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Processing Status and Utilization Strategies of Antarctic Krill (*Euphausia superba*) in China

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Abstract: Antarctic krill resources were previously abundant and the total allowable amount of Antarctic krill caught is roughly equal to fishery production around the world. Thus exploiting Antarctic krill is one of the best approaches to pelagic fishing in China. Antarctic krill is a high-quality protein source with low fat content compared to other fishery products. Therefore, products and by-products of the krill were widely applied. However, problems still hindered development of the Antarctic krill. The aim of this article is to assess the nutritional value, existing products and potential benefits of Antarctic krill. Relevant problems and strategies were implemented, according to the recommendations in the paper. These recommendations were guided by the high value products and focused on research of processing equipment and technology. From here we built long-term plans based on markets. Lastly, support is provided for the strategies utilized to process Antarctic krill in China.

Key words: Antarctic krill・Process status・Utilization strategies

INTRODUCTION

Krill are in the family of pelagic marine planktonic crustaceans and there are about 85 species of krill widely distributed throughout the world's oceans. The species of krill that large-scale nineteenth century commercial fisheries mainly targeted were Antarctic krill (*Euphausia superba*) and North Pacific krill (*Euphausia Pacifica*) [1]. The biology of krill has recently been reviewed and the commercial value of krill is now well documented, especially for Antarctic krill because of their huge biomass and potential fishery resources [2-5].

Antarctic krill are shrimp-like invertebrates that occupy a unique position in the marine Antarctic ecosystem [6]. Antarctic krill are considered to be one of the most promising protein sources for human consumption [7]. The latest reports show that the total allowable catch of Antarctic krill is equal to global fishery output [8]. This shows the great development and potential utilization of Antarctic krill.

Krill fishing began in 1961 by the Union of Soviet Socialist Republics. The international study on krill for processing and utilization began around the same time. Before that, Japan, the United States, Poland, Norway and Chile had successively begun fishing and research of krill [8]. When China took part in officially catching Antarctic krill in 2009, the era of processing and utilization of Antarctic krill arose.

There was extensive research on the processing and utilization of Antarctic krill [3, 9, 10]. However, this research focused on the theoretical utilization of Antarctic krill and neglected the relevant risks in actual utilization and processing. In this paper, we begin with the nutrition value and chemical composition of Antarctic krill and then introduce current national and international developments and utilization of Antarctic krill. During this section we also look at the corresponding problems of utilization and processing. Some advice on the utilization of krill is provided based on former research, to hopefully boost processing and utilization of Antarctic krill in China.

Processing Status of Antarctic Krill: Nutrients and healthcare functions of Antarctic krill: Currently, researches on Antarctic krill are still at a fundamental stage in China [3, 11, 12]. Evaluation of the nutritional content of Antarctic krill was detailed, introduction of healthcare functions was comprehensive and research on essential components was transparent. Specifically, Antarctic krill were found to be rich in protein, essential animal acids were suitable and types of liquids and

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mineral substances were suitable for human assimilation and utilization. Primary nutritive analysis of whole Antarctic krill showed a range of 77.9% to 83.1% for moisture, 11.9% to 15.4% for crude protein and 0.5% to 3.6% for total liquids [3]. Compared with other types of seafood, Antarctic krill had good high-quality protein resources and low fat content, which provided more nutritive value and potential health benefits and reduced the risks of various diseases when consumed.

