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Influence of physicochemical properties of Croatian maize hybrids on quality of extrusion cooking

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ABSTRACT

Extrusion cooking of maize grain is widely used in the food and feed industries. While numerous studies have sought to optimise process conditions, few studies have examined the influence of the physical and chemical properties of the raw material. In this study, several commercial maize hybrids of Croatian origin were subjected to extrusion cooking under the same conditions in a laboratory single-screw extruder. The hybrids showed the following ranges for physicochemical characteristics (all in dry matter): total starch, 679–750 g/kg; crude protein, 80.4–111.2 g/kg; crude fat, 36.3–42.8 g/kg; resistant starch, 1.63–3.03%; amylose content, 23.8–27.1% of total starch; average equivalent diameter, 11.1–12.9 μm; and circularity of starch granules, 0.90–0.92. The nutritional value of the various extrudates was assessed using resistant starch content, which varied from 0.28% to 0.40% of dry matter. Quality of the extrudates was assessed based on the expansion index, which ranged from 2.6 to 4.7. This index was higher for hybrids showing lower levels of resistant starch, amylose and crude protein, as well as larger and more spherical starch granules. These results show that selecting hybrids for extrusion can lead to more desirable product attributes.

1. Introduction

Extrusion cooking is a versatile, low-cost and efficient food processing technique. It cooks more rapidly than other techniques because it combines moisture, pressure, temperature and mechanical shear. Extrusion cooking induces numerous chemical and structural transformations in starchy and proteinaceous food materials; these transformations include starch gelatinisation, protein denaturation, complex formation between amylose and lipids, and degradation of vitamins or pigments (Ding, Ainsworth, Tucker, & Marson, 2005). In the case of starch gelatinisation, the high temperature, pressure and shear forces of extrusion cooking disrupt starch granules and create a dispersion. The higher the amylose content of the food material, the more energy is required to break the polymer bonds and gelatinise the starch molecules, leading to a rigid and stiff gel. The extrusion process fragments starch polymers, improving starch retrogradation (Chang & Wang, 1999), in which neighbouring starch molecules crystallise due to hydrogen bonding between their hydroxyl groups, and amylose forms a double-helical crystalline structure.

Extrusion cooking is widely used in the food and feed industries, where it forms the basis of preparing ready-to-eat cereals, salty and sweet snacks, indirectly expanded products, textured meat-like materials from deflated high-protein flours, precooked food mixtures for infant feeding, dry food for pets and fish and processed feed for animal diets (Medel, Salado, De Blas, & Maeos, 1999; Oryschak, Korver, Zuidhof, Meng, & Beltranena, 2010; Singh, Gamlath, & Wakeling, 2007). The quality of the extrusion product depends greatly on process parameters, including extruder type, screw speed and configuration, the temperature profile in the barrel sections of the extruder and the moisture content of the raw material (Ali, Hanna, & Chinnaswamy, 1996; Chinnaswamy & Hanna, 1988a; Ding et al., 2005; Ding, Ainsworth, Plunkett, Tucker, & Marson, 2006; Gutkoski & El-Dash, 1999; Riaz, 2000; Ryu & Walker, 1995; Thymi, Krokida, Pappa, & Maroulis, 2005; Zhuang et al., 2010).

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Although extrusion parameters have the largest impact on extrudate quality, the physical and chemical properties of the raw material also affect it (Al-Rabadi, Torley, Williams, Bryden, & Gidley, 2011; Carvalho, Takeiti, Onwulata, & Pordesimo, 2010; Chinnaswamy & Hanna, 1988b; Lee, Bean, Alavi, Herrman, & Waniska, 2006). However, these properties are rarely taken into consideration in studies evaluating raw materials for extrusion cooking. In addition, these properties vary with genotype, so it may be useful to identify which strains or variants of a food material are more suitable for extrusion cooking.

Maize grain is one of the most important cereals in the world and is widely processed by extrusion. Its high starch content makes it an ideal energy source. Maize with different genotypes can vary widely in characteristics that affect extrusion. For example, amylose content – one of the most important factors in the extrusion process – varies from 1% in waxy genotypes to up to 70% in amylomaize (Mercier, 1973). Although genotypes widely used in production and food industries are often high-yielding commercial hybrids without large variations in chemical and physical properties, differences between commercial maize hybrids do exist, leading to different nutritional values and to different responses in the extrusion process, as Lee et al. (2006) and Robutti, Borras, Gonzalez, Torres, and De Greef (2002) have shown. Determining how the various physicochemical characteristics of commercial maize hybrids affect extrudate quality may guide the selection of hybrids to yield extrudates with desirable attributes.

