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Co-effect of salt and sugar on extrusion processing, rheology, structure and fracture mechanical properties of wheat–corn blend

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ABSTRACT

The effect of salt (0–2%) and sugar (0–10%) on the extrusion of wheat–corn blend was studied using a co-rotating twin screw extruder under the same processing settings. Reducing salt and sugar levels increased torque, die pressure and specific mechanical energy. The increased die pressure resulted in higher expansion of the extrudate with more porous structure. This was particularly evident when both salt and sugar were eliminated in the formulation. Reducing salt and sugar did not appear to influence the shear viscosity of the melt except when eliminated from the formulation. Similarly the maximum force to fracture the extrudates was also not significantly affected, except when salt and sugar were removed completely. Salt and sugar has synergistic effect on processing energy, extrudate expansion and mechanical strength. This provided a potential to decrease the sugar and salt in extruded products but still maintain textural quality.

1. Introduction

Extrusion cooking is used worldwide for the production of expanded snack foods, ready-to-eat breakfast cereals, confectionery and pet food products (Burey et al., 2009; Guy, 2001; Harper and Clark, 1979; Tran et al., 2008). Despite increased use of extrusion processes in the food and feed industries, extrusion is still art that has yet to be fully understood with regard to processing variables, ingredient interactions and the effect of material modification on textural properties of the end-products. The amount of water added to the feed for extrusion is generally low, ranging from 18% to 30%. Textural characteristic and mechanical properties of the product are the result of product microstructure that is largely dependent on the viscoelastic properties of the material matrix in the molten state before and during its expansion (Barrett and Peleg, 1992; Kokini et al., 1992; Moore et al., 1990; Robin et al., 2010).

In low moisture thermo-mechanical processing such as extrusion, the starch and protein components undergo modification at molecular levels. The semicrystalline starch granules are melted and transformed into a cohesive viscoelastic molten matrix which governs the expansion of extrudate as the material passes through the die and reaches the atmospheric temperature and pressure (Chinnaswamy, 1993; Moraru and Kokini, 2003; Robin et al., 2010). The proportion of amylose and amylopectin in starch can have a significant influence on the viscosity of starchy melt and expansion volume of extrudates. Amylopectin-rich starches expand more than amylose-based starches because the presence of short chain branches in amylopectin reduces the ability of amylopectin molecules to form entanglements, whereas the linear structure of amylose molecules allows them to form stronger interactions and thus increase the viscosity of molten starch (Chinnaswamy, 1993; Lai and Kokini, 1991). On the other hand, by increasing the moisture content and extrusion temperature, starches with amylose content at ~50% can achieve good expansion (Chinnaswamy, 1993; Launay and Lisch, 1983). Different compositions of amylose and amylopectin and starch granule morphology originated from different cereal sources (e.g. wheat vs corn) at least in part, may contribute to the differences in extrusion processing and physiochemical properties of extrudates. In addition to starch transformation, heat and shear in extrusion also changes protein conformation and allows alignment of the denatured protein molecules in the direction of flow through a restricted die. As a result, proteins form insoluble protein aggregates or fibril type networks that confer unique functional characteristics or textural properties (Areas, 1992; Harper and Clark, 1979; Ledward and Tester, 1994; Onwulata et al., 2010).

While starch and protein are the major biopolymers of feeds used for the extrusion of cereal-based foods, salt and sugar are also commonly included as minor constituents in the formulation. Although, the major driver for salt and sugar addition to food formulation is primarily to enhance the sensory properties of

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Table 1
Dry feed formulation of wheat-corn blend with various levels of salt and sugar.

Formulation	Wheat Flour (% w/w)	Corn Polenta (% w/w)	Wheat Gluten (% w/w)	Calcium Carbonate (% w/w)	Salt (% w/w)	Sugar (% w/w)
2% Salt/10% sugar	39.2	46.1	1.70	1.0	2.0	10.0
1% Salt/10% sugar	39.7	46.7	1.56	1.0	1.0	10.0
0% Salt/10% sugar	40.3	47.3	1.42	1.0	0	10.0
2% Salt/5% sugar	41.8	49.2	1.00	1.0	2.0	5.0
1% Salt/5% sugar	42.4	49.8	0.86	1.0	1.0	5.0
0% Salt/5% sugar	42.9	50.4	0.72	1.0	0	5.0
2% Salt/0% sugar	44.8	52.2	0.29	1.0	2.0	0
1% Salt/0% sugar	45.0	52.9	0.15	1.0	1.0	0
0% Salt/0% sugar	45.5	53.5	0	1.0	0	0

extruded foods such as ready-to-eat breakfast cereals and snacks, each of these ingredients also have specific physico-chemical functionality contributing to the processing characteristics and textural quality of the product. High intakes of salt and sugars have been associated with high risk of coronary heart disease, obesity, type-2 diabetes and other dietary health implications (Brown et al., 2009; Moreira, 2013; Strazzullo et al., 2012). Thus salt (more specifically sodium) and sugar reduction in extruded products is one of the important goals for food manufacturers to produce healthier foods.