Protein: Protein contents in Antarctic krill muscle were rich and protein accounted for about 16% of muscle weight and 60% to 65% of dry weight [13]. Thus Antarctic krill are considered a high protein food. Currently, protein products are prepared because they contain a higher protein concentration than is normally found in food. Meanwhile, processing technologies have matured, which allows the protein from Antarctic krill to be better utilized. Related research was carried out to produce a product with protein recovery as high as 80% [14]. Proportions of amino acids in Antarctic krill were moderate. Wang [15] measured amino acid content in Antarctic krill. The results showed that Antarctic krill are rich in essential amino acids, especially leucine, lysine, isoleucine and arginine. When Antarctic krill autolyzes, its muscle tissue is broken down into a peptide and amino acids (mainly glycine, glutamic acid and lysine). This provides a good basis for developing krill as a healthy food and also an amino acid drink. Types of animal acid were abundant after hydrolysis [13] (Table 1). Compared with two other types of seafood, Antarctic krill had a higher percentage of Amino acids and the ratios of essential animal acid to total animal acid were more than 40%. The essential amino acids identified were: methionine, cysteine, phenylalanine and tyrosine. Amounts of sulphur amino acids were low, which showed that the quality of the Antarctic krill protein remained within mid-to-high levels based on FAO/WHO standards and contents of essential animal acids met dietary needs based on the FAO/ WHO/ UNU1985 recommendations [16].

Liquids: Antarctic krill liquids consisted of phospholipids and triglycerides. Phospholipids and triglycerides combined took up about 90% of the liquids and 40% to 60% of the liquids were phospholipids [3]. There were various fatty acids in Antarctic krill and most of them were polyunsaturated fatty acids, consisting of EPA ($C_{20:5}$), DHA ($C_{22:6}$) and oleic acid ($C_{18:1}$). Meanwhile, applications of EPA ($C_{20:5}$) and DHA ($C_{22:6}$) on medical and physical effects were widely recognized [17]. Lipid compositions of

Table 1: Amino acid compositions of Antarctic krill (mg/g dry weight)

Amino acid	Antarctic krill	Trout	Salmon
Isoleucine	25	9.4	10.0
Leucine	40	16.6	17.6
Lysine	44	18.8	19.9
Methonine cysteine	24	8.3	8.7
Phenylalanine tyrosine	50	14.9	15.7
Throsine	22	9.0	9.5
Tryptophan	70	2.3	2.4
Valine	26	10.5	11.1
Histidine	11	6.0	6.4
Arginine	38	12.3	12.9
Alanine	29	12.4	13.1
Aspartic acid	53	21.0	22.1
Glutamine	67	30.6	32.3
Glycine	34	9.8	10.4
Proline	23	7.2	7.6
Serine	19	8.4	8.8

Table 2: Contents of mineral substances of Antarctic krill between whole krill and muscle [16, 21, 21] (mg/g dry weight)

	Contents	
Mineral substances	Whole krill	Muscle
Calcium	1334.701	327.1
Phosphorus	1415.17	913.2
Iron	1.54	4.7
Magnesium	333.20	--
Manganese	--	0.5
Selenium	--	0.34
Zinc	18.0	4.5
Arsenic	0.35	0.0029
Mercury	£¼LOQ	ND
Lead	£¼LOQ	ND
Copper	5.2	0.5
Cadmium	0.05	0.0021

ND: Not detected £¼LOQ: Limit of quantization --: No data

Antarctic krill caught in winter were analyzed and results demonstrated that Antarctic krill were abundant in n-3 polyunsaturated fatty acids. EPA and DHA content accounted for about 19% of total fatty acids. The simple report [18] also found that the levels of Antarctic krill fatty acids harvested in winter and summer were most similar. Currently, applications of omega-3 polyunsaturated fatty acids have focused on omega-3's extracted from Antarctic krill in the markets of Norway and Canada. However, polyunsaturated fatty acids deteriorated easily via oxidization. In Antarctic krill, the combined effects of phospholipids and α-VE produced about 40% to 60% un-oxidized polyunsaturated fatty acids. Antarctic krill powder could be stored at ambient temperature for 18 months post freeze-drying and after removal of hyperoxides [17].

