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Assessment of color development due to twin-screw extrusion of rice–glucose–lysine blend using image analysis

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Abstract

An image analysis method was developed to determine the color change of rice–glucose–lysine blend during extrusion. The color of extrudates was analysed and compared by using different extrusion conditions. Extrusion process variables included moisture content, screw speed, barrel temperature, and screw geometry. The influence of specific mechanical energy input (SME) and product temperature on the color of extrudates was significant. The color parameters were related to product temperature and SME by a 4th degree polynomial. Product temperature and color were modeled and tested using rice–glucose–lysine blend at various screw configurations and extrusion conditions with reasonable accuracy. Validations of product temperature and color models were done using different screw geometries and other processing variables with reasonable accuracy. Extrusion tests indicated that the developed predictive models can be of use for extrusion processing. The results also showed that the image analysis method developed provides an objective and efficient approach for assessing the color development of extrudates.

Keywords: Twin screw extrusion; Browning; Color; Imaging analysis; Maillard reaction; Empirical modeling

1. Introduction

In many areas of the food industry, extrusion is an important manufacturing method. Uniformly processed products can be obtained in a continuous operation with variable thermal and mechanical energy inputs. Extrusion significantly increases overall palatability of foods by enhancing flavor, color, texture, and appearance characteristics. Understanding the reaction kinetics in food extrusion processing is essential for predicting food quality and controlling extrusion. Change in food color after thermal processing can be used to predict the extent of quality deterioration of food resulting from exposure to heat.

Nonenzymatic browning reactions are important phenomena that occur during food processing and storage and, depending on the system, can be either desirable or undesirable (Baisier & Labuza, 1992). Nonenzymatic browning can involve different compounds and proceed via different chemical pathways. It includes a wide number of reactions such as Maillard reaction (MR), caramelization, maderization, and ascorbic acid oxidization. Nonenzymatic browning is stated to be dependent on the temperature and water activity of the food (Driscoll & Madamba, 1994; Rapusas & Driscoll, 1995; Saguy & Karel, 1980; Warmbier, Schnickels, & Labuza, 1976). Nonenzymatic browning may develop at varying reaction rates in samples due to processing, which may cause differences in temperature and moisture distribution within the food and subsequently localized concentration of reactants (Gogus, Wedzicha, & Lamb, 1998). Fluorescence

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and browning development in MR are generally used as indicators of the reaction rate and MR product formation (Leong & Wedzicha, 2000). Many authors use color as a quality control indicator of processes because brown pigments increase as browning and caramelization reactions progress (Cammarn, Lange, & Beckett, 1990; Moss & Otten, 1989).

With high temperature, high pressure, and low moisture content of the feed, extrusion cooking often results in a colored product even though the residence time is low. As in traditional cooking processes, flavor and color are generated during cooking by a number of reactions which are controlled by the composition, temperature, and residence time. However, in extrusion cooking, these reactions are accelerated because of shear force. Although the effect of extrusion conditions on the properties of extruded starch-based foods was previously studied using a one-variable-at-a-time approach or response surface methodology (Desrumaux, Bouvier, & Burri, 1998; Govindasamy, Campanella, & Oates, 1996; Kirby, Ollett, Parker, & Smith, 1988; Miladinov & Hanna, 2001; Singh, Smith, & Frame, 1998), data on the effect of extrusion cooking conditions (such as the extrusion process variables) on the color of the product are scarce. According to Bhattacharya (1997), researchers used single-screw extruders to report the effect of extrusion variables on product characteristics that do not include the product color, whereas reports on color changes by employing twin-screw extruders are scarce.

To control the browning of food materials and keep it consistent will require more accurate and efficient browning assessment. For the evaluation of food color, instrumental methods involving colorimeters or spectrophotometers are employed. Image analysis techniques using computer vision systems have been increasingly adopted for variety classification and quality evaluation of food materials and products such as fruit (Han, Bowers, & Dodd, 1992), meat (Gwartney, Gao, Tan, & Gerrard, 1996), and pizza (Sun, 2000). Researchers also used image analysis methods to analyse the color of pork (Lu, Tan, Shatadal, & Gerrard, 2000), beer (Smedley, 1995), and potato chips (Segnini, Dejmek, & Oste, 1999). Image analysis methods provided an efficient and sample-non-destructive way to assess color properties of food materials and products. However, little work has been reported on the evaluation and quantification of the color of extruded foods with image analysis technology.

The objective of this research was to investigate whether the color of extrudates could be determined with the aid of an image analysis system. The influence of moisture content, screw speed, barrel temperature, and screw geometry on the color of rice blend was analysed and modeled. A systematic evaluation and modeling of the color development due to the twin-screw extrusion process using image analysis methods enabled us to link the color with system parameters such as product temperature (PT) and specific mechanical energy input (SME).

2. Materials and methods

2.1. Preparation of extruded model system

Rice flour (Rivland Partnership, Houston, Texas) at 9 g/100 g moisture content (wet basis), D-(+)-glucose, anhydrous (ACROS Organics, New Jersey), and L-lysine mono hydrochloride (ICN Biomedicals, Inc., Aurora, Ohio) were mixed (96.9, 3, and 0.1 g/100 g by weight) to give a homogeneous extruder feed. Particle size of rice flour was provided by Rivland to be: 95–100 g/100 g through US standard testing sieves with the openings of 320 μm, 45–65 g/100 g through 149 μm, and 25–40 g/100 g through 106 μm.

2.2. Extrusion test

The experiments were carried out with a co-rotating twin-screw extruder (DNDL-44/28D twin-screw extruder, Buhler Inc. Uzwil/Switzerland). The extruder is comprised of seven barrels, each of 4 L/D (screw length/screw diameter), and a die holder plate of 0.5 L/D. The total machine L/D is 28.5. Four separate temperature controlled oil circulating units were connected to the extruder barrels to maintain a preset temperature. Cooling water was connected to the first barrel (feed barrel). The second and last barrels were allowed to have their own temperatures. Barrels 3 and 4 were connected to one circulating oil heater. Barrels 5 and 6 were connected to another circulating oil heater. A temperature probe and a pressure transducer were inserted into the extruder channel right before the die to measure the PT and pressure at the entrance of the die. The extruder has digital displays for torque (% and Nm), PT (°C), and pressure (bar) developed during extrusion. Shaft torque is a percent number of a maximum torque. It can be displayed as % and Nm. SME is calculated from

$$\mathrm{SME} = \frac{M_{\mathrm{d}}\omega}{\dot{m}}, \quad (1)$$

where SME is the $\mathrm{w\,h\,kg^{-1}}$, M_{d} the torque [Nm]; ω the angular velocity [radian $\mathrm{s^{-1}}$, 1 rpm = 2π/60 radian $\mathrm{s^{-1}}$], $\dot{m}$ the throughput [kg/h] (van Lengerich, Meuser, & Pfaller, 1989).

Rice–glucose–lysine blend was added to the extruder with a loss-in-weight feeder (K-ML-KT20, K-Tron AG. Industrie Lenzhard, Niederlenz, Switzerland). Water was added directly to the feed barrel from an electromagnetic flow metering system (Proline Promag 50, Endress + Hauser Flowtec AG, Reinach, Switzerland). This system permits precise control of the water flow rate. The steady state of processing conditions was achieved as indicated by constant pressure, temperature, and torque readings.

Extrusion conditions (Table 1):

(1) Die geometry: two circular die holes of 3 mm diameter and a length of 6 mm