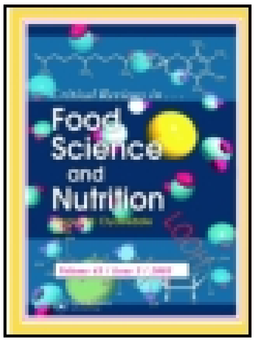

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

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To cite this article: Xu Shen, Min Zhang, Bhesh Bhandari & Zhongxue Gao (2018): Novel technologies in utilization of byproducts of animal food processing: a review, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2018.1493428

To link to this article: https://doi.org/10.1080/10408398.2018.1493428

Published online: 04 Oct 2018.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2018.1493428

REVIEW

Novel technologies in utilization of byproducts of animal food processing: a review

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ABSTRACT
China is one of the countries with most abundant livestock and poultry resources in the world. The average annual growth rate of output value of livestock and poultry industry reaches 13%, and the output value of livestock and poultry industry accounts for more than 35% of total agricultural output. A large number of byproducts are produced in animal slaughtering and processing operations. If livestock and poultry byproducts are effectively utilized, this will make a huge contribution to GDP. At the same time, aquaculture is China's pillar industry. During fish processing, a large number of byproducts (including fish heads, fish skins, fish bones, fish scales, and viscera) are produced, which weighs approximately 40-55% of the raw fish. The byproducts of freshwater fish are more than 2.5 million tons per annum, most of which are not used. The effective use of byproducts has a direct influence on China's economic and environmental pollution. The nonuse or underutilization of byproducts not only leads to loss of potential revenue, but also results in to an increase in these products and their disposal costs. This paper makes a comprehensive review of the research progress of animal byproduct utilization to date, and aims to provide reference for the utilization and research of animal byproducts.

KEYWORDS
Byproducts; livestock; poultry; fish; utilization

Introduction

The rapid development of food processing industry makes the production of food waste more concentrated. The original scattered in the family of food materials more gathered in the enterprise, those who produce convenience food. Waste is geographically concentrated, and waste collection points are relatively small and waste is increasing. These two factors make the food industry more and more pressure on waste disposal. Therefore, the planning and management of these food waste and comprehensive utilization has become an important task of food processing enterprises.

Waste is a substance that has lost its original use value in the production, life and other activities or has not lost its value but is discarded. Because the waste produced in the food processing process is not in a uniform form and the waste is generally a solid material consisting of food ingredients, some food producers do not consider the waste to be waste, and even consider some food waste to be environmentally safe. They did not take a positive approach to dealing with waste in the food industry. Reasonable handling and use can not only protect the interests of consumers and reduce environmental pollution, but also for the sustainable development of the food industry is also of great significance.

The waste of the food industry mainly includes waste from the processing of specific foods, such as beer brewing in beer production, waste from the production of slaughterhouses, and its main ingredient is organic matter. Main features:

1. Easy to corruption: Because it contains a large number of microorganisms or through microbial activities, waste will soon deteriorate, which will lead to unacceptable health conditions.
2. High water content: The water content of meat waste lies between 70 and 95% by mass. The High water content will increase understanding of the cost of transport of waste.
3. Rapid oxidation: High fat content of the waste is easy to oxidation, which will lead to the release of bad smell of fatty acids.
4. Changes due to enzyme activity: Most of the waste enzyme is still active, it accelerates the speed of corruption (Paraman et al. 2015).

The byproducts of fish, livestock and poultry are rich in nutrients. However, they have a high water content and are therefore susceptible to deterioration in the presence of microorganisms. Microorganisms can contaminate these materials through fish, livestock and poultry themselves, for example, from the gastrointestinal tract or by contamination from hoof or skin. Pollution may also come from the

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processing environment, for example, due to poor cleanliness of worker hygiene or processing facilities. The most common type of pollution is bacteria, but yeast and mold also contaminate these byproducts (Aspevik et al. 2017). A series of techniques, such as hydrostatic pressure treatment, hurdle approach, active packaging and pulsed electric field, are used to improve the safety of meat products (Sohaib et al. 2016), and also apply to byproducts (Brocklehurst 2007). In the processing of meat industry, preservation can be done before processing or combined with processing methods, for example, in the case of fish silage. If the slaughterhouse is near or even connected to processing facilities to obtain byproducts, preservation can also be minimized or possibly eliminated. This ensures the added value of absolutely fresh byproducts.

Comprehensive utilization of livestock and poultry byproducts

Statistics show that the total output of meat in China has reached 84 million tons in 2008, resulting in a large number of livestock and poultry byproducts. Taking pig as an example, China's annual slaughtering volume is nearly 600 million, producing about 3 million tons of pig blood, 30 million tons of pig bone, 12 million tons of viscera and 400 thousand tons of pig brain. However, due to the limited size of slaughtering and backward processing technology, most of the byproducts are abandoned except for a certain amount used in simple processing to make feed, which not only greatly wastes the byproduct resources, but also seriously pollutes the environment. Today, the cost of animals is higher than the price of carcasses. Therefore, the value of byproducts must be paid for slaughter and bring profits to the livestock, poultry and aquaculture industries (Irshad et al. 2015). Animal byproducts account for 10–15% of the value of living animals in developed countries (Chatli et al. 2005). Proper use of these byproducts contributes significantly to the profitability of the meat business because it can compensate for all the costs of slaughterhouse operations and even benefit farmers, processors and consumer.

