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Thermorheological evaluation of gelation of gelatin with sugar substitutes

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ABSTRACT

The effects of replacing sucrose with sugar substitutes in gelatin gels were investigated. Oscillatory shear tests were performed to determine the rheological properties of gelatin-glucose syrup-sweetener (GGS) gels. The sweeteners used were sucrose and commercial sugar substitutes, Splenda® and Equal®. Gelation temperature (*Tgel*) was determined at the crossover point of storage modulus and loss modulus, during temperature sweep. The use of sugar substitutes did not alter the gelation temperature of gels. However, the rheological data of GGS gels were not amenable to time–temperature superposition and hence WLF/free-volume theory was not applicable. The gelation kinetics was also investigated using differential scanning calorimetery (DSC). The glass transition temperature (Tg) for different GGS gels determined from the DSC data were similar, ranging from −25.0 to −32.4 °C. Uniaxial compression test results showed that gel made with sucrose was softer with modified measure of toughness of 49.1 J/m^3 at 20% strain compared to corresponding values of 91.4, 74.3, and 94.8 J/m^3 for gels made with Splenda®, Equal®, and glucose syrup, respectively. Based on the results from sol–gel/gel–sol transition studies, both Splenda® and Equal® could be good candidates to replace sucrose in gelatin products if suitable non-nutritive bulking agent is added to maintain total solids content.

1. Introduction

Gelatin, derived from collagen, is a high molecular weight polypeptide used widely in the food and pharmaceutical industries. It can form a three-dimensional (3-D) network after its triple helix structure forms junction zones (Guo, Colby, Lusignan, & Howe, 2003). The number of junction zones increases as the gelation proceeds. Factors including temperature, pH, ash content, thermal history, concentration, and interaction with other food components can influence the gelation or glass transition temperature (*Tg*) of gelatin (Kasapis, Al-Marhoobi, & Giannouli, 1999; Sobral & Habitante, 2001). Food components such as sugars can stabilize the structure of globular or fibrous proteins by strengthening hydrophobic interactions or an enhanced hydration of proteins (Choi, Lim, & Yoo, 2004).

Addition of sucrose is important to many food products including table jellies, desserts, confectionary, and bakery. The role of sucrose in gelatin-based products with high solids content has been studied extensively by many research groups (Al-Marhoobi & Kasapis, 2005; Choi et al., 2004; Kasapis, Al-Marhoobi, Deszczynski, Mitchell, & Abeysekera, 2003). However, the high concentration of sucrose in food products has several adverse effects (Blaak & Saris, 1995; Ruxton, Gardner, & McNnulty, 2010). Using commercial sugar substitutes such as Splenda® or Equal® in gelatin products may be a solution for tackling some of these adverse effects. In general, there are three major reasons for using sugar substitutes or artificial sweeteners: 1) potential for weight loss because of lowering of calorie intake, 2) improved dental hygiene since most sugar substitutes cannot be fermented by the dental plaque microflora to favor their growth and destroy the tooth enamel, and 3) potential control of diabetes mellitus for patients who have difficulty regulating their blood sugar level, especially after eating. Limiting the sugar intake by using sugar substitutes can allow this type of consumers to have a more pleasurable diet while they can control their sugar intake. Some sugar substitutes can still be metabolized by the body but the metabolism rate is much slower so that the sugar levels do not fluctuate over time.

Splenda® contains sucralose with small amount of common food ingredients such as dextrose and maltodextrin as bulking agents. Sucralose (1,6-dichloro-1,6dideoxy-β-fructofuranosyl-4-

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chloro-α-D- galactopyranoside) is derived from sucrose molecules by selective chlorination, during which three hydrogen-oxygen groups on sucrose molecule are replaced with three chlorine atoms. Its relative sweetness compared to sucrose is about 600–800 times (Lindley, 2002; Wiet & Beyts, 1992). After consumption, human body does not recognize sucralose as a carbohydrate so it could pass through human digestive system without being broken down for energy. As a result, sucralose is a calorie-free sweetener that will not be metabolized by human body. Equal® is another zero-calorie sweetener, which contains aspartame and bulking agents dextrose and maltodextrin. Aspartame (L-aspartyl-L-phenylalanine methyl ester) is a dipeptide made from aspartic acid and phenylalanine. Its relative sweetness to sucrose is approximately 180–200 times (Lindley, 2002; Wiet & Beyts, 1992). Aspartame is made when aspartic acid and phenylalanine are linked together along with a methyl group. These two amino acid building blocks are found in all food that contains protein. Under acidic or alkaline conditions or at elevated temperature, aspartame undergoes hydrolysis. Aspartame will break down into its own constituent amino acids leading to rapid degradation. These two disadvantages have made aspartame undesirable in baking products or pH-dependent products. In most carbonated diet soft drink, aspartame is still used as most of the replacement for high fructose corn syrup because the rate of sweetness loss is only gradual and aspartame is quite stable in this type of products.

