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Review article

# Status and prospects of product processing and sustainable utilization of Chinese mitten crab (*Eriocheir sinensis*)

Fang Xu [b], Xiumei Xing [a], Kai Zhang [a], Cong Zhang [a,*]

[a] *College of Marine Science and Engineering, Nanjing Normal University, Jiangsu Province Engineering Research Center for Aquatic Animals Breeding and Green Efficient Aquacultural Technology, Nanjing, 210023, China*
[b] *College of Social Development, Nanjing Normal University, Nanjing, 210023, China*

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ABSTRACT

Chinese mitten crab, *Eriocheir sinensis*, is a migratory crustacean that grows in freshwater and reproduces in seawater. As a traditional aquatic product treasure in China, the industry of *E. sinensis* has become one of the unique freshwater fishery pillar industries. With years of development, a relatively complete industrial chain model has been initially formed, and its culture area, output and trade are constantly growing. However, the lag of aquatic product processing industry limits the large-scale development of the *E. sinensis* industry chain. In order to further explore the industry advantages and scale, it is urgent to vigorously develop the *E. sinensis* processing industry and promote the industrial optimization and upgrading. Moreover, strengthen scientific and technological support and reduce market risks by means of technological innovation to promote the healthy development of the industrial chain. This review expounds the current situation and existing problems of crab product processing in China, and the prospects of future product processing and sustainable utilization, in order to provide new insights for the large-scale development of *E. sinensis* industry chain.

## 1. Introduction

In China, more than 80 % of commercial Chinese mitten crab (*Eriocheir sinensis*) are sold alive, and the market sales time is mainly concentrated in the fourth quarter. This traditional production and consumption method gradually fails to meet consumer demand and restricts industrial development. The mainstream sales model of *E. sinensis* must be changed from seasonal to year-round in order to meet the annual consumption needs of consumers, thereby ensuring the relative stability of the market and the sustainable development of the industry. Therefore, off-season storage and product processing technology of *E. sinensis* are crucial to the integrity and sustainability of the industrial chain. At present, most of the crab processing products are still in the primary processing stage, and the off-season storage and processing technology lacks innovation and breakthrough [1]. The processing technology of crab products is the weakest link in the *E. sinensis* industrial chain. In addition, the neglect of systematic research and the lack of innovative results of processing products have limited the large-scale development of the *E. sinensis* processing industry. Furthermore, food safety issues that are prone to occur during product processing also need urgent attention, such as paragonimiasis caused by eating and processing liquor-saturated crab [2,3]. In summary, the development of aquatic products processing technology in China is relatively lagging behind, especially in the processing of *E. sinensis* products, which needs to be vigorously developed, including establishing brand

* Corresponding author. 1 Wenyuan Road, Nanjing, 210023, China.
*E-mail address:* zhangc@nnu.edu.cn (C. Zhang).

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awareness, developing new products and ensuring food safety. This review summarizes and discusses the present situation and problems of *E. sinensis* processing products and sustainable utilization, and puts forward comments and prospects for the future large-scale development of crab product processing and industry, in order to provide new insights and references for the improvement of *E. sinensis* industry chain and the large-scale development of the industry.

## 2. Main categories of crab processing products

The processed products of *E. sinensis* can be mainly divided into food series, health care product series, pharmaceutical series and industrial raw material series.

### 2.1. Food series

The common commercial processed foods of *E. sinensis* on the market include crab roe sauce, crab roe meal, crab meat dried products, crab meat quick-frozen food, liquor-saturated crab, food additives, flavor seasonings, snack foods [4].