Utilization of livestock and poultry blood

Blood is the main part of animal weight (2.4–8.0% of animal body weight). The average percentage of blood that can be recovered from pigs, cattle and lambs is 3.0–4.0, 3.0–4.0 and 3.5–4.0%, respectively (Jayathilakan et al. 2012). Blood can be used as an emulsifier, stabilizer, clarifier, coloring additive and as a nutritional component in foods (Silva and Silvestre 2003). Animal blood has a high level of protein, which is an important edible byproduct (chen et al. 2015), among which hemoglobin is the most abundant compound (Ofori and Hsieh, 2014). Hemoglobin can be used to prepare bioactive peptides by hydrolysis, and their hydrolysates have antibacterial, antioxidant, ACE inhibitory, and opioid activities (Chang et al. 2007), of which antimicrobial peptides are more studied (Adje et al. 2011; Nedjar-Arroume et al. 2008). Hu et al. (2011) identified the peptide VNFKLLSHSLLVTLASHL in the central part of the bovine hemoglobin alpha-subunit, purified the peptide by a combination of cation exchange and reversed-phase high-performance liquid chromatography, and found the purified peptide had antimicrobial activity against *E. coli*, *Staphylococcus aureus*, and *Candida albicans*. Deng et al. (2014) isolated angiotensin I-converting enzyme (ACE) inhibitor from pepsin hydrolysate of porcine hemoglobin. Results showed that pepsin was the most effective protease in the production of active peptides, and the activity of pepsin hydrolysate of porcine hemoglobin was the highest, and porcine hemoglobin peptide had significant ACE-inhibitory effect in vitro. At the same time, colour former can also be prepared by extracting hemoglobin from the blood. The nitroso hemoglobin was prepared by using NO as ligand and hemoglobin, and the stability, water solubility and emulsifying properties of the products is better, which has been well used in meat products (Li et al. 2015). Zhang et al. (2012) improved the stability of nitroso hemoglobin by the incorporation of β-cyclodextrin and glycosylation. In recent years, in order to solve the shortcomings of nitroso hemoglobin instability, niacin, histidine and other ligands and hemoglobin complex preparation of color former were also developed.

Animal blood has long been used to make blood sausage, blood clots, blood pudding, biscuits and bread (Fontes et al. 2015). However, the use of blood in meat processing may mean that the color of the final product is dark and not very tasty. Plasma is the most interesting part of the blood because of its functional nature and lack of color. Hot hams added with 1.5 and 3.0% frozen plasma and hot dogs added with 2.7% plasma were more satisfactory in color than those without it (Jayathilakan et al. 2012). Plasma has the ability to form gel as it contains 60.0% albumin. Plasma forms a gel at a protein concentration of 4.0–5.0%, the strength of the gel increases with increasing concentration (Liu et al. 2010). Plasma also has excellent foaming power and can be used to replace proteins in the baking industry (Del Hoyo et al. 2008). Sorapukdee and Narunatsopanon (2017) evaluated the chemical and functional characteristics of pig, chicken and duck blood. The results showed that the fastest reaction to form a strong gel was found in chicken blood compared to duck and pig blood, especially at 70° C and 80° C; the result of emulsion activity index and stability index at low protein concentrations showed that chicken blood had the best emulsion properties. In addition, duck blood had similar foaming properties to pig blood. The application of transglutaminase (TGase) from animal blood and organs or microorganisms to meat products has received a great deal of research. Blood Factor XIII is a transglutaminase that acts as a zymogen in plasma and platelets. Transglutaminase catalyzes cross-linking reactions between proteins and peptide molecules of meat products with improved functional properties (Santhi et al. 2017). Transglutaminase is extracted from bovine blood to increase the binding capacity of fresh meat products at freezing temperatures (Han et al. 2015). In addition, the recombinant meat product can be processed without heating by adding

Table 1. Potential uses and preparation of edible meat byproducts.

Kind of meat	Storage and Preparation	Way in which it is used
Liver	Frozen, fresh or refrigerated	Braised, broiled, fried, in loaf, patty and sausage
Kidney	Whole, sliced or ground Fresh or refrigerated	Broiled, cooked in liquid, braised, in soup, grilled, in stew
Heart	Whole or sliced Frozen, fresh or refrigerated	Braised, cooked in liquid, luncheon meat, patty, loaf
Brains	Whole or sliced	Sausage ingredient, broiled, braised and cooked in liquid, poached, scrambled
Tongue	Frozen, fresh or refrigerated Whole	Cooked in liquid, cured, sausage casing, sausage ingredient
Stomach	Fresh, refrigerated, smoked and pickled	Broiled and cooked in liquid, sausage casing, sausage ingredient
Spleen	Fresh, refrigerated and pre-cooked	Fried, in pies, in blood sausage
Tail	Frozen, fresh or refrigerated	Cooked in salty liquid
Intestines (small & large)	Whole, frozen, fresh, refrigerated. Remove feces, soak, wash, add salt before use	Sausage casing
Cheek and head trimmings	Frozen, fresh or refrigerated	Cooked sausage
Ear	Frozen, fresh or refrigerated	Smoked and salted, stewed with feet
Skin	Fresh, refrigerated	Gelatin
Feet	Frozen, fresh, refrigerated	Jelly, pickled, cooked in liquid, boiled, fried
Fat	Frozen, fresh or refrigerated	Shortening, lard
Blood	Frozen, refrigerated	Black pudding, sausage, blood and barley loaf
Bone	Frozen, fresh or refrigerated	Gelatin, soup, jellied products, rendered shortening, mechanically deboned tissue
Lung	Frozen, refrigerated, fresh	Blood preparations, pet food

TGase from animal blood, and its salt and phosphate content are reduced (Kieliszek and Misiewicz 2014). Therefore, animal blood can be used as food supplements or product development based on their potential applications.

