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Carbohydrate Polymers 65 (2006) 381–385
Carbohydrate Polymers
www.elsevier.com/locate/carbpol

Short communication

Effect of heating rate on starch granule morphology and size

Bhavesh K. Patel, Koushik Seetharaman *

Department of Food Science, Pennsylvania State University, University Park, PA 16802, USA

Received 2 October 2005; received in revised form 10 January 2006; accepted 16 January 2006
Available online 10 March 2006

Abstract

Changes in starch granule morphology and size during heating were monitored continuously, when heated at either 5 or 25 °C/min on a hot stage. The results showed that granule morphology was different as a function of the heating rate and granule swelling was governed kinetically. These observations visually demonstrate the significant influence of processing conditions, i.e., heating rate, on starch granule size and morphology and therefore potentially have implications in determining structure and texture of baked products.

Keywords: Wheat starch; Heating rate; Granule swelling; Granule morphology

1. Introduction

Starch, when heated in the presence of water, undergoes irreversible changes that are dependent on the amount of water and heat available in the system. Thomas and Atwell (1999) described gelatinization and pasting as distinct stages of change during heating of starch, i.e., thermal processing. The first set of changes during heating is termed as gelatinization and is characterized by the irreversible disruption of molecular order depending on temperature and moisture, and the initial increase in granule size resulting in increased suspension viscosity. These changes render part of the material in granule soluble following heat treatment and thus contribute to food properties such as texture, viscosity, and moisture retention. When a majority of the granules have undergone these changes, the starch is considered to be "pasted". Thus, pasting is the phenomenon following gelatinization. It involves granular swelling, exudation of molecular components from granule, and eventually total disruption of granules (Atwell, Hood, Lineback, Varrianomarston, & Zobel, 1988). The subsequent changes that occur following gelatinization and pasting during storage are termed as retrogradation, where starch polymers in the solubilized starch fraction and the remaining granular fragments re-associate imparting firmness to the gel.

Wheat starch has a bimodal size distribution comprising of A-type and B-type granules whereas cornstarch has a normal size distribution. The pasting properties of wheat starch are reported to be a function of A- and B-type granules and a strong positive correlation was reported between A-type granules and starch pasting parameters (Shinde, Nelson, & Huber, 2003). Morphological changes have also been documented for A-type granules during heating (Bowler, Williams, & Angold, 1980). Starch granule size increased with increase in temperature and above a temperature of 70 °C, the granules tended to fold extensively. In addition to type of starch granule, physical parameters such as temperature, rate of temperature increase, and shearing during heating also influence the viscosity of starch suspensions (Doublier, Llamas, & Lemeur, 1987; Suh & Jane, 2003). Doublier et al. (1987) used different heating and shearing rates and observed that heating rate significantly influenced the flow characteristics. A higher heating rate resulted in a higher apparent viscosity. Similarly, Suh and Jane (2003) also reported higher peak viscosity at faster heating rate during pasting.

Influence of processing conditions on baked product texture has been reported (Patel, Waniska, & Seetharaman,

* Corresponding author. Tel.: +1 814 865 5644; fax: +1 814 863 6132.
E-mail address: Koushik@psu.edu (K. Seetharaman).

0144-8617/$ - see front matter
doi:10.1016/j.carbpol.2006.01.028

2005; Seetharaman, Chinnapha, Waniska, & White, 2002). The authors hypothesized that the different heating rates experienced by dough during baking result in different starch granule dispersions and subsequently have an impact on product texture and shelf life. Studies using non-conventional baking processes (Martin & Hoseney, 1991; Martin, Zeleznak, & Hoseney, 1991; Yin & Walker, 1995) have shown that baked product texture varied under different baking conditions as a result of different starch granule morphologies which were due to altered heating regime. The objective of this research was to demonstrate visual evidence of differences in the starch granule swelling and morphological changes as a function of heating rate in real time that potentially provides an explanation for the differences in product texture.