Crab roe sauce is a kind of paste seasoning with unique flavor, which is made from gonad and hepatopancreas of *E. sinensis* as raw materials, and the main process procedures are washing and mashing, seasoning fermentation and canning sterilization. The processed crab roe sauce food solves the limitation of seasonal consumption of commercial crabs. In addition, macromolecular substances such as proteins, fats and carbohydrates in the raw materials are degraded into small molecular metabolites such as amino acids, fatty acids and monosaccharides through the fermentation process, which are easier to be absorbed and utilized by the body [5]. Ye et al. (2020) studied the processing technology of crab roe sauce and the analysis of microbial contamination of finished products based on the primary processing products of frozen crab gonad, hepatopancreas and crab meat, and found that the main steps susceptible to microbial contamination in the process of sauce-making were raw materials themselves, mixing, stirring, and canning, while the key processes for controlling microorganisms were stir-frying sauce and sterilization [6]. Wang et al. (2016) added natural antioxidant (e.g. ascorbic acid and tea polyphenols) and preservative (e.g. nisin) to crab roe sauce by hurdle technology, combined with heat sterilization and ultra-high-pressure sterilization treatment, which could maintain the quality of crab roe sauce and extend the shelf life under room temperature storage conditions [7]. Crab meat floss is a high-protein and low-fat fast food made from *E. sinensis* muscle by cooking and stir-frying process, which is widely favored by consumers in the market. Tian et al. (2020) used microwave drying method to explore and optimize the processing technology conditions of crab meat floss derived from precocious crab, which provided a basis for the development and utilization of precocious crab with low market value [8].

In European and American countries, crabs are often derived from fishing and are important by-catch in some coastal countries [9]. The main edible part of the captured crab could be used as a processing by-product to combine with other edibles (e.g. starch) to be marketed as puffed food, or used to make flavored edible oils or sauces. Crabs are rich in trace elements and minerals, with a balanced amino acid composition and high protein content, which can be used to improve the nutritional value of traditional foods [10]. Crab food has been enduring in the European and American markets because the integrated factory process has transformed highly perishable crabs into stable shelf goods. Taking puffed food as an example, most of the crabs were coarsely chopped, the edible parts were selected, successive screened by mold, butylated hydroxytoluene was used to control lipid oxidation, and dried until the humidity standard, which was combined with edible starch to be put into the market [11].

In recent years, the variety of crab foods has gradually increased in the Chinese market, indicating that its unique flavor has begun to be recognized by consumers. Compared to shelf food with complete processing process, the quality and safety of live crab pickled food is not assuring. The processing and production of crab food in the Chinese market usually faces problems such as perishable raw materials, low added value of products, and loss of nutrients during processing. Therefore, with the development of modern food processing technology and the growing demand of consumers, the development and optimization of new food processing technology and new products have broad application prospects.

### 2.2. Health care product series

Crab carapaces are rich in astaxanthin and have a bright red color when heat, which can be used as an effective source of natural health colorants. Astaxanthin has strong antioxidant capacity and immune regulation ability, and can enhance the immunity and disease resistance through a variety of mechanisms. It is widely used in the field of nutrition and medicine [12]. Astaxanthin is mainly divided into natural astaxanthin and synthetic astaxanthin according to different sources. Synthetic astaxanthin products account for about 95 % of the current market share; With the improvement of awareness of food safety and the advancement of astaxanthin isolation and purification technology, natural astaxanthin has shown better development potential [13]. Liu et al. (2011) optimized the extraction process of astaxanthin by subcritical fluid extraction method, and the results showed that compared with the traditional organic solvent extraction method, the extraction rate of subcritical fluid extraction under optimal conditions could be 33.2 % higher, and the time consumption was reduced by 82.8 % [14]. Calcium is an important component of crustacean carapaces, and has attracted more and more attention in its efficient utilization [15]. The minerals in crab carapaces are mainly in the form of calcium carbonate, with a content of up to 50 %. Han et al. (2018) used lactic acid to neutralize the calcium salts in crab carapaces to convert calcium carbonate in shrimp and crab carapaces into calcium lactate, which is more conducive to absorption and utilization. This method realizes the demineralization and prepares calcium lactate at the same time, and the mass fraction of the product can reach 99.37 % [16]. Organic calcium is a micronized powder obtained by ultrafine grinding of crab carapaces and claws, which is easier to be absorbed and utilized than inorganic calcium. Organic calcium can be used as an additive to make high-calcium and high-iron bone powder or bone paste series foods, which have unique nutritional and health care functions [4].

