Contents lists available at ScienceDirect

Food Chemistry



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

The effects of sucrose on the sol-gel phase transition and viscoelastic properties of potato starch solutions



Piotr Owczarz, Magdalena Orczykowska, Anna Rył, Patryk Ziółkowski*

Department of Chemical Engineering, Faculty of Process and Environmental Engineering, Lodz University of Technology, Lodz, Poland

ARTICLE INFO	A B S T R A C T
Keywords:	In this paper, starch pastes in the form of solutions and gels were investigated to determine viscoelastic prop-
Potato starch	erties and sol-gel phase transition temperatures using rheological methods. The gelatinization process was
Gelation	carried out at a temperature of 95 °C with the use of a pressureless starch cell with a stirrer. Starch pastes
ucrose	obtained were used to determine rheological properties under isothermal conditions (in the temperature range of
Rheology	45-25 °C) by a cone-plate measurement system. The viscoelastic behavior of the tested medium was confirmed
Sol-gel	The range of gelation temperatures was determined and the influence of several factors was discussed, e.g. the
Fractional derivative rheological model	effect of sucrose addition and cooling rate on the phenomenon of sol-gel phase transition. In addition, me-
	chanical properties of the obtained starch gel structures were determined using a fractional rheological model.

1. Introduction

Starch is a biopolymer which constitutes the main source of carbohydrates for plants. It occurs in bulbs (potato), roots (tapioca), fruit and seeds (wheat, corn) in the form of semicrystalline insoluble granules. In terms of chemical structure, starch is a polymer built of α -Dglucose units. Glucose monomers are associated by 1,4-alpha and 1,6alpha glycosidic bonds, enabling the polymer to form a helical structure. Starch in the form of a polymer consists of two types of molecules: amylose and amylopectin. The fraction of amylose depends on the natural source of starch, and in the case of potato starch it is 16-24%, in high-amylose starch up to 70% and more, whereas in the starch with high-amylopectin (wax) content amylose occurs in trace amounts. Due to significant differentiation of the properties of amylose and amylopectin, their content in a starch granule determines physical properties and technological suitability. The differentiated chemical structure of starch (different ratio of amylose and amylopectin), even of the same origin, affects physical properties of suspensions and colloidal solutions obtained in industrial processes.

Transitions from liquid-like to gel-like structure during gelation are used in food industry, mainly in fruit and vegetable processing, confectionery production and meat processing (Kraak, 1992; Rouillé, Chiron, Colonna, Della Valle, & Lourdin, 2010). The sol-gel phase transition of starch and non-starch hydrocolloids enables their use as thickening, stabilizing and gelling agents (Nishinari, 1997; Tamaki, Konishi, & Tako, 2011). In the case of starch hydrocolloids, the sol-gel phase transition is induced by a change in temperature. The form of the product – liquid (sol) or cross-linked (gel) – is defined by the process temperature. Depending on the desirable product characteristics, it is necessary to maintain appropriate temperature.

The sol-gel phase transition phenomena are identified with a change in rheological properties of biomaterials. This enables the use of rheological methods to determine gelation temperature of the tested materials.

The cross-linked form of gel reveals viscoelastic properties. Characteristic parameters, such as total elasticity and strength of the network, cross-linking density, the coefficient of damping of mechanical vibrations by the formed network and gel stiffness, are important from an industrial point of view. Such properties characterizing cross-linked structures can be described using fractional rheological models (Kilbas, Srivastava, & Trujillo, 2006; Orczykowska & Dziubiński, 2014).

During the gelatinization process, the sol phase is formed. When the sample is heated, intermolecular starch bonds are broken. This leads to the formation of hydrogen bonds between amylose and water (Nishinari, 2000). The gelatinization process is the transition of ordered crystalline starch granules to the amorphous state while simultaneously losing the characteristic form of the 'Maltese cross'. Gelatinization occurs first in amorphous areas – while the system is heated, hydrogen bonds are weakened (Lu, Duh, Lin, & Chang, 2008). When temperature reaches a critical value (i.e. gelatinization temperature) the crystalline regions are dissociated.

Starch pastes reveal a reversible sol-gel phase transition (physical

* Corresponding author at: Lodz University of Technology, Department of Chemical Engineering, 90-924 Lodz, Wolczanska 213, Poland. *E-mail address*: patryk.ziolkowski@edu.p.lodz.pl (P. Ziółkowski).

https://doi.org/10.1016/j.foodchem.2018.07.195

Received 16 November 2017; Received in revised form 17 May 2018; Accepted 25 July 2018 Available online 26 July 2018

0308-8146/ © 2018 Elsevier Ltd. All rights reserved.

gelation) when the system is cooled. At the same time, when temperature decreases, the strength of the intermolecular interaction increases, e.g. hydrogen bonds or van der Waals forces (Ai & Jane, 2015). It is worthwhile noting that the sol-gel phase transition of colloidal starch solutions has not been comprehensively presented in the literature. There are no studies investigating the phase transition process near the gel point (Kawabata, Akuzawa, Ishii, Yazaki, & Otsubo, 1996). From several starch gelation mechanisms presented in the literature (Case et al., 1998; Teyssandier, Cassagnau, Gérard, & Mignard, 2011; Winter & Mours, 1997) only two seem to describe this phenomenon most accurately. The first mechanism assumes that initiation of gel formation results from the presence of non-covalent interactions. The crystalline regions are then separated (Case et al., 1998). The second mechanism refers to the formation of a network from macromolecular aggregates (Teyssandier et al., 2011). McGrane, Mainwaring, Cornell, and Rix (2004) formulated a thesis that amylose is a key compound that determines the phase transition. They found out that during the gelatinization process amylose and water are associated with a hydrogen bond. When the system is cooled down, the bonds are strengthened, which causes formation of a three-dimensional infinite network consisting of amylose and water. In free spaces of the network the crystalline form of amylopectin is located (McGrane et al., 2004; Oakenfull & Glicksman, 1987; Rao, 2010).