Utilization of livestock and poultry bone

Bone in the animal body accounts for about 20%–30% of body weight (Yude 2000). Animal bones are rich in a variety of minerals, such as zinc, phosphorus, calcium, iron, etc., and a variety of bioactive substances, such as methionine that Promote liver function hematopoiesis, neurotransmitters and other active substances (Heaney et al. 2001), Anti-aging collagen and chondroitin, as well as phospholipids and phosphoproteins indispensable to the human brain (Carpio et al. 2000), and the content is several times more than the fresh meat, so its nutrition is very rich (Sanyal et al. 2005). Through the development and utilization of bones, turning waste into treasure, social and economic benefits are enormous.

Micro-bone meal refers to bone granules with an average diameter of $100 \sim 500\,\mu$m that are obtained after animal bone crushed by the micro-crushing technology, and ultra-micro-bone meal refers to fine particles with the grain size of 10–25 μm (Zhang et al. 2016). Bone meal has large surface area and void ratio, and has good adsorption and fluidity after crushing, which makes nutrients in animal bone become more easily absorbed. The traditional methods for preparing micro-bone meal can be divided into several kinds of cooking, high humidity and pressure, biochemical methods (Zhang et al. 2016), but these methods have some limitations. In order to prepare micro bone meal better, researchers have improved the preparation process based on the traditional methods, mainly including acid hydrolysis, alkaline hydrolysis, enzymatic hydrolysis, and microbial fermentation. Micro-bone meal can be used for Western-style intestines, bone noodles, chutney, beverages, biscuits and other food. Bone meal is an excellent supplement for human minerals, especially calcium (Xiu-Fang 2007). It can effectively solve the problem of solubility and bioavailability of calcium by biological engineering technology, which will enhance the physiological function of food. Potential applications and storage and preparation aspects of meat by-products are illustrated in Table 1. In the increasingly aging population of today, the market has great potential. Ossein is a kind of pure natural condiment obtained by extracting water-soluble substances from fresh bones, which is rich in amino acids, peptides, nucleic acids, sugars and inorganic salts, and is the concentrated natural product of bone white (Wu and Ma 2005). In addition to improving the quality of products, and also to prevent a variety of nutritional deficiencies, ossein is used in meat products in the amount of 0.5%–5%.

In addition, the bones of livestock and poultry are rich in soluble protein. In addition to some of the essential amino acids, the hydrolysate contains almost all the amino acids that make up the protein molecule. 90% of bone protein is collagen, which has the function of enhancing the activity of metabolism and delaying senility (Flood and Rolls 2007). In many countries, researchers mainly use biological enzyme technology to carry out bone protein research. The potential uses of fish waste are depicted in Table 2. Natural meat reaction flavors obtianed mainly from natural raw materials through enzyme engineering technology, Maillard reaction and other bio-engineering technology and decomposition of macromolecules in the protein material, are more conducive to digestion and absorption (Moon et al. 2011). Collagen is the most abundant protein in the many meat industry byproducts and is the main component of animal bones (Toldrá et al. 2016). Collagen is very useful as a source of bioactive peptides (Herregods et al. 2011). Many researchers attempted to produce natural antioxidant peptides and anti-hypertensive peptides by controlled enzymatic hydrolysis technique. In collagen hydrolysates, ACE-inhibition and

Table 2. Potential uses of fish wastes.

Final Products	Treatment	Physicochemical characteristics	Uses
Fish waste (mainly heads, bones, skin, viscera and sometimes whole fish and parsley)	Heat treatments at 65, 80, 105 and 150 °C for 12 h for moisture content reduction to 10–12%	High source of minerals, 58% protein, 19% fat, detection of toxic substances (As, Pb, Hg and Cd) at non-problematic concentrations, decrease of waste digestibility with temperature	Fish waste (mainly heads, bones, skin, viscera and sometimes whole fish and parsley)
Raw fish oil	Filtration pretreatment with or without the presence of two catalysts	Almost identical HHV (10700 kcal/kg) and lower flash and pour points (37 °C and −16 °C, respectively) compared to commercial diesel fuel, no production of sulfur oxides, lowered or no soot, polyaromatic and carbon dioxide emissions	Raw fish oil
	(iron oxide and calcium phosphate monobasic) and ozone treatment (5 g/h, 16 g/m 3 (about 8000 ppm)) at room temperature for 1 h and 30 min, respectively		
Fish skin, bone and fin	Collagen isolation	36–54% collagen recovery and denaturation temperatures of skin collagen (25.0 ± 26.5 °C), bone collagen (29.5 ± 30.0 °C) and fin collagen (28.0 ± 29.1 °C)	Fish skin, bone and fin
Fish bone waste	Heat treatment of raw bone at 600 °C for 24 h or 900 °C for 12 h	Better removal capacity and well-crystallized hydroxyapatite at 600 °C, raw bone showed lower activity and crystallinity, bone sample heated at 900 °C showed developed similar activity with raw bone and developed crystallinity of hydroxyapatite	Fish bone waste
Fish waste (mainly heads, bones, skin, viscera and sometimes whole fish and parsley)	Heat treatments at 65, 80, 105 and 150 °C for 12 h for moisture content reduction to 10–12%	High source of minerals, 58% protein, 19% fat, detection of toxic substances (As, Pb, Hg and Cd) at non-problematic concentrations, decrease of waste digestibility with temperature	Fish waste (mainly heads, bones, skin, viscera and sometimes whole fish and parsley)

