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Review

A review: Protein isolates recovered by isoelectric solubilization/precipitation processing from muscle food by-products as a component of nutraceutical foods

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ABSTRACT

It is possible to recover muscle protein isolates from food processing by-products and under-utilized or difficult to process sources that otherwise would be discarded or diverted from direct human consumption by using isoelectric solubilization/precipitation (ISP). ISP selectively induces water solubility of muscle proteins by changing pH. When muscle proteins are dissolved, they are separated from lipids and other insoluble fractions such as skin, bones, scales, etc. Following separation, the dissolved proteins are subjected to subsequent pH change that causes protein precipitation and yields protein isolate. ISP processing efficiently recovers protein isolates of high quality from both nutritional and technological stand point. However, attempts at commercializing food products developed from the ISP-recovered protein isolates have been very limited. Results from laboratory-scale product development research demonstrate the potential for the use of ISP-recovered protein isolates as a base and functional ingredient for prototypes of nutraceutical foods with specific health benefits. This article reviews ISP as an innovative means to recover functional protein isolates from low-value sources. It also covers recent attempts to develop prototypes of nutraceutical food products using the ISP-recovered protein isolates targeting diet-driven cardiovascular disease.

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1. Introduction

Processing of raw aquatic foods into final food products generates variety of by-products such as frames, heads, bones, skin, scales, and viscera. When fish are processed mechanically on a commercial scale, typically 60–70% of the live fish weight may be discarded as the processing by-products with only 30–40% of live fish weight being marketable as fillets (Gildberg, 2002). Fish meat left over on the by-products, especially heads and frames, typically accounts for 20–30% of live fish weight. This high quality protein is sometimes rendered for animal feed, "ground-and-discarded", or diverted from human consumption in other ways. However, with the growing world population and dwindling natural resources, this approach is no longer appropriate. Therefore, technologies facilitating more efficient use of natural resources to fulfill human nutritional needs are required.

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The terms "offal," "waste," and "by-products" (sometimes referred to as "co-products") are used frequently and interchangeably to describe the secondary products generated as a result of muscle food (seafood, meat, and poultry) processing and may include both edible and inedible materials left over following processing of the primary product (Gehring, Davenport, & Jaczynski, 2009). Unfortunately, "offal" and "waste" often conjure up negative connotations because these terms imply that those materials have no value and need to be disposed of. On the other hand, the terms "by-product" or "co-product" imply that there could be some value in the secondary products and, if they are recovered properly, they could be valuable (Gehring et al., 2009). Therefore, the food industry and scientific literature should refer to these materials as "by-products" or "co-products" instead of "offal" or "waste" so that the negative consumer bias towards value-added products made using these materials would be minimized.

For example, when fish are headed, eviscerated, skinned, and filleted for market fillets, the market fillets would be considered the primary product; whereas the frames, heads, and viscera would be the secondary products. At the time of filleting, the quality of fish meat left on the heads and frames is comparable to the meat in the primary products, i.e. fillets; and therefore, it is a misrepresentation to label the secondary products of fish processing as "waste". In fact, advances in meat recovery technology make it possible to recover the meat proteins that were previously discarded/rendered, which can result in added revenue for a processor.

With an understanding of fundamental properties of muscle food proteins, it is possible to control their behavior and consequently, maximize the protein recovery yields for use in human food products. Isoelectric solubilization/precipitation (ISP) is a protein recovery process that solubilizes and precipitates protein based on their isoelectric behavior when subjected to pH changes. The ISP process efficiently recovers high quality protein isolates in terms of nutritional quality and functional properties from sources difficult to process such as krill, fish, chicken, and beef processing by-products (Chen & Jaczynski, 2007a; Gigliotti, Jaczynski, & Tou, 2008; Jaczynski, 2010; Nolsoe & Undeland, 2009; Taskaya, Chen, Beamer, et al., 2009b; Taskaya, Chen, & Jaczynski, 2009c). Nutritional quality and functional properties are important considerations in the development of human food applications such as value-added or nutraceutical/functional food products. Commercial-scale production of food products made with ISP protein isolates has not yet been attempted. However, results from laboratory-scale product development research show potential for nutraceutical food products whose base, bulk ingredients are the ISP protein isolates. ISP processing may be a useful technology to recover nutritious and functional protein isolates for development of nutraceutical food products destined for direct human consumption from underutilized fish resources such as krill and invasive nuisance species like Asian carp, fish and meat processing by-products (i.e., frames, heads, etc.), and other low-value animal protein sources that otherwise may be discarded.

