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Effects of electron beam irradiation on physicochemical properties of corn flour and improvement of the gelatinization inhibition

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ABSTRACT

The properties and viscosity-reduction mechanism of corn flour irradiated by electron beam have not been understood properly. Here, we investigate the effects of electron beam irradiation (EBI) on the gelatinization and physicochemical properties of corn flour irradiated by 0–5.40 kGy of electron beam. The total starch and crude fiber contents of corn flour decreased significantly ($P < 0.05$) after EBI treatment, while the moisture and reducing sugar contents increased significantly ($P < 0.05$). EBI caused perforations on the corn flour particle surfaces, and the irradiated parts of the particles would gradually peel off and afford smooth surfaces, spherical structures, and smaller sizes. Molecular chains of corn flour broke owing to EBI. After irradiation, the pasting peak viscosity decreased dramatically ($P < 0.01$) from 1251.74 to 7.16 Pa·s, showing that the gelatinization of corn flour was completely inhibited. Thus, EBI can be used to inhibit the gelatinization of corn flour, which may be beneficial for industrial and food formulations.

1. Introduction

Corn flour is used for the processing and development of a wide variety of foods and products, such as corn starch, corn syrup, and corn peptides. Because of the increasing growth and interest in green chemical industry, corn syrup is being widely used as a raw material for processing and producing of alcohol, succinic acid, citric acid and other organic chemicals (Blanchard & Geiger 1984; Melanson et al., 2009). Enzymatic hydrolysis is the main method to saccharify corn flour. This process consists of liquefaction and saccharification. In the liquefaction process, thermostable α-amylase is used at 120–145 °C, and the minimum temperature is 90 °C (Nielsen & Rosendal, 1980). However, high-temperature conditions cause a series of problems in the liquefaction process, such as strict equipment requirement and the fact that the viscosity of corn flour after gelatinization becomes very high. This leads to a very high consumption of water, electricity, and gas and also makes the mixing of corn flour difficult.

Several years ago, we engaged in studies on corn syrup in order to solve these problems; we examined inhibiting gelatinization to reduce the viscosity and enhance the quality of corn syrup. The viscosity of corn flour slurry above 80 °C is mostly caused by the gelatinization of starch, the main component of corn flour. According to previous reports, starch gelatinization can be inhibited through amylose-lipid complex formation and increases in the number of equatorial OH (e–(OH)) groups in saccharides (Larsson, 1980; Li, Li, & Gao, 2015). These methods changed the gelatinization temperature of starch, rather than reducing the overall viscosities of starch slurries.

Radiation processing technology utilizes the interaction between radiation and matter, including the physical, chemical, and biological effects, to process illuminated objects for applications such as material modification, sterilization, and waste treatment (Martins & Silva, 2014). Structurally, corn starch is in the particulate form and surrounded by a continuous phase of protein (Chanvrier, Colonna, Valle, & Lourdin, 2005). After it is crushed, starch granules are usually attached to the broken protein, which affects the quality of subsequent fermentation. Irradiation can disrupt gluten and protein molecules and cause the degradation of polypeptide chains (Lee, Lee, & Song, 2005; Soliman & Furuta, 2009). Therefore, radiation can theoretically allow the protein impurity to be peeled off and improve the quality of corn syrup. Studies on the reduction of the viscosity of starch using irradiation have also been reported. Al-Kaisey, Mohammed, Alwan, and Mohammed (2002) reported that gamma irradiation does not exert any major effects on the chemical composition of barley and can

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significantly reduce the viscosity. Similar experimental results for pasting viscosity reduction have also been reported (Gani et al., 2014; Kang et al., 1999; Wu, Shu, Wang, & Xia, 2002) for corn, wheat, rice, and potato starch treated by γ-irradiation.

In contrast to the equipment used in other irradiation methods, the equipment for electron beam irradiation (EBI) does not require a radiation source. It also does not generate radioactive waste or radioactive hazards. Additionally, the EBI equipment is simple to maintain and has a low cost of operation. Unlike other radiation sources with spherical radiation, the utilization rate of EBI is much higher. The accelerator in EBI can generate a high dose rate and a same-direction electron beam with good concentricity. Thus, a high energy can be obtained within a short time. Additionally, foods with high fat and protein contents irradiated by an electron beam have fewer unexpected flavors and tastes (Lopez-gonzalez, Murano, & Brennan, 2000). EBI is also more efficient in reducing the swelling capacity and viscosity of starch (Kerf, Mondelaers, Lahorte, Vervaet, & Remon, 2001).