antioxidant activity are most relevant when exogenous proteases are used (Di Bernardini et al. 2012; Gómez-Guillén et al. 2011). Arihara et al. (2004) hydrolyzed porcine skeletal muscle protein with exogenous proteases and found that two peptides Met-Asn-Pro-Pro-Lys and Ile-Thr-Thr-Asn-Pro can be were obtained by hydrolysis with thermolysin, both of which had a higher inhibitory rate on the activity of angiotensin converting enzyme (ACE EC 3.4.15.1). Herregods et al. (2011) reported that thermolysin hydrolysates showed the highest in vitro ACE-inhibitory activity and an important in vivo antihypertensive effect in spontaneously hypertensive rats. Collagen hydrolysates can effectively scavenge free radicals and have a positive effect on antioxidants and anti-aging. Studies have shown that valine, histidine, proline, and aspartic acid in protein hydrolysates have high antioxidant activity (Najafian and Babji 2014).

Utilization of livestock and poultry skins

Raw hides and fur are usually one of the most valuable byproducts of animals. Poultry hides can be used to produce elastin, which is usually incorporated into the production of functional foods due to its antioxidant properties. Nadalian et al. (2013) extracted elastin from chicken skin with three successive solvent extracts of NaCl, acetone and NaOH respectively and found that both skin sources contained glycine as the main amino acid (19–20%), followed by glutamic acid. Pig and sheep skin can be made into sausage casings, sausage skin and edible gelatin (Benjakul et al. 2009).

Gelatin is produced by controlled hydrolysis of the water-insoluble collagen from the protein (Jayathilakan et al. 2012). Skin and bone all contain large amounts of collagen. Gelatin processing from hides comprises three main steps. The first step is to remove the non-collagenous material from the feedstock. The collagen is then hydrolyzed to gelatin. The final step is to recover and dry the final product. Currently, livestock skins are mainly used in the form of gelatin. Gelatin is a hydrophilic gel formed by the conversion of collagen contained in the bones, bones, tendons and connective tissues of animals (Hanani et al. 2012). Gelatin extracted from animal skins can be used in foods to improve elasticity, consistency, and stability (Mariod and Fadul 2013). Gelatin is widely added to jelly and aloe to form the main ingredient, the main purpose of which is to produce gel desserts because of its "mouth-melting" nature, but also added to a range of meat products, especially meat pies (Jamilah and Harvinder 2002). Gelatin is also widely used as a stabilizer for ice cream and other frozen confections. High-frost gelatin is added as a protective colloid to ice cream, yogurt and cream patties as gelatin inhibits the formation of ice crystals and recrystallization of lactose during storage (Mariod and Fadul 2015). Collagen protein is the main component of livestock skin. It is widely used in food processing, which can be used to improve the quality of meat and can also be used as a calcium supplement for health foods (Gelse et al. 2003). Collagen extracted from hide and skin also serves as an emulsifier in meat products because it can combine large amounts of fat. In the meat industry collagen extracted can be made into collagen intestinal (Karim and Bhat 2008).

Utilization of lard and edible animal fat

Animal fats are an important byproduct of the meat slaughter industry. The main edible animal fat are lard and butter. Lard is a fat extracted from a clean tissue of healthy pigs. Butter is a hard fat extracted from the fat tissue of cattle or sheep. Lard and edible animal oil are obtained by dry or wet refining. In the process of wet extraction, the adipose tissue is usually heated at a low temperature and in the presence of water (Jayathilakan et al. 2012). The quality of lard or butter from the wet extraction is superior to that of dry-extracted product (Sharma et al. 2013). Low-quality lard and almost all of inedible animal oils are made by dry method. Refined lard can be used as edible oil without any further processing (Yen and Chen 2000). More and more researchers are using enzyme to extract high quality edible animal oil. Wang et al. (2016) extract lard from pig fatback, a byproduct of the slaughter plant, by an aqueous enzymatic extraction method. They found that Alcalase 2.4 L was more effective for oil extraction with a yield of 95.19%. Compared with the lard product obtained by traditional methods, basic physical and chemical indexes of the lard extracted by enzymatic method are all superior. However, due to the needs of consumers, lard and tallow are now often bleached and deodorized before being used for food (O'brien 2008).

