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Krill for Human Consumption: Nutritional Value and Potential Health Benefits

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The marine crustacean krill (order Euphausiacea) has not been a traditional food in the human diet. Public acceptance of krill for human consumption will depend partly on its nutritive value. The aim of this article is to assess the nutritive value and potential health benefits of krill, an abundant food source with high nutritional value and a variety of compounds relevant to human health. Krill is a rich source of high-quality protein, with the advantage over other animal proteins of being low in fat and a rich source of omega-3 fatty acids. Antioxidant levels in krill are higher than in fish, suggesting benefits against oxidative damage. Finally, the waste generated by the processing of krill into edible products can be developed into value-added products.

Key words: human health, krill, nutrition

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INTRODUCTION

Human consumption of fish-derived food products has been increasing steadily, however, the global capture of fish has remained fairly stable for the past 20 years and has been forecasted as unlikely to increase in the future.[1] Reports of health benefits has contributed to the rise in seafood consumption. For example, the American Heart Association recommends eating fish at least twice a week as part of their guidelines for reducing heart disease.[2] One way to minimize the gap between the steadily increasing consumption and dwindling resources of fish is to identify new sources that may be utilized for human consumption. Krill is one such resource.

The Norwegian word "krill" translates into "young fry of fish" and has been adopted as the term used to describe marine crustaceans belonging to the order Euphausiacea. Krill is widely known as whale food, but is also a source of food for seals, squid, fish, seabirds, and, to a much lesser degree, humans. In appearance, krill resembles shrimp (Figure 1).[3] Similar to other crustaceans, krill possess a chitinous exoskeleton but are distinguishable from other crustaceans by the presence of visible external gills, luminous organs, and a cephalothorax content consisting of extremely active proteolytic enzymes. During harvest, these proteolytic enzymes are released, resulting in krill meat being rapidly liquefied.[4] A more detailed discussion of the biology of krill is available elsewhere.[5]

Krill range in size from 0.01 to 2 g wet weight and from 8 mm to 6 cm length.[6] Despite their small size, krill are capable of forming large surface swarms that may reach densities of over 1 million animals per cubic meter of seawater,[7] making them an attractive species for harvesting. In addition, krill are found in oceans worldwide, making them among the most populous animal species. Despite this abundance, the commercial harvest of krill has mainly focused on its use as feed in aquariums, aquaculture, and sport fishing.[8] Of the different species of krill, only Antarctic krill (*Euphausia superba*) and Pacific krill (*Euphausia pacifica*) have been harvested to any significant degree for human consumption. The underutilization and abundance of krill make it an untapped food source for humans that, when coupled with a conscientious ecosystem approach to managing krill stocks, should result in its long-term sustainability.

Commercial krill products currently available for human consumption consist mainly of frozen raw krill, frozen boiled krill, and peeled krill meat.[9] However, interest in krill as a food source for human consumption is expected to increase with the emergence of technological advances and new product development. Still, widespread acceptance of krill as part of the human diet will

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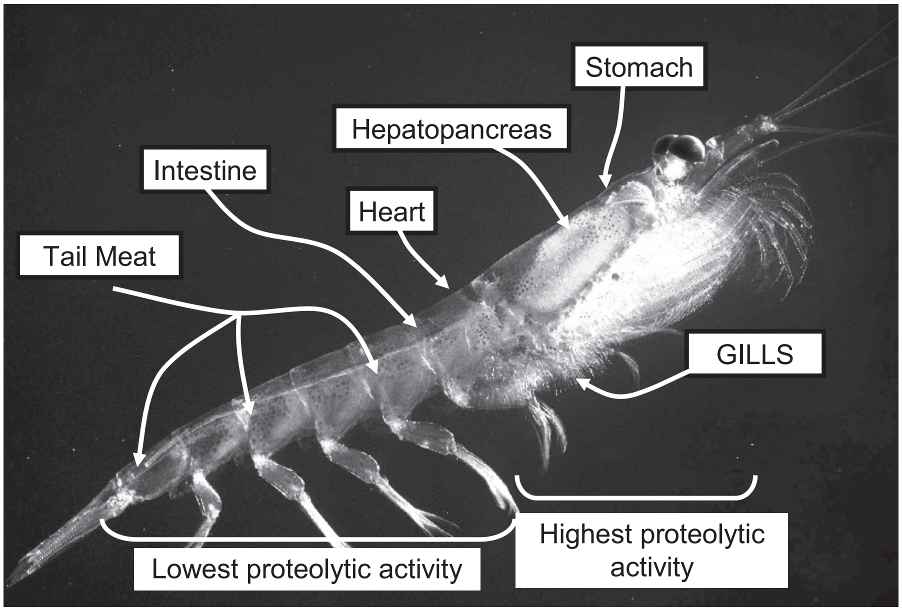

Figure 1. Photograph showing krill body structure. (Adapted with permission from Torres et al.[3])

depend on the consumer's perception of it as a nutritious as well as "healthy" food. Therefore, the aims of this article are to evaluate the nutritional value of krill as a food for human consumption and to review the scientific evidence regarding its health benefits.