Since consumers demand healthy and nutritious foods, creating nutritional products is the permanent goal of food manufacturers (Yu, Ramaswamy, & Boye, 2013). Extruded maize flour products can be significantly improved to provide higher content of protein, fibre and/or resistant starch (RS). Existing amylose–lipid complexes are ranked as RS5, while high-amylose maize starch is usually classified as RS2 (Jane, Jiang, & Hasjim, 2010). RS escapes enzymatic digestion in the small intestine and passes into the colon, where microflora metabolise it into secondary products (Alsaffar, 2011). In this way, RS behaves like dietary fibre. Amylose content in maize starch can influence RS content in extrudates. The formation of new amylose–lipid complexes during extrusion (Bhatnagar & Hanna, 1994) and the formation of amylose double-helices by retrogradation during prolonged storage of extrudates is associated with higher RS content. Similarly, Rohlfing, Paez, Hyun, and White (2010) found that high-amylose tortillas had high amounts of RS, and Chiu, Henley, and Altieri (1994) described a patented technology using high-amylose starch with pullulanase to produce RS.

While increasing RS content can have beneficial dietary effects similar to those of fibre, the extrusion process can also reduce RS content (Mahasukhonthachat, Sopade, & Gidley, 2010; Wolf, 2010), which is associated with increased digestibility (Svihus, Uhlen, & Harstad, 2005). Greater starch digestibility means greater energy availability, which is important when rapid weight gain is desired. For this reason, extrusion cooking is used in animal feed production. To evaluate these changes (Utrilla-Coello et al., 2014) or to characterise selected maize varieties (Pollak & White, 1997), the thermal and rheological properties of starch are often evaluated.

The quality attributes of expanded foods are judged by their crispness, crunchiness, texture, water absorption, water solubility and pasting properties. All these attributes are directly related to the expansion of the raw material during extrusion (Ali et al., 1996; Lazou, Krokida, & Tzia, 2010; Yao, Ekenstedt, & White, 2011), with higher expansion volume associated with consumer perception of higher quality. Thus an expansion index, which can be calculated in various ways (Ali et al., 1996; Frame, 1994), was chosen as a measure of the quality of the extrudate expansion, as Ali et al. (1996) have shown for maize grits. This index facilitates the screening of hybrids as well as analysis of how genotype affects extrudate quality. Among the possible indices capturing sectional, longitudinal or volumetric expansion, we selected the sectional (radial) expansion index because of better physical sense in relation to the process.

To improve our understanding of how the physical and chemical properties of maize affect extrudate quality and thereby optimise product quality and RS content, we screened several commercial high-yielding Croatian maize hybrids. We tightly controlled extrusion process conditions within a narrow range to ensure that observed differences were due solely to hybrid characteristics.

2. Materials and methods

2.1. Materials

2.1.1. Maize samples and milling

Samples of 15 high-yield maize hybrids (Bc 244, Bc 282, Bc 354, Bc 408b, Bc 418b, Bc 462, Bc 4982, Bc 572, Bc 574, Bc 582, Bc 5982, Bc 622b, Bc 672, Klipan and Pajdaš) were provided by the Bc Institute, Zagreb, Croatia. All hybrids were grown under the same agro-climate and production conditions during the 2010 season. Each hybrid was planted in a test field of 560 m^2 in central Croatia. Maize was harvested at physiological maturity and representative samples were used for chemical analyses. They were ground in a continuous coffee mill (Eta 006790100, Eta, Slovakia) to obtain nearly identical granulation for the extrusion process. Prior to analyses, samples of maize grain and extrudates were obtained by grinding in a laboratory mill (Laboratory mill 3100, Perten, Hägersten, Sweden) equipped with a 0.8 mm screen.

2.1.2. Extrusion process

Prepared maize grits were conditioned with 100 g of water per kg of grits in a kitchen mixer for 5 min, 24 h prior to extrusion. Water content of the mixtures ranged from 196 g/kg to 206 g/kg. This step was based on our previous work showing that addition of 10% water to maize grits led to significantly higher RS in the extrudate (Smrčková, Saglamtas, Hofmanová, Šimková, & Šárka, 2013). Extrusion was performed using a single-screw laboratory extruder (Kompaktextruder KE 19/25; Brabender, Duisburg, Germany) with a barrel diameter of 19 mm and a length:diameter ratio of 25:1. The extruder was operated at a 2:1 compression ratio and loaded with prepared maize samples at a constant dosing speed of 20 rpm (feed rate range, 2.11–2.44 kg/h). The screw was rotated at a constant 120 rpm, and temperatures of barrel sections 1–4 were set to 50, 90, 110 and 130 °C, respectively. The die nozzle diameter was 4 mm. Motor torque, screw speed, barrel temperatures and melt pressure were monitored using Extruder – Winext software (Brabender). Calculated specific mechanical energy (SME) of maize extrusion ranged from 630 to 720 kJ/kg. Extrudates were cooled to room temperature and sealed in plastic bags for further analysis.

2.2. Analyses

2.2.1. Chemical analyses

Content of total starch (TS) and resistant starch (RS) was measured in grain before extrusion and in the extrudate using the Total Starch Assay, based on the amyloglucosidase/α-amylase method, and the Resistant Starch Assay, both from Megazyme International (Ireland). Apparent amylose content was determined as described by Knutson (1986) using a standard curve obtained with pure amylose (Sigma Aldrich, St. Louis, USA). True amylose content was calculated by correcting the apparent amylose content for amylopectin, according to the formula provided by Knutson (1986). Amylose content was further expressed as a percentage of TS.