Food Hydrocolloids 60 (2016) 405–414

Contents lists available at ScienceDirect

Food Hydrocolloids

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

Sucrose release from agar gels and sensory perceived sweetness

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ARTICLE INFO

Article history:
Received 14 December 2015
Received in revised form
26 February 2016
Accepted 4 April 2016
Available online 6 April 2016

Keywords:
Sucrose release
Texture
Agar gels
Time–intensity
Sensory evaluation
Mastication

Chemical compounds:
Agar
Sucrose

ABSTRACT

Sweetness resulting from sucrose released from agar gels of varying concentrations of agar (0.5, 1.0, and 1.5% w/w) and sucrose (10%–50% w/w) was evaluated. The intensity of sweetness as perceived by subjects was investigated during consumption of the gels. A time–intensity method was applied: the maximum intensity and area under the time–intensity curve were higher in gels with lower concentrations of agar as expected from previous studies. The intensity of sweetness as estimated by the area under the time–intensity curve increased with sucrose concentration, but the maximum intensity tended to reach a plateau above a certain sucrose concentration. The manifestation of the maximum sweetness was delayed with increasing concentrations of sucrose and agar. The total duration of the perception of sweetness was longer in gels with higher sucrose concentrations but did not depend on the concentration of agar in the range examined. Instrumental characterization of these gels was also conducted. Young's modulus, fracture stress, fracture strain, and energy obtained from a conventional uniaxial compression test of sample gels increased with sucrose concentration and the modulus, stress, and energy were higher in gels with higher agar concentration. Although mechanical characteristics such as Young's modulus, fracture stress, strain, and energy, increased with increasing sucrose concentration, the sweetness intensity tended to a plateau; therefore, physiological and psychological factors experienced during oral processing should be taken into account to understand the perceived sweetness intensity.

1. Introduction

Texture and flavor are sensory properties that are important factors influencing the palatability of foods (Chen, 2009; Kohyama, 2015; Nishinari, 2004; Szczesniak, 2002). Various hydrocolloids are used for modifying food texture and controlling the release of flavor (Funami, 2011). Food acceptability is determined using many oral receptors that detect special sensations during eating such as deformation, static force, vibration, kinematics, basic tastes, and temperature (van Vliet, van Aken, de Jongh, & Hamer, 2009; Kohyama, 2015). Food acceptability is also greatly influenced by odors perceived by nasal receptors. Information sensed by those receptors may interact (Boland, Delahunty, & van Ruth, 2006; Bult, de Wijk, & Hummel, 2007; van Vliet et al., 2009; Knoop, Sala, Smit, & Stieger, 2013; Kohyama, 2015). In addition to the ortho-nasal odors that can be sensed before ingestion, retro-nasal flavors sensed after oral processing play an important role (Boland et al., 2006; Bult et al., 2007; Gierczynski, Guichard, & Laboure, 2011; Salles et al., 2011).

Differences in texture, composition, or structure of solid foods result in the perception of different tastes during oral processing (Chen, 2009). Gels are often used as model foods and are consumed through oral processing (Nishinari, 1997; Nishinari & Fang, 2016; Vilgis, 2015). Marshall and Vaisey (1972) studied the perception of sweetness of several hydrocolloid gels including agar and found that the measured mechanical textural variables, including hardness, cohesiveness, springiness, chewiness, and gumminess, accounted for 52.3% of the variability in sweetness. The type of gelling agent influenced the dynamic release of flavors even when gels composed of different hydrocolloids had similar hardness (Guinard & Marty, 1995). Moritaka and Naito (2002) compared the suppression of sweetness, saltiness, and bitterness in agar and gelatin gels and examined the dependence of the suppression of taste on the concentration and rupture properties of gels. Bayarri, Duran, and Costell (2003) reported that gellan gels were

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http://dx.doi.org/10.1016/j.foodhyd.2016.04.003
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perceived to be sweeter than κ-carrageenan gels, which was attributed to the brittleness of gellan gels. Morris (1993) showed that the perceived intensities of sweetness for κ-carrageenan, calcium alginate, and xanthan/locust beam gum gels with the same sucrose concentration decreased systematically with increasing yield strain. Clark (2002) demonstrated the flavor release from hydrocolloid gels as model foods. The rupture force and the sensory score for overall flavor were negatively correlated, but a melting gelatin gel had an exceptionally strong flavor. Moreover, a cohesive gellan + xantan/locust beam gum gel showed a lower score for overall flavor. Therefore, the reports by Morris (1993) and Clark (2002) are not contradictory but rather complementary.

Mosca, van de Velde, Bult, van Boekel, and Stieger (2010; 2015) studied the sweetness of model gels and found that the inhomogeneous distribution of sucrose in gels resulted in a higher perceived sweetness (Holm, Wendin, & Hermansson, 2009; Mosca et al., 2010). The intensity of sweetness was mainly affected by the total surface area of gel fragments formed during mastication (Mosca et al., 2015). As more mastication is required for gels with a stronger structure, flavor-related sensory attributes decreased under a condition of fixed oral processing. Some researchers used agar gels containing fat as model foods (Frank et al., 2015; Mosca et al., 2010; Sala & Stieger, 2013). In general, the higher concentrations of hydrocolloids resulted in stronger gels and weaker flavor perception. They were commonly observed in systems with and without fat.