NUTRIENT COMPOSITION OF KRILL

Seafood is low in calories compared with other animal foods. For example, a 100-g serving of shrimp provides approximately 106 kcal, whereas the same amount of fish provides 110 to 150 kcal, lean beef 250 kcal, and roasted chicken 200 kcal.[10] Proximate analysis of whole krill shows a range of 77.9% to 83.1% for moisture, 0.5% to 3.6% for total lipids, 11.9% to 15.4% for crude protein, 3% for ash, and 2% for chitin and glucides.[11] To assess the food value of krill, the nutrient composition of krill meat was compared with other seafoods in the human diet. Shrimp was selected for comparison because it is a crustacean familiar to the human diet; fish was also selected because it is widely regarded to be a "healthy" food.

As shown in Figure 2, the nutrient composition of krill closely resembles that of shrimp. Total protein and ash content of krill are comparable to fish, but its total lipid content is lower than fatty and lean fish species. Overall, krill resembles other seafood in being low in fat and a good source of protein. Based on proximate analysis, krill offers an attractive food addition to the human diet. However, proximate analysis does not provide information regarding the type of fat or the quality of the protein provided by krill. The next sections of the article assess individual components of krill for nutritive value and potential health benefits.

KRILL OIL

Current dietary recommendations suggest reducing fat consumption because high-fat diets have been implicated in weight gain and in increased risk of various diseases, most notably cardiovascular disease (CVD). In addition to the amount of fat, the type of fat also has an important impact on health. Foods high in saturated fatty acids (SFAs) have been linked to increased risk of CVD, whereas the omega-3 polyunsaturated fatty acids (ω-3 PUFAs), particularly eicosapentanoic acids (EPA, 20:5ω-3) and decosahexanoic acid (DHA, 22:6ω-3), have been linked to reduced risk of CVD.[12] Thus, the nutritive value of krill oil was evaluated due to the consumer's desire for foods that are low in fat and SFAs and high in ω-3 PUFAs.

Nutritional Value

Saether et al.[13] analyzed the lipid content of three species of krill and reported values ranging from 12% to 50% on a dry-weight basis. The wide range in lipid content was attributed to the sampling occurring during different seasons. A reduction in lipid content occurred in the spring, when food was scarce, whereas it increased in the autumn and early winter, when food was abundant. Kolakowska[14] reported that the lack of reproductive activity in the winter raised the lipid content of female krill to over 8% of their wet weight. Thus, the lipid

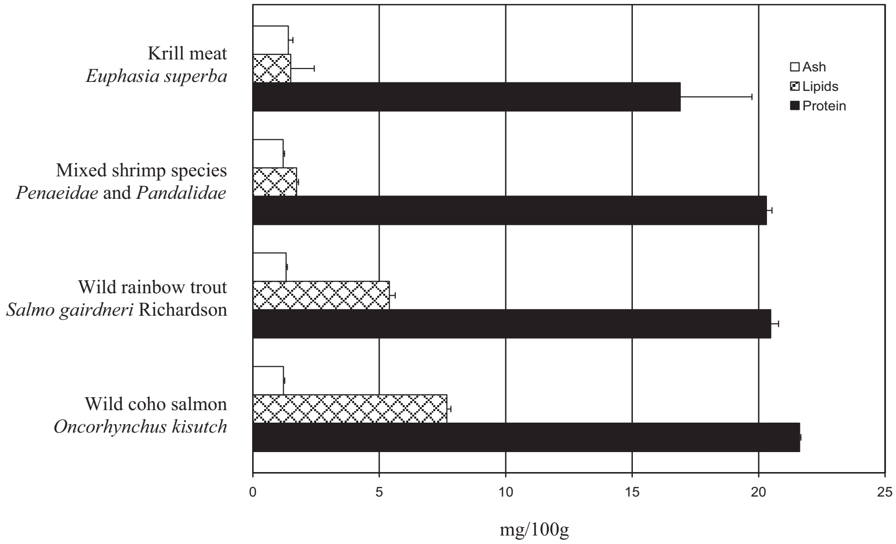

Figure 2. Proximate analysis of krill, shrimp, and lean (trout) and fatty (salmon) fish. Values for krill are based on Suzuki and Shibata[9]; values for shrimp, trout, and salmon are based on based on USDA.[10]