### 2.3. Pharmaceutical series

Chitin is a nitrogen-containing polysaccharide and a vital component of the carapaces of shrimps and crabs. The crab carapace was mechanically crushing and immersed in a dilute sodium hydroxide solution to remove protein, and then calcium was removed with a dilute hydrochloric acid solution to obtain chitin [4]. Chitin and its derivatives have a strong affinity for human cells. Moreover, because of its non-toxicity, low immunogenicity and can be dissolved by enzymes in the human body, it is widely used as surgical sutures, artificial skin or hemostatic materials in the field of medical materials. Chitosan is a derivative of chitin. Chitosan and chitin have broad-spectrum antibacterial activity, and have bactericidal effect on gram-positive/negative bacteria and molds in infection and traumatic treatment [17]. Chen et al. (2017) reported that the temperature-sensitive hydrogel prepared from chitin has good hemostatic properties, and the temperature-sensitive hydrogel has a short absorption time in the body, which could reduce the inflammatory response of bleeding organ and facilitate postoperative healing [18].

The common preparation methods of chitin mainly include acid-base method, enzymatic method and microbial fermentation method. The advantages and disadvantages of the three methods are shown in Table 1.

Based on the different characteristics of chitin preparation methods, optimizing the chitin preparation method to overcome the defects of traditional technology, improve the purity of the product and achieve large-scale production, which is of great significance for the development and utilization of crab carapace resources. Li et al. (2020) extracted chitin from shrimp and crab carapaces by ultrasonic intermittent assisted acid-base extraction, which increased the productivity of the extract by 19.6 %, and the ash and protein content of the product were reduced to 0.42 % and 1.12 %, respectively [20]. Liang et al. (2021) optimized the process of preparing chitin from *E. sinensis* carapace by response surface method, and the results showed that the preparation of chitin by fermentation combined with enzymatic method had mild conditions and environmentally friendly, and had favorable application prospects [21].

### 2.4. Industrial raw materials series

Crab carapaces is rich in chitin and ketoacid, which is an excellent chemical raw material with a wide range of uses. Uranium is an important raw material for the atomic energy industry, the processing of ketoacid has a positive effect on the extraction of uranium from seawater [4]. Some of the non-renewable biomass contained in crab carapaces could be used to produce biogas [22]. In addition, crab shells have been found to be used to make battery materials, known as “crab carbon”. Crab carbon is a very promising material, it has many excellent properties and could be widely used in the manufacture of various types of batteries [23]. Many studies have tried to use chemical methods to prepare crab carapaces into high-performance biopolymers, using waste as raw materials and energy sources, which means that crab carapaces have splendid application prospects in industrial production applications.

## 3. Sustainable utilization and problems

### 3.1. Study on rapid separation technology of crab meat

The separation of crab carapaces and meat is one of the most important processes in the product processing. The separation method of *E. sinensis* carapaces and meat is mainly manual separation, which has slow production efficiency, and easily causes raw material pollution. Therefore, developing efficient separation technology of raw materials and maintaining the quality of crab meat is a crucial means to break through the production bottleneck and enhance the development of *E. sinensis* product processing industry. Ouyang et al. (2012) classified crab body, periopods and cheliped, and separated the shell and meat by belt extrusion, roller extrusion and vacuum suction filtration, respectively [24]. The results showed that the belt extrusion method had the best effect on the separation of carapaces and meat of the crab body, and the meat yield was about 68.2 %, and the separation efficiency was 50 kg/h; the roller extrusion method was the best for the separation of shell and meat of the periopods, the meat yield was about 35.8 %, and the separation efficiency was 6.8 kg/h; the vacuum suction filtration was the most suitable for the separation of shell and meat of cheliped, the meat yield was about 44.1 %, and the separation efficiency was 5.1 kg/h. This study provides a vital basis for accelerating and improving the processing and preparation of raw materials. Chen et al. (2016) designed a roller extrusion device to separate shell and meat of the periopods, which solved the problems of high labor intensity, low efficiency and crab meat contamination [25]. Ye et al.

