International Journal of Biological Macromolecules 87 (2016) 28–33

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

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

Understanding how the aggregation structure of starch affects its gastrointestinal digestion rate and extent

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ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form
31 December 2015
Accepted 5 January 2016
Available online 17 February 2016

Keywords:
Wheat starch
Multi-scale structure
In vitro digestion properties

ABSTRACT

Regulating the starch gastrointestinal digestion rate by control of its aggregation structure is an effective way, but the mechanism is still not clear. Multi-scale structure of waxy and normal wheat starches were studied by confocal laser scanning and scanning electron microscopes, as well as wide-angle and small-angle X-ray techniques in this study. *In vitro* digestion kinetics of those two starches and structure–digestion relationship were also discussed. Both waxy and normal starches show A-type diffraction pattern, but waxy variety shows a slightly higher crystallinity. Small-angle X-ray scattering results show that waxy wheat starch has higher scattering peak intensity (I_{max}) and a larger crystallinity lamellar repeat distance (L_p) compared with the normal wheat starch. We suggested that the higher digestion rate of waxy starch at initial stage is mainly due to more small-size particles, but the higher crystallinity and the larger crystalline lamellar size limit the digestion extent.

1. Introduction

Glycemic index (GI) is an important parameter to evaluate nutritional properties for carbohydrate-containing foods according to Food and Agriculture Organization (FAO) and World Health Organization (WHO) [1]. Starch, a major carbohydrate source in human diets, is a key component to control the blood glucose level in human body. The starch in a high GI food is digested and absorbed rapidly, resulting in high postprandial blood glucose and insulin levels, which over the long term are enhancing the risks of diet-related diseases including type-2 diabetes and cardiovascular disease [2]. Therefore, controlling the digestion rate and extent of granular starches and understanding the factors to affect the starch digestion is important for starch-based food design and development [3].

The application of Log of Slope (LOS) analysis of digestibility curves based on the well-documented first-order reaction kinetics of amylolysis has been used to characterize the reaction rate of starch amylolysis. LOS plots could be very sensitive to changes in digestion rate constant from the conventional digestion curves, and assist in understanding how starch digestion rates change deduced by structure differences [4–6]. The digestion rate (k) could be affected by the molecular level and aggregation structure of granular starches. For molecular level, it have been reported that the digestion rate tends to increase with longer chain length of long amylose branches and smaller ratios of long amylopectin to short amylopectin branches, as well as smaller relative amount of long amylose branches to short amylopectin branches [7]. The aggregation structures dominant by lamellar and crystalline structures [8], also play a key role in determining the digestion rate and extent. For example, Zhang et al. used extrusion technique to induce low-order starch with a relatively lower digestion rate [9]. However, the aggregation structures of granular starches are complicated, the mechanism to control the digestion rate and extent is still not fully understood [3].

Waxy wheat was firstly developed in Japan through traditional hybridizations genetic modification in 1995 [10], then was successfully introduced to Australia, USA, Canada and China [11,12]. Waxy wheat starch, which is biosynthesized when the three granule-bound starch synthesis (GBSS) genes are absent or nonfunctional, has distinct structural characteristics such as very low amylose content and high crystallinity. The special structure leads to the desirable functional properties such as high swelling power and peak viscosity, low retrogradation level, setback viscosity and pasting temperature. With the increasing applications of waxy wheat starches in foods, a good understanding of the aggregation struc-