content and profile of krill may vary considerably depending on factors such as season, species, age, and the lag time between capture and freezing. These factors must be taken into consideration to ensure the consistency of krill oil. Regardless of this variability, krill is similar to other seafood in being low in fat compared with other animal foods. The lipid content of krill meat is 1.5%,[9] compared with approximately 26% for lean beef, 3.6% for chicken, 5.9% for fatty fish, and 3.5% for lean fish on a wet-weight basis.[10]

The lipid content in krill was analyzed for fatty acid composition. Table 1 shows that krill provides both of the essential fatty acids: α-linolenic acid (ALA, 18:3 ω-3) and linoleic acid (LA, 18:2 ω-6). In addition, krill is low (26.1%) in both SFAs and (24.2%) monounsaturated (MUFAs) but high (48.5%) in PUFAs. Palmitic acid (16:0) is the predominant SFA, oleic acid (18:1ω-9) is the predominant MUFA, and the PUFAs consist mainly of ω-3 fatty acids. Kolakowska et al.[15] reported that ω-3 PUFAs accounted for approximately 19% of total fatty

Table 1. Lipid Content and Fatty Acid Composition of Krill, Shrimp, and Lean (Trout) and Fatty (Salmon) Fish*

Lipid	Krill	Shrimp	Trout	Salmon
Total lipids (g/100 g)	1.50	1.73	3.46	5.93
SFA (%)	26.1	19.0	20.9	21.1
14:0	4.9	1.2	2.3	4.5
16:0	18.8	10.6	12.2	12.7
18:0	1.0	6.0	4.0	3.5
MUFA (%)	24.2	14.6	32.6	36.0
16:1 (ω-7)	4.9	4.8	5.9	8.5
18:1 (ω-9)	16.4	8.5	17.7	20.3
PUFA (%)	48.5	38.7	35.8	33.6
18:2 (ω-6)	3.3	1.6	6.9	6.5
18:3 (ω-3)	1.1	0.8	3.4	2.6
20:4 (ω-6)	0.5	5.0	3.2	2.2
20:5 (ω-3) EPA	17.4	14.9	4.8	7.2
22:6 (ω-3) DHA	12.4	12.8	12.1	11.1
Cholesterol (mg/100 g)	66.1	152	59	45

* Whole krill (*Euphausia superba*), mixed shrimp species (*Penaeidae* and *Pandalidae*), wild rainbow trout (*Salmo gairdneri* Richardson), and wild Coho salmon (*Oncorhynchus kisutch*). Values for krill are based on Suzuki and Shibata[9]; values for the other species are based on the USDA.[10]
DHA, decosahexanoic acid; EPA, eicosapentanoic acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

acids in Antarctic krill caught during the winter. Of the ω-3 PUFAs, EPA and DHA were particularly abundant. This was not surprising given that krill feed on marine phytoplankton such as single-cell microalgae, which synthesize large amounts of EPA and DHA.

The fatty acid composition of krill meat was compared with that of shrimp, rainbow trout (a lean fish), and coho salmon (a fatty fish). As shown in Table 1, the DHA content of krill is similar to that of shrimp and fish, but its EPA content is higher than either lean or fatty fish. Overall, the fatty acid profile of krill resembles that of shrimp and fish. However, most of the fatty acids in fish are incorporated into triglycerides, whereas 65% of the fatty acids in crustaceans are incorporated into phospholipids.[16] Arai et al.[17] reported that phospholipids comprise 29.9% of the lipid content of krill, whereas Bottino[18] reported even higher levels of 54% to 58%. The variations in krill phospholipid content in these studies may be due to differences in krill species, age, season, or harvest time.