Traditionally, tallow and lard have been used for frying. However, this use is declining in the fast food industry due to consumer health concerns. Alternative liquid butter products have been developed for the preparation of French fries and other fast food products because less fat is absorbed. Butter and lard are also used in margarine and shortening (Ghotra et al. 2002). Some edible lard products are used in sausage or emulsified products (Toldrá et al. 2012). Some studies have found that although the crystal form and size of lard and emulsified lard have not changed significantly, lard, as a shortening, has the disadvantage of coarse crystal grains which affects the quality of its product (Campbell et al. 2002). Xu et al. (2018) studied the effect of ultrasound and glutamine transaminase treatments on the in vitro digestibility of emulsified lard. The results showed that ultrasound treatment rendered emulsified lard more digestible, while glutamine transaminase treatment slowed down the digestion of emulsified lard.

Other livestock byproducts can also be used. The liver is the most widely used food organ and is used in many processed meats such as liver sausages and liver sauces (Devatkal et al. 2004). Swine, calf and sheep lungs are also used to make fillings and some types of sausages and processed meats (Darine et al. 2010). The animal intestines are also used to make sausage casing (Bhaskar et al. 2007).

Comprehensive utilization of fish byproducts

According to the report of Food and Agriculture Organization of the United Nations in 2010, the annual production of fish in the world was over 145 million tons, but the output of the world's effective use in 2010 was about 24 million tons, accounting for only 16.54% of the total amount (Sila and Bougatef 2016). The production and processing of industrial fish produces a large number of byproducts. The byproducts produced by the global fish processing industry account for more than 60% of the total amount of processed fish, including fish viscera, fish head, fish tail, fish fin, fish skin, fish bone, fish meat, and so on(Chalamaiah et al. 2012). If the disposal of these byproducts is unreasonable, it will pollute the environment and even harm human health. The byproducts of aquatic products are rich in nutrients and useful components, and some components have certain functional properties and physiological activities, which can be an important biological resources.

Utilization of fish scales

Fish scales are similar to skeletons of terrestrial animals in structure and composition, but their inorganic salt content is low. Protein and hydroxyapatite are the main components of fish scales, and protein accounts for about 70% of the total weight, which is mainly composed of collagen and keratin; hydroxyapatite accounts for about 30% of the total weight and is mainly distributed in the skeletal layer (Wu and Kang 2017). Therefore, the chemical composition of fish scales facilitates the extraction and purification of collagen. Undenatured collagen can be extracted at low temperatures using acid or enzymatic methods, whereas denatured collagen is primarily extracted by heating. The acid method can use hydrochloric acid, citric acid and acetic acid to extract collagen. Lu et al. (2013) extracted collagen from grass carp at an acetic acid concentration 1 mol/L, temperature 28 °C, and extraction time 25 h. The extraction rate reached 15.33%. Bhagwat and Dandge (2016) studied the isolation of acid-soluble collagen from salmon scales. Fish scales were treated with EDTA and acid-soluble collagen was extracted from the demineralized fish scales with a yield of 9.79%. They also developed a milk based food product-paneer by incorporating extracted collagen. The enzymatic method can use papain, pepsin and neutral protease to extract collagen. Wang et al. (2013) successfully extracted collagen from tilapia fish scales under papain concentration 2.5%, temperature 50 °C, and hydrolysis time 5 h. In addition, Ikoma et al. (2003) used EDTA to remove minerals from fish scales, and then hydrolyzed with pepsin to obtain collagen I-type, which is an underutilized medical material. Denatured collagen can be extracted by immersing and heating decalcified fish scales in water (Wu and Kang 2017). There is no impurity in the hot water extracted collagen, but inappropriate temperature control may lead to protein denaturation. At the same time, extrusion is widely used in the food industry, with the advantages of convenient operation, continuous production, high yield, and less waste. Huang et al. (2016) extracted collagen from tilapia fish scale using a novel extrusion-extraction process. The protein extraction rate of extruded sample was 2–3 times higher than that of the non-extruded sample.

Fish scales can be used to produce fish scale gelatin. Scale gelatin is a gelatin made from the collagen in fish scales. Gelatin extracted from fish scale can be used as thickener, emulsifier, stabilizer and clarifier in the food industry. It can be used in canned food, beverage, dairy processing, meat processing and wine making. The gelatin also has the function of nourishing yin and stopping bleeding, and has unique function in moistening lung and supplementing lung. Scale gelatin contains all essential amino acids except tryptophan, which has high nutritional value. As a gelling agent, it can be added in cans and sausages at about 4%–10%, which can prevent the separation of meat and juice (Bhagwat and Dandge 2016). As a foaming agent, scale glue can prevent fudge from crystallizing in soft candies, and can also reduce the melting speed of ice cream and keep the texture of the ice cream very fine (Wasswa et al. 2007). It is also used in the beer industry as a clarifier in a dosage of 0.5% ~ 1% (Nagai et al. 2004). Fish scale glue can be made by acid-base or enzymatic method. The fish scale gelatin obtained by enzymatic method has better quality (Himonides et al. 2011). Huang et al. (2017) studied the effect of pectin and microbial transglutaminase (MTGase) on rheological behavior and gel properties of complex modified fish scales gelatin (FSG). They found that the combined modification of pectin and MTGase can be used to obtain fish gelatin with better rheological properties, higher gel strength and melting temperature, which has higher gel and thermal properties than mammalian gelatin. At present, the complex modified fish scale gelatin instead of mammalian gelatin is widely used in the food industry. Some functional components can be extracted from fish scales. Stepnowski et al. (2004) used fish scales to adsorb pure astaxanthin, an emerging antioxidant, with a maximum adsorption capacity of 360 mg/kg. Recycling of astaxanthin from wastewater of food industry is very cost effective.

