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Textural and structural breakdown properties of selected hydrocolloid gels

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ABSTRACT

Textural and structural breakdown properties of bovine serum albumin (BSA), starch, gelatin, and gellan gels were investigated using texture profile (TPA) and multiple extrusion cell (MEC) analyses, respectively. TPA was conducted under ambient conditions whereas MEC analysis was performed at 37 °C with addition of artificial saliva. Each type of gel exhibited distinct textural characteristics and breakdown behaviours. Soft and hard starch gels could not be distinguished using the TPA parameters, however the force and work needed to rupture these gels differed significantly ($P<0.05$) during MEC analysis. BSA gel was the hardest, strongest, most elastic and required the highest amount of energy during the extrusion cycles as compared to other gels. Although the amounts of work done for BSA and starch gels during extrusions were similar, the breakdown of starch gel was faster due to the action of α-amylase in the artificial saliva. Gelatin gel was several times harder than gellan gel, but its breakdown was the fastest due to its susceptibility to melt at 37 °C. TPA parameters provided information on textural properties of gels. However, MEC analysis provided additional information on the structural breakdown behaviours of the gels in conditions that resemble oral processing.

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1. Introduction

Gel is a system comprised of two components (i.e. gelling polymer and solvent). It is formed by a continuous network of solid material as matrix that holds a continuous or finely dispersed liquid phase (Olsson, Langton, & Hermansson, 2002; Silva & Rao, 1999). Gels have been used as model systems to study food texture as they can provide good descriptions of mechanical behaviour of numerous food systems and hence provide valuable information about food texture (Jones, Steffe, & Harte, 2003). Starch and protein are main biopolymers that exist in most of the food products, which contribute to textural properties. On the other hand, gelatin and gellan are two common hydrocolloids that have been used as functional ingredients in order to develop a desired textural characteristic for food products.

Bovine serum albumin (BSA) comprises 582 amino acids with an average molecular weight of 66 kDa and its isoelectric point of approximately 5.2 (Donato, Garnier, & Doublier, 2005; Donato, Garnier, Novales, Durand, & Doublier, 2005). As compared with other proteins, BSA is more feasible to be used as high protein food models due to its high water-solubility (Easa, Hill, Mitcheel, & Taylor, 1996). BSA molecules experience two-stage conformational changes during heat treatments. The initial stage of denaturation is reversible where protein molecules start to unfold and expose their hydrophobic zones. When heating is above 65 °C, the exposed reactive zones lead to the formations of hydrophobic interactions and disulfide bridges among molecules. This conformational change becomes irreversible due to the covalent bonds of disulfide bridges. Further aggregation occurs leading to the gel formation (Donato, Garnier, Novales, et al., 2005). The aggregation process is governed by the balance between attractive and repulsive interactions between denatured protein molecules. The structure and properties of the gel formed are greatly dependent on net charge of protein, pH and ionic strength of the medium (Veerman, Sagis, Heck, & Linden, 2003).

Starch gels are commonly regarded as composite systems, consisting of swollen particles embedded in a three-dimensional network of aggregated amylose chains. Heating of starch granules in the presence of water results in gelatinization where the granules start to hydrate, swell and leach out of soluble components (mainly amylose). Upon cooling, retrogradation occurs where the linear amylose chains re-crystallise forming junction zones that comprise continuous three-dimensional network. Above critical concentration, a gel is formed. The dispersed phase of the network consists of amylopectin and the granule remnants (Glicksman, 1969b; Kapri & Bhattacharya, 2008). The structure of starch gel formed depends on the starch concentrations, amount of leached-out components, configuration of swollen granules, and the ratio of amylose/amylopectin as well as their interactions (Kapri & Bhattacharya, 2008).

Gelatin is derived from hydrolytic degradation of collagens through either acid or alkaline treatment; producing Type A and Type B gelatin, respectively. Gelatin forms thermoreversible gels upon cooling; the gels are soft, elastic, and translucent (Glicksman, 1969a). The unique characteristic of gelatin gel is its 'melt-in-mouth' texture that provides excellent mouthfeel and flavour perception (Ledward, 2000). Gelatin is not soluble in cold water but swells and forms large

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visible particles (Glicksman, 1969a). When heated to ~40 °C, the hydrated particles dissolve and form flexible single random coils (Mao, Tang, & Swanson, 2001). Upon cooling, the polypeptide chains forms a triple-helix-liked structure through formations of junction zones (Williams & Philips, 2003). The sol–gel transition of gelatin is reversible as the junction zones formed are weakly held by hydrogen bonds. Therefore, gelatin gel will melt when it is heated to 35–40 °C (Ledward, 2000). The three-dimensional gelatin network is held together by either primary bonds, secondary forces localised at certain points on the molecule, or the non-localised secondary attractive forces (Glicksman, 1969a).

Gellan gum is an extracellular anionic heteropolysaccharide. It is produced from fermentation of bacterium *Sphingomonas elodea* (formerly known as *Pseudomonas elodea*) (Koliandris, Lee, Ferry, Hill, & Mitchell, 2008; Nussinovitch, 1997). Gellan gum forms highly transparent gels on cooling in the presence of electrolyte. Two types of gellan gums are commercially available i.e., high-acyl and low acyl gellan. The high-acyl gellan produces soft, elastic and thermoreversible gels; while the low-acyl gellan gels are clear, firm to touch, brittle and usually non-thermoreversible (Huang, Kennedy, Li, Xu, & Xie, 2007). These gels do not melt in the mouth but crumble easily to mimic the 'melt-in-mouth' sensation with release of water and associated flavours from the weak gel network (Koliandris et al., 2008). Gellan gum cannot dissolve in cold deionised water, it is necessary to heat the dispersion to at least 70 °C in order to achieve complete hydration (Gibson, 1992). Gellan chains appear in random coils in hot aqueous solutions. Upon cooling, gellan chains form threefold left-handed double helices that are stabilised by internal hydrogen bonds and above the critical gelling concentration, the helices tend to self-associate to form a transparent gel (Sworn, 2000).