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http://dx.doi.org/10.1016/j.ijbiomac.2016.01.119
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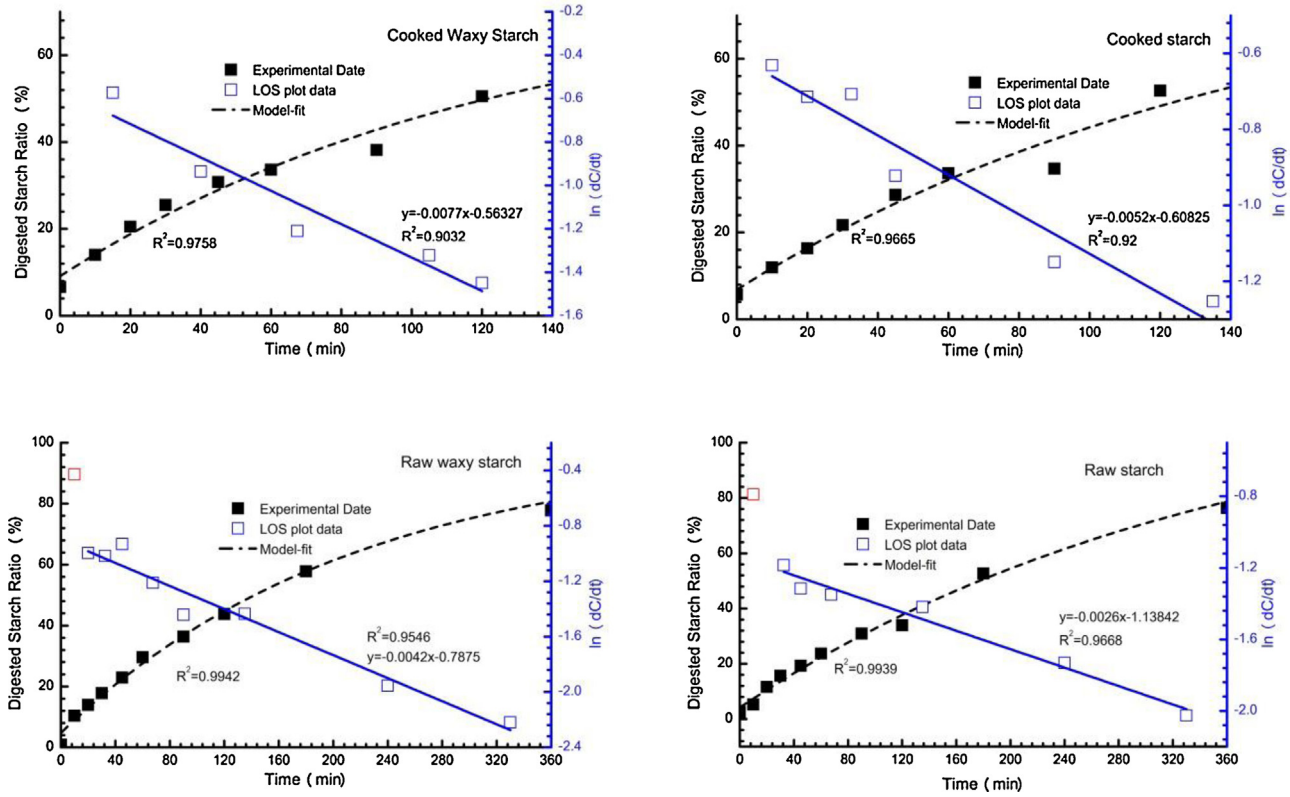

Fig. 1. Typical starch digestion curves and LOS plots of cooked and raw wheat starches.

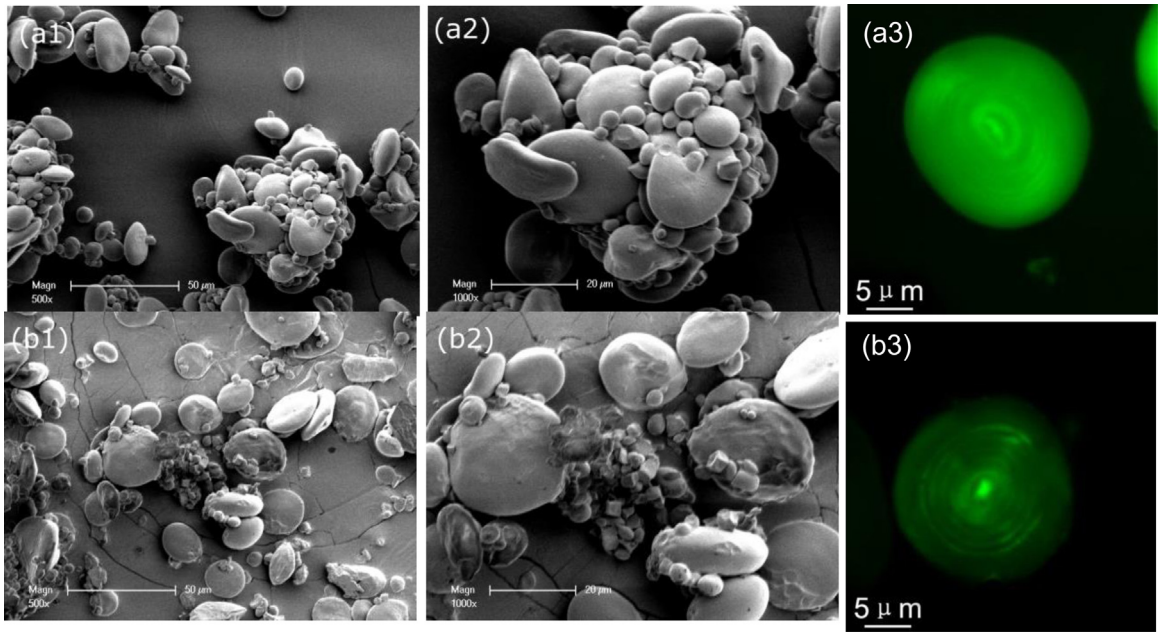

Fig. 2. Starch granules of waxy wheat starch (a1, a2, a3) and normal wheat starch (b1, b2,b3) observed by SEM and CLSM.

ture differences between waxy and normal wheat starches is required and further results in the different digestion rate and extent becoming increasingly important to the area of food processing and nutrition. Moreover, the thickness of crystalline and amorphous lamellar structure of waxy wheat starches as measured by small anger X-ray scattering (SAXS) and their relationship with the molecular structure are not fully understood as well. In this study, the multi-scale aggregation state structure of normal and waxy wheat starches were investigated, and the digestion rate and extent were evaluated by LOS methods. In addition, the structure–digestion relationship of wheat starches were also discussed.