Food Hydrocolloids 58 (2016) 267–275

Contents lists available at ScienceDirect

Food Hydrocolloids

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

Effects of sugars on the gelation kinetics and texture of duck feet gelatin

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ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form
22 February 2016
Accepted 24 February 2016
Available online 26 February 2016

Keywords:
Duck feet gelatin
Gelation kinetics
Rheological properties
Gel strength gelling temperature
Melting temperature

ABSTRACT

Gelatin extracted from avian sources, such as duck feet is a potential alternative to mammalian-derived gelatin. The effects of sugars (sucrose and lactose) at different concentrations (0, 5, 10, 20 and 40%) on the gelation kinetics, and thermal and rheological properties of duck feet gelatin (DFG) (6.67% w/w) were investigated using a mechanical rheometer. The secondary structure of the gelatin was investigated using Fourier transform infrared (FTIR) spectroscopy. The results showed that the addition of sugars affected the physicochemical and structural properties of the gelatin. The gelation rate constant (k_{gel}) and gel strength decreased with increasing amounts of sugars at low concentration (i.e., 5–20% for sucrose and 5–10% for lactose). These data suggest that the addition of sugars at these concentrations prevented gelatin chains from approaching each other kinetically during gelation. However, the k_{gel} and gel strength increased upon further addition of sugars, likely due to the formation of additional small junction zones that led to development of a more rigid gel. Additionally, gelling and melting temperatures increased as the concentration of added sugars increased. Sucrose had more pronounced effects than lactose, probably because of its greater solubility and number of e-OH groups. These results illustrate the potential for use of DFG in confectionery products.

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1. Introduction

Gelatin is a class of water soluble, high-molecular weight polypeptides derived from collagen. Gelatin is obtained by destroying the tertiary, secondary, and, in most cases, some aspects of the primary structure of the parent protein (i.e., collagen) (Ziegler & Foegeding, 1990). Gelatin can be obtained from the collagen-containing tissue of various animals. For food applications, it is generally derived from the skins, hides, and bones of either porcine or bovine sources (Mariod & Adam, 2013). Gelatin obtained from an acid-pretreated raw material is known as Type A (isoelectric point at pH 6.5–9.0), whereas that derived from alkaline-pretreated material is known as Type B (isoelectric point at pH 4.8–5.2) (Gómez-Guillén, Giménez, López-Caballero, & Montero, 2011). Currently, about 98.5% of the world's gelatin production is extracted from cattle hides, beef bones and pork skin (Karim & Bhat, 2009). However, in some countries the use of pork is restricted for religious reasons, and in other countries cows have been afflicted with diseases that can be passed on to human consumers (Karim & Bhat, 2009). Thus, an alternative source of gelatin, such as from avian sources, is needed.

The food industry is a major user of gelatins for numerous applications due to its gelling ability when aqueous solutions are cooled. Gelatin forms gels similar to those polysaccharides by forming a micro-structural network (Mariod & Adam, 2013). The gelation of gelatin solution usually occurs at concentration greater than 0.5% by weight between 30 and 40 °C, resulting from the partial return of the disordered gelatin molecules to the collagen triple-helix structure which act as the gel junction zones (Mariod & Adam, 2013; Ziegler & Foegeding, 1990). However, when temperature increases, the gelation gel converts to a solution, thus gelatin gels tend to melt in the mouth (Morimura et al., 2002). These unique properties make gelatin a useful component of foods such as clear dessert jellies, mousses, fruit gums and marshmallows (Johnston-Banks, 1990). The gelation of gelatin are influenced by temperature, pH, ash content, methods of extraction, amino acid

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http://dx.doi.org/10.1016/j.foodhyd.2016.02.025
0268-005X/© 2016 Published by Elsevier Ltd.

composition, thermal history, concentration, and interaction with other food components such as sugars (Ledward, 1986).

The use of gelatin in food for nutritional and functional purposes dates back many centuries, but our understanding of the relationship between structure and function has developed only during the last 30–40 years (Owusu-Apenten, 2004). How gelatin acts in a complex food system and how other ingredients alter its structure, function, and intrinsic properties need to be studied to obtain reproducible information for development of potential applications of gelatin. Gelatin can be studied in either simple systems or in real food systems (Luyten, Vereijken, & Buecking, 2004; Owusu-Apenten, 2004). These methods are entirely different and provide different information. In structure/function studies using a simple system, care is taken to avoid interactions with other food components during the experiment (Owusu-Apenten, 2004). In real food systems, the interaction of gelatin with other components is studied. For example, sugar is commonly applied in gelatin food systems, as sugar is fundamental to many food products based on gelatin. Table jellies, desserts and confections all include mixtures of sugars and gelatin in varying proportions (Johnston-Banks, 1990). Therefore, it is of considerable practical importance to understand how sugars affect the gelation properties of gelatin in order to predict the rheological properties of gelatin-sugar composites.

