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Salt taste perception in hydrocolloid systems is affected by sodium ion release and mechanosensory–gustatory cross-modal interactions

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ABSTRACT

The perceived salt taste intensity of viscous solutions and gels of agar–agar and starches varying in their amylose/amylopectin ratio, as well as cellulose suspensions with fine, compact particles up to coarse, fibrous particles was systematically investigated. Saltiness intensity was correlated with instrumental-analytical data on viscosity, gel firmness, and sodium ion availability upon chewing. Salt taste perception was demonstrated to be dependent on the type and concentration of the polysaccharide. It was directly affected by viscosity, gel firmness, the mechanosensory perception of solid particles, and the rate of sodium release. On the one hand, sodium ion availability seemed to be a limiting factor determining salt taste perception in highly viscous and firm gel systems. On the other hand, texture-induced cross-modal interactions between taste and mechanosensory cues seem to play the key role impairing perceived taste impact at lower polysaccharide concentrations and, in particular, in the presence of solid particles. Intriguingly, solid particles that only minimally increased the viscosity drastically reduced perceived taste intensity, not only for saltiness, but also for sour, umami, and sweet tastes, with the exception of bitterness. These findings provide new knowledge on the impact of mechanosensation on taste perception.

1. Introduction

The reduction of sodium chloride in food has become an urgent target due to health reasons. In approximately 30–50% of the population, the so-called salt-sensitive persons, an excess sodium intake is reported to lead to arterial hypertension which is directly linked to cardiovascular diseases (Aburto et al., 2013; Savica, Bellinghieri, & Kopple, 2010). Therefore, the World Health Organization recommends a reduction of the current salt intake from 8 to 11 g/day in industrialized nations to 5 g/day (World Health Organization, 2007). In particular, bread and cereal products have recently been in the focus of salt reduction strategies, because they account for about 25–35% of daily sodium intake in the western diet (Angus, 2007; National Nutrition Survey II, Germany, 2008). However, the reduction of sodium chloride in bread turned out to be a considerable challenge, less from the technological, but particularly from the sensory point of view (Lynch, Dal Bello, Sheehan, Cashman, & Arendt, 2009). The most important sensory function of sodium chloride in bread is the mediation of salt taste induced mainly by sodium ions. Sodium release in the mouth during mastication is a crucial step in salt perception as the sodium ions have to be dissolved in saliva in order to be detectable by sodium-receptive proteins. Moreover, perceived saltiness has been reported to improve the flavor of bread as a whole (Pflaum, Konitzer, Hofmann, & Koehler, 2013a).

A partial salt reduction can be achieved by the use of salt substitutes like potassium and magnesium salts (Cauvain, 2007; Man, 2007; Salovaara, 1982a, 1982b; Wyatt & Ronan, 1982) and salt taste enhancers such as, e.g. L-lysine, L-arginine, and L-arginyl dipeptides (Schindler et al., 2011), by a gradual salt reduction over a longer period of time (Girgis et al., 2003), or by an inhomogeneous salt distribution in the food (Konitzer et al., 2013; Noort, Bult, & Stieger, 2012; Noort, Bult, Stieger, & Hamer, 2010). Very recently, the modification of crumb texture was reported as a novel approach to salt reduction in bakery products (Pflaum, Konitzer, Hofmann, & Koehler, 2013b). For example, a significantly accelerated sodium release and intensified saltiness was perceived during mastication of a coarse-pored bread crumb when compared to a fine-pored bread crumb.

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As the salt perception in bread crumb was, however, affected not only by the kinetics of sodium release, the observed impairment of salt taste intensity in bread crumb when compared to iso-concentrated sodium chloride solutions was suggested by texture-induced cross-modal interactions in the brain (Pflaum et al., 2013b). Whereas different neurons were found to be responsive to taste and texture in the primate primary taste cortex, convergence onto single neurons was observed in the orbitofrontal cortex (OFC) and amygdala, where tactile–gustatory interactions may occur (Kadohisa, Rolls, & Verhagen, 2005; Rolls, 2005; Verhagen & Engelen, 2006). Such texture-induced modulation of taste and aroma perception has been reported, e.g. an increase in viscosity (semi-solid systems) and hardness (gel systems), respectively, was found to impair the perceived intensity of taste (Cook, Hollowood, Linforth, & Taylor, 2002; Lethuaut, Brossard, Rousseau, Bousseau, & Genot, 2003) and aroma stimuli (Boland, Delahunty, & van Ruth, 2006; Ferry et al., 2006). Furthermore, Cook, Hollowood, Linforth, and Taylor (2003) found an impaired sweetness for sucrose in polysaccharide solutions, which could not be fully explained by diffusion/mass-transfer, and they suggested that somatosensory tactile stimuli could interact with taste signals to modulate taste perception. However, the impact of viscosity and particle size of polysaccharides on salt taste perception has not been systematically studied so far.

