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The effect of moisture content on physicochemical properties of extruded waxy and non-waxy rice flour

Ornpicha Jongsutjarittam, Sanguansri Charoenrein*

Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok 10900, Thailand

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ABSTRACT

The properties of waxy rice flour (WRF) and non-waxy rice flour (RF) were modified using an extrusion process with different feeding material moisture contents. WRF was more affected by the thermomechanical stress from extrusion; consequently, it had a lower glass transition temperature but higher water solubility index (WSI) indicating higher molecular degradation than extruded RF. The lower moisture content of the feeding flour caused more severe flour damage (coarser surface of the extruded flour) and lowered relative crystallinity compared to higher moisture content processing. Moreover, low moisture content processing led to complete gelatinization, whereas, partial gelatinization occurred in the higher moisture content extrusion. Consequently, the extruded flours had a lower peak viscosity and gelatinization enthalpy but a higher water absorption index and WSI than native flour. In conclusion, the rice flour type and the moisture content of the extrusion feeding flour affected the physicochemical properties of the extruded flour.

1. Introduction

Rice (*Oryza* sp.) is one of the staple foods consumed worldwide, especially in Asia. The composition of rice granules varies widely depending on the variety. Non-waxy rice has 15–27% amylose, while waxy varieties have almost 100% amylopectin (Guy, 1994) resulting in different properties, such as a higher gelatinization temperature and higher retrogradation of rice flour than for waxy rice flour, and also different functional properties. Similar to other types of flour, the use of native rice flour in foods is limited by its physical and chemical properties. Physical modification not involving any chemical reagents or genetic modification could improve the properties of native starch/flour including its processing, food texture and food stability and achieve maximum overall performance in the process and product (Manson, 2009).

Extrusion is a versatile process that is a highly adaptable, cost effective and energy efficient technology having been applied in the food industry for more than 50 years (Harper, 1989). The extrusion parameters, screw configuration, barrel temperature profile and moisture content, have an effect on the processability and product quality. For starch-based materials, the combination of temperature, moisture and mechanical shear force in the extrusion process causes structural transformations, such as granular disruption, loss of crystalline structure and polymer degradation (Colonna, Tayeb, & Mercier, 1989). Researchers have considered using extrusion to modify the properties of starch and flour, in corn starch (Blanche & Sun, 2004; El-dash, Gonzales, & Ciol, 1983), banana starch (Soto, Escobedo, Sánchez, Rivera, & Pérez, 2007) and barley four (Gill, Vasanthan, Ooraikul, & Rossnagel, 2002). Sompong, Ehn, Berghofer, and Schoenlechner (2011) found that the amylose content of rice flour was correlated with the water absorption index and final viscosity of pregelatinized rice flour produced by extrusion cooking. Guha and Ali (2002) studied the molecular degradation of high, intermediate and waxy amylose rice starches and reported that the degradation of the high molecular weight fraction of rice starch resulted from extrusion cooking and was extended with increasing severity of the extrusion process. The maximum molecular degradation was observed in waxy rice starch.

The glass transition temperature (T_g) defines the transition from a brittle, metastable, amorphous supercooled solid to a rubbery, unstable, amorphous liquid (Kaletunc & Breslauer, 1993). The relationship between the T_g and molecular weight is well described for amorphous and partially crystalline linear homopolymers (Billmeyer, 1984). For a starch polymer, a reduction in the T_g is attributed to molecular fragmentation (Kaletunc & Breslauer, 1993) which could result from the extrusion process.

Many studies have worked on the influence of extrusion on the properties of starch/flour and some have focused on using a response surface methodology to create mathematical models of the relationship between the extrusion parameters and the

* Corresponding author. Tel.: +66 2 562 5025; fax: +66 2 562 5021.
E-mail addresses: fagisscr@ku.ac.th, charoen1234@yahoo.com (S. Charoenrein).

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Table 1
Moisture content of waxy rice flour (WRF) and rice flour (RF) with different water feed rates in extrusion process.

Water feed rate (l/h)	Moisture content (%)	
	WRF	RF
Native	12.55	11.88
0.5	20.50	19.89
0.6	21.92	21.32
0.7	23.29	22.70
0.8	24.61	24.03
0.9	25.89	25.32
1.0	27.13	26.57

properties of modified starch/flour. However, information on the change in physicochemical properties, such as the granular structure, pasting and gelatinization properties of starch/flour is still limited. Moreover, most researchers studied the combination effect of the screw speed, temperature and moisture content in extrusion, and did not focus on the effect of each extrusion parameters on the changes in properties of the extruded starch/flour. The amount of water in the extrusion is one of the important parameters that controls the extrusion process because it has an influence on mixing, viscosity and the retention time of the mass in the extruder barrel (Martínez-Bustos, Aguilar-Palazuelos, & Galicia-García, 2012). Therefore, it is of interest to specifically study the influence of the water content in the extrusion process on the physicochemical modification of starch/flour. Furthermore, only Kaletunc and Breslauer (1993) has reported on the T_g of extruded flour in relation to the moisture content in the extrusion process and apart from the crystalline structure, they did not study the changes in other physicochemical properties of extruded corn flour. Therefore, the current work aimed to study the effect of different moisture contents in the feeding material for extrusion on the physicochemical properties including disruption of the granular structure, loss of starch crystallinity, the pasting and gelatinization properties and the water absorption and water solubility of waxy rice flour and rice flour. Moreover, the effect of the moisture content in the extrusion process on the T_g value of extruded rice flour was also investigated.