Utilization of fish offal

Fish Offal is rich in proteases. Chymosin is an aspartic protease that exists in the abomasum of newborn cattle and is commonly used in the production of cheese. With the development of the cheese industry, nearly 50 million calves are killed each year to obtain rennet, resulting in a global shortage of calves. As a result, scientists are trying to find a substitute for calf chymosin. Tavares et al. (1997)studied the extraction of chymosin from tuna stomach mucosa in place of calf chymosin. The results showed that the pH required for the activation of the two enzymes was in the range of 4.0 ~ 6.0. When the temperature was between 21 and 38 °C, the curd abilities of the two enzymes were similar. The ability of both to be curd was affected by the pH of the milk and coagulation. The pH required for curd is in the range of 5.5 ~ 6.3. In addition, Ketnawa et al. (2014) isolated alkaline proteases from the Catfish viscera using a thermoseparating aqueous two-phase system (T-ATPS). They found that by using T-ATPS without loss of activity, the target enzyme can be efficiently separated from Catfish viscera. T-ATPS will be a better choice for the enzyme industry because of its economic process, short processing time and low energy consumption. Enzymatic hydrolysis is one of the most effective techniques for recovering valuable proteins from fish Offal without losing their nutritional value. Klomklao and Benjakul (2017) hydrolyzed skipjack tuna viscera with Alcalase, and found that the optimal conditions were pH 10, temperature 65 °C, Alcalase concentration 3%, reaction time 20 min, and fish visceral/buffer ratio 1: 2 (w/v), under which, protein content of the freeze-dried hydrolysate reached 81.04% dry weight. The hydrolysate contained a large amount of essential amino acids (43.13%), mainly aspartic acid, methionine and glutamic acid. Therefore, it can be used for various food additives, pharmaceutical preparations and dietary nutrients. Hathwar et al. (2011) used four different commercial proteases (Protex 7 L, Neutrase, Alcalase, and Protease-P-Amano6) to hydrolyze fish offal to simultaneously recover lipids and proteins. It was found that the highest degree of hydrolysis was achieved using fungal proteases (Protease-P-Amano6), and the prepared protein hydrolysate had a higher diphenylpyrazinoyl radical scavenging activity; it was also found that the fungal protease produced the greatest lipid recovery (74.9%), followed by Alcalase. The low molecular weight peptides obtained by hydrolysis exhibit various biological functionalities, such as antioxidant activity, which can reduce oxidative stress in animal systems. The recovered lipids are rich in polyunsaturated fatty acids that have a variety of health benefits and can be a better alternative to fish oil.

Fish offal contains oil, which is rich in eicosapentaenoic acid, docosahexaenoic acid and docosahexaenoic acid, with the type and season of fish, fish oil in these unsaturated fatty acids is in the range of 15%–30% (Calder 2001). There are many methods for the separation of fish oil and its physiologically active substances EPA and DHA, such as organic solvent extraction, high performance liquid chromatography, silver resin chromatography, urea inclusion method, distillation, low temperature crystallization and supercritical CO_2 Extraction method (Rubio-Rodríguez et al. 2012). Belarbi et al. (2000) used three main steps in the separation and purification of EPA from fish oil: 1) simultaneous extraction and esterification of crude extracts of fish oil 2) crude extract was chromatographed by silver silica gel chromatography. The concentration of EPA in the esterified crude extract of the fish oil contained 70% EPA and can be concentrated to more than 90%. This proved that it is a cheap and efficient separation and purification method.

Utilization of fish bones and heads

Fish bone is the main product of aquatic products processing Fish bone contains large amounts of collagen, bone mucopolysaccharides and various inorganic substances. Calcium content in fish bone is about 30%, thus is a very good source of calcium (Flammini et al. 2016). Active calcium in byproduct fish bone is easy to be absorbed by the body. Thus utilization of fish bonenot only solves the pollution problem, but also increases the efficiency of calcium absorption. Martínez-Valverde et al. (2000) evaluated the effects of fish bones in supplementing mineral elements (Fe, Zn, Cu, Mn, Na, K, Ca, Mg and P) on three species of fish, such as cod and sole. Fish bones were found to have no special contribution in the supplementation of Fe, Zn, Cu, Na and K, but were of importance in considering Ca and P supplements. Thus, fish bones can be considered as fish weaning food nutrition enhancer.