Nutraceutical foods have shown a sustainable and upward trend gaining popularity with health-conscious consumers. Nutraceutical foods typically contain a small amount of nutraceutical ingredient (s) with specific and scientifically documented health benefits in humans such as improved cardiovascular status. Although nutraceutical ingredients such as omega-3 oil, vitamins, antioxidants, and fiber are typically added at low concentrations, these concentrations are physiologically meaningful and trigger beneficial health effects in humans. Because nutraceutical ingredients constitute only a small part of a nutraceutical food product, there needs to be a base ingredient making the bulk of such a product. The ISP-recovered protein isolates could serve this role of the base, bulk ingredient for the development of nutraceutical foods. The types of food products developed from ISP protein isolates recovered from the processing by-products will not only enable the fish, poultry, and meat processing industries to diversify their product offerings, but also offer another source of highly nutritious protein for direct human consumption; and therefore, increase more responsible use of natural resources and their sustainability.

According to the American Heart Association, cardiovascular disease (CVD) has had an unquestioned status of number one cause of death in the U.S. since 1921 (American Heart Association, 2009). Therefore, addressing this significant issue via dietary intervention using ISP protein-based nutraceutical foods may have a market potential. Omega-3 polyunsaturated fatty acids (ω-3 PUFAs), especially eicosapentaenoic (EPA, 20:5 ω-3) and docosahexaenoic (DHA, 22:6 ω-3) FAs are associated with multifaceted health benefits, in particular improvement of cardiovascular health in humans. DHA and EPA are primarily found in fatty fish, whereas other ω-3 PUFAs such as α-linolenic acid (ALA, 18:3ω-3) are found in seeds and nuts with the exception of single-cell marine microalgae such as *Crypthecodinium cohnii* and *Schizochytrium sp*. that biosynthesize DHA. To suppress chronic inflammatory diseases like CVD, a ratio of ω-6/ω-3 ranging from 1:1–1:5 has been suggested (Simopoulos, 2002). However, the ratio for Western diets is 15–20:1. Another dietary contributor to CVD is excessive dietary intake of sodium. Mainly due to the high sodium content of processed foods, the current dietary sodium intake in the U.S. exceeds 3400 mg/day, which is much higher than the recommended maximum of 2300 mg/day for the general population and bellow 1500 mg/day for those with elevated CVD risks. It has been suggested that if sodium intake were reduced by half, $38 billion in health care costs could be saved (Bibbins-Domingo et al., 2010). Similar to ω-3 PUFAs and sodium reduction, dietary fiber has proven cardiovascular benefits (Anderson et al., 2009). The American diet is deficient in fiber with the average intake of only 15 g/day. The Institute of Medicine recommends fiber intake to be 25–38 g/day. Therefore, in an effort to improve cardiovascular health, health and professional organizations recommend increased consumption of foods rich in ω-3 PUFAs and dietary fiber with a concurrent reduction of sodium intake (Morrison & Ness, 2011; Simopoulos, 2002). A new range of nutraceutical food products could be developed using a three-prong strategy to address the diet-driven CVD. The strategy would entail formulating foods with ω-3 PUFAs (prong 1) and fiber (prong 2) as well as reduced sodium (prong 3). The ISP protein isolates could serve as a base, bulk ingredient for such food products (Debusca, Tahergorabi, Beamer, Partington, & Jaczynski, 2013; Tahergorabi, Beamer, 2012b; Tahergorabi, Sivanandan, & Jaczynski, 2012c; Tahergorabi, Sivanandan, et al., 2012d).

Foods formulated using the ISP protein isolate as a base, bulk ingredient and the three-prong strategy could contribute to the increased cardiovascular health without the need for dietary supplements in a pill or capsule form. Therefore, these foods would be typical examples of nutraceutical food products. The ISP protein isolate would be the main, bulk ingredient providing technological functionalities such as protein gelation, water holding capacity, fat binding (emulsification), and texture; while ω-3 PUFAs, fiber, and sodium reduction would provide nutraceutical functionalities targeting improved cardiovascular health in humans. Nutraceutical (also referred to as functional) food products are those that resemble typical food products, but contain ingredients that support good health or have medicinal benefits. They are sometimes formulated to achieve a desired biochemical effect without requiring a major change in dietary habits or having to ingest dietary supplements or medications.

2. General characteristics of muscle food proteins

Muscle proteins are divided into three major categories: myofibrillar (contractile), stromal (connective), and sarcoplasmic (intracellular fluid). Myofibrillar proteins make up the largest component of these categories, with over 55% of the total muscle protein belonging to this group. Myofibrillar proteins form myofibrils, the basic cellular unit of muscle tissue. They are predominately composed of myosin and actin as well as regulatory proteins such as tropomyosin, troponin, and