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Sucrose release from agar gels: Effects of dissolution order and the network inhomogeneity

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ABSTRACT

The effect of sucrose addition prior to or following the dissolution of agar on sucrose release from 1 wt% agar gels was studied. The order of addition was found to affect the fracture stress, fracture strain and sucrose release ratio. At sucrose concentrations below 30%, the rheology (fracture stress and strain) and structure of the gels did not depend on the order of addition of sucrose and agar. At sucrose concentrations >40%, however, the network structure of gels where sucrose was dissolved before agar addition was weaker than that of gels where sucrose was added after agar dissolution. The weaker network structure resulted in lower fracture stress and strain values. For gels prepared by adding agar to sucrose solutions, both fracture stress and strain decreased with increasing sucrose concentration in the range 40–55%. The decrease in fracture stress and strain led to an increase in the sucrose release ratio. The sucrose release ratio decreased monotonously with increasing concentration of sucrose when agar was dissolved prior to sucrose addition. The findings are discussed in relation to recent publications on gel inhomogeneity.

1. Introduction

The palatability of foods is classified into chemical and physical factors. Chemical factors, or flavours, relate to various odours and the five basic tastes: sweetness, sourness, saltiness, bitterness and umami. Physical factors consist mainly of texture, which is a sensory property (Nishinari, 2004; Szczesniak, 2002). Sugar, salt and other ingredients play an important role in the palatability of food, while they can also affect the texture. Increasing attention is being paid to healthy foods, which consumers have, justifiably or not, often come to associate with low sugar, salt, fat and caloric content. Part of the reason for such market expectations is that excessive consumption of salt and sugar has been related to high blood pressure and diabetes.

Sacks et al. reported that excessive salt intake causes high blood pressure (Sacks et al., 2001), and many research groups have shown that salt reduction reduces cardiovascular events (He, Li, & MacGregor, 2013). In spite of the recommendation of the World Health Organization on the maximum intake for adults of 5 g per day (WHO, 2012), an international review of salt consumption revealed that most countries exceed this limit (Elliott & Brown, 2007). Consequently, an international study was also conducted on salt intake and associated health issues in the general population (Newson et al., 2013). The food industry has responded with considerable efforts to reduce sugar and salt content in processed foods while preserving palatability.

The effect of hydrocolloids on the taste intensity of solutions has been studied widely. Pangborn and Trabue (1973) summarised earlier works. There have been contradictory conclusions on the effect of thickening agents: some basic tastes are found to be intensified by thickening agents, while in other cases the opposite tendency has been reported. Morris (1993) showed that the flavour intensity remained constant with increasing hydrocolloid concentration at low concentrations, and then decreased. A similar

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phenomenon was reported for sweetness, which has been known to decrease with increasing viscosity (Christensen, 1980; Hollowood, Linforth, & Taylor, 2002). Some authors have, however, shown the opposite results (Kanemaru, Harada, & Kasahara, 2002; Stone & Oliver, 1966). The change in perception was related to the molecular origin of viscosity increase above the coil-overlap concentration c* of random-coil polysaccharides by Cook, Hollowood, Linforth, and Taylor (2002). They reported that the magnitude of sweetness reduction was different in different polysaccharide solutions. Malkki, Heinio, and Autio (1993) studied the influence of solutions of three hydrocolloids, oat gum, guar gum and carboxymethyl cellulose (CMC) on the sensory perception of sweetness, and found that the effect of the thickener type was greater than that of the viscosity.

Solid foods are more complicated than liquid foods. Differences in texture, composition and structure lead to different flavour perception. Moritaka, Naito, Nishinari, Iahihara, and Fukuba (1998, 1999) found that milk and lemon flavours were intensified by sweetness (aspartame) and sourness (citric acid), respectively. Such complex taste–taste (and odour-taste) interactions have been studied extensively, and should be taken into account to interpret the influence of the texture on the taste (Lawrence, Salles, Septier, Busch, & Thomas-Danguin, 2009). Moritaka and Naito (2002) compared taste suppression of sweetness, saltiness and bitterness in agar and gelatin gels, and showed that flavour suppression, depending on gel concentration and rupture properties of gels, was affected by flavour compounds. Morris (1993) showed the perceived sweetness intensity of κ-carrageenan, calcium alginate and xanthan/locust beam gum gels with the same sucrose concentration decreased systematically with increasing fracture strain. Clark (2002) used various food gels, and found that there was an excellent negative correlation between the sensory sweetness score and the fracture force. One exception in his report was the gelatin gel, which showed a higher flavour release than expected from its high fracture force due to melting at body temperature. The other exception was a ternary mixed gel of gellan, xanthan and locust bean gum that exhibited lower flavour release from that expected based on the fracture force. This result was attributed to the high cohesiveness of the ternary gel. Thus, these two results by Morris (1993) and Clark (2002) are complementary.