Other studies have assessed the physicochemical and rheological properties of foodstuffs treated by γ-irradiation, including many types of grains and starch, such as corn, rice and wheat (Grant & D'Appolonia, 1991; Soliman & Furuta, 2009; Wu et al., 2002). In fact, it has been shown that irradiation can reduce the viscosity of starch, but some studies have shown that irradiation also increases the paste viscosity (Wattanchant, Muhammad, Hashim, & Rahman, 2003; Wu & Seib, 1990; Yeh & Yeh, 1993). The degradation theory reported in previous literature is not sufficient to explain the fact that the viscosity of the irradiated starch is significantly lower than that of the nonirradiated one (Kerf et al., 2001; Pimpa, Hassan, & Ghazali, 2007; Soliman & Furuta, 2009). Moreover, the effect mechanism of EBI is different from that of γ-irradiation. To date, there is not sufficient understanding of the properties and viscosity-reduction mechanism of corn flour irradiated by EBI. This study focused on elucidating the effects of EBI on corn flour. We investigated some physicochemical properties of corn flour irradiated by EBI with the aid of mid-infrared (MIR) spectroscopy and scanning electron microscopy (SEM). Using the experimental data obtained, we attempt to provide some new explanations for the dramatic decrease in the paste viscosity of corn flour after irradiation by an electron beam.

2. Materials and methods

2.1. Electron beam irradiation of corn flour

Corn flour was purchased from the local market of Changchun, Jilin Province (China) and was sieved using a 100 mesh sieve. Subsequently, every 100 g of the sifted corn flour was separately vacuum-sealed in polyethylene bags and flattened, with a material thickness of not more than 10 mm. The irradiation treatments were performed by YIFU Electronic Accelerator Co. Ltd (Changchun, China) using a 10 MeV/15 kW electron linear accelerator. Samples were irradiated under ambient temperature conditions at a dose rate of 1.08 kGy/h and compared with the nonirradiated samples. The doses were 1.08, 2.16, 3.24, 4.32 and 5.40 kGy. After irradiation, the samples were cooled to room temperature and stored under ambient conditions.

2.2. Determination of chemical constituent content

The methods of National Standard of China were used to determine the contents of chemical constituent content of corn flour, namely the moisture (GB/T 5497-85), crude protein (GB/T 5511-2008), crude fiber (GB/T9822-2008), lipid (GB/T 5512-2008), total starch (GB/T 5514-2008), reducing sugar (GB/T 5009.7-2008) and ash (GB 5009.4-2010). Nine measurements from three parallel sample sets were performed to obtain an average value for each of the properties mentioned previously. The α-amylase used for the total starch content determination was purchased from Sigma Chemicals Co. (St. Louis, MO, USA). Ethanol, glucose, hydrochloric acid, and all other assay reagents were purchased from Peking Chemical Plant (Beijing, China) and were all of analytical-grade purity.

2.3. Measurement of total soluble solid content

Corn flour samples (5.0 g) were dispersed in distilled water (45.0 mL) and stirred for 30 min at room temperature (25 °C), and approximately 3 mL of the suspensions was withdrawn for analyses. The remaining portions were heated in a 90 °C water bath for 30 min to facilitate the complete pasting of the samples. The suspensions, including nonheated ones, were centrifuged at 1000 rpm for 10 min at 4 °C to obtain supernatants. A digital Abbe refractometer (MZB–85; Midi Green Techtronic Industries Co. Ltd., Shanghai, China) was used to measure the total soluble solid content of irradiated corn flour (the *Brix degrees* of the supernatant). Each sample was measured three times in parallel and the results were averaged.

2.4. Scanning electron microscopy analysis of corn flour

The procedure for scanning corn flour, with some modifications, has been described by Zhang, Li, and Wang (1997). In this study, a JSM-6700F field emission scanning electron microscope (JEOL Ltd., Japan) was used to observe the surface of corn flour particles. Approximately 1 mg of sample granules was placed on a piece of adhesive tape attached to a circular aluminum specimen stub and coated with gold-palladium for 90 s under a 15 mA current using an E-1045 ion beam sputtering instrument (Hitachi High-Tech Co. Ltd., Japan). Afterwards, the specimen stub was placed in the observation room. The samples were photographed at an accelerator potential of 5 kV. The morphological characteristics were then studied using SEM micrographs at 1000×, 2000×, and 6000× magnifications.

2.5. Mid-infrared spectroscopy analysis of corn flour

MIR spectroscopy was used to investigate the chemical compositions and structural changes of corn flour after EBI treatment. The measurement procedure for the MIR spectroscopy of corn flour has been described by Wang et al. (2015). Nonirradiated corn flour samples and samples irradiated at 2.16 and 4.32 kGy were chosen as the representative samples for MIR spectroscopy experiments and were dried at 50 °C for 12 h. MIR spectra were measured using an IR Prestige-21 Fourier transform infrared spectrometer (Shimadzu, Japan) at a resolution of 4 cm^{-1} over the 400–4000 cm^{-1} range. Potassium bromide (KBr, spectral purity) was dried at 130 °C for 5 h and its spectrum was recorded as the background spectrum. KBr sample pellets were prepared by mixing 2 mg of sample with 200 mg of KBr. The sample pellets were placed in the sample compartment with automatic accessory recognition and scanned at a scanning speed of 2.8 mm/s. After background correction, all spectra were baseline corrected and the sample spectra were obtained.

2.6. Determination of corn flour viscosity

A 4.0 g corn flour specimen was blended thoroughly with 36.0 mL of distilled water. The mixture viscosity was determined using a Brookfield viscometer (Model DV-III Ultra, Brookfield Engineering Laboratories, Inc., MA, USA), which was controlled using