Another lipid class of interest is cholesterol. Consumer perception of krill as a food high in cholesterol may reduce its acceptance in the human diet. The cholesterol level in krill is higher than that of fish but lower than that of shrimp (Table 1), and ranges from 62.1 to 71.6 mg/100 g in tissue and from 17 to 76.3 mg/g in krill oil.[19] However, it should be noted that two-thirds of the sterols in shellfish are non-cholesterol sterols.[20] The non-cholesterol sterols in shellfish have been reported to interfere with cholesterol absorption.[21] Rats fed krill lipids for 3 weeks[22] or 2 months[17] failed to show an increase in liver or blood cholesterol. Any hypocholesterolemic effects associated with the cholesterol content of krill may be negated by its non-cholesterol sterols, low fat, low SFA, and high ω-3 PUFA content. More studies on the effects of non-cholesterol sterols and ω-3 PUFA-rich phospholipids derived from krill on CVD risk factors are needed before any definitive statements can be made regarding the impact of krill on heart disease. Consumer interest in reducing heart disease through dietary modification makes addressing the role of krill on CVD risk an important issue in its acceptance for human consumption.

Cardiovascular Health Benefits

Although krill oil is being advertised as a supplement with protective effects against heart disease, few published studies exist. Shagaeva et al.[23] reported that feeding krill meat to patients with type 1 diabetes reduced their incidence of atherosclerosis. However, we were unable to critically review this article because it is written in Russian. In a recent study, the effect of krill oil on hyperlipidemia was investigated.[24] The study design was a double-blind trial comprised of 120 male and female subjects (mean age of 51 $\pm$ 9.5 years) diagnosed with mild to high blood cholesterol and triglycerides. Subjects were randomly assigned to one of the following treatment groups: 1) low-dose krill oil: 1 g/d if BMI was under 30 kg/m^2 and 1.5 g/d if BMI was over 30 kg/m^2; 2) high-dose krill oil: 2 g/d if BMI was under 30 kg/m^2 and 3 g/d if BMI was over 30 kg/m^2; 3) 3 g/d of fish oil containing 180 mg EPA and 120 mg DHA; or 4) placebo containing microcrystalline cellulose. Assigned treatments were given daily for 12 weeks. The primary end points measured were total cholesterol, triglycerides, low-density lipoproteins (LDLs), and high-density lipoproteins (HDLs) at baseline and at 90 d.

The results on blood lipids indicated that placebo, fish oil, and low-dose (1.0–1.5 g/d) krill oil had no significant effect on triglycerides, whereas high-dose (2–3 g/d) krill oil significantly ($P < 0.05$) reduced triglycerides by 27% to 28% (Figure 3A). While the results of this study showed the absence of a significant effect of fish oil on triglycerides, others have reported that a similar dose of 3 g/d fish oil lowered triglycerides by 30%.[25] Total cholesterol was elevated in subjects taking a placebo, while both fish oil and krill oil treatment reduced total cholesterol ($P < 0.05$; Figure 3A). Krill oil induced higher reductions in cholesterol than fish oil, with the low-dose krill oil decreasing total cholesterol by of 13% to 14% and the high-dose krill oil by 18%.

The results on circulating lipoproteins indicated increased ($P < 0.05$) LDLs in subjects taking a placebo. Fish oil had no significant effect on LDLs, whereas krill oil significantly reduced LDLs. Low-dose krill oil reduced LDLs by 32% to 36%, and high-dose krill oil by 37 to 39% (Figure 3B). In addition, krill oil significantly increased HDLs compared with fish oil. Low-dose krill oil increased HDLs by 43% to 44%, and high-dose krill oil by 55% to 60% (Figure 3B). Based on these findings, Bunea et al.[24] concluded that krill oil was more effective at improving blood lipids and lipoproteins than fish oil. Smith and Sahyoun[26] reviewed the evidence regarding fish oil consumption on CVD and concluded that fish oil produced only modest changes on lipoproteins. In some cases, high doses (3 g/d) of fish oil have been observed to raise LDLs.[27] Bunea et al.[24] attributed the greater lipogenic action of krill oil to the ω-3 PUFAs in krill being associated with phospholipids; the ω-PUFAs in fish are mainly associated with triglycerides. Future research should compare the lipogenic effects of providing ω-3 PUFAs as phospholipids or triglycerides.