2. Experimental procedures

Wheat starch (Midsol-50; Midwest Grain Products, Inc., Atchison, KS, USA) suspensions were prepared by suspending ∼10.0 mg starch in 1.0 ml of water by using a vortex mixer. The suspension was transferred onto a slide, covered with a coverslip, and sealed with Cytoseal 60 (Richard Allan Scientific, Kalamazoo, MI, USA) to prevent moisture loss during heating. The sealed specimen was then mounted on a Linkam LTS 350 hot stage (Linkam Scientific Instruments, Tadworth, Surrey, UK) and observed under 40× magnification using Olympus BX41TF microscope (Olympus Optical Co. Ltd., Shinjuku-ku, Tokyo, Japan) during heating. Different heating rates (5 or 25 °C/min) were achieved by using Linkam LNP and Linkam TMS94 temperature controller (Linkam Scientific Instruments, Tadworth, Surrey, UK). The actual temperatures at each heating rate were measured by using a T-type thermocouple placed on slide and sealed with a coverslip on top and have been used in the results. The images were captured using SPOT Insight QE camera (Diagnostic Instruments Inc., Sterling Heights, MI, USA) and the granule dimensions were calculated using the SPOT 3.5.6 for windows (Diagnostic Instruments Inc., Sterling Heights, MI, USA) software.

3. Results and discussion

The microscopic images of wheat starch granules heated at 5 or 25 °C/min are shown in Fig. 1. The arrowmarks facilitate tracking the morphological changes of A- and B-type granules through the different frames. The typical native wheat starch morphology with two types of granules, large lenticular A-type and small spherical B-type as has been previously reported (Bowler et al., 1980; Franco, Ciacco, & Tavares, 1998; van-de Velde, Van Riel, & Tromp, 2002; Williams & Bowler, 1982), is visible in the micrograph. The granule size did not increase before 50 °C but above that progress in swelling could be observed visually. Significant variability was observed among the granules in their respective size increase with increase in temperature above 50 °C as would be expected. Most A- and B-type granules appear swollen at 60 °C/min when heated at 5 °C/min while only a few A-type granules were swollen when heated at 25 °C/min. At 65 °C/min many of the B-type granules did not swell when heated at 25 °C/min. At 70 °C/min, the typical folding of A-type granules was observed when heated at 5 °C/min. Similar results have been reported before at slower heating rates (Bowler et al., 1980; Choi & Kerr, 2004). However, the extent of folding was much less when heated at 25 °C/min even at 80 °C and the circular granule contours are clearly visible. Granules heated at 5 °C/min, on the other hand, appear extensively folded and wrinkled.

The granule size increase of A- and B-type granules was plotted as a function of time to highlight these differences based on time during heating (Fig. 2). Wheat starch granule size increase is presented as absolute change in dimensions as well as percentage change from original native granule at 25 °C. The data points in Fig. 2 are average values calculated at 30, 40, 50, 60, 70, or 80 °C. Granule dimensions were not measured above 80 °C since the deformation, folding, and disruption of granules made it difficult to calculate the size. A-type granules showed substantial increase in size between 50 and 70 °C when heated at 5 °C/min; from 5.3% to 103.4% change in 250 s, whereas at 25 °C/min the change was from 9.1% to 148.1% within 50 s. Similarly, for B-type granules heated at 5 °C/min, granule size changed from 2.2% to 113.6% in 250 s, and at 25 °C/min heating rate it changed from 2.4% to 116.5% within 50 s. Swelling of B-type granules occurred at a higher temperature than for A-type granules, which is in agreement with previous reports that suggested that B-type granules were more resistant to gelatinization (Chiotelli & Le Meste, 2002; Eliasson & Karlsson, 1983; Peng, Gao, Abdel-Aal, Hucl, & Chibbar, 1999; Wong & Lelievre, 1982).

Therefore, the two key observations reported here based on visual observations are: (1) extent of granule swelling and folding are different when heated at different heating rates; and (2) granule swelling is a kinetic phenomenon, i.e., at higher heating rates, granule swelling occurs at a higher temperature. This delay is not due to a temperature lag at the higher heating rate because the temperatures reported are actual measured temperatures.