The use of starch in sugar industry requires the addition of low molecular weight saccharides, in particular sucrose and glucose, to its colloidal solutions. The effects of mono- and disaccharides on the gelatinization process and rheological properties are extremely important for industrial processes (Sarker et al., 2013). The effect of the addition of saccharides on the starch gelatinization process was described in the literature (Beleia, Miller, & Hoseney, 1996; Gunaratne, Ranaweera, & Corke, 2007; Tomasik, Wang, & Jane, 1995; Zhang, Tong, Zhu, & Ren, 2013; Zhou, Zhang, Chen, & Chen, 2017). However, these studies do not discuss the effect of mono- and disaccharides on viscoelastic properties of the gels and phase transition temperature. It should be expected that the temperature and mechanism of the sol-gel phase transition will be different, depending on the addition of saccharides (while maintaining the same parameters of gelatinization process, paste storage time, etc.). This is due to various intermolecular interactions that arise in pastes with the addition of saccharides. Discussions on phase transitions, both in the case of pastes containing saccharides and those without them, are based mainly on the study of structural properties of the prepared gels (BeMiller, 2011; Zhang et al., 2013). In the case of starch pastes with the addition of saccharides which does not exceed 40 wt%, the structure of the obtained gel was strengthened. In the case of starch gels with the content of saccharides exceeding 40 wt %, weakening of the gel structure was observed. This is due to the smaller number of hydrogen bonds that contribute to the formation of a three-dimensional network (Kasapis, Mitchell, Abeysekera, & MacNaughtan, 2004). Gunaratne et al. (2007) explained the weakness of the formed structures with an increased sucrose concentration by the lack of ordered amylose structure.

The aim of the study was to investigate the effect of gelatinization process parameters and the addition of sucrose on the viscoelastic properties of starch pastes. Additionally, the sol-gel phase transition temperatures and mechanical properties of the obtained starch gels were determined.

2. Materials and methods

2.1. Materials

Materials for testing the dynamic viscoelastic properties of starch pastes and gels were 3% pastes of native potato starch (Melvit, Warsaw). Sucrose (Pfeifer & Langen Glinojeck S.A. Poznań) was added to some samples to make a comparison of starch pastes with and without the addition of saccharide. Sucrose in an amount of 50 wt%



Fig. 1. Gelatinization curve obtained for the starch paste without the addition of sucrose prepared for 60 min – sample 60'.

was added immediately before the cooling stage of starch pastes, i.e. between the second and the third stage (see Section 2.2). This allowed us to eliminate its impact on the gelatinization process.

2.2. Starch gelatinization

Gelatinization was preceded by the process of grain swelling carried out for each sample at room temperature for 30 min. The gelatinization process was carried out in three stages: 1st – heated from 25 °C to 95 °C at a constant heating rate of 0.1 deg/s, 2nd – thermostating at 95 °C (30 min for sample 30' or 60 min for sample 60'), 3rd – cooling to 50 °C at a constant rate of 0.1 deg/s. For samples containing sucrose the index "+S" was added. During the entire gelatinization experiment the sample was stirred at 300 rpm. The obtained starch pastes were stored under two different conditions. The first one was kept at 50 °C for 24 h to prevent gelation. The second one was stored at 5 °C for 24 h to enable gel structure to form. Additionally, rheological measurements of the starch paste obtained immediately after gelatinization were performed. Gelatinization was carried out using an Anton Paar Physica MCR 301 rotational rheometer in a pressureless starch cell with a stirrer. During the gelatinization process dynamic viscosity was recorded.

2.3. Rheological measurements

Mechanical properties of the starch gels were investigated in a coneplate measuring system (60 mm diameter, 1° slope angle, 0.117 mm truncation).

Viscoelastic properties were determined in a frequency sweep test (0.005 rad s⁻¹ < ω < 500 rad s⁻¹) in the linear viscoelastic region at the fixed amplitude strain y = 5%. The tests were performed for all samples at 45 °C, 35 °C and 25 °C. All tests were repeated three times and the final results were expressed as an average. The determined error did not exceed 4%.

The effect of cooling rate on gelation kinetics was determined by analyzing mechanical properties when cooling colloidal solutions from 45 to 20 °C. Four different cooling rates were used (0.1, 0.05, 0.01 and 0.005 deg/s). These studies allowed us to determine the phase transition temperature observed as a rapid change in rheological properties of the medium. The measurements were carried out for freshly prepared pastes and for the pastes stored at 50 °C for 24 h.

Experiments for collecting light scattering data with simultaneous registration of rheological properties were performed using double-gap

Download English Version:

https://daneshyari.com/en/article/7583789

Download Persian Version:

https://daneshyari.com/article/7583789

Daneshyari.com