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Rheological properties of wheat starch influenced by amylose–lysophosphatidylcholine complexation at different gelation phases

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ABSTRACT

Amylose is able to form helical inclusion complexes with lysophosphatidylcholine (LPC). This complexation influences the functional and rheological properties of wheat starch; however it is well known that the formation of these complexes lead the starchy systems to a slower enzymatic hydrolysis. Based on this, to benefit from both the structuring properties of starch and also lower digestibility of the inclusion complexes, the objective of this study is the formation of amylose–LPC inclusion complexes while developing a firm network providing the desired functional properties in a starchy system. To investigate the influence of amylose–LPC complex formation at different stages of starch gelation on the viscosity behavior of wheat starch, 3% (w/w) LPC was added at three different points of the viscosity profile, obtained by rapid visco analyzer (RVA). LPC addition at all points affected the gelation behavior of wheat starch as compared with the reference. LPC addition at half-peak and peak of the viscosity profile resulted in a viscosity increase during cooling. Measuring the dynamic rheological properties of the freshly prepared gelatinized samples showed a decrease of storage modulus (G') and loss modulus (G'') in the presence of LPC. During storage, in the presence of LPC, a lower elasticity was observed which indicates a lower rate of amylose retrogradation due to complexation with LPC.

1. Introduction

Starches from several plant sources; such as wheat, corn, rice and potato, have received extensive attention in relation to their structure and physico-chemical properties. Starch plays an important role in the textural properties of foods as a thickener, stabilizer and gelling agent (Singh, Singh, Kaur, Sodhi, & Gill, 2003). The wide applicability of wheat starch in food industry has resulted in several studies being carried out on its morphological and rheological properties. Wheat starch modifies the texture and consistency of foods because of its ability to form a viscoelastic paste when heated in water. It is therefore of relevance to fully understand how other ingredients, typically used in foods, are able to modify the structuring properties of starch. In a number of previous papers, we studied the formation of amylose inclusion complexes with LPC, in great detail. We reported that such complexes alter swelling behavior of starch granules and subsequently influence amylose leakage (Ahmadi-Abhari, Woortman, Hamer, Oudhuis, & Loos, 2013) and therefore its susceptibility to amylolysis (Ahmadi-Abhari, Woortman, Oudhuis, Hamer, & Loos, 2013 and Ahmadi-Abhari, Woortman, Hamer, & Loos, 2013). This paper focuses on the effects of the formation of amylose–LPC complexes on the rheological properties of wheat starch, influenced by the phase that complex formation is induced.

Previous studies have shown that addition of complexing ligands exhibit higher moduli of deformability compared to the control (Conde-Petit & Escher, 1995). Eliasson and Kim (1995) also studied the effect of the interaction between starch and lipids on the rheological properties of starch gels during heating and cooling. However, the effect of the formation of inclusion complexes at several points of heating process has not been adequately discussed. Based on this, the present study is considering in detail how amylose–LPC inclusion complexation influences the rheological properties of wheat starch; while adding LPC at different phases of the gelation process.

A large number of techniques are used to characterize the rheological properties of starch that mainly depend on the proportion of amylose:amylopectin and also on the ingredients added

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to a food system. Viscosity behavior and dynamic rheological properties are the key characteristics that are influenced by ingredients present in a starchy system. These parameters can be studied by a rapid visco-analyzer (RVA) and a rheometer, respectively. Crystallinity and thermal properties are the other parameters widely used to study the behavior of starches (Eliasson, 1980; Hernandez-Hernandez et al., 2011).

Rheological properties of starch are measured by a dynamic rheometer which continuously assesses the dynamic moduli during temperature and time sweep testing of the starch suspensions. The storage dynamic modulus (G') is a measure of the energy stored in the material and recovered from it per cycle. The loss modulus (G'') is a measure of the energy dissipated or lost per cycle of sinusoidal deformation (Ferry, 1980). The ratio of G'' to G' for each cycle is defined by $\tan\delta$ which presents the physical behavior of the system. The rheological properties of starches depend on the granular structure, the morphology of the granules, the source of starch and the presence of other components (such as lipids, phospholipids and proteins). For instance, irregular shaped granules in potato starch exhibit higher storage and loss modulus and lower $\tan\delta$ compared to small granules (Singh et al., 2003). The lack of lipids and phospholipids in potato starch can be another cause of high G' and G'' since no amylose inclusion complexation occurs (Conde-Petit & Escher, 1995).

In presence of lipids and surfactants, amylose twists around the ligands. This complexation considerably affects the functional and rheological properties of starch (Ghiasi, Varriano-Marston, & Hoseney, 1982) which highly depend on the amount of the formed complexes. Furthermore, recent studies have demonstrated a lower digestibility of these complexes as compared with native starches (Ahmadi-Abhari, Woortman, Hamer, & Loos, 2013; Putseys et al., 2010). Therefore, finding approaches to benefit of amylose inclusion complexation (slow digestibility) while controlling the structuring properties of starchy products, is of importance.