2. Materials and methods

2.1. Materials

Waxy rice flour (WRF) and rice flour (RF) with moisture content of 12.55 and 11.88%, respectively, (AACC, 2000) were purchased from Cho Heng Rice Vermicelli Factory Co., Ltd. (Nakhon Pathom, Thailand). $Mg(NO_3)_2$ was purchased from Lobachemie, India.

2.2. Extrusion process

Extrusion was performed in a co-rotating twin screw extruder (EV25-A120, Clextral, France). The extruder barrel was segmented into 6 zones with the controlled temperature profile as follows: 30–30–45–45–60–75 °C. The feed rate of flour and the screw speed were set at a constant 5 kg/h and 350 rpm, respectively. The water feed rate was varied from 0.5 to 1.0 l/h which resulted in different moisture contents of the feeding material as shown in Table 1. A single circular die with 3.2 mm diameter was used. The extruded products were cut into about 1 cm lengths before drying in a hot air oven (ULE500, Memmert, Germany) at 40 °C for 24 h. The dried extruded products were ground using a blender (Turbora TRK-01, Napat Inter Ltd., Thailand) and passed through a 100-mesh sieve screen.

2.3. Characteristics of native and extruded WRF and RF

2.3.1. Microstructure

For sample dehydration, the native and extruded WRF and RF were dried in hot air oven at 40 °C for 3 d. After that, they were fixed on a stub and coated with gold. The samples were observed using scanning electron microscopy (SEM; JSM-5600LV, JEOL, Japan) with the magnifications and accelerating voltages as shown on the SEM images.

2.3.2. Crystallinity

The flour samples were equilibrated for 3 d in a desiccator containing saturated K_2SO_4 solution in order to prepare flour samples containing 20% H_2O (wet basis) according to the method of Phothiset and Charoenrein (2007). The crystallinity of native and extruded WRF and RF was determined by X-ray diffractometry (JDX-3530, JEOL, Japan) with Cu-$K\alpha$ radiation (wavelength = 1.5406 Å) and a Ni filter. The scanning diffraction angle (2θ) ranged from 5 to 40° and the X-ray generator was operated at 45 kV and 45 mA. The relative crystallinity (%) of the samples was calculated according to the method of Cheetam and Tao (1998).

2.3.3. Water absorption index (WAI) and water solubility index (WSI)

The WAI and WSI of native and extruded samples were measured according to the method of Anderson, Conway, Pfeifer, and Griffin (1969). The samples (2 g dry basis) were dispersed in water at 30 °C for 30 min with gentle stirring every 5 min. Then, they were separated using a centrifuge (Z206A, Hermle, Germany) at 3000 × g for 15 min. The supernatant was placed into an aluminum can and dried in the hot air oven at 90 °C for 6 h. The WAI and WSI were determined as follows:

$$\text{WAI}\,(\text{g/g}) = \frac{\text{weight of wet sediment}}{\text{dry weight of sample}}$$

$$\text{WSI}(\%) = \frac{\text{weight of dry solid in supernatant}}{\text{dry weight of sample}} \times 100$$

2.3.4. Glass transition temperature

Each extruded flour sample (6 mg on a dry basis) was weighed and placed in an aluminum pan and equilibrated for 24 h to a relative humidity of 52.9% at 25 °C using saturated $Mg(NO_3)_2$. After that, the pan was immediately sealed and accurately weighed before analysis with a differential scanning calorimeter (DSC; Pyris-1, Perkin Elmer, USA) using nitrogen as the purge gas. The pans were cooled from 25 °C to 5 °C, held at this temperature for 1 min and then heated to 170 °C at a rate of 10 °C/min. Then, they were cooled to 5 °C and re-heated to 170 °C at the same rate. No shift in the heat capacity could be observed in the second scan; therefore, the T_g values were determined from the onset of the heat capacity change over the glass transition. All measurements were performed in triplicate.

2.3.5. Pasting properties

Suspensions of native and extruded flour were prepared at 8% (w/w) in distilled water. The pasting properties of each suspension were measured using a rapid visco analyzer (RVA; RVA3D, Newport Scientific Instrument and Engineering, Australia). The paste was held at 50 °C for 1 min before heating to 95 °C at a constant rate of 12 °C/min, and then it was held at 95 °C for 2.5 min. After that, it was cooled to 50 °C at the same constant rate and held at 50 °C for 2 min. All measurements were performed in triplicate.