ABSTRACT

Title of Document: Texture optimization of soy protein isolate post high-moisture extrusion as an alternative dietary protein source

Haiqin Ge, Master of Science, 2011

Directed By: Y. Martin Lo, Ph.D.

Nutrition and Food Science

Soy protein isolate (SPI) has been used as an alternative protein source in texturized meat analogs due to its high protein content and health benefits. Twin-screw high-moisture extrusion was capable of texturing and shaping SPI into fibrous slabs similar to that of cooked skinless chicken breast yet harder and more rubbery due to significant post-extrusion moisture loss. The texture of extruded SPI was further optimized in the present study to reduce hardness and rubberiness. The combination of acetic acid treatment under pH 4.5 at 65°C for 50 min with addition of 0.1% (w/v) mixture of cornstarch and xanthan gum at a 3:2 (w/w) ratio yielded a tender SPI meat analog with desirable color closest to that of cooked skinless chicken breast. A novel vegetarian nugget based on the modified SPI meat analog was formulated and received consumer acceptance superior to commercial counterparts in its texture without detectable soy flavor.

2.1.2 Factors affecting SPI properties

Numerous amounts of research has been conducted to evaluate the effects of various factors such as pressure, pH, temperature, polysaccharides, and salts that affect the properties of SPI (Table 2.3) (Hermansson,1986; Carp, 1998; Kim, 2004; Puppo, 2005; Jaramillo, 2011). The emulsifying capabilities of 7S and 11S could be significantly improved by pressure, both pH and polysaccharides can increase the solubility of the SPI (Carp, 1998; Kim, 2004), in addition, polysaccharides can also increase the stability of SPI (Ye, 2008), and finally, salt can cause the denaturation temperature to increase by approximately 8 ºC (Braga, 2006).

2.1.3 Texturized SPI

Texturized SPI, usually obtained by extrusion, has been used as a meat replacement in dry fermented sausage and co-extruded snack sticks (Hoogenkamp, 2005; Qammar et al., 2010); it is also a major component in fabricating the structure of meat analog (Rareunrom et al., 2007), and is considered to be the major type of texturized plant protein (TPP). The extrusion of texturization isolate does not appear to reduce the nutrient content of human diets, compared with that of non-extruded soy protein isolates (Hsieh et al., 2009). Research has demonstrated that the extruded soy protein isolate yields a similar growth rate in the weight of rats within a certain period of time to that obtained from commercial soy protein isolates, indicating that the process does not significantly alter the overall digestibility of the soy isolate (Hsieh et al., 2009).

Table 2.3. Various processing parameters affecting the physicochemical properties of soy protein isolate (SPI)

Parameters	Effects	References
Pressure	• Significantly improves the emulsifying activity of 7S and 11S at 400 and 200 MPa • In terms of structural properties, increased pressure levels decrease the α-helix content and increase the random coil content • Significantly increases aggregate formation (combined with insoluble and soluble aggregates) to a similar extent between pressure levels of 200-600 MPa • Extends the molecular structure of soluble aggregate formation above 400 MPa	Puppo, 2005 Tang, 2009
Temperature ↑	• Increases the dispersibility, corresponding to an increases in hydrophobicity • Increases storage modulus and hardness of glucono-δ-lactone induced gel with soy protein • Heat-denature helps modify the structure of glycinin	Hermansson, 1986 Kim, 2004
pH ↑	• Significantly increases solubility	Jaramillo, 2011
Polysaccharides ↑	• Improves solubility • Increases stability	Ye, 2008 Carp, 1998
Salt ↑	• Increases denaturation temperature by about 8ºC	Braga, 2006

Additionally, general sensory evaluation of foods indicated that the moisture content of the product is a significant factor in relation to "toughness," "chewiness," "springiness," and "mushiness" (Lin et al., 2002). According to this study, products with a more orderly directional structure possess a higher degree of hardness or chewiness (Lin et al., 2002). As chewiness and hardness remain the largest textural hurdles in consumer acceptance, particularly in Western-style diets, it is critical that the texture of the extruded SPI be further modified in order to expand the market for these products, enabling more consumers to enjoy the nutritional quality of extruded/texturized SPI.