The changes in granule morphology reported in this study need to be interpreted in the context of time taken to reach a specific temperature at the different heating rates. For example, the difference in time required to heat from 25 to 50 °C between 5 and 25 °C/min is 240 s, while the difference in time increases to 614 s at 90 °C. Therefore, the residence time at a given temperature range is greater at slower heating rates. Granule swelling at 60 °C when heated at 5 °C/min occurred over 420 s. Therefore, the particular changes associated with starch gelatinization, i.e., glass transition, swelling, amylose leaching, and granule folding occur over a time interval of more than 5 min. These same events will have to occur over a much shorter time frame

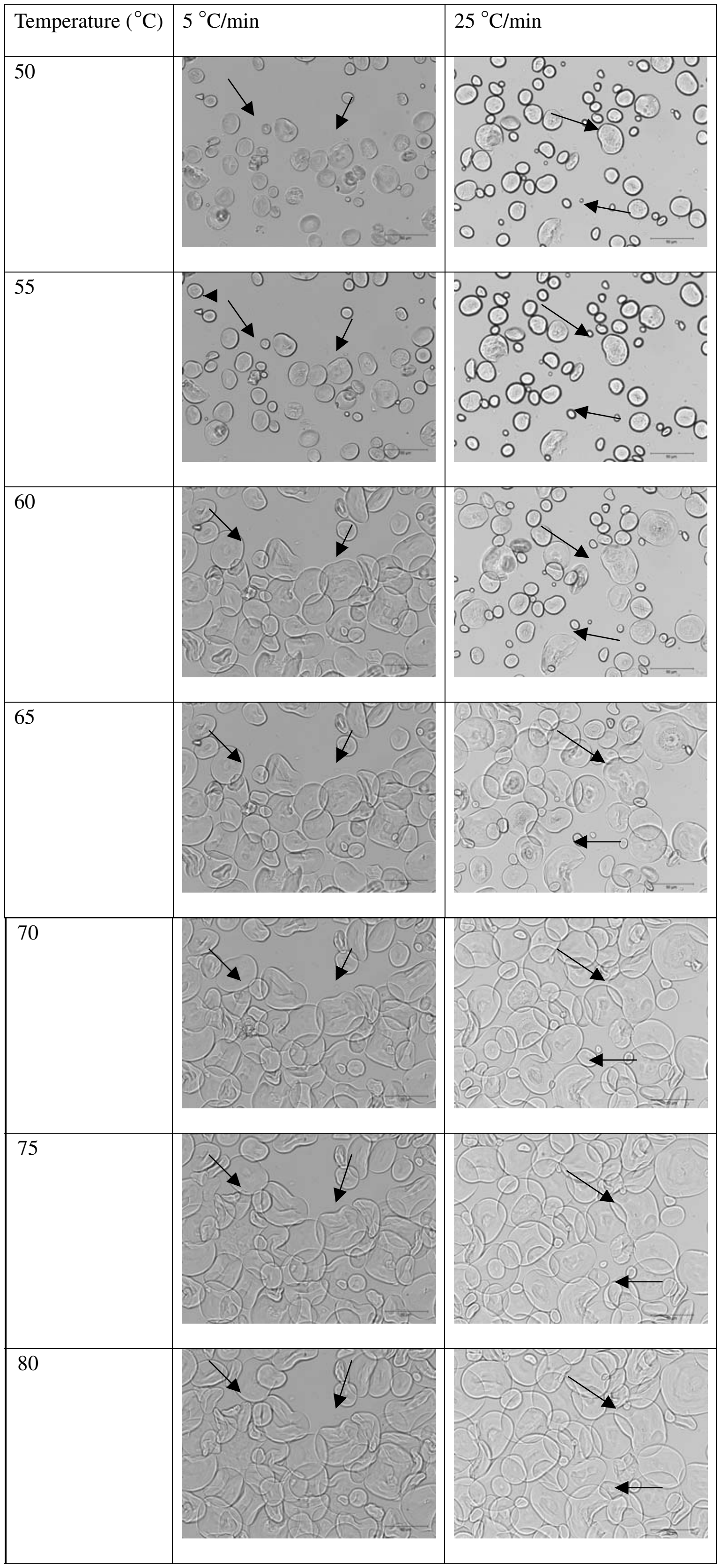

Fig. 1. Light micrograph of wheat starch at different temperatures during heating at 5 or 25 °C/min. Magnification (40× X 10); bar in each micrograph is 50 μm in length.

