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High moisture extrusion cooking of pea protein isolates: Raw material characteristics, extruder responses, and texture properties

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ABSTRACT

The production of palatable meat analogues using high moisture extrusion cooking is a complex process that depends on both the properties of the protein ingredients and the extrusion conditions. Three commercial pea protein isolates were compared in order to investigate which protein properties affect extruder responses and product texture properties. The comparison revealed that although their basic chemical compositions were similar their functional properties affected the viscosity of the protein mass during the initial heating phase of the extrusion process. The product texture properties depended on the cooking temperature and were basically similar among the proteins, although considerably different energy input was observed during texturization. Our findings show that pea protein isolates are valuable raw materials for the development of fibrous whole-muscle meat alternatives, opening up a wide range of products for different consumer requirements.

1. Introduction

By 2050 the world's population is projected to reach 9 billion and 70% more food will be required (Aiking, 2011). Between 1950 and 2000 meat production increased from 45 to 229 million tons and this is expected to increase to 465 million tons by 2050 (Steinfeld et al., 2006). The inherently inefficient conversion of plant protein into animal protein as a result of animal metabolism makes meat production responsible for a disproportionate share of environmental pressures such as land use, freshwater depletion, global warming and biodiversity loss (Steinfeld et al., 2006). A promising solution to reduce the impact of meat production on the environment could be offered by partial replacement of meat protein with plant protein products in the human diet (Smil, 2000).

Since the 1960s extrusion cooking has been employed to produce meat analogues using common starches and proteins as raw materials. The traditional extruded meat analogues produced by low moisture extrusion (< 35%) have a sponge-like texture and require rehydration prior to consumption (Guy, 2001). These products are used as meat extenders or ground meat substitutes. However, they fail to mimic the appearance and texture of fibrous whole-muscle meat.

One promising technology for obtaining fibrous meat-like structures from plant proteins is the high moisture extrusion cooking (HMEC) process. The proteins are plasticized and texturized in a long cooling die by varying the moisture, temperature, pressure and shear respectively (Noguchi, 1990). The combination of these process parameters results in molecular transformation and chemical reaction of the protein molecules which contribute to stabilization of the three-dimensional network formed after the extrusion step (Chen et al., 2011; Liu and Hsieh, 2007).

One key feature of high moisture meat analogues is their fibrous structure which resembles muscle meat. In order to investigate textured protein products, several methods for textural profiling have been used. Texture profile analysis, a common method that determines the compression force of a probe, has been reported to relate little to fiber formation under high moisture extrusion conditions (Lin et al., 2000). Another approach is to measure the force and deformation at rupture upon stretching of extrudates. Due to high variability of the results, Thiebaud et al. (1996) suggested texture determination by shearing. This resembles the sensation when food is first cut by the front incisors when introduced into the mouth and is a common objective method for evaluating beef tenderness (Caine et al., 2003; de Huidobro et al., 2005). Evaluation of the cutting strength in longitudinal and transverse directions, with respect to the flow direction in the cooling die, has been used to assess the quality of fiber formation (Chen et al., 2010; Fang et al., 2013).

The effects of the protein ingredients and extrusion conditions on final product texture are reflected by their influence on extruder responses such as motor torque, die pressure, and specific mechanical energy (SME). Upon thermal energy input, macromolecular transformations influence the rheological properties of the protein–water melt in the extruder barrel and the cooling die

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resulting in specific texture characteristics of the extrudates (Chen et al., 2010). Consequently, SME values relate to the apparent viscosity within the extruder barrel and can help to monitor and compare changes in the proteinaceous matrix during extrusion texturization.

In order to improve the process stability and fiber formation during HMEC, it is important to investigate the relationships between the protein ingredient properties, extruder responses, and product texture. Earlier work on low moisture extrusion of soy protein showed that both the processing conditions and texture properties are affected by the protein properties, in particular the protein concentration and protein solubility (Riaz, 2004). Under high moisture conditions, there are several published studies about the effects of process parameters on extruder responses and product properties such as texture and protein solubility (Chen et al., 2010; Fang et al., 2014; Lin et al., 2002). Until now, it is not clear which raw material properties might affect extruder responses and product texture.

Recent HMEC studies have focused on soy as a raw material (Chen et al., 2011, 2010; Lin et al., 2000; Liu and Hsieh, 2008; MacDonald et al., 2009). However, a number of drawbacks are associated with the use of soybean such as the presence of antinutritional factors, its allergenic potential, and the introduction of genetically modified organisms (Martínez-Villaluenga et al., 2008). As an alternative to soy, pea protein is of special interest due to its nutritional characteristics and low potential for allergic responses (Nowak-Wegrzyn et al., 2003). Only a few studies have been undertaken using pea seeds (Alonso et al., 2000), pea flour (Hood-Niefer and Tyler, 2010) and pea protein concentrate (Wang et al., 1999) for texturization under low moisture conditions. To the best of our knowledge no work has been published on HMEC with pea protein isolate (PPI) and, in detail, about the effect of extrusion temperature on extruder responses and product texture.

