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Effects of extrusion cooking conditions and chemical leavening agents on lysine loss as determined by furosine content in corn based extrudates

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ABSTRACT

The aim of this study was to investigate the effects of different variables on lysine loss as determined by furosine content in corn-based extrudates. Three formulations were prepared to study the effects of different chemical leavening agents, processing conditions (feed moisture content: 22, 24 or 26%; exit die temperature: 110 or 150 °C), and extrusion cooking methods (with/without CO_2 injection) on furosine formation. Furosine levels of extrudates from both extrusion methods decreased around 20% when feed moisture content was increased from 22% to 26%. Amadori compounds (precursor of furosine) are formed in the early stages of the Maillard reaction, and later they are converted to further products. Consequently, furosine contents of extrudates significantly decreased as exit die temperature increased from 110 to 150 °C. Furosine contents of extrudates produced with sodium- and ammonium-bicarbonate at 150 °C exit die temperature significantly decreased, while the ones produced at 110 °C significantly increased. This may be due to accelerated formation of fructosyllysine at higher pH values followed by early degradation at 150 °C. The CO_2 injection method did not have a significantly different effect on furosine content of extrudates than that produced by the conventional extrusion method, but had a positive effect on the physical properties of extrudates.

1. Introduction

Extrusion cooking is a high-temperature-short-time process, which cooks, forms and dries the product in one integrated operation. It is one of the most important processing techniques used in the development of food products (Moscicki and van Zuilichem, 2011; Singh et al., 2007). Extrusion cooking is a continuous process which operates in dynamic steady state equilibrium (Guy, 2001). It has been observed that functional and nutritional properties of food components might change due to extrusion, e.g., starch granules are gelatinized, proteins are denatured and cross-linked, vitamins are degraded and protein digestibility is increased. On the other hand, the extrusion process combines the application of high temperature and low moisture, which favors the development of Maillard reaction products (MRPs). Therefore, nutritional quality of proteins might be decreased due to loss of lysine. In the related literature, there is limited amount of information on the loss of nutrients (Repo-Carrasco-Valencia et al., 2009) and formation of Maillard reaction products during the extrusion process (Masatcioglu et al., 2014). It was reported by Singh et al. (2007) that mild extrusion conditions (high moisture content, low residence time, low temperature) improve the nutritional quality, while high extrusion temperatures, low moisture contents and/or improper formulation (e.g. presence of high-reactive sugars) can affect nutritional quality adversely.

Lysine content of cereal products is generally low and hence it is one of the limiting amino acids in the human diet if cereals are the staple food. Due to the severe conditions utilized (e.g. high temperature), extrusion cooking has the potential to significantly decrease the concentration of available lysine. During processing, lysine and other amino acids with a free amino group may react with reducing sugars through the Maillard reaction (Belitz et al., 2009). It was reported that lysine retention ranged from 51% to 89% during extrusion of maize grits, with higher lysine losses at lower moisture contents, longer retention times, and higher specific mechanical energy levels (Ilo and Berghofer, 2003).

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Furosine [ε-*N*-(2 furoyl-methyl)-L-lysine] is an amino acid derivative formed during the acid hydrolysis of Amadori products. During the heat processing of foods, Amadori products are generated in the early stages of the Maillard reaction (Erbersdobler, 1995; Erbersdobler and Hupe, 1991). For this reason, estimates of the extent of protein damage caused by heating are based on determinations of the amount of furosine (Nursten, 1981). Furosine can also be considered as a marker of dietary intake of AGEs (Advanced Glycation End products), which is involved with several complications of degenerative diseases (e.g., diabetic nephropathy, uremia, and cataracts) (Uribarri et al., 2007).

A new extrusion method utilizing injection of carbon dioxide (CO_2) gas into the extruder barrel has been introduced for the processing of expanded cereal products (Ryu et al., 2002). Many researchers have reported the advantage of the CO_2 injection method to protect the nutrients in the food materials from the effects of high temperature (Masatcioglu et al., 2013; Bilgi Boyaci et al., 2012; Schmid et al., 2005). However, previous publications were not concerned with the effects of CO_2 injection during the extrusion process on furosine content.

The aim of this research was to investigate the effects of cooking conditions (exit die temperature, feed moisture content, and CO_2 injection), and chemical leavening agents (sodium bicarbonate and ammonium bicarbonate) on loss of lysine as determined by furosine content in corn-based extrudates.