**Table 1**
Comparison of the characteristics of chitin preparation methods [19].

| Preparation methods | Advantages | Disadvantages |
|---|---|---|
| acid-base method | • simple process<br>• low-cost | • produce acid and alkali wastewater, serious pollution<br>• chitin severely degraded |
| enzymatic method | • mild reaction conditions<br>• recyclable<br>• little effect on the main chain structure of chitin | • time-consuming<br>• high-cost<br>• poor deproteinization effect |
| microbial fermentation method | • mild reaction conditions<br>• low energy consumption<br>• Undestroyed chitin structure | • time-consuming<br>• complex process and equipment<br>• insufficient demineralization and deproteinization |

(2019) obtained the optimum process parameters of ultra-high-pressure assisted shelling by response surface optimization: pressure 440 MPa, time 16 min, temperature 60 °C, the segmentation yield was 34.24 %, and the product quality score was 42.50 [26]. Compared with the traditional cooking shelling method, ultra-high-pressure treatment could save about 53 % of energy consumption. The level of myofibrils in the periopods muscle is higher than that of the muscle in the carapace, and could be processed at high pressure (300 MPa/2 min, 300 MPa/4 min, 500 MPa/2 min) to denature the cold protein of the muscle, which making the shell and meat easier to separate. This method could obtain higher yields and ensure the stability of polyunsaturated fatty acid content, which cannot be achieved by conventional heat treatment [27].

### *3.2. Full utilization of surplus raw materials*

Shrimp and crab processing waste is an environmentally friendly material in agriculture, industry, medicine and health, food industry and other fields. In recent years, it has achieved high value-added conversion of products and environmental protection in chito-oligosaccharide, green coatings, textile and papermaking, water treatment. The degree of intensive processing of wastes in China's aquatic processing industry is relatively underdeveloped, and the waste produced by processing is mainly used to produce feed. As a protein supplement for ruminants, it can be comparable to other protein sources such as soybean meal [28]. Interestingly, with dietary supplementation of crustacean waste material, the weight gain rate of cultured shrimps and crabs could be effectively improved and the carapaces could be made harder [29]. Wu et al. (2019) determined the nutritional components of the remaining scraps after processing *E. sinensis*, and the results showed that various edible substances such as minced crab meat, chopped crab roe or hepatopancreas had high nutritional value and needed to be further developed and utilized [30]. Liu et al. (2010) prepared a mixed hydrolase with neutral protease, flavor enzyme and papain at a ratio of 1: 2: 1, and hydrolyzed the by-products of sea crab processing at pH 6.5 and 50 °C for 5 h to obtain 17 free amino acids [31]. Jaswal et al. (2010) used tin hydrochloride as a hydrolytic reagent to hydrolyze crab waste to obtain an amino acid yield was 32 %, and about 42–44 % of the total amino acids hydrolyzed were essential amino acids, mainly including leucine, arginine, valine and threonine; the remaining non-essential amino acids were mainly including glutamic acid, aspartic acid and glycine [32]. Tao (2009) studied the processing and extraction technology of crab oil, protein powder, sauce and micro-powder with *Portunus trituberculatus* scraps as raw material, and basically realized the waste-free comprehensive utilization of scraps [33]. Therefore, the remaining scraps produced by shrimp and crab processing could be processed by biotechnology to achieve higher development and application value.

In addition, chitin and its derivatives have shown great market potential in the application of different fields, and extracting chitin from the processing waste of *E. sinensis* is an effective way to reduce resource waste and improve economic value. However, at present, the development and application technology of chitin in China is relatively slow, and it is difficult to achieve large-scale industrial production [34].