The use of sugar substitutes also poses certain disadvantages. In bakery products, for example, sugar substitutes often cannot provide the desired browning effect. Sometimes, using heat-sensitive sugar substitutes such as aspartame can lead to unstable products. Unless working with beverages, replacing the natural sugars with sugar substitutes often leads poor texture development. Since substitutes are intensively sweet and only small amount can provide the same sweetness as sucrose could, bulking agents must be used to augment the body and texture of foods. With bulking agents, the kinetics of texture formation is altered, especially when interacting with polysaccharides or proteins.

When sugar substitutes are used with gelatin, for example, the texture of gelatin products will be weakened because the contribution from regular sugar solids will be missing. Therefore, components such as gelatin, a co-solute, or another bulking agent should be increased and/or added to maintain the total solids content. No comprehensive studies have been reported on the effect of sugar substitutes on gelation or stability of gelatin in terms of the rheological or thermal properties. Thus the overall objective of this study was to examine the effect of sugar substitutes on the rheological and thermal properties during gelation of gelatin-glucose syrup system with sugar substitutes, sucralose-based Splenda® and aspartame-based Equal® to determine if these sugar substitutes could afford gelatin gels properties similar to those obtained when using sucrose. The specific objectives were to investigate the sol–gel or gel–sol transition, glass transition temperature (Tg), and large-deformation mechanical properties of gelatin-glucose syrup-sweetener (GGS) gels prepared with and without sugar substitutes.

2. Materials & methods

2.1. Materials

Pigskin gelatin Type B NF (GX0048/1, Lot # 755 & Lot #885B, CAS # 900-70-8) was purchased from EM Science (An Affiliate of Merch KGaA, Darmstadt - Germany). The physiochemical characteristics of this gelatin sample is presented in Table 1. Glucose Syrup (Lot #C001738, DE 43.4, 80.53% TS) was provided by Cargill (IA, USA). Sucrose (Saccharose, certified A.C.S., Lot # 034273, CAS # 57-50-1) was from Fisher Scientific (USA). Sucralose-based sweetener Splenda® and aspartame-based sweetener Equal® were purchased locally. The chemical composition of Splenda® and Equal® are shown in Table 2. All materials were used as received, without further purification.

Table 1
Physiochemical characteristics of gelatin sample used.

Characteristic	Amount
Bloom* (g)	<200
Arsenic (ppm)	<0.8
Heavy metal (%)	<0.002
Residual after ignition (%)	<0.44
Sulfur dioxide (%)	<0.004

*Bloom is a measure of gel strength. This is the force in grams required to press a 12.5-mm diameter plunger 4 mm into 112 g of a standard 6.67% w/v gelatin gel at 10 °C without breaking it (GMIA, 2012).

2.2. Sample preparation

A gummy candy product was prepared with the ultimate goal of replacing as much sucrose as possible. Typical gummy product has approximately 65% total solids (TS), composing of about 5% gelatin, 30% glucose syrup, and 30% sucrose. When artificial sweeteners are used to replace sucrose, another component should be increased or added to act as a bulking agent to make up for the TS. For example, if a product has 5% of gelatin, 30% glucose syrup, and 5% of artificial sugars, the product will not have desired texture or elasticity. Therefore, either the gelatin content or glucose syrup has to be increased or another bulking agent should be added to keep the solid content high. Increasing the glucose syrup is not a desirable option due to added calories to the product. Therefore, increasing the gelatin content is considered a suitable choice. However, to avoid too much gelatin yielding a very tough product, gelatin content was limited to 15%. Therefore, the system studied contained 15% gelatin, 25% glucose syrup, and 25% of either sucrose or Splenda® or Equal®, which are identified as 'sucrose gel', 'sucralose gel,' and 'aspartame gel,' respectively.

The GGS gels were prepared following published methods (Kasapis et al., 1999). The required amount of gelatin was soaked in approximately 200 mL of distilled water for at least 30 min, and then heated to 60 °C with stirring until it was totally dissolved. The required amount of sweetener was measured in another beaker and dissolved in water at 45 °C, to which measured quantity of glucose syrup was added with stirring until they became homogeneous. To this the gelatin solution was added and the mixture was heated to 90 °C for 20 min with continuous stirring. Excess water was heated away in a multi-cooker (Presto® Kitchen Kettle™ Model 0600004) at 121.1 °C for approximately 8.5 min to bring TS to 65% (i.e., 65% Brix) comprising 15% gelatin, 25% glucose syrup, and 25% sweetener. The sample was poured into a beaker, covered with Parafilm M®, and degassed in an ultrasonic cleaner (Branson, Model 1510, Danbury, CT) for 5 min. The TS content was measured with an Abbe refractometer (Atago N-3E, Brix range 58–90%, Japan). When the final mixture was still hot, a sample was drawn

Table 2
Composition (%) of Splenda® and Equal®.

Ingredient	Splenda®	Equal®
Dextrose	95	93
Maltodextrin	4	3
Sucralose	1	0
Aspartame	0	4