Mineral Substances: Table 2 illustrates the mineral content of Antarctic krill. The mineral contents of Antarctic krill are located in the exoskeleton in large part as other shellfish. The mineral substances were removed from the exoskeleton to produce meat or protein. In whole krill, the main minerals were calcium, phosphorus and magnesium, all of which are involved in bone health and meet the RDA mineral requirements for adults. Based on the recommended intake for adults in China, selenium contents in Antarctic krill were higher, thus Antarctic krill was deemed a good source of selenium. Iron is another important dietary mineral substance. Identification of food sources containing iron is important, because iron deficiency is the most common nutritional disorder worldwide [19]. Iron contents decreased slightly during processing, thus, iron in the krill could potentially contribute towards dietary intake. However, iron contents did not meet the RDA for women (18 mg/d) or men (8mg/d). Compared with other shellfish and red meat, (except oysters, mussels and clams) Antarctic krill had a higher iron content [20]. At the same time, Vitamin A contents of Antarctic krill eyes were recognized, however reported amounts were negligible.

Utilization and Processing of Antarctic Krill: There were several major techniques involved in the utilization and processing of Antarctic krill. One was original processing technology for seafood (initial processing) and direct placement into markets. Currently primary products of Antarctic krill are boiled, frozen, peeled and used in meals. The second technique is to further process the Antarctic krill, into higher value-added high-end consumption products. Antarctic krill resources are gradually transformed into goods for consumers and industries both domestically and internationally. The last technique includes using experimental parts of the krill as food additives. Currently, there are large investments in this process. However, krill products are still flawed because of errors in research.

Human Consumption: Successful applications of Antarctic krill for human consumption have been reported [17]. In Japan, about 43% of Antarctic krill were used for food directly and indirectly [23]. Currently, Japanese companies do not make use of the peel and discard the peel and tail of the Antarctic krill. These companies are more focused on obtaining food additives gradually. Dishes include soup, rice and flouring, which are better suited to match the color and flavor of the krill.

In 2002, an American company, Top Ocean Co. Ltd. began research on Antarctic krill. Top Ocean Co.'s frozen krill meal was of a higher quality. Attached company, Kodaik, mainly produced food additives that were derived from various animals. These products were promoted in America, Japan and some European countries.

In China, utilization and processing of Antarctic krill was at its primary stage. Zhu [24] and Zou [25] proposed some views of their own and put forth some opinions on the craft. Currently, dried meat floss of Antarctic krill is sold in China. However, raw materials from Antarctic krill were still imported, so "autonomous" production is needed.

High-End Consumption: There were some attempts to prepare Antarctic krill for high-end consumption. In Japan, 70% of fresh Antarctic krill were sold as bait for consumers and 10% of those were used for official competition [23] thus the amounts of Antarctic krill used as bait has increased. In England, Murex Aqua Food Co., Ltd. succeeded in making good use of Antarctic krill as fish bait after freeze-drying. Based on an evaluation report, more than half of Antarctic krill were treated and used as fish bait in England.

Feed Additives in Aquaculture: The evaluation of Antarctic krill as a food additive in aquaculture had been widely approved. Storbakken [26] investigated and evaluated the nutritive value of several krill as food additives in aquaculture. The results showed that krill provided sufficient nutrition, especially as sources of protein. Additionally, rational rates of animal acids in krill played important roles in assimilation. In Japan, *Pugrus major*, *Oncorhynchus kisutch* and *Salmo gairdnerii* were first fed Antarctic krill [27, 28] and were succeeded by *Seriola quinqueradiata* and *Oncorhynchus kisutch*. Nowadays, researchers focus on carotenoid extraction during the production of food additives to make the fish or fish skin red [27]. The results indicated that the fish were tasty after being fed Antarctic krill and did not absorb residual fluorine. In China, freeze-dried grinding or grinding of Antarctic krill were techniques used to produce aquaculture food additives. Zhang [29] reported on Antarctic krill additives fed to *yellowtail bait*. The results showed that the quality of the *yellowtail* improved after they were fed Antarctic krill oil. Effects of dietary freeze-dried Antarctic krill powder on the growth of juvenile groupers (*Epimephelus malabaricus*) were reported [12] and the results demonstrated that the optimum dietary intake was at 4% krill addition. These grouper showed the most significant gains, weight gain, special growth rate and protein efficiency were the highest while food conversion rate was the lowest. Four groups of fish were compared ($P<0.05$). The testing indices, (such as contents of DHA, EPA and amounts of polyunsaturated fatty acids) were much higher than the control group. Additionally the quality of the flesh was improved post-feed.

