decrease of both the number of fragments and their total surface area. The gel texture affected in a similar fashion both the sucrose release ratio and the total fragment surface area. The sucrose release ratio decreased with increasing agar concentration.

1. Introduction

Health foods have recently gained much attention by both the public and the scientific community. However, it is clear that the term "Health Food" is often used inaccurately (Cuthbertson, 1989; Korver, 1997). Generally speaking, the image of Health Foods is that of a high natural fiber, low sugar, salt, fat, calorie and cholesterol, "natural" or "green" food. Of course, no unanimously accepted agreement on the precise definition can be found. Food ingredients, such as sugar, salt, and fat play important roles in many food properties. When discussing "healthy foods", we cannot ignore food palatability. Texture and flavor are two major aspects constituting food palatability. A major problem is how to reduce the amount of food additives such as salt and sucrose while maintaining food palatability.

Many studies have been carried out to investigate the effect of food texture on flavor release. Flavor preservation and release depend on the nature and concentration of volatile compounds contained in the food, as well as their availability for perception as a result of interactions between the main food ingredients and the aroma compounds. Boland, Buhr, Giannouli, and van Ruth (2004) investigated gelatin, starch and pectin gels and found that flavor release was evidently affected by the gel texture. Gels with a higher Young's modulus showed lower flavor release. A difference in flavor release was also observed between starch and pectin gels. Boland, Delahunty, and van Ruth (2006) found that compared with pectin, gelatin gels showed higher static headspace concentrations of strawberry flavor and lower flavor release. When the stiffness of the gels increased, the air/gel partition coefficient decreased and the maximum value of the concentration in nose space increased. Guinard and Marty (1995) observed that rigid carrageenan and gelatin gels released flavor with a lower mean value for perceived maximum intensity than soft or medium-strength gels. Moreover, their study concluded that both texture and the type of gelling-agent affect flavor release. Morris (1993) related perceived sweetness and flavor release to gel rheology and found a strong negative correlation between the yield strain and flavor intensity perception. A possible interpretation is that exposure of fresh gel surfaces during chewing enhances the flavor release and therefore the taste perception. Bayarri et al. (2001) investigated the influence of gel properties on the diffusion and perception of sweetener molecules. They found that the hydrocolloid used had an effect on the diffusion of sucrose and aspartame. The measured diffusion coefficients were higher in κ-carrageenan than in gellan gels, and it was partially attributed to the incipient melting of the κ-carrageenan gel. In

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addition, the diffusion coefficient decreased with increasing elastic moduli. Koliandris, Lee, Ferry, Hill, and Mitchell (2008) studied the relationship between the structure of hydrocolloid solutions and gels and flavor perception. They concluded that the intensity of flavor perception in hydrocolloid solutions and gels was dominated by the release of the tastant. Such results underscore, as suggested by Cook, Hollowood, Linforth, and Taylor (2005), the importance of investigating the effect of gel composition on flavor release. Lian, Malone, Homan, and Norton (2004) presented a mathematical model of in-mouth volatile release from gelled emulsion particles dispersed in a continuous aqueous phase. From their model, three regimes of aroma release from dispersion of gelled emulsion particles were identified. Some interesting studies focused on enhancing the perception intensity using less food ingredients. Thus, the odor–taste interaction and pulsatile stimulation have been reported as effective methods to enhance taste intensity (Burseg, Brattinga, de Kok, & Bult, 2010, Burseg, Camacho, Knoop, & Bult, 2010; Homl, Wendin & Hermansson, 2009; Lawrence, Salles, Septier, Busch, & Thomas-Danguin, 2009; Mills, Spyropoulos, Norton, & Bakalis, 2011; Panouillé, Saint-Eve, de Loubens, Déléris, & Souchon, 2011).

Effects of sucrose on rheological properties of polysaccharide gels have been extensively studied by many research groups (Kawai, Nitta, & Nishinari, 2008; Loret, Ribelles, & Lundin, 2009; Nishinari et al, 1992; Normand et al, 2003). It is widely accepted that the addition of sucrose increased the elastic modulus and the fracture strain of polysaccharide gels. Many workers have demonstrated that more brittle gels show a stronger sweetness intensity because the total surface area became larger when gels were broken down in oral cavity. Sala and Stieger (2013) recently reported that the velocity of formation of new surfaces of emulsion-filled gels of gelatin/agar broken down influences sweetness intensity in addition to the total surface of broken down pieces.