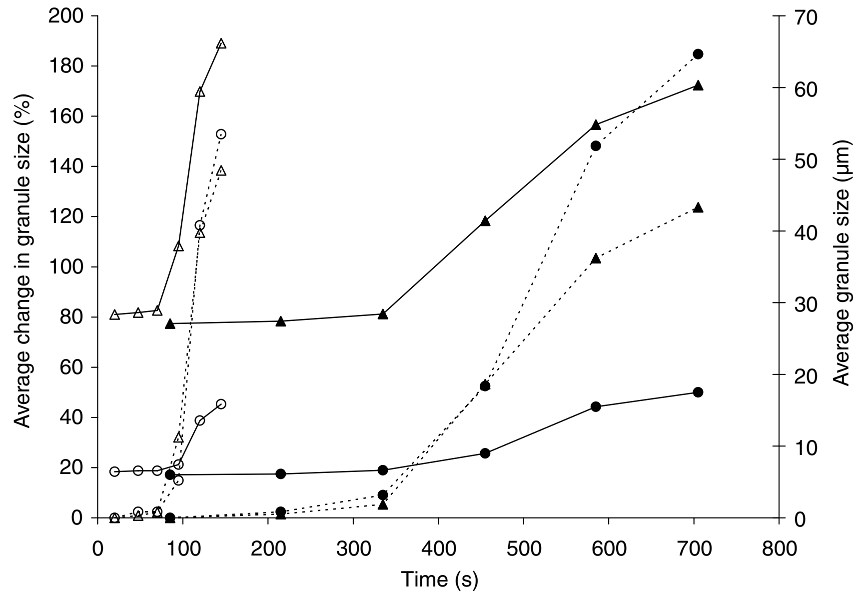

Fig. 2. Average size and average change in granule size of A- and B-type wheat starch granules as a function of heating rate. (△) A-type wheat starch granule; (○) B-type wheat starch granule; open symbols represent 25 °C/min and closed symbols represent 5 °C/min heating rates; solid line represents average granule size (μm); dotted line represents average change in granule size (%); each data point represents data at temperatures ranging from 30 to 80 °C at 10 °C interval.

(84 s) if heated at 25 °C/min. However, the data reported here show that there is a kinetic limitation to granule swelling, and consequently to amylose leaching, and likely other associated processes that are reflected in altered paste viscosity as has been reported earlier (Doublier et al., 1987; Suh & Jane, 2003).

Several studies have reported that granule swelling and amylose leaching occur concurrently (Ghiasi & Hoseney, 1982; Sakonidou, Karapantsios, & Raphaelides, 2003; Tester & Morrison, 1990). Furthermore, the kinetic limitations at higher heating rates will likely influence the extent of amylose leaching and the nature of amylose reassociation. One can conceive an image of amylose leaching out of the granule and rapidly reassociating on the granule surface and/or phase separating from amylopectin within the granules at higher heating rates; while at slower heating rates, a more extensive amylose network could be formed due to the slower increase in the temperature and phase separation from amylopectin (Miles, Morris, Orford, & Ring, 1985). These alternative scenarios would likely explain the differences in gel texture and property at higher starch concentrations. We recognize that results from this study are based on a dilute system and the particular changes in morphology and polymer leaching will be different in product systems at higher starch concentrations. However, research from our laboratory has demonstrated differences in product texture and shelf life as a function of the heating rate during baking (Patel et al., 2005; Seetharaman et al., 2002). These observations, therefore, at least set the stage for possible alternative scenarios to interpreting textural differences in products. Other results from our laboratory also demonstrate similar trends in granule size and morphology changes as a function of heating rate for normal corn and waxy corn starches (data not shown).

4. Conclusions

The results presented here provide visual evidence for differences in starch granule morphology and size increase as a function of heating rate. More extensive folding of granules was evident when starch was heated at 5 C/min compared to those heated at 25 C/min. Furthermore, the increase in granule size occurred at a higher temperature when heated 25 C/min compared to 5 C/min. These differences potentially result in altered patterns of amylose leaching and network formation thus providing an explanation for differences in gel properties and baked product texture.

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