2.2 Extrusion and Extruders

A thermo-mechanical operation providing continuous mixing, kneading, and shaping (Akdogan et al., 1999), extrusion cooking involves three key steps: (1) the raw material is fed into a hopper and gradually mixed (mixing); (2) the mixture is forced to flow through the passage between a rotating screw and a stationary barrel, usually steam-heated (kneading); and (3) the well-mixed ingredients are pressurized against the end of the barrel and exit via a small outlet called die (Sebastian et al., 1991; Riaz, 2000). It is the combination of all three steps that determines the physical attributes of the final product (Akdogan et al., 1996; Sun et al., 2011). Four types of commonly used extruders include: single-screw wet extruders, single-screw dry extruders, single-screw interrupted-flight extruders, and twin-screw extruders. Table 2.4 highlights the different characteristics with the pros and cons of each type of extruders currently available.

Among those extrusions mentioned before, regular and high moisture extrusion, different in the moisture content during the process, are widely used among industries (Akdogan et al., 1999). In fact, extrusion has long been used to fabricate meat-like texture and plexilamellar structure using plant protein (Burgess and Stanley, 1976).

Table 2.4. Comparison of the key characteristics of different extruders (adapted from Riaz, 2000)

Extruders	Features	Advantages	Disadvantages	Applications
Single-screw wet extruder	Live bin Feeding single screw Preconditioning cylinder Extruder barrel Die Knife	Easy operation Less training required Low cost Higher capital investment	Poor mixing ability Not self-cleaning enough Limitation on the size, species of raw ingredients	Precooked or thermally modified starches
Single-screw dry extruder	Live bin Feeding single screw Preconditioning cylinder Screw segments Steam-locks Extruder barrel Die Knife	Relatively low capital investment Can be adjusted to fit all types and sizes of installations Less training required	High power requirement Limitation on sizes of final products Functions poorly with ingredients with high fat content and highly viscous materials Initial moisture content is important	Recycling wet waste from food and animal by-products

Table 2.4. Characteristics of different extruders (Riaz, 2000) (cont.)

Single-screw interrupted-flight extruder	Feeding zone Rotating worm shaft Single screw extruder barrel Die Knife	Relatively less expensive Easy to operate Easily replaceable A wide variety of preconditioners can be adapted Lower power requirement High shear, turbulent mixing action can knead solid formulation	Limitation on heating in the barrel Limitation on maximum barrel temperature (150°C) Less versatile Difficult to control processing conditions	Oilseed preparation for solvent extraction
Twin-screw extruder	Live bin Feeding screw Preconditioning cylinder Extruder barrel Jacketed heads Rotating screw Die Knife	Uniformly-shaped products Higher internal fat content ingredients can be accepted (up to 18%) Variety in the range of raw materials that can be included: oily, sticky, or wet Wide range of sizes of the materials	More expensive and higher cost to maintain Relatively complicated to operate	Ravioli; meat analog; spaghetti

Nevertheless, high moisture extrusion is gaining popularity due to the fact that the products obtained often have a more tenderized texture compared to other types of extrusion and the moisture of the product is easy to control (Akdogan et al., 1999; Ranasinghesagara et al., 2006; Singh et al., 2007; Sun et al., 2011).

2.2.1 Effects of extrusion

During the extrusion process, the control of operating parameters, including prior processing history of feed materials, material feed rate, screw speed and configuration, barrel temperature, and die configuration, has a critical effect on the physical properties and chemical characteristics of the final product (Lin et al., 2000; Chevanan et al., 2008; Wei et al., 2009), which can directly or indirectly impact the final product's nutritional quality (Table 2.5). For instance, due to the high barrel temperature, most vitamins are destroyed, whereas the mineral content of final products may be increased as a result of the abrasion of the interior of the extruder barrel and screws by certain types of food materials.

