Tuna – Getting To Know The Flesh You Ignore

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World fisheries overview

World production from capture fisheries and aquaculture supplied about 100.7 million ton for direct human consumption in 2002, providing a per capita supply of 16.2 kg as live weight equivalent. According to FAO Fisheries Department (2004), fish provide more than 2.6 billion people with at least 20 percent of their average per capita animal protein intake. The share of fish proteins in total world animal protein supplies grew from 14.9% in 1992 to a peak of 16.0% in 1996 and remained close to that level (15.9%) in 2001 (FAO Fisheries Department, 2004). Total amount of fish available for human consumption increased continuously from 1998 to 2003, but on average the per capita supply was fairly stable due to increase in world population. The world export trade value of fish and fishery products increased 45% between 1992 and 2002, to reach US$ 58.2 billion (FAO Fisheries Department, 2004). Shrimp and tuna were the first and second most valuable seafood commodities accounting for 18.8% and 8.8% of the total value of internationally traded fishery commodities, respectively (Vannuccini, 2003).

In many developing countries, trade in fish represents a significant source of foreign currency earnings and plays an important role in income generation, employment and food security (FAO Fisheries Department, 2004). Because fish is highly perishable, more than 90% of internationally traded fish and fish products are in processed forms and trade in developing nations is gradually evolving from the export of raw material for processing in developed countries to high-value live fish or value-added products (FAO Fisheries Department, 2004).

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Tuna species

Tuna are fast swimming, warmed-blooded (Katz, 2002; Altringham and Block, 1997; Wikipedia contributors, 2006), ocean-dwelling fish of the family Scombridae, mostly in the genus *Thunnus* (Collette and Nauen, 1983; Gibbs and Collette, 1967). Unlike most ocean fish species, which have white flesh, the flesh of tuna is pink or red due to the higher oxygen carrying capacity of their blood (Wikipedia contributors, 2006). Some of the larger species can raise their blood temperature above the water temperature using muscular activity and this enables them to live in cooler waters and survive a wider range of circumstances (Wikipedia contributors, 2006).

There are six main commercial Scombridae fish that are commonly named "Tuna" and each has its own unique quality attribute that dictates its utilization. These species are Skipjack tuna (*Katsuwonus pelamis*), Yellowfin tuna (*Thunnus albacares*), Big-eye tuna (*Thunnus obesus*), Albacore tuna (*Thunnus alalunga*), Northern and southern bluefin tuna (*Thunnus thynnus*), and Tonggol tuna (*Thunnus tonggol*).

Tuna meat portions

According to Raa (1996) and Bertoldi *et al.* (2004) the fish fillet industry generated processing waste that accounted for as much as 60% of raw material weight. The canned tuna industry divides the meat into four portions; red meat, dark meat, liquids and scrap (Food Market Exchange, 2003). The standard recovery yields of each portion are 42% red meat, 12% dark meat, 21% liquid and 25% scrap (Food Market Exchange, 2003). Currently, only tuna red meat is used for human food production whereas dark meat, liquid and scrap are regarded as waste or by-products and are used as raw material for non-food applications (Ahn and others 1996; Chia Ling and Wen Ching, 2000; Chia Ling and Wen Ching, 2001; Chia Ling and Wen Ching, 2002; Food Market Exchange, 2003)

The flesh and colour

Flesh colour is an important attribute that determines consumer judgment of fish quality (Chinnamma, 1975; Bekhit and Faustman, 2005) and consumers generally expect the flesh of white fish such as bream, to be white (Huss, 1988). Consumers discriminate against meat cuts which lack fresh appearance (Kropf and others 1986) and interpret surface discolouration as an indication that the meat is not wholesome (Pong and others 2000), even though the eating quality may still be acceptable (Huss, 1988). In addition, dark meat contains more fat than white or red meat, making it is tastier (Thankamma and others 1985) but also causing it to go rancid more quickly than white meat during cold storage (Chinnamma, 1975). Generally, fresh tuna meat is bright red, but a portion of tuna meat is intrinsically dark in colour, bitter in taste, and less suitable for use (Bertoldi et al., 2004; Bernard and Vouille, 1999).