Texture is one of the factors determining the eating quality of foods. In order to obtain a better understanding of food texture perception, most experiments have been carried out at large deformation employing the texture profiles analysis (TPA) (Lau, Tang, & Paulson, 2000). Texture perception largely depends on the behaviour of the food breakdown during mastication (Renard, Velde, & Visschers, 2006) while the mechanical properties and structural changes of food are the key elements to elucidate the breakdown path during mastication (van den Berg, van Vliet, van der Linden, van Boekel, & van de Velde, 2007). Hence, the breakdown path is a dynamic process that is governed by oral processing (Engelen & Bilt, 2008). However, information obtained from TPA may not be sufficient to predict the breakdown pattern of food during mastication due to the design limitation. The environment conditions of oral processing are not been able to include during the assessment. An alternative was suggested in this study that was an analysis using the multiple extrusion cell (MEC). The design of this texture analyzer attachment enables the test to be carried out under a controlled temperature in the addition of artificial saliva. This device can be used to study the food structural breakdown by monitoring the consistency of the sample with its interaction with artificial saliva under continuous extrusion cycles (Janssen, Pijpekamp, & Labiausse, 2009).

The objective of this study was to reveal the textural properties of gels formed by four different types of hydrocolloids (i.e., BSA, starch, gelatin and gellan) with two levels of concentrations through texture profile analysis (TPA). Further aim was to evaluate the use of multiple extrusion cell (MEC) analysis as an additional method for the assessment of structural breakdown of the gels at 37 °C with the addition of artificial saliva.

2. Materials and methods

Modified tapioca starch and the chemicals for artificial saliva preparation were supplied by Systerm Sdn. Bhd., Selangor, Malaysia. Bovine serum albumin (BSA) was purchased from Merck, Darmstadt, Germany. Gelatin (source: bovine, bloom strength 160, pH 5.3) was obtained from Halagel Sdn Bhd, Kedah, Malaysia. Low acyl gellan was supplied by Fluka Chemical Corp., Ronkonkoma, USA. Xanthan gum and α-amylase from porcine pancreas were purchased from Sigma Chemical Co., St Louis, USA.

2.1. Gel preparation

Four hydrocolloids (i.e., BSA, starch, gelatin and gellan) employed in this study were selected based on different origins (animal, plant and microbiology), gelling mechanisms (heat-set and cold-set) and susceptibility towards either mechanical action, body temperature, or/and α-amylase digestion. From preliminary tests, 'soft gels' were prepared based on the minimum amount of hydrocolloid that was able to yield free-standing gels without sagging. The concentrations of each type of gels were according to Table 1. 'Hard gels' were prepared with 20% addition of the amount of hydrocolloid of the 'soft gels'. To form self-standing gels with minimum amount of hydrocolloid, starch gel required the highest amount of polymer (25%) followed by BSA and gelatin gels (12%), while gellan gel only required 2% of hydrocolloid concentration. Soluble starch was dispersed in deionised water and the starch slurry was preheated at 65 °C under vacuum condition for 10 min. Then, the slurry was poured into syringes (20 ml, diameter of 19 mm) to heat at 90 °C for 20 min in a water-bath. BSA powder was dissolved in deionised water and vacuumed for 10 min. The solution was then transferred into syringes and heated at 90 °C water bath for 30 min. Gelatin or gellan was dispersed in deionised water and then heated at 80 °C in a water bath and stirred constantly until a clear solution was formed. The solution was then transferred into syringes. A thin layer of paraffin oil was dropped on the surface of the samples in each syringe to prevent excessive evaporation of water. All the gel samples were cooled to room temperature (25 °C) and subsequently refrigerated at 4 °C for 18 h. The gels were cut into 20 mm in length for TPA and 60 mm in length for MEC analysis. Prior to analysis the gels were left to equilibrate at 20 °C for 1 h.

2.2. Texture profile analysis (TPA)

TPA was carried out using a TA-TX2 Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK), attached with a 30 kg load cell. A 75 mm diameter compression platen was used to compress a cylindrical sample at a constant speed of 1 mm/s. The deformation level was set at 75% strain of the original sample height (Koliandris et al., 2008). The bottom plate and the top of the gel were covered with a thin layer of paraffin oil to allow sample expansion in order to avoid barrel effect during compression. At least five measurements were recorded for each type of gel.

2.3. Multiple extrusion cell (MEC) analysis

MEC analysis was carried out using a TA-TX2 Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK) attached with a 30 kg load cell. The MEC was attached to the texture analyzer with proper alignment and calibration. The probe height was calibrated with a contact force of 200 g and a return distance of 95 mm. The settings of the rest were as followed: *Mode*: measure force in compression; *Option*: cycle until

Table 1
Concentrations of polymers for gel preparation.

Hydrocolloid	Concentration (% w/w)	
	'Soft gel'	'Hard gel'
BSA	12	14.4
Starch	25	30
Gelatin	12	14.4
Gellan	2	2.4

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