Therefore, the aim of this study was to investigate the influence of viscosity and textural properties of polysaccharides on saltiness perception in close detail. For this purpose, the perceived saltiness intensity, viscosity, and firmness of sodium-containing agar and starch solutions and gels were determined and correlated with the in-mouth sodium release during mastication. The impact of the starch composition on sodium release and saltiness intensity was studied using gels from corn starches with different ratios of amylose/amylopectin. Besides viscosity and gel firmness, the influence of small particles on salt perception was examined by means of cellulose suspensions with different particle sizes and shapes. The results from this study should provide new fundamental insights into the complex interactions between texture and salt taste perception.

2. Materials and methods

2.1. Chemicals

The quality of all reagents was pro analysis (p.a.) or stated otherwise. Sodium chloride, starch from corn (high amylopectin, regular, and high amylose), sucralose, and wheat starch were from Sigma–Aldrich (Steinheim, Germany). Tris(hydroxymethyl)-aminomethane was obtained from Merck (Darmstadt, Germany). Food-grade agar–agar was from Dragonspice Naturwaren (Reutlingen, Germany) and different types of food-grade cellulose (Jelucel PF30, PF75, PF150, PF300, PF1000X, PF2000) were kindly donated by JELU-Werk (Rosenberg, Germany).

2.2. Determination of amylose and amylopectin content in starch

The content of amylose and total starch in high amylopectin, regular, and high amylose corn starches, and wheat starch was determined by means of an enzymatic assay kit for amylose/amylopectin (Megazyme, Bray, Ireland) (Gibson, Solah, & McCleary, 1997).

2.3. Preparation of polysaccharide gels and suspensions

2.3.1. Starch

100 mL water containing 0, 57.0, or 109.7 mmol/L NaCl was heated to 40 °C on a magnetic stirrer and the appropriate amount (5, 12, 24, or 48 g) of starch from wheat or corn (high amylopectin, regular, high amylose) was added under vigorous stirring. The mixture was heated to 95 °C, kept at this temperature for 5 min to ensure complete gelatinization (Ferry et al., 2006), and subsequently left to cool for 5 min while stirring. The gel was filled into round (diameter: 5 cm), covered sensory flasks so that the resulting thickness of the starch gel layer was always 1.5 cm. All samples were stored at 4 °C for 16 h prior to sensory and instrumental analyses. The repeatability of this procedure was consistently checked by texture measurements (see Section 2.5), which showed that the maximum force [N] needed to compress the gel by 4 mm differed no more than 10%. The viscosity of suspensions containing 5 g starch was measured as described in 2.4. The viscosity was adjusted to 200 mPa s for wheat starch, the three types of corn starch, and cellulose PF1000 by diluting the samples with 57.0 or 109.7 mmol/L NaCl solution, respectively.

2.3.2. Agar–agar

100 mL water containing 57.0 or 109.7 mmol/L NaCl was heated to 90 °C on a magnetic stirrer and the appropriate amount (0.05, 0.10, 0.15, 0.20, 0.40, 0.81, 1.62, 2.46, or 3.31 g) of agar–agar was added while stirring. The temperature was kept at 90 °C for 5 min until the solution turned clear. Then the hot solution was filled into round, covered sensory flasks and treated as described for the starch gels (Section 2.3.1).

2.3.3. Cellulose

2.07, 4.17, 8.70, or 13.67 g cellulose PF75, 0.50, 2.07, or 4.17 g cellulose PF1000X, and 4.17 g cellulose PF30, PF150, PF300 and PF2000, respectively, was added to 57.0 or 109.7 mmol/L NaCl in 100 mL water. After stirring the obtained cellulose suspensions for 30 min at room temperature a 30 mL aliquot was used for the sensory analyses (Section 2.7) while the rest was kept for the determination of water content (Section 2.6), sodium release (Section 2.8), and viscosity (Section 2.4).

2.4. Measurement of viscosity

Referring to Galindo et al. (2012), an LVDV-II + Pro Extra digital viscosimeter (Brookfield Engineering Laboratories, Middleboro, MA, USA) with a UL Adapter for low viscosity materials and ULA, LV-1, LV-2 and LV-3 spindles was used for the analyses of 3 × 20 mL aliquots of starch, agar, and cellulose suspensions. All measurements were carried out at room temperature using a shear rate of 50 s^{-1}, which best simulated the shear rate in the mouth (Wood & Goff, 1973). Six successive measurements were made per aliquot at 30 s intervals and the overall average was used for calculations using the software Rheocalc v3.2. At the sodium concentrations (57.0 and 109.7 mmol NaCl/L) used in this study, no changes in the viscosity of starch, agar–agar, or cellulose solutions were observed at the shear rate of 50 s^{-1} compared to the solutions without added sodium.

2.5. Measurement of gel firmness

Starch and agar gels with a thickness of 1.5 cm were measured with a TA.XT plus Texture Analyzer (Stable Micro Systems, Godalming, UK). The gel was compressed by 4 mm using a plexiglass cylinder (diameter: 2 cm) directly in the sensory flask (diameter: 5 cm), because especially some softer gels tended to show syneresis. Two consecutive measurements were made per sample, force–distance diagrams were recorded similarly to Selmair and Koehler (2008) and data analysis was performed with the software Texture Exponent (Stable Micro Systems).