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Instrumental and sensory properties of pea protein-fortified extruded rice snacks

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ABSTRACT

Characteristic attributes of pea-protein fortified, extruded rice snacks were evaluated by mechanical, acoustic and descriptive sensory analysis. The addition of pea protein isolate (0 to 45% (w/w)) to rice flour and extruder screw speed strongly affected the expansion behaviour and therefore, textural attributes of extruded snack products. The sensory panel described the texture of highly expanded extrudates as crisp, while low expanded extrudates were perceived as hard, crunchy and non-crisp. Results of the instrumental and sensory analysis were compared and showed a high correlation between mechanical and sensory hardness ($r = 0.98$), as well as acoustic and sensory crispness ($r = 0.88$). However, poor and/or negative correlations between acoustic and sensory hardness and crunchiness were observed ($r = -0.35$ and -0.84, respectively).

1. Introduction

Extruded snacks often exhibit an expanded and crisp texture. These textural properties are generally achieved by the use of starchy materials (Day & Swanson, 2013). Many starch-based snack foods are characterised by a poor amino acid profile, but the addition of proteins to feed formulations can improve the nutritional value of extruded snacks (Brennan, Derbyshire, Tiwari, & Brennan, 2013; Day & Swanson, 2013). Legumes, such as peas, contain high quantities of proteins and essential amino acids, including lysine which is often deficient in cereals. However, protein-fortification affects the structural and textural properties and, therefore, final extrudate quality (Day & Swanson, 2013).

The texture perception of extruded snacks depends on their fracture behaviour, which in turn is determined by the extrudates' structure and the force required to crush the sample (Cheng, Alavi, Pearson, & Agbisit, 2007; Roudaut, Dacremont, Vallès Pàmies, Colas, & Le Meste, 2002). Moreover, the fracture of food is accompanied by auditory sensations and consumers usually use the emitted sound as an indication of the textural food properties and quality (Lawless & Heymann, 2010b; Roudaut et al., 2002).

Crispness and crunchiness are important quality attributes used to describe the texture of extruded snack products (Duizer, Campanella, & Barnes, 1998). Crisp products are characterised by a brittle and low-density structure, which easily breaks and generates loud and high-pitched sounds when fractured (Roudaut et al., 2002; Tunick et al., 2012). Crunchy foods exhibit harder textures and emit sounds at lower frequencies than crisp foods (Dacremont, 1995; Tunick et al., 2012).

The most reliable texture assessment of food is performed by human senses during consumption. However, sensory analysis is time-consuming, cost-intensive and the outcomes of different studies and panels are often difficult to compare (Gondek et al., 2013; Roudaut et al., 2002). Results of instrumental techniques can be related to sensory perceptions and mechanical and acoustic analysis have been used to assess the textural properties of extruded snack products (Duizer et al., 1998; Gondek et al., 2013). Extrudate expansion as well as physical and microstructural properties of rice-based extruded snacks are affected by fortification with pea protein isolate (PPI) (Philipp, Oey, Silcock, Beck, & Buckow, 2017). However, the effect of different structural properties on instrumental and sensory perceived texture of protein-fortified extruded snacks is largely unknown.

Therefore, the main objective of this study was to investigate the effect of PPI content and selected extrusion conditions on instrumental and sensory properties of extruded rice snacks. Furthermore, textural properties, such as crispness, crunchiness and hardness of extrudates were determined using instrumental methods and compared to the results obtained by descriptive sensory analysis.

Abbreviations: ANOVA, Analysis of variance; BF, Breaking force [N]; ER, Expansion ratio; F, Factor; FFT, Fast Fourier transform; ID, Identification; MFA, Multi factor analysis; PC, Principal component; PCA, Principal component analysis; PPI, Pea protein isolate; r, Pearson correlation coefficient; T, Die temperature [°C]

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Table 1
Raw material and feed formulation characteristics used in this study.

Sample	Rice flour to PPI ratio [% (w/w)]	Moisture content [% (w/w)]	Protein content [% (d.b.)[a]]
PPI 0%	100:0	12.7 ± 0.1[b]	7.9 ± 0.0[b]
PPI 2%	98:2	12.3 ± 0.1	9.8 ± 0.0
PPI 13%	87:13	11.7 ± 0.1	17.8 ± 0.1
PPI 23%	77:23	11.1 ± 0.2	26.8 ± 0.1
PPI 45%	55:45	10.3 ± 0.1	41.9 ± 0.1

[a] d.b.: dry mass basis.

[b] Standard deviation (n = 3).

2. Materials and methods

2.1. Materials

Rice flour (medium; starch: 88.5% (amylose: 15%; amylopectin: 73.5%); protein: 8%; lipid: 1%; dietary fibres 1%; ash: 1.5%; results are based on a dry mass basis) was purchased from Scalzo Food Industries (West Melbourne, Victoria, Australia) and pea protein isolate (Nutralys S85F; protein: 81.5%, lipid: 6%, ash 5%, carbohydrates: 3%, dietary fibres: 1%, other fibres: 3.5%; results are based on a dry mass basis) from Axieo Pty Ltd. (Kew, Victoria, Australia). Formulations with different ratios of rice flour to PPI were prepared to obtain total protein contents ranging from 9.5 to 42% on a dry mass basis. The moisture and protein content of the raw materials and feed formulations used during extrusion processing were determined as described by Philipp et al. (2017) and are summarised in Table 1.