### *3.3. Automation and intelligent processing equipment needs to be improved*

Compared with the common economic crabs in Europe and the United States, the product processing equipment of *E. sinensis* is relatively backward, and the variety of equipment is insufficient. In order to achieve high-value and large-scale production of aquatic products, it needs to be supported by reliable and advanced processing equipment [35]. Therefore, it is necessary to vigorously develop the research and application of superb processing technology and circulation equipment, move closer to mechanization, automation and intelligence, break through the status quo of the industry, and enhance the competitiveness of *E. sinensis* processing industry, so as to achieve transformation and upgrading and sustainable development. The product processing equipment of *E. sinensis* usually includes crab cleaning machine, splitting machine, conveyor line, hepatopancreas suction machine, flesh separator. Tan (2020) published a cleaning device for *E. sinensis*, which solved some drawbacks of traditional devices, such as the inability to clean both sides of the crab, easy residual impurities and wear on the brush, and greatly improved the efficiency and cleanliness of crab cleaning [36]. Yu (2017) invented an automatic crab bundling system including separation mechanism, male and female separation mechanism, automatic weighing mechanism, bundling mechanism and intelligent automatic control system [37]. Liu et al. (2019) developed an intelligent sorting system based on the recognition algorithm combining histogram of oriented gradient features and support vector machine classifier, which could accurately identify crabs and their size and quality, and provide a new reference for the development of intelligent processing and sorting procedures for crab products [38].

### *3.4. Product preservation technology is not mature*

Aquatic products are prone to spoilage due to their strong endogenous enzyme activity and a multitude of microorganisms. In order to improve the freshness and prolong the shelf life of *E. sinensis*, physical, chemical or biological technology are usually used to inhibit endogenous enzyme activity and microbial growth [39]. Although the shelf life of aquatic products could be prolonged under low temperature conditions, the large amount of highly unsaturated fatty acids and proteins contained in the product itself will still be oxidized and decomposed, which will have adversely impact on its storage and processing. Chen et al. (2019) found that initial freezing had no significant effect on the quality of *E. sinensis* meat, whereas frozen storage (−20 °C) would cause protein denaturation and severe juice loss in crab meat [40]. Therefore, the frozen storage method is not applicable to the market circulation of commercial *E. sinensis*. Peng et al. (2017) froze fresh *E. sinensis* with −20 °C slow freezing and four kinds of quick freezing (−20 °C, −40 °C, −60 °C and liquid nitrogen quick freezing) treatment, respectively, and found that the muscle biochemical characteristics in the quick-frozen groups were better than those in the slow-frozen group [41]. In order to minimize the adverse impact of refrigeration technology on the quality and flavor of crab meat, Liu et al. (2018) used edible salt as water-retaining agent and combined with quick-freezing treatment, and the results showed that the muscle quality and flavor of frozen crab were effectively protected [42]. Modified atmosphere preservation is a preservation technology that inhibits the respiration, growth and reproduction of endogenous microorganisms and enzymatic reaction in aquatic products by adjusting the gas composition and proportion of the environment in which aquatic products are located [43]. Tang et al. (2021) analyzed the effects of air and different gas component packaging methods on the biochemical indexes of cooked crab meat and hepatopancreas, and the results showed that 40 % $CO_2$ and 60 % $N_2$ were the best modified atmosphere packaging methods for products under storage conditions at 4 °C [44].

However, with the improvement of consumers' food safety concept, a single modified atmosphere packaging preservation technology has been unable to meet the needs of food storage and preservation industry. Therefore, the application of comprehensive modified atmosphere packaging and other preservation technologies (e.g. low temperature, ultraviolet sterilization, ozone treatment, ultra-high-pressure treatment, chemical preservatives, and bio-preservatives) is booming [45]. Zhang et al. (2012) found that oxygen-free combined compound bio-preservative packaging to inhibit the growth and reproduction of microorganisms in crab sticks could be used as an effective packaging process to extend the shelf life [46]. The immaturity of preservation technology and serious losses after production have become one of the important factors restricting the development of agricultural products and food processing industry. The average loss rate of agricultural products in developed countries such as Europe, the United States and Japan is about 1.7 %–5 %, while the loss rate of aquatic products in China is as high as about 15 % [47]. The key to the development of new functional foods lies in the preservation and processing of raw materials. Based on the advantages and disadvantages of various common preservation techniques, the development of comprehensive preservation techniques, such as ensuring the quality and sensory flavor, effectively extending the shelf life, low energy consumption, no oxidation products and preservative residues, and flexible operation, is the key to break through the bottleneck of the *E. sinensis* processing industry.

