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Fish protein isolate: Development of functional foods with nutraceutical ingredients

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ABSTRACT

Fish processing by-products are usually discarded. However, they contain protein and ω-3 fatty acids. Isoelectric solubilization/precipitation (ISP) allows efficient recovery of fish protein isolate (FPI) that can be used in the development of nutraceutical products destined for human consumption. In the United States, market for nutraceutical food products in 2007 was estimated to be worth $27 billion. Forecasts for growth of nutraceutical food products range between 8.5 and 20% per year or about four times that of the food industry in general. With this demand for new products comes a need for product development and supporting literature. Consumers expect nutraceutical food products to have good sensory quality that is similar to the traditional foods in the market. Thus, this contribution focuses on the development of nutraceutical seafood products from ISP-recovered FPI by incorporating such ingredients as ω-3 oil, dietary fiber, and salt substitute.

1. Introduction

Consumers' demand for healthy food products is increasing worldwide. New products must fit not only the consumer needs, but also their lifestyle and income. Although health aspects have to be considered for all foods, the market growth for functional foods currently outpaces traditional food products. The global demand for functional foods was estimated to be about $100 billion in 2013 (Smith & Charter, 2010). Development of functional foods involves incorporation of specific compounds (or ingredients) with demonstrated health benefits (Hamer, Owen, & Kloek, 2005). There is a variety of strategies to modify food products in order to achieve desirable health effects (Duchateau & Klaffke, 2008). In addition to the importance of the health effects; sensory attributes such as taste, texture, and flavor as well as convenience remain crucial factors for consumers.

In the fish industry, processing of raw fish into food products generates large quantities of by-products that contain proteins and lipids. If recovered, these proteins and lipids could be a source of nutrients for humans; and therefore, could be used in the development of food products destined for human consumption. Isoelectric solubilization/precipitation (ISP) allows selective, pH-induced water solubility of meat proteins with concurrent separation of lipids and removal of materials not intended for human consumption such as bones, skin, etc. (Chen & Jaczynski, 2007a, 2007b; Gehring, Gigliotti, Moritz, Tou, & Jaczynski, 2011). Although ISP offers efficient recovery of high-quality fish protein isolate (FPI), there have been no success-

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ful food products launched in the market. Functional seafood products could be developed from the ISP-recovered FPI.

The diet of industrialized nations has been characterized as being (1) high in saturated fat, ω-6 fatty acids, trans-fatty acids, and sodium; but (2) insufficient in ω-3 fatty acid and fiber (Eaton & Konner, 1985; Eaton, Konner, & Shostak, 1988; Simopoulos, 1999a). These characteristics are considered dietary risk factors for cardiovascular disease (CVD), which has had an unquestioned status of the number 1 cause of death in the United States since 1921 (American Heart Association, 2009). Therefore, this article discusses a 3-prong strategy to address the diet-driven CVD by developing functional foods whose main ingredient is the ISP-recovered FPI with added omega-3 polyunsaturated fatty acids (ω-3 PUFAs) (prong 1), salt substitute (prong 2), and soluble dietary fiber (prong 3). The health benefits of these added nutraceutical ingredients and their current intakes have been extensively reviewed in the literature; and therefore, are not discussed in this article.

2. Fish processing by-products as food ingredients

Definitions of food processing “by-products” have been misunderstood. Three terms, namely “offal”, “waste”, and “by-products” are frequently and interchangeably used in the fish processing industry and scientific literature to describe the same material (Gehring et al., 2011). The first two terms imply that this material simply cannot be used for any application and should be disposed of; and therefore, are often misleading and trigger a negative connotation. The third term suggests to some extent that there may be some valuable components to be recovered if the “by-products” are treated properly; and therefore, it is a positive term. Currently, the most common definition of “by-products” is all of the edible and inedible materials left over following processing of the main product. A typical example is fish filleting to recover boneless and skinless marketable fillets. The fillets would be considered the main product and the frames, heads, and viscera would be typical “by-products” (Strom & Eggum, 1981).