2. Materials and methods

2.1. Materials

Commercial white corn flour (WCF) was obtained from ADM Milling Company (Jackson, TN, USA), soy protein isolate (SPI) and glucose were provided by ADM Specialty Food Ingredients Co. (Decatur, IL, USA). Sodium bicarbonate and ammonium bicarbonate were provided by Church & Dwight Co., Inc. (Ewing, NJ, USA).

2.2. Methods

2.2.1. Sample preparation

Three formulations were prepared (Table 1) to investigate the effects of (i) processing conditions (feed moisture content, exit die temperature), (ii) different chemical leavening agents, and (iii) extrusion cooking methods (conventional, CO_2 injection) on furosine formation. Control sample (WCF), Formulation 1 (WCF + SPI) and Formulation 2 (WCF + glucose) were used in the production of extrudates at 150 °C exit die temperature and 22% feed moisture content. Formulation 3 (WCF + SPI + glucose) was used in the production of extrudates at 110 and 150 °C exit die temperature and 22, 24 and 26% feed moisture contents. The mixtures were prepared in several steps to achieve a reasonable and uniform level of mixing/blending without concentrated pockets of components of formulations (Wesley, 2013).

Table 1
Composition of the formulations used in the extrusion cooking.

Formulations	White corn flour (WCF)[a]	Soy protein isolate (5%, w/w)	D-glucose (2%, w/w)
Control	+	−	−
Formulation 1	+	+	−
Formulation 2	+	−	+
Formulation 3	+	+	+

[a] The total amount (%, w/w) of other ingredients was subtracted from 100% (w/w) to calculate the amount of WCF in each formulation.

2.2.2. Extrusion process

2.2.2.1. Conventional extrusion method. A laboratory-scale co-rotating twin-screw extruder (MPF19, APV Baker Ltd, Staffordshire, England) with a 25:1 screw length to diameter ratio (L/D) and with five temperature zones was used to produce corn extrudates at different process variables. The screw speed, feed rate, and die hole diameter were kept constant at 200 rpm, 2.5 kg/h, and 2.0 mm, respectively. The screw configuration is given below:

5 *D* Twin lead feed screws
8 × 30° Forward kneading paddles
8 *D* Twin lead feed screws
8 × 60° Forward kneading paddles
4 × 30° Reverse kneading paddles
2 *D* Single lead feed screws
2 *D* Twin lead feed screws
4 × 30° Reverse kneading paddles
4 × 30° Forward kneading paddles
1 *D* Single lead feed screw
Screw diameter = 19.0 mm (1 *D*)
One kneading paddle = 1/4 *D*

Extrusion was carried out with an exit die temperature of 110 or 150 °C and with a feed moisture content of 22, 24 or 26%. Extrusion temperature profile was set depending on the temperature of the exit die. Extrusion temperature profiles were 60/90/110/110/110 °C and 60/90/110/150/150 °C (increasing temperature toward die) when the temperature of the exit die was adjusted to 110 and 150 °C, respectively. When the extrusion system reached steady state as indicated by constant torque, pressure and temperature, extrudate samples were collected. The extruder was equipped with a cooling system and the temperature of the melt was measured at the die exit with a thermocouple. The actual melt temperature was ±3 °C of the set temperature. All collected samples were oven-dried at 50 °C to adjust the moisture content to less than 9% before grinding in a laboratory mill (Straub Model 4-E Grinding Mill, Warminster, PA, USA), followed by passing through a 212 μm sieve. The ground and sieved extrudates were stored in air-tight plastic containers and held at 4 °C until analysis. The extrudates were produced in two replicates at two different times.

2.2.2.2. CO_2 injection method. The same extrusion equipment was also used for the CO_2 injection method, with the same exit die temperatures, extrusion temperature profiles, and constant screw speed and feed rate. The feed moisture contents were also the same as in conventional extrusion (22, 24 or 26%). CO_2 was injected into the extruder barrel through a valve at a pressure of 1034 and 517 kPa for 110 and 150 °C exit die temperature, respectively. The point of CO_2 injection was 120 mm before the die exit. Preliminary experiments indicated that it was possible to use a higher CO_2 pressure at 110 °C exit die temperature since the melt exhibited higher viscous flow properties at 150 °C in the barrel and the higher pressure (1034 kPa) forced the molten feed material towards the feeding section. Therefore, a lower CO_2 pressure was used at the higher exit die temperature.

2.2.3. Moisture determination

Moisture contents of raw materials and extrudates were determined according to AACC International Method No. 44-01 (AACC International, 2000).

2.2.4. Analysis of furosine

Furosine contents of extrudates were determined according to the slightly modified method of Resmini and Pellegrino (1991). The extrudate samples were ground, and 0.5 g of sample was weighed