Limitations of the Bunea et al.[24] study include the small subject size and the absence of adjustments for

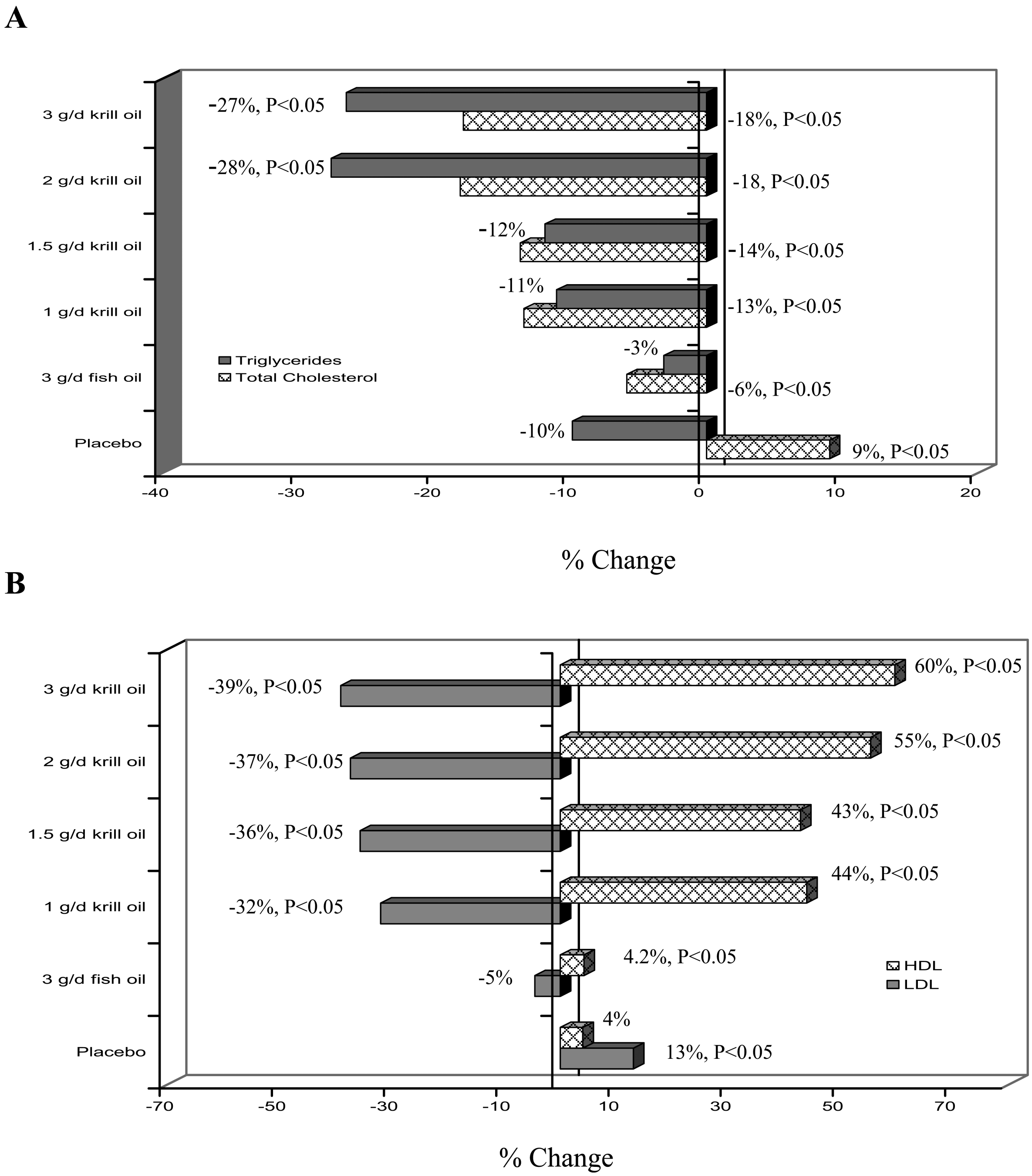

Figure 3. The effect of krill oil, fish oil, or placebo on blood lipids and lipoproteins. Adapted with permission from Bunea et al.[24] $P < 0.05$ indicates a significant change from baseline to day 90 of treatment.

other factors such as diet, smoking, gender, and genetics, all of which influence blood lipids and lipoproteins. Furthermore, the anti-atherosclerotic effects of EPA and DHA in fish oil have been attributed to mechanisms other than lipogenic actions. Fish oil has been reported to reduce CVD risk through diverse mechanisms of reducing blood pressure, inflammation, arrhythmia, and atherosclerotic plaque growth, as well as by promotion of endothelial function, anti-thrombosis, and the improvement of insulin sensitivity.[28] Whether ω-3 PUFAs provided from food sources other than fish oil exert similar effects remains to be determined.

Other Possible Health Benefits

The major focus on ω-3 PUFAs has been their effects on CVD. However, ω-3 PUFA research has expanded into other health issues such as neurological

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