Since mastication leads to fracture of food, large deformation and fracture of gels have attracted much attention. Bayarri, Costell, and Duran (2002) showed that fracture stress increased while the fracture strain decreased with addition of sucrose for concentrated gellan gels. Bayarri, Duran, Izquierdo, and Costell (2005) also compared the influence of sucrose on gellan, κ-carrageenan, and κ-carrageenan/locust bean gum gels. They found that sucrose addition increased the fracture stress of all these gels, but this effect depended on the type and concentration of hydrocolloids. Addition of sucrose to soft gels did not influence the fracture strain, while sucrose addition to gels with higher hydrocolloid concentrations led to a slight decrease in the fracture strain. Kawai, Nitta, and Nishinari (2008) reported that a 0.8 wt% gellan gel at a high sucrose concentration (60%) showed strain hardening behaviour and a high fracture strain, while gellan gels without sucrose had a much lower fracture strain.

It is well known that fracture stress of agar gels increases with increasing concentration of agar and sucrose. The sucrose release is reported to decrease with increasing fracture stress and strain (Bayarri, Duran, & Costell, 2003; Clark, 2002; Moritaka et al., 1998, 1999; Morris, 1993). Different gel preparation methods have been reported with either polysaccharide powder dissolved in sucrose solutions (Normand et al., 2003) or sucrose dissolved in polysaccharide solutions (Kasapis, Al-Marhoobi, Deszczynski, Mitchell, & Abeysekera, 2003). Hirashima, Takahashi, and Nishinari (2005) compared the rheological properties of cornstarch pastes containing various sucrose concentrations by adding sucrose before and after the heating of starch dispersions. They found that the viscosity of starch pastes heated in the presence of sucrose increased with increasing sucrose concentration up to 20 wt%, and decreased at higher concentrations. No decrease in the viscoelasticity of the pastes was observed above 20% sucrose when sucrose was added after heating the starch dispersions.

Although Japanese artisanal dessert jelly makers always add sucrose after dissolution of agar, some researchers add sucrose before, or together with agar. Many common recipes, for example, for preparation of sweet beans, assume sucrose addition after extensive swelling of beans. This order has been known to produce a softer product. It is the aim of the present study to examine the effect of the order of sucrose and agar dissolution on the rheological properties of agar gels and sucrose release.

In compression experiments, low compression speeds have been used widely; 50 mm/min (Normand et al., 2003), 60 mm/min (Bayarri, Duran, & Costell, 2003), and 180 mm/min (Bayarri et al., 2005). The mastication speed depends both on the food and the individual. Usually, the mastication speed is above 1000 mm/min. For example, the mean mastication speed of chewing gum is 1200 mm/min (Bourne, 2002). Seeing as the rheological parameters are dependent on compression speed (McEvoy, Ross-Murphy,& Clark, 1985; Sala, van Vliet, Stuart, van Aken, & van de Velde, 2009; van Vliet & Walstra, 1995), we studied the effects of compression speed on the deformation behaviour and sucrose release, changing the compression speed from 10 mm/min to 1200 mm/min in the present study.

2. Experiment

2.1. Material and gel preparation

Agar powder (XW-907, Sample No.: 110418, sulphur content 0.18%) was supplied by Ina Food Industry Co. Ltd. (Japan). AnalaR grade sucrose was supplied by San-Ei Gen F.F.I., Inc. (Japan). Two preparation methods were used. Method 1: Sucrose was dissolved in deionised water followed by agar powder addition. The solution was stirred at 40 °C for 2 h, heated up to 75 °C and stirred for 30 min, then heated up to 95 °C and stirred for 30 min. Method 2: Agar powder was added to deionised water and stirred at 40 °C for 2 h, heated up to 95 °C and stirred for 10 min. Then sucrose was added to the agar solution which was stirred for another 30 min.

Following heating, the hot solution was poured into cylindrical moulds (13 mm in diameter and 10 mm in height). Specimens for the compression test were obtained by curing in a refrigerator (5 °C) for one night. Absorbance measurements were carried out at a wavelength 400 nm following the same curing in quartz cells. The agar concentration was fixed to 1 wt%, and sucrose concentrations were varied in the range from 10 to 55 wt%. Gels were left at room temperature (22 ± 2 °C) for 1–2 h before measurements. All preparations were repeated in triplicate, and at least 10 specimens (3 for absorbance measurements) were measured from each preparation.

2.2. Compression test

A cylindrical gel sample (13 mm in diameter and 10 mm in height) was placed in a stainless steel dish (60 mm in diameter and 20 mm in height), and 0.8 g deionised water placed around the gel. Because sucrose release from agar gels is very similar in distilled water and in artificial saliva (Wang, Yang, Brenner, Kikuzaki, & Nishinari, 2014), only distilled water was added in the present investigation. Compression tests were performed using a TA-plus