The principle colour pigments in muscle tissue are haemoglobin (Hb), which transports O_2 from lungs or gills to cells, and myoglobin (Mb) which stores O_2 in cells (Pong et al., 2000). However, when an animal is stunned and bled, the Mb becomes the primary pigment responsible for meat colour as the Hb leaves with the blood (Pong et al., 2000). Meat colour is impacted by several factors including quantity of Mb, age within species (Mb loses its affinity for oxygen with age), type of muscle, chemical state of Mb, metmyoglobin reducing activity (MRA), activity of bacteria, and curing (Aberle and others 2001). The Mb in fresh dark meat of tuna is 3–14 times greater than that in red meat (Kanoh and others 1986).

The colour of fish muscle tissue depends on the species, but even many white fleshed species have a certain amount of dark tissue of a brown or reddish colour (Huss, 1988). The axial muscle of fish can be divided into two major types, fast-twitch or red muscle and slow-twitch or dark muscle, which are typically anatomically discrete (Altringham and Shadwick, 2001). The dark meat is located just under the skin laterally, while particularly active species like tuna may also have an area near the spine as shown in Figure 1. In tuna, the position of dark muscle is critical to the mechanism of undulatory locomotion, due to its connection to the posterior oblique tendons, and lies internally along the horizontal septum (Westneat and Wainwright, 2001). The dark muscle of the myomeres, which are the functional muscle segments, play a dual role, production of locomotor forces and production of heat for endothermy (Carey, 1981; Graham, 1975; Westneat and Wainwright, 2001).

The ratio of dark to light meat varies with the activity of the fish species, because the two muscle types have different functions. The dark meat principally functions as a cruising muscle for slow continuous movement while the light meat is a sprinting muscle used for sudden, quick movements needed for escaping from a predator or for catching prey (Chinnamma, 1975; Huss, 1988; Love, 1978). Thus, constantly swimming pelagic fish species have a greater proportion of dark muscle, up to 48% of body weight, than benthic species (Boddeke and others 1959; Videler, 1993; Altringham and Shadwick, 2001; Love, 1978; Huss, 1988). A distinctive seasonal variation in the darkness of flesh has been noted in North Sea cod, the flesh being darker in July and August, probably because the fish are actively in feeding at this time (Love, 1978). Intrinsically dark flesh cannot be made white, though minced fish that is too dark can be whitened by washing (Love, 1978).