### *3.5. Quality of processed products and food safety are at risk*

From the farm to the dining-table, aquatic products go through multiple steps such as breeding, culture, processing and market circulation, and each step has the risk of potential safety hazards. Therefore, the construction of aquatic product standardization system should be supervised and risk controlled from various levels such as culture standards, transportation standards, food quality specifications and sampling inspections. In terms of product quality and safety, Lu et al. (2018) applied hazard analysis critical control point quality management system to the processing and production of *E. sinensis* and achieved favorable results [48]. The main factors affecting the safety of aquatic products are physical, chemical and biological hazards, of which biological hazards have the greatest impact, mainly manifested as parasites, viruses and bacteria. Therefore, it is particularly crucial to use the corresponding toxic and harmful component detection technology in aquatic product processing [49]. In addition, with the development of emerging technologies, the improvement of aquatic product traceability system should be strengthened to improve the ability of traceability and supervision.

Aquatic crustaceans are one of the main foods that cause food-borne allergies, and the biotoxins in crustaceans can cause human allergies and even shock death. Therefore, strengthening the study on the allergenic mechanism of *E. sinensis*, establishing allergen detection technology and desensitization methods, and developing hypoallergenic products are crucial ways to ensure product quality safety and broaden the product market [50]. In recent years, crustacean allergenic activity reduction technologies such as thermal processing method, radiation technology, enzyme treatment method and ultra-high-pressure method have been gradually established and formed. Liao et al. (2015) found that seven proteins with molecular weights between 37.2 and 89.1 k Da were the main allergens of *E. sinensis*, and the protein concentration and immunogenicity of the crude protein extract decreased with the increase of irradiation dose [51]. Cheng et al. (2020) studied the effects of different processing methods on the digestive stability and allergenicity of tropomyosin in *E. sinensis*, and the results showed that reverse pressure cooking and high temperature and pressure treatment could significantly promote the degradation of tropomyosin and significantly reduce the allergenicity [52].

### *3.6. Relevant industry standards are incomplete*

Up to now, there are 640 national standards and industry standards for fisheries have been implemented in China, including 65 national standards and 575 industry standards. However, the systematic collection, organic integration and reasonable division of technical standards for aquatic product industry chain have not yet formed a complete standard system [53]. Compared with shrimp and other aquatic products industries, the development of *E. sinensis* processing industry is very backward, and the processing standards of related products have not been created. Therefore, attaching importance to talent training, accelerating the transformation of scientific and technological achievements, supplementing and supervising relevant standards, and strengthening the construction of implementation systems are the necessary trends in the future development of aquatic product standardization.

## 4. Prospects

Accelerating the large-scale development of *E. sinensis* processing industry and solving the problem of sustainable utilization require multiple measures in parallel. Firstly, it is necessary to emphasized and strengthen the investigation of consumer eating habits and market demand, and carry out consumer-oriented processing product development. Moreover, promoting the development of product diversification, strive to open domestic and foreign markets, and broaden sales channels. The next is to improve the standardized management of raw materials for deep-level processing products and ensure the quality and safety of processing products from the source. Furthermore, strengthening the construction of enterprise innovation ability and technology innovation teams, supporting enterprises to build R&D centers independently or jointly with colleges and enterprises. In addition, through technical challenge overcoming to obtain a series of innovative achievements with independent intellectual property rights and good application prospects, and enhancing the continuous innovation ability and development potential. Finally, establishing a food safety traceability system for *E. sinensis* processing to ensure health and transparency of the processing process. In conclusion, multiple measures in parallel will effectively reverse the status quo and existing problems of *E. sinensis* product processing, and promote the large-scale and sustainable development of the industrial chain.

## Ethics approval and consent to participate

No ethics approval was required for this review that did not involve patients or patient date.

## Consent for publication

All authors consent to publication.

## Date availability statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

## CRediT authorship contribution statement

**Fang Xu:** Formal analysis, Conceptualization. **Xiumei Xing:** Investigation. **Kai Zhang:** Investigation. **Cong Zhang:** Supervision, Funding acquisition, Formal analysis, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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