Fish bone can also be processed into fish meal, and can also be used in bone paste, crisp and other fields. However, these products often have problems with high oil content and insufficient maturity (Lee et al. 2010; Murado et al. 2010). Fish bone is rich in Chondroitin sulfate (CS) (Hashiguchi et al. 2011), which has many medicinal activities and has broad application prospects in the field of health foods (Lauder 2009). The extraction methods of CS mainly include alkali method, enzymatic method and ultrasonic method, but these methods have some limitations (He et al. 2014). He et al. (2014) extracted chondroitin sulfate from fish bone using a high-intensity pulsed electric field. Studies have shown that high-intensity pulsed electric fields have faster extraction rates and higher chondroitin sulfate content than conventional methods. High-intensity pulsed electric fields can be widely used to extract non-thermal, high-speed, low-contamination chondroitin sulfate. Some scholars have also studied the extraction of oligopeptides from fish bone. Oligopeptides can be completely absorbed by the intestinal mucosa and can directly participate in the synthesis of protein in the body. Some oligopeptides have anti-oxidation and anti-hypertensive effects (Bamba et al. 1992). By enzymatic treatment of aquatic byproducts, we can obtain some high physiological activity of oligopeptides. Morimura et al. (2002) extracted oligopeptides from herring bones and hydrolyzed the herring bones with 16 commercial enzymes. The resulting oligopeptides were then analyzed and found to have the same antioxidant activity and blood pressure lowering effect as other peptides These peptides are easily absorbed by the body. The peptides can be used as food additives. Jung et al. (2005) did enzymatic hydrolysis of fish bone to prepare oligomeric phosphate polypeptide. The oligomeric phosphate polypeptide has stronger ability to adsorb calcium than casein phosphopeptides.

Fish heads contain type-I collagen, which may serve as a potential resource to compensate for the lack of collagen in terrestrial vertebrates. (Morimura et al. 2002) have found that the contents of tryptophan, threonine, leucine, histidine and other amino acids in the recovered collagen protein (extracted from herring byproduct) are even higher than those in collagen protein standard. The product also lower the blood pressure and shows other physiological activity. Bougatef et al. (2008) prepared protein hydrolysates by treating heads of sardinelle with chymotrypsin, Alcalase, crude enzyme preparations from Bacillus licheniformis NH1 and Aspergillus clavatus ES1, and crude enzyme extracts from Sardine pilchardus viscera, and found that all hydrolysates showed inhibitory activity on ACE. The crude enzyme extracts from the sardine viscera producing hydrolysates with the highest ACE inhibitory activity. In addition, the fish head can also be used to separate the fish oil. The head is also rich in lecithin and EPA and DHA. The crude oil EPA, DHA content is about 6.4% and 7.3% (Khoddami et al. 2009). EPA and DHA are effective in preventing and treating cardiovascular disease, improving memory (McLennan et al. 1996). (Chantachum et al. 2000) used wet reduction to separate fish oil from preboiled or uncooked tuna heads and found that both temperature and time of heating affected fish oil separation and quality of fish oil. They found that the crude fat extracted from the preheated fish head was of poorer quality, but had a higher content DHA (25.5%). Ferdosh et al. (2016) used supercritical carbon dioxide to extract fish oil from tuna heads and successfully extracted DHA, omega-3 and omega-6 at optimized conditions of 40 MPa, 65 °C, and a flow rate 3 mL min^{-1}, which can be used as value-added health product.

Utilization of fish skin

Fish skin is a rich source of collagen and gelatin. The skins of low-value fresh water fish and sea water fish contain large amounts of collagen, up to 50%. Because of high content of collagen and low content of miscellaneous protein, it can be obtained by pure purification, which is an ideal raw material for extracting collagen. Type-I collagen can be extracted from the skin of various types of fish. The denaturation temperature of this kind of collagen is 7 ∼ 12 degrees lower than that of pigskin collagen so it is a good source of collagen (Nagai and Suzuki 2000). Blanco et al. (2017) extracted pepsin soluble collagen (PSC) from the skin of two species of teleost and two species of chondrychtyes by pepsin. The study found that the extraction rate of the method was between 14.16% and 61.17%, and the denaturation temperature of collagen ranged between 23 °C and 33 °C. At the same time, they discovered that PSC hydrolysates provided a valuable source of peptides with antioxidant capacity, which provides a viable way to effectively raise the skin's biomass. In addition, Ketnawa et al. (2017) produced protein hydrolysates with desirable bioactivities by hydrolyzing fish skin gelatin using visceral peptidase from catfish. The results show that the gelatin hydrolysate exhibits the highest ACE-inhibitory activity, DPPH, ABTS radical scavenging activity and FRAP, which can become potential functional ingredients of food formulations. Kumar et al. (2012) obtained protein hydrolysates by hydrolyzing skin of horse mackerel (*Magalaspis cordyla*) and croaker (*Otolithes ruber*) using gastrointestinal proteases (pepsin, trypsin and α-chymotrypsin) and purified two peptides with antioxidant properties, Asn-His-Arg-Tyr-Asp-Arg and Gly-Asn-Arg-Gly-Phe-Ala-Cys-Arg-His-Ala, from protein hydrolysates by continuous chromatographic fractionations including ion exchange chromatography and gel filtration chromatography. Both peptides were found to be more active for polyunsaturated fatty acid peroxidation than the natural antioxidant alpha-tocopherol, which can be effectively used as a food additive and a pharmaceutical preparation. Fan et al. (2017) used trypsin-assisted method to extract gelatin from salmon skins and determined the optimal conditions by response surface methodology: tryptic concentration of 1.49 U/g; extraction temperature at 45 °C; and extraction time at 6 h 16 min. Compared to the method without trypsin, this method achieved twofold higher yields of gelatin with high molecular weight protein chains.