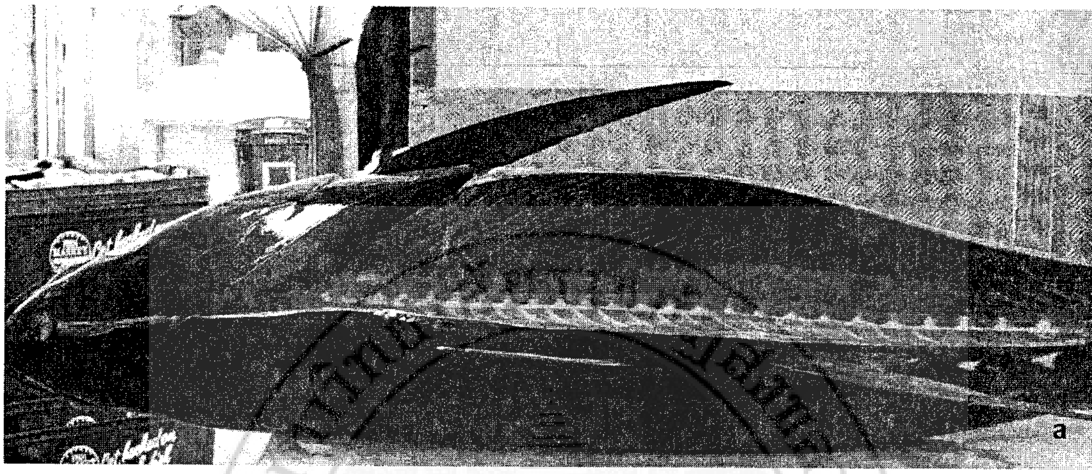

Figure 1 Dark meat of yellowfin tuna located along side of backbone

Nutritional value

The nutrient composition and physiochemical properties of fishery by-products will ultimately determine their value for utilisation as food. The nature of the by-products varies with fish species and type of fish meat. Few studies (Kang and others 2000; Watanabe and others 1989; Mukundan and others 1979) have been done on the nutritional value of tuna processing by-products. Kang *et al.* (2000) investigated nutrients contained in skipjack tuna processing by-products, Watanabe *et al.* (1989) studied lipids in albacore tuna head as well as vitamin A and E and Mukundan *et al.* (1979) reported biochemical and nutritional quality of red and dark meat from bonito tuna *(Euthynnus affinis)*. Kang *et al.* (2000) have completed the most comprehensive study so far. Their results of the proximate composition of skipjack tuna by-products are reproduced in Table 1.1. They found the protein content of skin (26.3%) to be higher than that of skin flesh (22.0%), abdominal flesh (22.0%), tail flesh (21.6%), and dark flesh (21.5%). The crude fat level in skin and tail flesh were 15.6% and 6.0% respectively, higher than fat level in skin flesh(1.7%), abdominal flesh (1.4%), and dark flesh (0.8%).

When analyses for trace elements were conducted, Kang *et al.* (2000) found phosphorus, potassium, sodium, magnesium, and calcium to be major minerals in all tuna portions (Table 1.2). Iron was six times higher in dark flesh than most of other parts. Aluminium levels were highest in tail and abdominal flesh, whereas calcium levels were higher in abdominal flesh and skin

Table 1.1 Proximate composition (%) in processing by-products of skipjack tuna reported by Kang *et al.* (2000)

Composition	Skin flesh	Skin	Tail flesh	Dark flesh	Abdominal flesh
Moisture	74.7	48.5	70.2	76.1	71.6
Ash	1.0	9.1	1.2	1.9	3.6
Crude protein	22.0	26.3	21.6	21.5	22.0
Crude fat	1.7	15.6	6.0	0.8	1.4
Carbohydrate	0.6	0.5	1.1	0.3	1.5

Table 1.2 Mineral contents (mg/100g) in processing by-products of skipjack tuna reported by Kang *et al.* (2000)

Minerals	Skin flesh	Skin	Tail flesh	Dark flesh	Abdominal flesh
Na	94.3	296.7	128.1	63.1	221.9
P	219.5	1360.3	164.4	225.1	146.9
K	369.3	126.7	307.6	464.6	403.0
Fe	1.1	0.6	1.0	6.1	1.1
Mg	29.9	75.3	25.7	30.6	49.2
Al	0.8	0.01	33.1	8.8	245.1
Cu	< 0.1	< 0.1	< 0.1	0.1	< 0.1
Ca	13.2	425.6	66.9	10.4	872.2

The amino acid profiles of various skipjack tuna by-products are reproduced from Kang *et al.* (2000) in Table 1.3. All by-products had high protein quality with all essential amino acids represented in appreciable amounts and lysine, leucine and histidine the major components.

Table 1.3 Amino acid composition (g/100g) in processing by-products of skipjack tuna reported by Kang *et al.* (2000)

Amino acids	Skin flesh	Skin	Tail flesh	Dark flesh	Abdominal flesh
Aspartic acid	1.7	1.9	1.8	1.8	2.0
Threonine*	0.8	1.2	0.9	0.9	1.0
Serine	0.8	1.3	0.8	0.8	0.8
Glutamic acid	2.7	3.2	2.9	2.9	3.0
Proline	1.6	4.3	0.7	0.7	0.7
Glycine	1.8	9.1	0.9	0.9	1.0
Alanine	1.5	4.8	1.2	1.2	1.3
Cystine	0.03	ND[1]	0.02	ND	0.1
Valine*	0.9	0.9	1.0	1.0	1.2
Methionine*	0.6	0.7	0.6	0.6	0.7
Isoleucine*	0.7	0.5	0.9	1.0	1.1
Leucine*	1.2	1.0	1.5	1.5	1.6
Tryptophan*[2]	ND	ND	ND	ND	ND
Tyrosine	0.5	0.3	0.7	0.7	0.8
Phenylalanine*	6.2	0.8	0.7	0.7	0.8
Histidine*	0.9	0.4	1.4	1.5	1.6
Lysine*	1.9	1.7	2.2	2.2	2.3
Arginine	1.8	3.4	1.4	1.4	1.5

