Krill: Biology, Ecology and Fisheries
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Chapter 10
Products Derived from Krill

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10.1 Introduction

Small-scale krill fisheries, which have provided sources of fishing bait and feed for fish culture, have developed in a number of regions (Fisher *et al.*, 1953; Mauchline & Fisher, 1969). In some areas these fisheries have grown into larger-scale operations (Nicol & Endo, 1997, 1999). Lately, a fishery for Antarctic krill (*Euphausia superba*) has been carried out on a large scale (Miller, 1991). The Antarctic krill fishery developed primarily because of the large size of the krill population and its apparent ease of harvesting, but development has slowed recently because of the high cost of fishing, and the lack of a suitable product, or products, with a reliable and effective economic return (Bykowski, 1986). Because most of the northern hemisphere krill fisheries were developed to supply localised markets for bait and for aquaculture feed, there has been limited development of new products from northern fisheries, until recently. In contrast, there has been a considerable effort devoted to producing a range of products from the fishery for Antarctic krill, and in developing a market for its products. The products of the Antarctic krill fishery have been reviewed a number of times (Eddie, 1977; Everson, 1977; Grantham, 1977; Suzuki, 1981; Budzinski *et al.*, 1985; Suzuki & Shibata, 1990). We will concentrate primarily on recent developments in fisheries products and their uses.

10.2 Constraints to using krill

Introduction

Krill are generally smaller in size than most other organisms that have been commercially harvested. Antarctic krill, with a maximum wet weight of approximately 2 g, is the largest euphausiid that has been harvested, while the smallest harvested krill are of the order of 0.01–0.02 g (Nicol & Endo, 1997). Although other small species of crustaceans have been commercially harvested, and there are large fisheries for species such as sergestid shrimps (Parsons, 1972; Omori, 1978; Neal & Maris, 1985), the small size of krill, and some of their biological characteristics, have made their harvesting and processing particularly problematic.

Rapid spoiling

The digestive gland in the cephalothorax of krill contains powerful hydrolytic enzymes, including proteases, carbohydrases, nucleases and phospholipases, which begin to break down the body tissues immediately following death, particularly if crushing has occurred (Bykowski, 1986). Because these enzymes cohabit, they are mutually protected against their degrading effects, a property rare in nature (Anheller *et al.*, 1989). These enzymes are controlled by an inhibitor system which is disabled on death, facilitating the rapid process of autolysis (Sjodahl et al. 1998). The characterisation of these enzymes has been most complete for Antarctic krill (Sjodahl *et al.*, 1998), but there has been some research into the enzymes of *Meganyctiphanes norvegica* (Peters *et al.*, 1998) as well. Because of the different trophic niches of species of krill, it is likely that they will possess different suites of enzymes, but it appears that most species, certainly those that are currently harvested, all suffer from rapid spoiling as a result of autolytic processes (Bykowski, 1986). Although this property of krill has its drawbacks for commercialisation, it also has been utilised in the development of commercial products (see later sections).

The level of digestive enzymes in krill is highest in those individuals that have been actively feeding. These animals have a distinct greenness in the digestive gland, which is associated with a 'grassy' flavour in krill products manufactured for human consumption (Bykowski, 1986). Actively feeding krill also contain more acids and some ketones, alcohols and sulphur compounds than non-feeding krill, and the presence of volatile compounds affects the odour of krill (Gajowiecki, 1995). For these reasons, green krill are avoided by the Antarctic fishery and the catch is graded on its quality by reference to its greenness (Ichii, Chapter 9). Charts for this purpose have been produced (CCAMLR 1993; Plate 2, facing p. 182).

Krill proteins have a relatively high level of solubility, when compared to fish proteins, and this solubility increases with the degree of autoproteolysis (Kolokowski, 1989). This can present challenges in temporary storage prior to processing (Bykowski, 1986), when loss of soluble fractions can occur. The high solubility of krill proteins also has some advantages for producing certain types of end product, however (see hydrolysates in section on aquaculture feed additives).

The lipids of *E. superba* are subject to change during refrigerated storage (Kolakowska, 1988), with the critical factors being the time between capture and freezing and the temperature of freezing. Free fatty acids increase markedly following death, and rapid deep freezing is necessary to maintain product quality.