The objective of this study was therefore to investigate high moisture extrusion of three different PPIs with regard to the protein ingredient characteristics, extruder responses, extrudate texture properties, and their interactions. This could lead to improved understanding of the way proteins interact and form a fibrous meat-like texture.

2. Materials and methods

2.1. Characterization of protein ingredients

Three commercial pea protein isolates (*Pisum sativum* L.) were used: Pisane®M9 (Cosucra Groupe, Warcoing, Belgium), Emvital®E7 (Emsland-Stärke GmbH, Emilchheim, Germany), and Nutralys®F85M (Roquette Frères S.A., Lestrem, France), which were designated PPI 1, PPI 2, and PPI 3. These materials were all kindly provided by the respective manufacturers.

The chemical compositions of PPI 1-3 are summarized in Table 1.

2.1.1. Chemical composition

The total dry matter was analyzed according to the German Food Act (2005). Samples were dried to weight constancy at 105 °C in a thermogravimetric system (TGA 601, Leco Corporation, St. Joseph, MI, USA). The ash contents were determined in a thermogravimetric system (TGA 601, Leco Corporation, St. Joseph, MI, USA) at 950 °C until weight constancy (AOAC International, 1990). The protein contents were calculated based on the nitrogen content (N) according to the Dumas combustion method described in the German Food Act (2005) using a Protein/Nitrogen Analyzer FP 528 (Leco Corporation, St. Joseph, MI, USA) with a conversion factor of 6.25 (Shand et al., 2007; Sumner et al., 1981). The total lipid content was determined including fatty acids from phospholipids according to the method of Caviezel, DGF K-I 2c (00) (DGF-Einheitsmethoden, 2004). Native and partially hydrolyzed starch was analyzed by determination of glucose units following complete hydrolysis with amyloglucosidase, using a Biopharm assay kit (R-Biopharm AG). All analyses were performed in duplicate.

Table 1
Major chemical composition of PPIs.

Material	Dry matter (%)	Ash (%)	Protein (%)	Lipid (%)	Starch (%)
PPI 1	93.4 ± 0.1	5.1 ± 0.0	84.9 ± 0.4	7.7 ± 0.3	0.4 ± 0.0
PPI 2	94.2 ± 0.0	4.2 ± 0.0	87.3 ± 0.1	8.3 ± 0.1	0.0 ± 0.0
PPI 3	94.3 ± 0.0	5.4 ± 0.0	83.2 ± 0.1	7.4 ± 0.1	0.4 ± 0.1

2.1.2. Particle size distribution

The particle sizes of the protein powders were determined using a Malvern laser diffraction particle size analyzer (Mastersizer S Long Bed Version 2.15, Malvern Instruments Ltd., Malvern, UK). Powders were dispensed in a wet dispersion unit using 1-butanol (VWR, Germany). Volume diameters D(v, 0.1), D(v, 0.5) and D(v, 0.9) were calculated from the particle volume distributions of the respective isolates.

2.1.3. Thermal properties

Differential scanning calorimetry (DSC) was used to analyze the thermal properties of pea protein slurries (30% w/w) according to the method of Sousa et al. (1995). Approximately 10 mg of the protein slurry was weighed into aluminum pans. The pans were hermetically sealed and heated from 40 °C to 120 °C at a rate of 5 °C/min on a DSC instrument (Q2000, TA Instruments, USA). Each sample was reheated one time to verify that there was no reversibility of denaturation. The onset temperature (T_0), peak transition temperature or denaturation temperature (T_s), and enthalpy of denaturation (ΔH) were computed from the thermograms. Triplicate measurements were carried out for each sample.

2.2. Functional properties

2.2.1. Protein solubility

Protein solubility was determined according to the procedure used by Morr et al. (1985) by mixing an aliquot of 1 g of protein with 50 mL 0.1 M sodium chloride solution and incubating at ambient temperature in a shaking water bath for 60 min. The pH was adjusted using 0.1 M hydrogen chloride or sodium hydroxide solution respectively. The non-dissolved fraction was separated by centrifugation at 20,000*g* for 15 min at ambient temperature. The protein content in the supernatant was measured by a combustion method based on an AOAC method according to Dumas using a LECO analyzer. Duplicate measurements were undertaken for each sample.

2.2.2. Water binding capacity, oil binding capacity, emulsifying capacity

The determination of the water binding capacity (WBC) was performed according to the AACC (1982) method and expressed as the weight of water bound by 1 g of sample.

The oil binding capacity (OBC) was determined by the procedure used by Lin et al. (1974) and expressed as grams of oil bound by 1 g protein sample.

The emulsifying capacity (EC) was determined according to the method of Wäsche et al. (2001) by continuous addition of oil to an oil-in-water emulsion to the point of phase inversion of the emulsion. The volume of oil needed for phase inversion was used to calculate the emulsifying capacity (mL oil per g protein isolate). In order to compare the functional properties of the PPIs at the