Exploitation of Antarctic Krill for Biological Materials

Enzymes: Enzymes in Antarctic krill have special and powerful structures. Both purification and characterization of Antarctic krill proteases were clearly mentioned in earlier reports [30-32]. Purified Antarctic krill trypsase showed strong degradation efficiency at 37°. The efficiency was measured to be about 12 to 60 times greater than that of a cow pancreatic protease [33]. Hellgren [34] reported on enzyme systems that contained particular excision and incision enzymes which had simultaneous actions in Antarctic krill. It was determined that the excision enzyme was responsible for degradation of the protein structure, thus the quality of Antarctic krill degraded quickly even when stored at low temperatures [35, 36].

Due to their abundant protease contents, Antarctic krill was widely used in surgical treatments. The research of Westerhof [37] looked at utilizing Antarctic krill for malignant ulcer tissue experiments. This research is an excellent example because no side effects developed after the experiment. Applications of manufacturing Antarctic krill enzyme drugs were successfully developed and products to relieve spinal pressure and ischioneuralgia were put on the market [38]. Mekkes [39] performed experiments on skin tissue using Antarctic krill. The results showed that the treatment groups had eutherapeutic results compared to the control group. Antarctic krill preparations also accelerated wound healing. Thus, the by-products of Antarctic krill enzymes have broad prospects in both medicine and food.

Chitin: Krill are considered good sources of chitin. Nicol [40] analyzed total krill chitosan yields. Chitosan contents of Antarctic krill were found to be 2.4% to 2.7% of dry weight. Currently, applications of chitin are widespread, which will give the Antarctic krill industry a new by-product for future sales.

Others: Sun [41] reported that the organic amine extracted from Antarctic krill was effective in screening ultraviolet radiation. This proposed use for Antarctic krill provided a new topic for the in-depth study.

Antarctic krill have a high carotenoid content; about 30µg/g. Carotenoids were added into Antarctic krill-based drugs to reduce the risks of myocardial infarction, angina and thrombosis [14].

Studying preparation of ACEI from shellfish, using enzymes and fermentation are widely researched topics. Successful methods to prepare ACEI from Antarctic krill using neutral endopeptidases were reported. Purified peptides Leu-Lys-Tyr and Leu-Lys-Trp had obvious effects on reducing blood pressure [42].

Taurine has many physiological functions including brain promotion, eyesight strengthening, nerve conduction adjustment and more. Taurine is added into food as a nutritional supplement and additions to infant food and health care products were applied. Compared with other fishery products (except octopus), Antarctic krill taurine content reached 289mg/100g, which is higher than squid's taurine content (230mg/100g) [42].

Potential Problems with Antractic Krill Utilization

Autolysis: Autolysis plays an important role in the spoilage of Antarctic krill. Autolysis begins after post mortem. The quality of the krill deteriorates quickly, regardless of processing techniques or utilization. Related research was launched and Chi [35] and Li [43] described the quality changes that Antarctic krill undergo in frozen and ordinary temperatures. Thus the role of temperature in quality changes was expounded. Simple research was carried out previously and the same principles were presented, however autolysis was a main focus of the new research. The roles of enzymes in autolysis of Antarctic krill were studied in detail. The digestive glands of Antarctic krill produce hydrolytic enzymes including proteases, carbohydrases, nucleases and phospholipases [44]. Autolysis became the biggest obstacle to overcome in the processing and utilization of Antarctic krill. However, more and more research was conducted based on autolysis. Based on the autolysis of Antarctic krill, relevant research added Antarctic krill hydrolysates into soy to create and exploit new products [3]. In addition, Kolakowski [14] deposed of the hydrolysates by using curdlan and sedimentation to recover Antarctic krill protein. The percentage of recovery was above 80%.