Bacteria

The bacterial flora of Antarctic krill have been described, and their activity in the gut may contribute significantly to spoilage (Donachie & Zdanowski, 1998), but their abundance and role as krill symbionts is uncertain (Fevolden, 1981; Virtue *et* *al.*, 1997). They do seem, however, to play a smaller role in the post-capture breakdown of krill than do auto digestive processes (Rakusa-Suszczewski & Zadanowski, 1980). Bacteria have also been shown to have a digestive function in *M. norvegica*, but the spoilage effect of bacteria on species of krill harvested at higher temperatures is unknown (Donachie *et al.*, 1995).

Parasites

Krill may be intermediate hosts of parasites, which can be passed on to other organisms that ingest them; this may be of particular importance when uncooked or unprocessed krill are used in aquaculture feeds. The issue of biosecurity has been viewed as the greatest threat to shrimp aquaculture, and there is particular sensitivity concerning the introduction of viruses in feed produced from other crustaceans (Lotz, 1997). Nothing is known about the viral infections of krill.

There is evidence that *M. norvegica* and *Thysanoessa raschii* are important intermediate hosts of the helminth *Anisakis simplex* (Hays *et al.*, 1998). North Pacific euphausiids have a low level of occurrence of larval digeneans, cestodes, nematodes and acanthocephalans (Kagei, 1985), and such parasites were looked for but not found in Antarctic krill (Kagei *et al.*, 1978). Other symbionts of krill with less harmful potential have also been reported (Nemoto, 1970; Kulka & Corey, 1984; Nicol, 1984; Rakusa-Suszczewski & Filcek, 1988), but reports on studies examining parasitism in krill are rare.

Fluoride

The high fluoride content of the exoskeleton of krill was first indicated by research into *E. superba* (Soevik & Breakkan, 1979), but all other species of krill so far examined have been found to have similarly high levels (Sands *et al.*, 1998). It seems likely that high exoskeleton fluoride concentration is a general feature of euphausiids and that fisheries on krill will have to take this feature into account when assessing potential products.

The fluoride in krill is localised in the exoskeleton, where it can reach concentrations of 3500 μg F g^{-1} dry weight (Virtue *et al.*, 1995), but concentrations in the muscle and other internal tissues appear to be less than 100 μg F g^{-1} dry weight (Sands *et al.*, 1998). Once krill die, however, there is very rapid leaching of the fluoride from the exoskeleton into the tissue (Adelung *et al.*, 1987), even if frozen to −20°C (Christians & Leinemann, 1983). Freezing to temperatures lower than −30°C is necessary to prevent migration of fluoride from the shell into the muscle tissue. Rapid peeling appears to be the most efficient way of separating the fluoride-rich shell from the flesh, although boiling also fixes fluoride in the shell (Bykowski, 1986). The chemical form of fluoride in the shell is unknown but there are techniques which can produce a low fluoride (5–21 μg F g^{-1} dry weight) krill paste or krill protein concentrate by washing with organic acid or water (Tenuta-Filho, 1993).

Vertebrates that are fed on krill tend to accumulate fluoride to deleterious levels in their bones and tissues (Krasowska, 1989) and the levels of this element in krill meal are as much as four times the allowable levels in feed for the European Community (Bykowski, 1986). Those animals with a natural diet that contains krill, however, appear to be able to maintain low tissue fluoride levels and tolerate high bone fluoride levels (Schneppenheim, 1980; Oehlenschläger & Manthey, 1982). Many fish species naturally eat krill and do not appear to accumulate fluoride in their tissues or bones, consequently, whole krill can be used as an aquaculture feed for many species without long-term accumulation of tissue fluoride (Grave, 1981).

Despite many feeding trials on the use of krill meal for a variety of domestic animals, it seems that the high fluoride level of most krill meal, and its high cost, have prevented further developments in this area (Kotarbinska & Grosyzk, 1977; Oehlenschläger, 1979; Bykowski, 1986).