* Essential amino acid

[1]ND = not detected

[2]Tryptophan is not detected as it was destroyed during analysis

Table 1.4 summarises the content of vitamins C, B_1 and B_2 in skipjack tuna by-products as reported by Kang *et al.* (2000). The by-products were found to be a rich source of vitamin C and B groups. Vitamin C content was high in abdominal flesh and skin flesh and is comparable to banana at 8.7 mg/100g (U.S. Department of Agriculture, 2005). The content of vitamin B_1 was similar for all tuna portions whereas vitamin B_2 level was lower in skin flesh and abdominal flesh than in other parts analysed. These results are supported by the finding of Mukundan *et al.* (1979) who found dark meat of bonito tuna was high in vitamin A, B_1, B_2, and B_{12}.

Table 1.4 Vitamin content (mg/100g) in processing by-products of skipjack tuna reported by Kang *et al.* (2000)

Vitamins	Skin flesh	Skin	Tail flesh	Dark flesh	Abdominal flesh
Vitamin C	11.6	1.8	9.3	9.7	17.7
Vitamin B_1	0.3	0.3	0.3	0.4	0.3
Vitamin B_2	0.1	0.2	0.2	0.3	0.1

Fish lipids are rich in omega-3 fatty acids, known as long chain n-3 polyunsaturated fatty acids or PUFAs, which are reported to be active components in preventing heart disease and other illnesses in human humans (Ward and Trenerry, 1997; McLennan, 2004; Wade, 2005a; Wade, 2005b; Ruxton and others 2004; Buss and Mellentin, 2004; Al Numair and Lewis, 2004; Rice, 2004; Singer and Wirth, 2003; Ohr, 2003; Hu and Willett, 2002; Hu and others 2002; Hilliam, 2001; Williams, 2000; Sloan, 2000; Sheard, 1998; Simopoulos, 1997; Prichard and others 1995; Mori and others 1994; Parkinson and others 1994; Sinclair, 1993; Simopoulos, 1991; Neutze and Starling, 1986; Sinclair and O'Dea, 1984) Fish obtain PUFAs when they feed on algae, the primary organism that can efficiently synthesise these long chain PUFAs (Ward, 1995). As a result, fish lipids are rich source of PUFAs, which include eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that are essential in the human diet (Birch and others 2005; Lock and Bauman, 2004; Nettleton, 2005; McLennan, 2004; Verlengia and others 2004). Determination of the fatty acid composition is important as this relates to the possibility of fat rancidity, which decreases storage life and influences the acceptability of food made from tuna by-products. Additionally, it is important to know the content of essential marine fatty acids such as omega-3 fatty acids because of the health benefits derived.

The results of Kang *et al.* (2000) for the fatty acids composition of by-products fromskipjack tuna are given in Table 1.5. Although levels of EPA and DHA were recorded in all tissues analysed, the results show the skin and skin flesh to be the richest sources.