Heat reaction flavor is generated by the use of amino acids, peptides and other protein hydrolysates, carbohydrates. And lipids. Under the heating reaction of the flavor material, thermal reaction responsible is mainly Maillard reaction (Pippen et al. 1969). However, some Maillard reaction products possess human health hazards, such as acrylamide, 1,2-dicarbonyl compounds, glycosylated proteins and lipid peroxidation end products (Delgado-Andrade 2014). In order to avoid the generation of these toxic and harmful substances, research and development of new raw materials, the use of some nonfat, macromolecular protein and aspartic acid is necessary. Fish skin is rich in protein but low in fat. The protein extraction process is simple, so fish skin can be used as an excellent protein source for producing Maillard-reactive flavor product.

Utilization of shell byproducts

The processing of aquatic foods produces a large number of shrimp shells, crab shells and shells. These shells contain large amounts of chitosan. Chitosan is very strong in antibacterial property which inhibits microbial cell growth. Chitosan is thus a natural polysaccharide, nontoxic side effects, safe and reliable, and can be used as food preservative. The antibacterial rate is as high as 99.99%. Japan's Nissin successfully extracted food preservatives from these shell. The method is: first soaking of shells in hydrochloric acid, removal of calcium carbonate and other ash, and then removal of the residual protein with sodium hydroxide. Finally with 40%–45% of the Sodium hydroxide high temperature deacetylation, a kind of polymer polysaccharide chitosan is obtained (Varun et al. 2017). Lafarga et al. (2013) used shrimp shells to produce chitosan-containing bread and found that Chitosan inhibited the growth of Bacillus cereus and the formation of rope in bread at 3–5 days. At the same time, it was also found that natural mold growth in bread prepared using chitosan substitution of flour at 1% was significantly inhibited compared to the control bread. Chitin is one of the most abundant bioactive polymers. It is commercially extracted from seafood shell by-products through harsh thermochemical processing. Extraction conditions, source of raw materials and pretreatment have a significant effect on its quality and biological activity. Chitin and its main derivatives chitosan are used in many fields and its applications are constantly expanding. Nidheesh and Suresh (2015) used response surface methodology (RSM) to optimize the conditions for the separation of chitin from shrimp shells. The results showed that the best conditions obtained through RSM would help to isolate high quality (>98% purity) chitin from shrimp shell by-products.

Other aquatic byproducts can also be used. For example, the protein content of the swim bladder is as high as 80% and the fat content is very small. Rich in high-level collagen protein, such as sturgeon swim bladder contains more than 80% of collagen, and calcium, iron, phosphorus and other minerals, mucopolysaccharides and vitamins. It is an ideal high protein low-fat food. Swim bladder is usually made of dry goods in China, which is also currently the main processing form of the swim bladder at home and abroad. The fish gallbladder is usually discarded in fish processing. Bile can be made into bile pigment calcium salt, bile salt and taurine through the use of processing.Scientists at the University of Bochum in Germany studied the properties and mechanism of antifreeze glycoproteins in Antarctic cod blood (Harding et al. 2003). It was found that antifreeze glycoproteins can produce a hydration of water molecules that can prevent liquid ice from crystallizing, and this effect is more significant at low temperatures than at room temperature.Fish testis is commonly known as fish white, because it has a unique smell The mature fish testis rich in protamine which is an alkaline protein. Protamine has an inhibitory effect on the growth and reproduction of common spoilage microorganisms in food, especially in yeast and mold (Kim et al. 2015). Therefore, it can be used as a food preservative for dairy products, noodles, fruits and vegetables and other non-acidic food shelf life.

Concluding remarks

Although meat processing industry is large in size and sales, it is still one of the worst profitable industries as a whole. Therefore, it is necessary to reduce expenses by adopting new or improved processing methods, in which byproducts can be recycled and upgraded to more valuable products. A large number of scientific research and technological innovation provide strong theoretical and technical support for the development of livestock and poultry byproducts, and make the livestock and poultry byproducts showing broad prospects in the improvement of protein function and nutrition, the preparation of bioactive peptides, the production of edible gelatin and calcium supplement products. In addition, byproducts is classified and processed when the fish is slaughtered. According to its main characteristics, the active substances are extracted, such as fish skin collagen, fish bone calcium, fish visceral oil, and so on, to improve the added value of the product, which provides a new idea for the comprehensive exploitation and utilization of fish byproducts.

With the continuous expansion of meat processing industry and the continuous improvement of the high-value utilization technology for byproducts, the key active factors in the pharmaceutical, food, or nutritional components are searched through the analysis of nutritional value of byproducts to further study and develop the high-value products which are safe and effective. While eliminating the waste of resources, we would protect the environment and achieve the three harvest of economic, social and ecological benefits.

Acknowledgments

We acknowledge the financial support from National Key R&D Program of China (Contract No. 2017YFD0400501), National First-class Discipline Program of Food Science and Technology (No. JUFSTR20180205), Jiangsu Province(China) "Collaborative Innovation Center for Food Safety and Quality Control" Industry Development Program, Jiangsu Province Key Laboratory Project of Advanced Food Manufacturing Equipment and Technology (Contract No. FMZ201803), all of which enabled us to carry out this study.

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