Fluorine contents: The problem of fluorine contents was another hurdle in Antarctic krill processing and utilization. Low doses of fluorine have a positive bioavailability; on the contrary, high doses of fluorine are harmful. Antarctic krill fluorine content was found to be quite high; therefore fluorosis may be up-regulated after krill consumption. For a long time, researchers insisted that fluorine was transferred into muscle tissue from the shell after post mortem. Soevik [45] discovered that fluorine levels in Antarctic krill reached 2400ppm/dw and fluorine contents were mainly distributed in the shell. Simple research experiments were carried out, even exposing the Antarctic krill to temperatures under -30°C [46]. Some research analyzed the fluorine content in Antarctic krill muscles, but the results were not conclusive because of differentiations in data. Others proposed that fluorine in Antarctic krill could not transfer to muscle tissue. Unclear muscle tissue separation and contamination caused high fluorine contents to be displayed in the muscle. Adelung [47] proved this point after feeding seals the fluorine-rich krill. Additionally, no records displayed that Antarctic animals had complications relating to fluorine. Currently there are many reliable and safe methods to absorb fluorine.

Others: China is far from Antarctica and long-range fishing and logistics supplies were in high demand. Similarly, long-distance transport and conservation increased costs and technical requirements. Therefore this experiment could not have been accomplished without a comprehensive plan. Due to seasonal nutrition differences, formulating the right plans and fishing targets were much easier. From this experiment alone, little information about Antarctic krill was gained, so it is necessary to vigorously develop new technological innovations that can help shed light on this subject.

Utilization of Antarctic Krill in China

Process Technology Perfection: Processing, technology and perfection are key steps in commercial fishing. The final outcome was failure without reasonable plans. Technology preparations were not ready, manufacturing technology for high value-added products had not been successfully applied and shell separation techniques for Antarctic krill were not used. Therefore, the principles for products were determined first and the focus was then shifted to technology for high value-added products, which defused the financial pressure. Antarctic krill had potential for the high value-added products market, based on complicated processing technologies. In China, processing technology and related processing equipment were the focus.

Fishing Technology Improvement: The costs for fishing in the Antarctic area were relatively high because of the far geographical locale. Moreover, traditional fishing efficiency was greatly reduced due to malfunctioning or broken fishing gear. This was a problem because high amounts of fluorine were able to permeate the krill and thus they lost their quality and value [8]. In recent years, Norway has exploited new fishing technologies that have sharply increased fishing production and significantly reduced the numbers of dead fish. Japan has made good use of fishing styles that separate processing and refrigeration by having two respective boats. The United States has reformed methods and machines to aid fishing and processing, which have positively impacted efficiency of the fishing world [48]. It is a key to meliorate Antarctic krill commercial fishing technologies to continue successful development.

Long-Term Development and Mechanisms of Establishment: The development of Antarctic krill products poses not only a scientific problem but also economic and technological problems. The strategies for the development of Antarctic krill in China highlight economic analysis techniques and market demands. These two subjects are integral in that economic costs and market demand analyses are the foundation of any business development plan. Meanwhile, the population of Antarctic krill was gradually reduced [3], establishing long-term preservation for the Antarctic environment as well as global ecology.

CONCLUSION

Due to excessive fishing, worldwide fishery resources are continuously depleted, which requires us to pay more attention to developing oceanic resources. Antarctic krill are the world's largest single species and can be used as a biological resource due to their rich protein, reasonable nutrition proportion and green, pollution-free characteristics. Antarctic krill are considered suitable for human consumption based on their nutrient composition. Development of processing and utilization techniques is on the cutting edge. Utilization of Antarctic krill oil in aquaculture has been a success, human consumption of Antarctic krill has increased, a variety of low-end and high-end products have been developed, research topics have continually expanded and krill is now present in a variety of foods, with gradual development in the areas of value-added foods and by-products. Despite this, Antarctic krill fishing has been restricted by economic and market factors and product development still faces many problems. Thus technological innovation and related equipment should be revised for complete development and markets for Antarctic krill should be targeted and analyzed. Finally, development and utilization of Antarctic krill resources in China should include a comprehensive and long-term plan to including Antarctic krill in the human diet.

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