2.2. Extrusion processing

Extrusion processing was conducted as described by Philipp et al. (2017) using a co-rotating, twin-screw extruder (Evolum, model EV032; Clextral, Firminy, France) with a screw diameter of 32 mm and a length to diameter ratio (L/D) of 24. The six barrel heating zones were set to 30/50/80/110/130/130 °C, respectively, with a die temperature of 130 °C. The total barrel moisture content of the different feed formulations (Table 1) was adjusted to 19, 21 or 23% (wet basis) through injection of water at ambient temperature. A total feed rate of 30 kg/h was used throughout the experiments with screw speeds of either 400 or 600 rpm. A circular single orifice die with an aperture diameter of 2 mm was used throughout. Samples were collected when the extruder was operating at a steady state and minimal variation of extrusion system parameters was observed. Extrudates were cut into pieces of approximately 150 mm length and dried in a temperature controlled room at 40 °C for up to 48 h. Dried extrudates were sealed in low-density polyethylene bags (Venus Hartung Pty Ltd., Richmond, Victoria, Australia) and stored at 20 °C until required for further analysis. The sample identification (ID) and extrusion conditions are outlined in Table 2.

Table 2
Sample ID of extrudates and extrusion processing parameters.

Sample ID	PPI content [% (w/w)]	Extrusion processing conditions[a]		
		T [°C]	MC [% (w/w)]	SSP [rpm]
S 1	0	130	21	600
S 2	2	130	21	600
S 7	13	130	21	400
S 8	13	130	21	600
S 9	13	130	23	600
S 10	13	130	19	600
S 3	23	130	21	600
S 4	23	130	21	400
S 5	45	130	21	400
S 6	45	130	21	600

[a] T = die temperature, MC = moisture content, SSP = screw speed.

2.3. Extrudate characteristics

2.3.1. Radial expansion ratio

The radial expansion ratio (ER) was determined using the method described by Philipp et al. (2017). The diameter was measured at five different locations along the 150 mm strand. Ten extrudates per experiment condition were analysed.

2.3.2. Colour

The colour of raw materials and extrudates was measured using a Chroma Meter (CR-300, Konica Minolta Pty Ltd., Melbourne, Victoria, Australia) with an 8 mm diameter measuring area and a 0° viewing angle. The instrument was calibrated (Y = 93.7, x = 0.3135, y = 0.3199) with a white calibration plate (CR-A43, Konica Minolta) before use. Extrudates were milled prior to colour measurements for up to 30 s in a mixer mill (MM 400, Retsch Inc., Haan, Germany) at a frequency of 20 Hz. The ground extrudates were passed through a 0.5 mm mesh sieve to ensure a uniform particle size distribution. The colour of raw feed materials and extrudates was expressed as the average of three L*, a* and b* readings.

2.3.3. Mechanical and acoustic texture properties

Mechanical texture properties of the extruded samples were determined by running a fracture test. Measurements were conducted using a universal testing machine (LRXPLUS 01/2962, Lloyd Instruments Ltd., West Sussex, United Kingdom) equipped with a 2.5 kN load cell. Four pieces of extrudates were cut to a length of approximately 80 mm and placed in a single layer across the bottom of a Kramer Shear Cell consisting of five blades. The travel distance of the blades was 40 mm and a compression speed of 60 mm/min applied. The peak force extracted from the force-displacement curve was taken as the breaking force (BF) of the samples.

The sound produced during the fracture of extrudates was recorded using an acoustic sensor (K6 modular microphone system, Sennheiser Electronic GmbH and Co. KG, Wedemark, Germany) and a Sound Blaster X-Fi™ PC card (Creative Technology Ltd., Jurong East, Singapore). The equipment was placed inside an acoustically isolated anechoic chamber to reduce the environmental noise. Mechanical and acoustic properties were recorded and analysed using the software "Run Lloyd instrument version 0209" and "Acoustic Analysis version 0509". Both applications were designed using the graphical programming packages LabView™ 6i and Sound and Vibration Toolkit™ 1.0 (National Instruments Corporation, Austin, Texas, United States of America). The software "Run Lloyd instrument version 0209" was used to control the recording of mechanical and acoustic signals at a real time digital conversion of maximal 44,100 Hz (points/sec). After collecting the mechanical-acoustic data by the first program, the application "Acoustic Analysis version 0509" was used to apply a multi-stage analysis where time based amplitude values were aligned with frequency bands from 25 to 16,000 Hz (given in third octave intervals) via Fast Fourier transform (FFT) functions. Furthermore, the use of "Acoustic Analysis version 0509" allowed a separation of the sound produced by the fracture of the samples from the noise created by the texture analyser. Specific settings were used to obtain a set of amplitude values that did not include any background noise: Maximum noise loop = 23, Minimum noise loop = 10, Start data loop = 25, Number of scans at a time = 22,050 points/0.5 s and noise subtraction of 3 dB (default settings). Five measurements were performed for each sample.

The obtained FFT data set contained amplitude and frequency data recorded over the time of extrudate fracture. The frequency data range (25–16,000 Hz) was divided into the three main intervals "low" (25–1000 Hz), "medium" (1250–6300 Hz) and "high" (8000–16,000 Hz) and associated with the textural attributes