In our previous study, we evaluated the effect of amylose inclusion complexation with lysophosphatidylcholine (LPC) on the physical properties of starch, such as viscosity and swelling power (Ahmadi-Abhari, Woortman, Hamer, Oudhuis et al., 2013), while LPC is added at the starting point of the process and an obvious effect of LPC, at high concentrations, on the functional properties of wheat starch was observed. Therefore, preserving the physical and technological properties of wheat starch, such as viscosity, while developing the formation of amylose–LPC inclusion complexes simultaneously, is the major aim of this study. This can propel the applicability of this study in the practical fields (bakery products), enabling to control the functional characterization of starch at a satisfactory level and benefit from the formation of amylose inclusion complexation, leading to a lower digestibility, simultaneously.

2. Materials and methods

2.1. Materials

Native wheat starch with a purity of 99% and a total lipid content of 0.4% was obtained from Sigma Chemical Company. 12.63% moisture content was measured by a moisture analyzer (Sartorius MA35 M, Sartorius AG, Germany). 2.8% damaged granules and 23.5% amylose content (wheat starch not defatted) were reported by Eurofins Food B.V. Starch was not defatted since that defatting can lead to a higher susceptibility of the granules during heating and subsequently a faster water ingression. Additionally, the low amount of lipids – naturally present in wheat starch – is a constant factor in all experiments. Therefore, its effect is negligible.

Egg yolk L-α-lysophosphatidylcholine (LPC) (PubChem CID: 24798682), type XVI-E, lyophilized powder, purity >99% and fatty acid content of 16:0 69%, 18:0 27% and 18:1 3%, from Sigma Chemical Company (St Louis, Missouri, USA) was used.

LPC was kept at −20 °C and wheat starch at room temperature under dark and dry conditions.

2.2. Viscosity measurement

A RVA-4 Newport Scientific (NSW, Australia) rapid visco analyzer was employed to study the temperature-viscosity profile of the starch suspensions used in this study.

An initial series of 9% (w/w) wheat starch suspensions in deionized water was prepared. The suspensions were kept 10 min at room temperature to equilibrate and loaded on RVA. The temperature of each suspension was first equilibrated at 50 °C for 60 s and increased to 93 °C and 95 °C separately (corresponding to the temperatures at half-peak and peak of the starch viscosity profile, respectively) at a rate of 6 °C/min. At these points, rotation speed was decreased from 160 RPM to 20 RPM for 5 s, allowing the addition of 0% and 3% LPC. 3% LPC solution was prepared – into a 2 mL Eppendorf tube – in 1 mL distilled water at ca. 40 °C and was injected to the RVA cup with a 4 mL Pasteur pipette; hence the reference received 1 mL distilled water. The temperature was increased and held at 95 °C for 300 s, decreased to 50 °C at the same rate of 6 °C/min and held at 50 °C for 120 s.

Our previous studies proved that an entire amylose complexation occurs while addition of 2–3% LPC (based on DM wheat starch). Based on this, we chose 3% LPC in this study. This amount is enough to prevent swelling of the starch granules, proved by no viscosity increase during the heat treatment in RVA (Ahmadi-Abhari, Woortman, Hamer, Oudhuis et al., 2013).

2.3. Rheological properties

The rheological properties of each sample, after the heat treatment in RVA, were straightly analyzed through the oscillatory tests within a linear viscoelastic region. The oscillatory time sweep applied a constant oscillation stress of 0.2 Pa at a frequency of 1 rad/s on the starch gels were measured during 16 h at 20 °C, posterior to measuring the strain sweep (0.001–1) at a frequency of 1 rad/s, using an Anton Paar Modular Compact Rheometer (Physica MCR 300) equipped with parallel plates system with 50 mm diameter and 1 mm gap. The samples were loaded on the plate and surrounded by low viscosity silicon oil to limit water evaporation of the samples. The data on storage modulus, loss modulus and their ratio ($\tan\delta$) were recorded and analyzed using Rheoplus software provided by the manufacturer of the equipment.

All samples, to evaluate viscosity behavior and also assessing the rheological properties, were measured in duplicate.

3. Results and discussion

3.1. Effect of amylose–LPC complexation on the viscosity profile

We previously studied the effect of LPC concentrations (0.1%, 0.3%, 0.5%, 1% and 5%, based on dry matter wheat starch) on the viscosity behavior of native wheat starch while addition at the starting point of the process (Ahmadi-Abhari, Woortman, Hamer, Oudhuis et al., 2013). In the current study, a set of viscosity measurements was performed on native wheat starch while LPC was added at half-peak and peak of the viscosity profile. This will help us to achieve a better insight into the effect of amylose–LPC complex formation on the viscosity behavior of wheat starch. Addition of LPC during the viscosity profile allows the viscosity to increase to some extent while the inclusion complexation also occurs. The key question is if LPC is also able to alter the viscosity behavior, when it is added