There are different estimates as to how much by-products are available. The FAO estimates postharvest losses related to processing to be 25% of the catch. The amount of by-products from seafood processing varies significantly depending on the species, size, season, and fishing ground (Falch et al., 2006). However, up to 50% of raw seafood is commonly discarded during commercial processing (Guerard, Sellos, & Le Gal, 2005). Others have reported that seafood processing discards and by-products constitute as much as 75% of the total catch weight (Shahidi, 1994). Nevertheless, with a grand total of approximately 100 plus 50 million metric tons of annual catch from marine resources plus aquaculture, respectively (FAO, 2011), the amount of seafood processing by-products is tremendous. Therefore, there is a significant opportunity for developing value-added products including nutraceutical seafood products from this raw material. However, a proper meat (i.e., protein) recovery technology has to be developed and successfully implemented at a commercial scale so that the recovered meat can result in added revenue for a processor as well as reduce environmental pollution associated with disposal of the seafood processing by-products.

3. Recovery of proteins and lipids from fish processing by-products using isoelectric solubilization/precipitation

In fish muscle homogenates, myofibrillar proteins are present as aggregates that are held together by weak protein–protein hydrophobic interactions (Undeland, Kelleher, Hultin, McClements, & Thongraung, 2003). However, depending on the conditions that the fish muscle proteins are subjected to, the protein side chains can assume different electrostatic charges (Fig. 1). This means that the solubility of fish muscle proteins can be “turned” on or off by providing conditions that either favor or disfavor protein solubility, respectively. When acid is added to a solution, it dissociates yielding hydronium ions (H_3O^+). Protonation of negatively charged side chains on glutamyl or aspartyl residues results in an increased net positive surface charge. Similarly, when base (^-OH) is added to a solution, deprotonation of side chains on tyrosyl, tryptophanyl, cysteinyl, lysyl, argininyl or histidinyl residues contributes to an increased net negative surface charge (Fig. 1). Consequently, solubilization of fish muscle proteins is ascribed to protonation of aspartyl and glutamyl ($pK_a = 3.8$ and 4.2, respectively) residues under acidic pH and deprotonation of lysyl, tyrosyl and cysteinyl ($pK_a = 9.5–10.5$, 9.1–10.8, and 9.1–10.8, respectively) residues at basic pH. When the charge equilibrium is reached and a protein solution attains homeostasis, the final status of a protein surface electrostatic charge at a given pH is referred to as the net charge. The accumulation of a net positive or negative charge induces protein–protein electrostatic repulsion and an increased hydrodynamic volume due to expansion and swelling (Kristinsson, Theodore, Demir, & Ingadottir, 2005; Undeland et al., 2003). As proteins assume more positive or negative net charge, they gradually start electrostatic interactions with water (i.e., protein–water interactions). Due to increased protein–water interactions, the protein–protein hydrophobic interactions decrease. Therefore, as the protein molecules become more polar (charged), more water associates on and around the protein surface and proteins become water soluble. However, it is possible to adjust the pH of a protein solution so that the number of negative charges on the protein’s surface is equal to the number of positive charges, and therefore, the protein molecule assumes a zero net electrostatic charge. The pH at which the net electrostatic charge of a protein is equal to zero is called the isoelectric point (pI) (Fig. 1). The pI is very specific for different proteins, and isoelectric focusing is often used to pinpoint the pI.

The aforementioned provides theoretical foundation for isoelectric solubilization/precipitation (ISP) that allows mechanistic understanding of pH-mediated protein solubility. Provided that the pI for the protein of interest is known, the ISP principles can be universally applied to recover muscle proteins from food animal processing by-products, including fish. Fish protein isolates (FPIs) have thus far been recovered using ISP in a batch mode at the laboratory scale (Choi & Park, 2002; Kim, Park, & Choi, 2003; Kristinsson & Hultin, 2003; Undeland,

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