Sugars and polyols are known to stabilize the gels prepared from globular proteins and fibrous proteins by enhancing the overall hydrogen bonding structure of water and thus strengthening the hydrophobic interaction of the gels (Gekko, Li, & Makino, 1992). The rheological properties of gelatin–sugar mixtures have been studied previously (Gekko et al., 1992; Gekko & Koga, 1983; Naftalin & Symons, 1974; Shimizu & Matubayasi, 2014). The extent of stabilization depends on the effect of the sugar on the solvent properties of water (i.e., the sugar's stereochemical structure) (Oakenfull & Scott, 1986). Naftalin and Symons (1974) suggested that the stabilization of sugar on the gel structure occurs through hydrogen bonds involving water and form ternary complexes that stabilize the gel. Thermodynamic studies of many solute/sugar–solvent interactions in gelatins (Gekko et al., 1992; Shimizu & Matubayasi, 2014) have revealed that the proteins are stabilized by sugars predominantly through a strengthening of hydrophobic interactions or a preferential hydration mechanism, originating from the water-structure-making characteristic of polyhydric compounds (Gekko et al., 1992). Because these compounds can stabilize globular and fibrous proteins, comparative studies of solvent perturbation of gelation kinetics could lead to a better understanding of their role in the stabilization of gelatin gels.

The effects of various electrolytes and sugars on the properties of gelatins have been studied extensively (Gekko et al., 1992; Gekko & Koga, 1983; Naftalin & Symons, 1974; Shimizu & Matubayasi, 2014), but the effects of lactose monohydrates have not been investigated. Lactose monohydrate is a disaccharide similar to sucrose, but its molecular weight differs slightly from that of sucrose due to differences between their monomers. Lactose, with a molecular weight of 360.32, consists of monosaccharides, glucose, and galactose joined via glycosidic bonds. In contrast, sucrose consists of glucose and fructose and has a molecular weight of 342.30 (Tester & Karkalas, 2003). The melting point for lactose falls within the range of 201–202 °C, while that for sucrose is 160–186 °C (Tester & Karkalas, 2003). In addition, their solubilities differ greatly. At 25 °C, the solubility (by weight) of sucrose is 67.89%, whereas that of lactose is only 21.6% (Tester & Karkalas, 2003). This characteristic plays an important role in the effects of sugar interactions on the gelation properties of gelatin.

By-products of the poultry processing industry are a readily available potential source of gelatin. In this paper, the gelation behavior of duck feet gelatin (DFG) and gels made of DFG containing sucrose and lactose in different concentrations was investigated. Experiments were conducted to characterize changes in physicochemical properties, kinetics of gelation, gel strength, and gelling and melting temperatures caused by the addition of sugars. Understanding the underlying mechanisms by which sugars affect the physicochemistry of DFG will provide the basis for further research into potential applications of this type of gelatin in food products.

2. Materials and methods

2.1. Materials

DFG was extracted from duck feet of the commercial strain of the Cherry Valley type of Peking ducks (*Anas domesticus*) procured from a halal certified breeding farm located in the northern region of Penang, Malaysia. The extraction of DFG followed a previously described method (Almeida & Lannes, 2013). Commercial bovine gelatin (BG) extracted from bovine skin (G9391, Type B), sucrose, and lactose monohydrate were acquired from the Sigma–Aldrich Company Ltd. (Petaling Jaya, Selangor, Malaysia). All reagents used were of analytical grade and were used without further purification.

2.2. Methods

2.2.1. Gel formation

A series of sucrose and lactose stock solutions were prepared at concentrations of 0%, 5%, 10%, 20% and 40%, respectively, prior to gel formation. DFG, at ambient temperature (~25 °C), were weighed and added into the prepared solutions at concentration of 6.67% (w/v), respectively. The dispersions were then allowed to hydrate for 1 h at room temperature (~25 °C) prior to dissolve in the 65 °C water bath for 15 min, with occasional swirling until all gelatins were properly dissolved in the stock solutions. A small amount of sample was used for viscoelasticity measurements. Bovine gelatin (BG) (model) was also prepared in the same manner.

2.2.2. Fourier transform infrared (FTIR) spectroscopy analysis

The prepared gelatin solutions were allowed to stand for 30 min at room temperature before being gelled in the refrigerator at 10 °C for 16 h. Subsequently, the gelatin gels were freeze-dried for FTIR analysis. The freeze-dried gelatins were milled into powder and ground with potassium bromide (KBr) powder (Merck KGaA, Darmstadt, Germany) at a ratio of 1 mg of gelatin to 100 mg of KBr. The KBr powder was stored and dried at 120 °C to eliminate moisture prior to use. A pellet was prepared using a press and was immediately placed in the sample holder. The FTIR spectra were recorded in the region of 4000–400 cm^{-1} for 32 scans. The background spectrum was collected before each scan. The spectra from a given sample were smoothed, baseline corrected, normalized, and averaged for qualitative interpretation of the spectra. Corrected band heights were used for FTIR analysis and were obtained using the software Omnic version 6.2 (Thermo Scientific, Waltham, MA, USA).

2.2.3. Gelation kinetics

Gelation kinetics of DFG containing sucrose and lactose were determined by measuring the viscoelastic properties of each sample using a stress-controlled rotational rheometer (AR-1000N, TA Instrument Ltd., New Castle, DE, USA) (Fonkwe, Narsimhan, & Cha, 2003). The rheometer with a cone-plate geometry (40 mm, 2° angle with 51 μm truncation gap) was attached to the instrument with the aid of silicon oil (Sigma cat. No. 14615-2), and the sample

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