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Impact of extrusion parameters on the properties of rice products: A physicochemical and X-ray tomography study

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A B S T R A C T

Rice pellets were produced by extrusion according to an experimental design varying temperature (120–135–150 °C), moisture content (17–20–23%) and screw speed (300–400–500 rpm). The internal expanded structure of the pellets was assessed by X-ray tomography and texture with a texture analyser. The extent of starch depolymerisation and the types of protein depolymerisation/interactions were studied in complement to the starch–proteins morphology assessed by microscopy. The physicochemical properties of the pellets were mainly affected by moisture and temperature, with moisture having the highest impact. High moisture content (23%) resulted in higher mean walls thickness of the extruded pellet, less starch depolymerisation, more protein aggregation through disulfide bonds and harder pellets. The internal expanded structure and texture of the rice pellets were mainly explained by protein changes and less by the extent of starch depolymerisation in this study. When proteins mainly interacted through medium energy interactions (disulfide bonds), protein aggregates were larger, cells walls thicker and pellets were less porous and harder with more fracture events. On the contrary, when proteins interacted through low energy (hydrogen and hydrophobic bonds) and high energy bonds (unextractable proteins), proteins were more depolymerised and aggregates were smaller and finely distributed, cells walls thinner and pellets were less hard with less fracture events.

Industrial relevance

- This study was undertaken in order to find the main structural attributes that are impacted by different extrusion conditions and that strongly impact the texture of extruded rice products.
- Mastering the sensory properties of extruded products is enabled by understanding the impact of processing conditions on the structure.
- In an industrial point of view, the links between process, structure, sensory and consumers' preference are key to develop products preferred by consumers.
- This study addresses the first steps of this approach, i.e. the links between process, structure and texture.

1. Introduction

Extrusion-cooking is a process of interest for the production of cereal products such as snacks and breakfast cereals. Through mechanical shear, high temperature and high pressure, it allows specific structure creation for the development of novel product properties, such as novel sensory textures.

The transformations that low hydrated flours undergo during a thermomechanical treatment such as extrusion-cooking are melting and depolymerisation of starch (Colonna & Mercier, 1983) as well as protein denaturation (Cheftel, Cuq, & Lorient, 1985). The loss of crystallinity and the destructuration of the starch granules can be observed by polarised microscopy (loss of Maltese cross and granular shape) and by the loss of gelatinisation enthalpy of the finished products measured by differential scanning calorimetry. The extent of the degradation at the molecular level, i.e. starch depolymerisation, is evidenced by a loss of apparent viscosity of the grounded products mixed with water and by the water solubility index increase (Chinnaswamy & Hanna, 1990; Hernandez-Diaz, Quintero-Ramos, Barnard, & Balandran-Quintana,

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2007). Actually, those measurements are the physical results of molecular weight modifications, bearing in mind that these measurements may be affected by the presence of other ingredients in the systems, such as hydrocolloid or fibres. Size exclusion chromatography remains then one of the best methods to quantify the extent of the depolymerisation and assess the molecular weight distribution in the final product. Regarding protein, most studies report a loss of solubility combined with protein polymerisation through the creation of disulphides bonds (Fisher, 2004; Stanley, 1989). It is thus now agreed in the extrusion field that proteins undergo changes in their molecular interactions involving covalent cross-linking, non-covalent molecular interaction, and protein–starch and protein–lipids interactions (Day & Swanson, 2013). Extrusion could also improve the digestibility of proteins (De Pilli, Fiore, Giuliani, Derossi, & Severini, 2011). Della Valle, Quillien, and Gueguen (1994) also pointed out that during extrusion, specific mechanical energy (SME) influences protein solubility of pea flour more than temperature. Jbilou et al. (2012) showed that proteins aggregation and dispersion in extruded corn flour are influenced by the screw configuration and the level of plasticizers such as glycerol. The challenge in studying chemical properties of proteins in extruded products comes from the extraction of the polymerised proteins that need to be done with reducing agents. The reducing agents allow breaking the disulphide's bonds; this consequently leads to changes in the molecular weight.