Sucrose is commonly contained in gel-type confectioneries and a relatively high concentration is generally preferred. One example is *Youkan*, a Japanese sweet agar gel containing red bean paste (Nishinari & Fang, 2016). The main ingredients of *Youkan* are as follows: sugar and/or syrup, sweet red bean paste, and agar at a concentration of approximately 1.1% w/w. The sucrose content sometimes reaches 72% w/w (Shimada, Hatae, & Shimada, 1990). Shimada et al. (1990) reported that perceived sweetness of solid foods (meringue, candy, cookie, chocolate, and *Youkan*) containing 7.8%–80% w/w sucrose was equivalent to that of 6.7%–25.7% w/w sucrose solutions. They found that the sweetness of chewed samples was affected not only by sucrose content but also by the increasing rate of surface area, amount of saliva, and water absorption. The hardness of *Youkan* containing 72% w/w sucrose was two-fold of that containing 62% w/w sucrose, and their sweetness values were equivalent to those of 18.5 and 23.4% w/w sucrose solutions, respectively (Shimada et al, 1990). In other words, the *Youkan* containing 72% w/w sucrose was perceived to be less sweet than that containing 62% w/w sucrose demonstrating that the sweetness was remarkably decreased by the hardness. Thus, the efficiency of sweetness decreases with increasing sucrose content in gels with higher sucrose content. This is an important issue to consider in the food industry for maintaining high palatability without increasing sucrose content because foods with low sugar and calorie content have recently been considered to be healthier (Nishinari & Fang, 2016).

Sucrose can change not only the taste of gels but also the mechanical properties. Higher the sucrose concentration harder the solid gel-like foods (Nishinari et al., 1992; Nishinari & Fang, 2016; Nishinari, Watase, Miyoshi, Takaya, & Oakenfull, 1995; Normand et al., 2003; Shimada et al., 1990; Wang, Yang, Brenner, Kikuzaki, & Nishinari, 2014; Yang et al., 2015a, b). The storage Young's modulus increased, and the melting temperature increased with increasing sucrose concentration in agarose gels, but the excessive addition of sucrose decreased the elastic modulus (Watase, Nishinari, Williams, & Phillips, 1990; Nishinari et al., 1992; Moritaka & Naito, 2002; Vilgis, 2015). Substitution of sucrose with other sweeteners resulted in the modification of the texture of gels. Partial substitution of sucrose with fructooligosaccharides decreased the solid character of dessert gels (Protonotariou, Karali, Evageliou, Yanniotis, & Mandala, 2013). Sucrose may promote the formation of hydrogen bonds and the stabilization of the structure of junction zones; however, the excessive addition of sucrose will reduce the amount of free water necessary to form junction zones (Nishinari et al., 1992). Normand et al. (2003) reported that Young's modulus and failure stress and strain increased with increasing sucrose concentration. They stated that the network structure became less heterogeneous based on the experimental observation that the turbidity and correlation length decreased with increasing sucrose concentration, which was in good agreement with previous results (Nishinari et al., 1992) in which the number of junction zones increased and the size of each junction zones decreased with increasing sucrose concentration. Kawai, Nitta, and Nishinari (2008) reported that the addition of sucrose to gellan gels increased both the fracture stress and strain and explained it using a modified reel-chain model (Nishinari, Koide, & Ogino, 1985). Gelation of agar is enhanced by the addition of sucrose as a cosolvent. Recently, Shimizu and Matubayasi (2014) proved that exclusion of cosolvents is a dominant contribution than a change in hydration around the biopolymer surfaces, based on a thermodynamic theory of gelation.

Food grade agar gels similarly exhibited an increase in fracture stress with increasing concentration of agar and sucrose (Wang et al., 2014; Yang et al., 2015a, b). The sucrose released from agar gels was reported to decrease with increasing fracture stress and strain (Moritaka & Naito, 2002; Wang et al., 2014; Yang et al., 2015a, b). Previous *in vitro* studies revealed the relationship between rheological and fracture properties, size distribution of fragments after fracture, sucrose release ratio, and preparation methods using agar gels (0.5, 1.0, 1.5, 2.0, 3.0% w/w) containing sucrose (0%–55% w/w) as model foods (Wang et al, 2014; Yang et al., 2015a, b). Total amount of sucrose released from the gels showed a maximum at a certain sucrose concentration in an instrumental compression test, but it depended on compression rate and agar concentration (Yang et al., 2015b). Next, these *in vitro* studies should be related to sensory studies to develop food processing in the industry.

Food gels are soft solids consumed through mastication (Cliff & Heymann, 1993; Guinard & Marty, 1995; Wilson & Brown, 1997; Hayakawa, Kazami, Fujimoto, Kikuchi, & Kohyama, 2009; Foegeding et al., 2011; Kohyama et al., 2014; Kohyama et al., 2015). Although gel-type confectioneries generally contain high concentrations of sucrose and are perceived as sweet, the sweetness is not perceived immediately after the moment of placing it into the mouth. The combined measurement of time–intensity and electromyography has been used for studies of dynamic flavor release during mastication of solid foods (Wilson & Brown, 1997; Sprunt, Raithatha, & Smith, 2002; Hayakawa et al., 2009). Hayakawa et al. (2009) studied the time–intensity of sourness of gummy jellies. The gel samples were broken in the mouth during the first chew within approximately 0.3 s, liquid-containing taste components were released from gel matrix, the taste components reached taste receptors in the taste buds, and then the perception of tastes occurred. The onset of sour taste took 1.2–1.6 s which occurred after a few chews of the gummy samples (Hayakawa et al., 2009).

Agar has been widely used for manufacturing gel-type confectioneries and is known as a hydrocolloid that causes rapid onset and offset of tastes and/or flavors from gels. This may be because of the brittle characteristics of gels as suggested in gellan gels (Bayarri et al., 2003; Morris, Nishinari, & Rinaudo, 2012). We attempted a time–intensity evaluation of sweetness from gels of varying concentrations of agar and sucrose, maintaining the texture and sweet taste within the range of commercially available foods. The results would be practically useful in the food industry.