Innovative Food Science and Emerging Technologies 37 (2016) 201–215

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Sustainable valorisation of seafood by-products: Recovery of collagen and development of collagen-based novel functional food ingredients

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ARTICLE INFO

Article history:
Received 30 October 2015
Received in revised form 8 March 2016
Accepted 30 March 2016
Available online 9 April 2016

Keywords:
Seafood
By-products
Collagen
Collagen hydrolysates
Bioactive peptides
Functional food ingredients

ABSTRACT

Aquatic, especially marine ecosystem is still an untapped reservoir of bioactive compounds, which have considerable potential to supply novel ingredients towards the development of commercial functional food products. Seafood products are an important part of the diet in many nations. Moreover, as a source of protein, seafood plays a significant role as functional components that are essential to human health. In industry or local seafood shops, processing of seafood generates a huge quantity (50–80%) of nonedible by-products, which are discarded as waste or underutilised in several parts of the world. These seafood processing by-products are rich sources of various novel and valuable biomolecules such as collagen and gelatin. In this review, scope of seafood by-products has been explored to recover the realistic collagen. The sustainable valorisation of seafood by-products may lead towards the development of healthy and functional food ingredients/products. Furthermore, the significant challenges towards the development of collagen-based functional food ingredients are also discussed.

Industrial relevance: With the increasing amount of seafood processing by-products worldwide, the recent trend towards the utilisation of collagen and their derived biomaterials to develop the various functional food and beverages is gaining momentum. Seafood processing by-products are a rich source of bioactive collagen molecules with potential nutraceutical/functional properties. Seafood processing industries are constantly trying to maximum utilisation of seafood by-products.

This review article puts forward an alternative use of seafood processing by-products which may help to accelerate their business with significant benefits. The collagen-based novel functional food ingredient contains a nutritional benefit, such as essential and non-essential amino acid to improve the quality of different food products. It can also be used as natural antioxidants and texturing agents that will reduce the utilisation of chemical preservatives and may be able to fulfil the consumer demands for safe and green food products.

In addition, the current status, challenges and the future directions in the development of seafood derived collagen peptides as functional ingredients is also discussed. This review suggests a biological solution for the disposal of the seafood processing by-products that creates an environmental pollution issues. This article reveals the opportunity to utilise the seafood by-products for the development of high value-added collagen-based functional food ingredients.

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1. Introduction

According to food and agriculture organisation (FAO), the term seafood includes a group of diverse edible animals consisting of freshwater fish, molluscan, shellfish, crustaceans, saltwater finfish, and other forms of aquatic animal life. Marine animals (such as frogs and turtles) and edible seaweeds, which are served as food are also considered as seafood all over the world (FAO, 2015; Suresh, Nidheesh, & Pal, 2015). The seafood (by capture fisheries and aquaculture) and its derived products are the most traded food commodities for global food security and food trade (Shahidi & Ambigaipalan, 2015; FAO, 2014, 2015; Menon & Lele, 2015; Watson et al., 2015).

According to FAO, more than 158 million tons (MT) of seafood were landed by capture fisheries or produced by aquaculture in 2012 of which about 136 MT (81%) were used for direct human consumption (FAO, 2014). A large quantity of seafood harvested is processed in a different way throughout the world owing to its highly perishable nature, export potential, and demand for processed and ready-to-eat seafood products (Suresh & Prabhu, 2013). In general, seafood processing recovers only 20–50% as edible portions and the remaining parts (80–50%) are discarded as "nonedible" by-products /co-products/leftover raw materials, with an average of 20 MT globally (Suresh & Prabhu, 2013; Pangestuti & Kim, 2014). These seafood by-products are rich sources of various valuable components including collagen and gelatin,

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http://dx.doi.org/10.1016/j.ifset.2016.03.015
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protein and peptides, oil and lipids, chitin, vitamins, minerals, enzymes, pigments, and flavours (Suresh & Prabhu, 2013; Pangestuti & Kim, 2014; Menon & Lele, 2015). However, a large quantity of non-edible by-products generated by the industrial processing of seafood is wasted or underutilised in many parts of the world. Disposal of seafood by-products may be a costly process in some countries (e.g., in Australia up to US$150 per tons) (Yan & Chen, 2015). With recent developments in the biotechnology, there is a vast scope to make better utilisation of seafood by-products as viable sources for nutraceuticals and other functional ingredients for food and nutrition. The importance of seafood derived functional foods, and functional ingredients have been well documented to improve/enhance the quality of life and reduce health care costs (Plaza, Cifuentes, & Ibáñez, 2008; Shahidi, 2009).

This review focuses on the recovery of seafood-derived bioactive collagen and collagen peptides/hydrolysates reported from seafood (both finfish and shellfish) and their processing by-products. Current methods for the extraction, characterisation and purification of seafood-derived bioactive collagen and their peptides will be outlined. Furthermore, most relevant existing knowledge of the collagen-based functional food and realistic challenges towards the development of collagen-based functional food ingredients are briefly discussed.

2. Need of functional food ingredients from seafood by-products

The sense of happiness and good health maintenance are top priorities for people all over the world. Food and its components may play a dynamic role to achieve these needs. The development and utilisation of seafood by-products as functional food ingredients have been accelerated with growing health benefits knowledge of seafood diet/products (Pangestuti & Kim, 2014). In recent years, the consumer interest in the relationship between seafood diet and health has increased significantly. Seafood by-products can be consumed as a portion of food for human health maintenance (Menon & Lele, 2015). In developed countries, diets are highly caloric, rich in the saturated fats and sugars. However, the consumption of complex carbohydrates and dietetic fibre is very low. As well as, a decrease in physical exercise has given rise in an increase of obesity, heart diseases, diabetes and hypertension problems (Plaza et al., 2008). The seafood derived functional food ingredients may create a positive contribution to health and well-being. These days consumers preferred the foods that have a significant potential to improve health, increase longevity, reduce the risk, or delay of the diseases (Harnedy & FitzGerald, 2012). Consumption of seafood helps to protect against these lifestyle diseases that pose health challenges globally. The clinical trials evidence support the health benefits of seafood and their products consumption is mainly derived from epidemiological studies (Hu et al., 2002; Lavie, Milani, Mehra, & Ventura, 2009; Mozaffarian & Rimm, 2006).