Any parameters that impacts melt viscosity, such as moisture, ingredients, and temperature, may affect the expansion of the product. The transformation of the main flour components, such as depolymerisation for starch and denaturation, aggregation for proteins modify their molecular weight and consequently, may affect melt viscosity and expansion (Fan, Mitchell, & Blanshard, 1994). The mixing of different compounds, especially the presence of particles (e.g. fibres), has also been described affecting the viscoelastic properties of the expanding matrix, as measured by on-line slit rheometry by Robin et al. (2012) for wheat flour supplemented with wheat bran. Changes in the viscoelastic properties were related to the loss of expansion of the extrudates added with wheat bran. In some cases, the presence of particles may also disrupt the continuous structure of the melt and limit its expansion (Hernandez-Diaz et al., 2007; Moraru & Kokini, 2003).

Sensory properties of such products are dependent on physicochemical characteristics of the extrudates. Mechanical measurement techniques for the assessment of products texture have been related to sensory evaluation (Duizer, 2001; Roudaut, Dacremont, & Le Meste, 1998). In order to master extruded cereals structure at different levels, i.e. expanded internal structure and macromolecules characteristics, understanding the impact of main extrusion parameters on extrudates characteristics is of importance.

Many studies deal with the impact of processing conditions on extrudates expansion at the end of the die for many types of flours (wheat, corn, oat). Extrudates are usually characterised in term of expansion ratio and bulk density, but only few studies deal with internal structure, and especially fewer on expansion of rice extrudates (Chen & Yeh, 2000), or rice extrudates with added bran (Grenus, Hsieh, & Huff, 1993). With the recent development in the microcomputed X-ray tomography area, it is now possible to assess the 3D internal structure of porous products, such as expanded extrudates, and quantify the structure by 3D image analysis (Babin, Della Valle, Dendievel, Lourdin, & Salvo, 2007; Lim & Barigou, 2004).

This study deals with extrusion of a rice-based recipe as a model system. The objective of this work was to assess the 3D internal structure of rice extrudates and their texture properties and understand the main extrusion parameters that affect them. The chemical characteristics of the main components of rice flours (starch and proteins) were also studied in order to understand the transformation they underwent during the process of extrusion-cooking in comparison to raw materials. The main components characteristics and their impact on the creation of the final 3D internal structure at the end of the die were also discussed.

2. Materials and methods

2.1. Materials

2.1.1. Raw material

Commercial rice flour Remyflo R6-200-TT was obtained from Remy Industries N.V. (Wijgmaal, Belgium) and used as raw material for extrusion. This recipe flour was composed of 90.9% starch and 8.3% proteins (db). The ash content was 0.4% and the moisture level was 9.4%.

2.1.2. Extruded products

Eleven variants of extruded rice pellets were produced with a BC21 extruder (Clextral, France) according to the experimental design described in Table 1. The extruder set-up was as follow: 5 barrels, screw length of 500 mm, and die diameter of 3 mm. The temperature of the product measured at the end of the extruder was 120 °C, 135 °C or 150 °C. The temperature profile of the extruder was set up in order to reach these temperatures. Moisture content during extrusion was adjusted to 17, 20 or 23% by water injection at the barrels. Screw speeds used were 300, 400 or 500 rpm. The resulting calculated specific mechanical energy

Table 1
Extrusion conditions used for the processing of rice flours and pellets structure.

Samples	Coded names (temperature/MC/screw speed)	Extrusion conditions				Pellets structure		
		Product temperature (°C)	Moisture content (%)	Screw speed (rpm)	SME (Wh/kg)	Porosity (%)	Mean cells size (μm)	Mean walls thickness (μm)
A1	120/17/400	120	17	400	98.8	91.0	946	62
A2	120/20/400	120	20	400	83.2	89.3	1926	82
A3	120/23/400	120	23	400	68.9	79.2	1144	118
A4	135/17/400	135	17	400	88.9	89.8	1329	75
A5	135/20/400	135	20	400	68.6	87.2	1065	68
A6	135/23/400	135	23	400	55.1	83.6	667	80
A7	150/17/400	150	17	400	79.6	87.6	446	56
A8	150/20/400	150	20	400	62.6	88.5	925	66
A9	150/23/400	150	23	400	50.1	81.5	449	74
A10	135/20/300	135	20	300	59.9	88.8	1108	71
A11	135/20/500	135	20	500	81.2	89.5	957	66