The effects of sugar on extrusion processing and extrudate quality parameters have been investigated extensively. The addition of sugars increases product density and result in a reduction in expansion and pore size of corn or wheat based products (Barrett et al., 1995; Carvalho and Mitchell, 2000; Farhat et al., 2003; Mezreb et al., 2006). As a consequence, it also affects the mechanical fracture properties of extrudates and their sensory properties. The phenomenon is believed due to the co-solute effect of sugar to compete for water with starch. However, opposite findings have also been reported by Hsieh et al. (1990) who observed that the addition of sugar enhanced the radial and axial expansions of corn meal extrudate, but reduced product bulk density and breaking strength. The effect of salt (NaCl) on extrusion properties of cereals has been studied much less. In the same study, Hsieh et al. (1990) also reported that high salt (up to 3%) in the feed decreased the die pressure, torque and specific (mechanical and thermal) energy input. The addition of salt had a similar effect on the extrudate expansion and breaking strength to the addition of sugar. It is believed that the presence of sodium chloride in the extrusion melt alters the viscosity and/or glass transition temperature (T_g) of starchy based materials, thus influences the processing temperature required to convert materials from glassy state to rubbery molten flow, resulting in changes in the expansion properties (Chinnaswamy, 1993).

Although sugar and salt are known to affect the structure and texture of corn and wheat extrudates, the findings of such effects have varied. In addition, there has been little research on the co-effect of salt and sugar in extrusion. Thus this work aimed to investigate the effect of reducing salt and sugar in a wheat and corn blend formation on the extrusion processing characteristics, production quality, expansion, microstructure and textural properties of extrudates and identify correlation between rheological properties of cereal melt with the microstructure and physical attributes of the final product.

2. Materials and methods

2.1. Materials

Wheat Flour (Bakers Flour) was obtained from The Manildra Group (Nowra, Australia). The flour has 14% moisture, 11.2% protein, 1.6% fat, and 70.2% carbohydrate. Corn polenta (No. 1; Allied Mills, Australia) was purchased from a local supplier. The polenta has 10% moisture, 8% protein, 5% fat and 74% carbohydrate. Calcium carbonate was obtained from IMCD Australia Limited, and the wheat gluten (83% protein), castor sugar and salt were purchased locally.

2.2. Preparation of samples

Extruded products were made of varying concentrations of corn, wheat, sugar and salt. The different experimental formulations used for this research are shown in Table 1. Ingredients for each treatment were blended in 5 kg batches using a planetary mixer (Model NCM10, Hobart Corporation, Troy, OH, USA) using a paddle at 56 rpm for 10 min to ensure an even distribution of the ingredients. Wheat gluten concentrations were altered to the keep the protein concentration of the dry-feed at approximately 10.2%. Concentrations of salt and sugar were studied at 0–2% (w/w) and 0–10% (w/w) respectively.

2.3. Extrusion cooking

Extrusion cooking was conducted using a co-rotating twin screw extruder (MPF 19:25, APV Barker Ltd., Peterborough, UK). The barrel diameter was 19 mm and the screw configuration with a length to diameter (L/D) ratio of 25 was as follows: 11 × feed screws, 4 × 60° forward kneading paddles, 1 × feed screw, 2 × single lead screws, 4 × 60° forward kneading paddles, 2 × single lead screws, 2 × single lead screws, 5 × 30° forward kneading paddles, 4 × 30° reverse kneading paddles, 1 × 30° single lead screw, 6 × 60° forward kneading paddles, 5 × 60° reverse kneading paddles and 1 × single lead screw–discharge. Screw diameter was equal to 19 mm (1D) and one kneading paddle was equal to 0.25D. Melt pressure was measured with a pressure transducer (Terwin 2076, Terwin Instruments Ltd., Bottesford, Nottinghamshire, UK) fitted into the die block. Motor torque, barrel temperatures, die temperature and pressure were recorded manually.

The dry-blend was fed 4.9 kg/h with a twin screw volumetric feeder (K-MV-KT20; K-Tron LLC, Niederlenz, Switzerland). Ambient temperature de-ionized water was injected through a port 85 mm from the start of the barrel using a peristaltic pump (504U/RL; Watson Marlow Pumps Group, Falmouth, Cornwall, UK) to achieve a total moisture content in the barrel of approximately 20%, taking into account the moisture content of the raw materials. Total feed rate was approximately 5.4 kg.

Based on preliminary experiments, the following conditions were kept constant: 250 rpm screw speed and 3 mm die. The barrel consisted of four independent zones, electrically heated and cooled by water. Barrel temperature zones were set at 90/100/120/140 °C.

Samples were collected when the extruder was operating at a steady state (i.e. steady values for both torque and die pressure)