Seafood by-product represents a leading valuable resource of bioactive materials. The seafood derived products have significant potential for various applications in food and health sectors such as bioactive compounds, nutraceuticals, natural food additives, biodegradable packaging, medicinal drugs, and as encapsulation materials (Menon & Lele, 2015). Bioactive substances such as collagen, gelatin, chitosan and their derived products from seafood by-products have been used in various biotechnological, nutritional, pharmaceutical, biomedical and other applications including food, cosmetics, drug delivery, and tissue engineering (Pal, Nidheesh, & Suresh, 2015; Suresh et al., 2015; Nidheesh, Kumar, & Suresh, 2015; Nidheesh, Pal, & Suresh, 2015). Seafood derived collagens are suitable and outstanding as ingredients of functional food due to their nutritive (presence of essential and non-essential amino acids) and functional properties. In food legislations, there is no restriction on the amount of collagen usage in food items. To complete the adequate nutritionally, and well-balanced diets, functional foods with seafood collagen can be consumed to fulfil the collagen need (Bilek & Bayram, 2015; Pal et al., 2015). The antioxidant activity of collagen can improve the oxidative stability of food products by preventing oxidation processes. Meat shelf-life can be extended with the application of a surface coating of collagen (Antoniewski & Barringer, 2010). Globally, the major ongoing research is addressed to improve the management of seafood by-products in terms of searching new bioactive collagen-based compounds and developing the new technologies that allow a more cost-effective utilisation (Pangestuti & Kim, 2014; Tahergorabi & Jaczynski, 2014).

3. Seafood by-products as potential source of collagen

There is a huge controversy to define the seafood 'non-edible' materials leftover after processing. Offal, viscera, waste and by-product terms are frequently and interchangeably used in the seafood industry and scientific literature to describe the same resources. Therefore, to overcome the negative connotation and misleading, the seafood materials cannot be used for any application and should be disposed of is called as 'offal' or 'waste'. However, by-products and co-products term suggest that there may be some high-value components to be recovered if treated properly (Tahergorabi & Jaczynski, 2014).

Collagen is the most abundant structural protein found in skin and bones of all animals and constitutes ~30% of the total protein content. Collagen is formed as a unique triple helix by three almost identical polypeptide amino acids chains. Collagen is the product of an almost continuous repeating of the Gly-X-Y-sequence, where X is mostly proline and Y is hydroxyproline. Presently, genetically distinct 29 types of collagen (type I-XXIX) with right-handed triple helical conformation have been identified in animal tissue that differs considerably in its amino acid composition, sequence, structural and functional properties, more likely associated with specific genetic variants (Pal et al., 2015; Gómez-Guillén, Giménez, López-Caballero, & Montero, 2011). Collagen and hydrolysed form of collagen (gelatin) are presently used in various sectors such as food, cosmetics, pharmaceutical, tissue engineering and biomedical (Fig. 2) (Gómez-Guillén et al., 2011; Liang et al., 2014a; Menon & Lele, 2015; Pangestuti & Kim, 2014; Pal et al., 2015). Currently, the primary sources of commercial collagen are the skin, bones and hides of land-based animals (bovine and porcine). In recent decades, the production of land-based animal's collagen has been decreased in part due to the concerns about outbreaks of bovine spongiform encephalopathy (BSE), foot mouth disease (FMD) and other prions disease. In addition, use of mammalian collagen is a hurdle in the development of kosher and halal products due to some religious factors (Wang et al., 2014a). Seafood by-products contain a remarkable amount of skin, scale, fins, bone, swim bladder, which have been recognised as a potential source of collagen and other biomaterials (Suresh & Prabhu, 2013; Pal et al., 2015) (Fig. 1). The production of collagen from seafood by-product is expected to attract the interest of the industry as a natural alternative source (Pal et al., 2015; Regenstein & Zhou, 2007; Gómez-Guillén et al., 2011). Seafood derived collagens are grouped into three types: fish collagens, collagens of invertebrate origin (jellyfish, sponges, mollusks), and marine mammal collagens (Ehrlich, 2015).

Further, collagen is the raw material for the preparation of gelatin. Gelatin is a heterogeneous mixture of water-soluble high molecular weight protein that does not have existence in nature. Gelatin is the partially hydrolysed form of collagen. They are derived from the parent protein collagen. For the production of gelatin, the polypeptide chains of collagen triple helix structure cross-linking are disrupted using a minimal level of polypeptide bond breakage. Heat denaturation efficiently converts the high-value collagen into gelatin. Gelatin is an important industrial biopolymer possesses the functional characteristics and gelling properties including encapsulating, colloid stabilisation, crystallisation, thickening, whipping, water holding, film formation, texture enhancer and emulsification that make it useful for their potential application in food, pharmaceutical, and other allied sectors (Regenstein & Zhou, 2007; Karim & Bhat, 2009; Kim, Mendis & Shahidi, 2007; Pangestuti & Kim, 2014). Seafood derived gelatin releases a kind of aroma, flavour and shows higher digestibility compare to animal gelatin. The functional

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