10.3 Current uses of krill

Introduction

There has been considerable effort expended in developing Antarctic krill products for human consumption, but, most of the krill catch has been used for domestic animal feed, and, particularly in recent years, for aquaculture feed. The Japanese Antarctic krill fishery, which takes most of the current catch, produces four types of product: fresh frozen (46% of the catch), boiled-frozen (10% of the catch), peeled krill meat (10% of the catch) and meal (34% of the catch). These products are used for aquaculture and aquarium feed (43% of the catch), for sport fishing bait (~ 45% of the catch) and for human consumption (~12% of the catch) (1999 figures, T. Ichii, Japan National Research Institute of Far Seas Fisheries, pers. comm.).

E. pacifica caught off Japan is used for sport fishing (~ 50% of the catch), feed for fish culture (particularly as a reddening agent), and a small amount is used for human consumption (Kuroda, 1994). Most of the *E. pacifica* from the Canadian fishery is frozen for export to the US, where it is used in the production of fish feed or pet food (Haig-Brown, 1994).

The proposed fisheries for *M. norvegica*, *T. inermis* and *T. raschii* off the East coast of Canada are aimed at producing frozen krill. In addition, it is intended to produce freeze-dried krill for ornamental fish and for public aquaria and freeze-dried krill as an ingredient in salmon feed and as a flavourant for food for human consumption (Nicol & Endo, 1997). *E. nana* caught off the Uwajima Bay, South East Japan, are used as feed for red sea bream (Y. Endo, pers. comm.).

Yields in the manufacture of products from Antarctic krill vary from nearly 100% for krill hydrolysates, to 80–90% for fresh-frozen and boiled-frozen (Plate 6, facing p. 182), to 8–17% for peeled krill and 10–15% for meal. There has been research into ways of improving the efficiency of recovery in the Antarctic krill fishery and reducing waste. Press waters and liquid by-products can contain significant amounts of protein and lipid, which can be removed by filtration, enzymatic or biotechnological methods (Dolganova, 1994).

Krill for human consumption

Individual krill products

Much of the available information on krill products for human consumption has been summarised in earlier reviews (Budzinski *et al.*, 1985; Suzuki & Shibata, 1990; Plate 7, facing p. 182). Currently, 43% of the Japanese Antarctic krill catch is processed for human consumption as boiled then frozen krill or peeled krill tail meat frozen in blocks on board. Canned tail meat is no longer produced from the Japanese catch. Information on products for human consumption from the Antarctic krill fisheries from nations other than Japan is not generally available. In the past, Antarctic krill has also been used for the production of fermented protein products, for spun protein products (i.e. surimi) (Suzuki & Shibata, 1990). A small amount of *E. pacifica* caught off Japan is also being used for human consumption (Kuroda, 1994).

Efforts have been made to produce low shell (hence fluoride) products. Krill paste produced by traditional methods (Budzinski *et al.*, 1985; Plate 8, facing p. 182) and alkaline and acid processed krill protein concentrates have been produced in a low fluoride form, by either organic acid washings or by simple water washings (Tenuta-Filho, 1993). Using either treatment, fluoride concentrations of less than 21 $\mu g\ g^{-1}$ (dry matter) were obtained, whereas untreated protein concentrates may have values of ~250 $\mu g\ g^{-1}$ (dry matter) (Oehlenschläger, 1981). These processes yield high protein recovery and a product with low enough fluoride concentrations for human consumption.

Considerable research has been carried out in Poland into producing krill precipitates using autoproteolysis, making use of krill's high level of proteolytic enzymes to produce a high yield (80% protein recovery) concentrate (Kolakowski & Gajowiecki, 1992). In this process, whole krill is mixed with water and heated. The hydrolysate is centrifuged to remove the shells and the precipitate is coagulated. The final product has low fluoride content (<29 mg F kg^{-1}), a protein content of 18–22%, fat less than 7% and a high level of carotenoid pigments, giving the precipitate a pink-red colouration. This product is used mainly as a colorant and a flavourant additive to fish feeds and other products for human consumption.

Krill as a food additive

Freeze-dried krill concentrate prepared from peeled tail meat is currently being marketed as a food additive and as a health food supplement by a Spanish company.[1] This 'Antarctic Krill Concentrate' is advertised as having a number of useful properties such as: high n-3 fatty acid content, moderate caloric content, high

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