Moreover, the texture of meat analog made from texturized SPI via extrusion is found to depend upon such processing parameters as moisture content and cooking temperature (Singh et al., 2007). The higher the moisture content, the lower the viscosity the product (Lin et al., 2002). On the other hand, reduction in the moisture content can cause the texturized soy product to become more directionally aligned, thus yielding a product showing similar texture to that of skinless chicken breast (Ranasinghesagara et al., 2006). However, increase in product hardness becomes

Table 2.5. Effects of extrusion process on nutrients contents

Nutrients	Nutrition Effects	Reference
Carbohydrates	Starch increases the rate of gelatinization at much lower moisture levels (12-22%) Branches on amylopectin molecules sheared off	Jin, 1994
Protein and amino acids	The digestibility of protein is improved from the enzyme-access sites	Camire, 2001
Lipids	Products will have lower lipid levels, and the recovery of lipids is improved	Camire, 2001
Dietary fiber	Total fiber values will remain balanced due to the increase in soluble fiber and the decrease in insoluble fiber	Camire, 2001
Vitamins	Most of the vitamins will be destroyed, aside from Vitamins D, K, and B_2	Camire, 2001 Andersson,1990
Minerals/Metals	The mineral/metal content (including possibly hazardous metal fragments) of the final products may increase	Camire, 1993

evident after frozen storage and consequently renders the product unpalatable. In order to enhance the quality of the product, it is critical that the hardness be reduced without giving off any soy (beany) flavor.

2.3 Polysaccharides

2.3.1 Xanthan Gum

Xanthan gum, a polysaccharide derived from the bacterial coat of *Xanthomonas campestris*, has served as an important commercial microbial polysaccharide (Katzbauer, 1997). This polymer consists of a linear (1-4)-β-D glucose backbone with a negatively charged trisaccharide side chain on each second glucose residue (Braga, 2006).

Xanthan gum is soluble in both cold and hot water, and its thermal stability against hydrolysis is generally superior to many other water-soluble polysaccharides or polymers (Stokke, 1996). It is also stable over a broad range of pH values, not only on account of its stability but also due to its shear-thinning behavior, also referred to as pseudoplasticity (Katzbauer, 1997). This stability can be explained by the fact that the conformational status of the polymer molecules contained in xanthan gum is stabilized by hydrogen bongs (Cuvelier, 1986). Pseudoplasiticy enhances certain sensory qualities (flavor release, mouth feel) in food products (Katzbauer, 1997).

Due to its stability, xanthan gum has been utilized in a variety of different industrial applications (Katzbauer, 1997). Table 2.6 summarizes its different applications,

Chapter 6: Conclusions

Post-processing frozen storage was found to adversely affect the quality of high-moisture-extruded SPI, yielding products with unsatisfactory texture (hard and rubbery) and undesirable color (dark and yellowish-brown). Such shortcomings were improved significantly by employing a series of optimized treatment combining pH adjustment, temperature modification, and polysaccharides. The modified SPI meat analog was softer than the original with a lighter color after rehydrating the SPI meat analog in an acetic acid solution at pH 4.5 and 65 °C for 50 min alongside the treatment with a cornstarch/xanthan mixture at a ratio of 3:2 totaling 0.1% (v/w).

Additionally, a novel product "M nugget" utilizing the modified SPI meat analog was successfully developed to mimic chicken nuggets, as evidenced by its desirable texture while eliminating soy flavor. These characteristics were confirmed by organoleptic evaluation against commercially available conventional chicken nuggets and vegan nuggets. The M nugget was shown to have significantly higher consumer acceptance especially among vegetarians for its texture; moreover, soy flavor was not detected. Not only are the texture and flavor of the M nugget desirable, its low fat, low sodium, and high protein content also makes the M nugget one competitive dietary protein source on the market.