Agar is one of the most popular gel-forming hydrocolloids in the food industry. It is extracted from the cell walls of agarophyte red algae and can be fractionated into two main components, agarose and agaropectin. Agarose is a linear polysaccharide consisting of a repeating β-1, 3-linked D-galactose-α-1, 4-linked 3, 6-anhydro-L-galactose disaccharide. Agaropectin is a heterogeneous mixture of smaller molecules that occur in smaller amounts. At least eleven different disaccharide structures have been identified in different agar bearing weeds depending on the gender, species, environmental conditions and the time of year, making agar a rather complex polysaccharide that varies depending on the exact source and extraction procedure (Lahaye & Rochas, 1991; Watase & Nishinari, 1981). Agar forms a thermoreversible gel. Agar is widely used in the food industry as a water binder and gelling agent, and is a healthier alternative to gelling agents of higher caloric and cholesterol contents, such as various proteins.

In this study, agar gels containing 20% sucrose were selected as a model food, and the effect of compression degree, number of compressions and compression speed on the sucrose release ratio were systematically investigated. In addition, the effect of water or artificial saliva addition to the compressed gel was investigated. The aim of the study is to present a detailed description of the relationship between sucrose release and texture for the model food chosen, agar gels.

2. Materials and methods

2.1. Ingredients

Agar powder (XL-180 and XW-907, Sample No.: 110418, sulfur content 0.18%), was kindly supplied by Ina Food Industry Co. Ltd. (Nagano, Japan). Food grade sucrose was provided by San-Ei-Gen F.F.I. Ltd. (Osaka, Japan). Agar and sucrose were swollen together in deionized water with magnetic stirring at 40 °C for 2 h, pre-heated at 75 °C for 30 min, and then heated at 95 °C for 30 min, yielding a transparent solution of the dissolved polymer. The solutions (sucrose content: either 0% or 20%, agar content 0.5–3%) were immediately poured into a Teflon mold and then left at 22 ± 2 °C for 12 h to yield cylindrical shape gel specimens. Specimen size was 13 mm in diameter and 10 mm in height, mimicking an average a bite-size. No bubbles or other defects were detectable by the naked eye. Artificial saliva was prepared according to a method described previously (Ishihara, Nakauma, Funami, Odake, & Nishinari, 2011a). Each gel preparation was repeated at least in triplicate.

2.2. Uniaxial compression measurement

Uniaxial compression measurements were carried out at 22 ± 2 °C using a TA-plus Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK) fitted with a flat plunger (50 mm in diameter). Different constant compression speeds (0.167–20 mm/s) were employed, but the speed for all results presented was 5 mm/s unless otherwise indicated. From each preparation, at least 5 samples were measured.

Polysaccharide gels are isotropic and incompressible, i.e., their volume is constant, except at very low deformation rates (Nakamura, Shinoda, & Tokita, 2001). We denote the initial cylinder height, radius and cross-section area h_0, R_0 and A_0, respectively, and the deformed height, radius and cross-section area h_1, R_1 and A_1, respectively. We therefore have:

$$h_0 \cdot \pi R_0^2 = h_1 \cdot \pi R_1^2 \tag{1}$$

The true fracture stress σ_F is calculated from the fracture force F_F and the deformed cross-section area A_1 through:

$$\sigma_F = \frac{F_F}{A_1} = \frac{F_F}{\pi R_1^2} = \frac{F_F h_1}{\pi R_0^2 h_0} \tag{2}$$

The Hencky fracture strain ε_F is given as:

$$\varepsilon_F = |\ln h_1/h_0| \tag{3}$$

2.3. Image analysis of gel fragments following fracture

Samples were dyed using 0.3% SAN-RED 3743-EM (San-Ei Gen F.F.I., Inc.), a food color extracted from red cabbage. Preliminary results showed that food color addition affected the fracture strain and stress by less than 3%. Gel specimens were fractured using compression (between 2 and 30 compression cycles) in the presence of 5 ml water or artificial saliva. Following fracture, the gel fragments were manually separated on a filter paper using deionized water, a metal sieve and a spatula. The filter paper was dried over night at room temperature. The filter paper was scanned, and fragment size distribution analysis was carried out with Image-Pro Express, image processing software (Media Cybernetics, Inc. USA) (Kobayashi, Kohyama, Sasaki, & Matsushita, 2006). The boundaries of fragments were initially automatically traced and then modified manually when they were deemed inaccurate. The image analysis software measured and calculated the size of the traced objects.

2.4. Determination of sucrose release ratio

Because sucrose can be released from the gels to the surrounding water by free diffusion, it is necessary to estimate the