In 2002, 24% (32.2 million tonnes) of fish based product was used for non-food purposes, mainly fish oil, fish meal, fertiliser, pet food and fish silage(Choudhury and Gogoi, 1995; Choudhury and Bublitz, 1996), which generally have low economic value(Kim and Mendis, 2006). Using by-products to produce human consumables would be more profitable and one area currently being explored is the use of bioactive compounds (Kim and Mendis, 2006). Recent studies have identified a number of bioactive compounds in remaining fish muscle proteins, collagen and gelatin, fish oil, fish bone and internal organs (Je and others 2005; Jeon and Kim, 2002; Kim and others 2001)

Table 1.5 Fatty acid composition (mg/100g) in processing by-products of skipjack tuna reported by Kang *et al.* (2000)

Fatty acid	Skin flesh	Skin	Tail flesh	Dark flesh	Abdominal flesh
Tetradecanoic (C14:0)	252.1	ND	291.9	ND	ND
Pentadecanoic (C15:0)	ND[1]	ND	ND	ND	ND
3-Hydroxytetradecanoic (3-OH-C14:0)	ND	ND	ND	ND	ND
cis-9-Hexadecenoic (C16:1)	500.9	ND	825.8	ND	ND
Hexadecanoic (C16:0)	1102.8	613.6	3756.6	129.6	86.2
15-Methylhexadecanoic (C17:0)	715.3	7973.9	265.2	26.42	21.2
cis-9, 10-Methyllenehexadecanoic (C17:0)	ND	ND	1231.1	ND	ND
Heptadecanoic (C17:0)	ND	ND	ND	ND	ND
2-Hydroxyhexadecanoic (2-OH-C16:0)	ND	ND	ND	ND	ND
cis-9,12-Octadecenoic (C18:2)	ND	ND	1338.8	ND	ND
cis-9-Octadecenoic (C18:1n9c)	1870.4	448.8	3977.0	112.6	51.9
trans-9-Octadecenoic (18:1n9t)	172.4	ND	ND	ND	ND
Octadecanoic (C18:0)	14768.8	8699.5	879.7	73.9	42.2
Cis-9, 10-Methyleneoctadecanoic (C19:0)	ND	1472.7	ND	ND	ND
Nonadecanoic (C19:0)	331.1	ND	930.1	46.9	18.9
Eicosanoic (C20:0)	930.1	1615.2	ND	ND	ND
Eicosapentaenoic (C20:5n3)*	3759.2	7053.9	4668.4	1323.6	1625.0
Docosahexaenoic (C22:6n3)*	6409.3	6301.3	3976.9	1541.9	1127.9

[1]ND = not detected

*Skipjack by-products was steamed for 30 min before being analysed

The future

Production and consumption of fish has increased considerably in the last 30 years and fish supply from oceans, which once seemed never ending, is now recognised as a finite resource (Delgado and others 2003). The rise in production from the aquaculture industry has attempted to fill the gap between supply and increasing demand but it is expected that eventually demand will outstrip supply. It is recognised that better use could be made of waste products by extracting bioactive compounds, but there is a question whether these extracts, particularly protein, could be made by fermentation of recombinant microorganisms(Kim and Mendis, 2006) If so, the processing reject may become waste again in the future. Marine fish processing by-products are used in many industries and their commercial applications are expanded every year but their applicability as bioactive compounds and their nutraceutical values are not well documented(Kim and Mendis, 2006). Thus, while these novel applications of fish processing wastes hold promise, developing human food products from waste could be a more sustainable approach in the long term.

References

Aberle ED, Forrest JC, Gerrard DE & Mills EW. 2001. Properties of fresh meat. In: Aberle, E. D., Forrest, J. C., Gerrard, D. E. & Mills, E. W., editors. Principles of meat science. 4th edn ed. Iowa: Kendall Hunt Publishing Company. p. 109-116.

Ahn CB, Kim HR & Godber JS. 1996. Utilization of tuna cooking juice for flavoring agents. United States of America: Institute of Food Technologists 1996 Annual Meeting.

Al Numair KS & Lewis NM. 2004. Omega-3 fatty acid intake and incidence of non-fatal myocardial infarction differ between coastal and internal regions of Saudi Arabia: Over and under nutrition in the Middle East. Ecology of Food and Nutrition 43(1-2):93-106.

Altringham JD & Block BA. 1997. Why do tuna maintain elevated slow muscle temperatures? Power output of muscle isolated from endothermic and ectothermic fish. Journal of Experimental Biology 200(20):2617-2627.

Altringham JD & Shadwick RE. 2001. Swimming and muscle function. In: Block, B. A. & Stevens, E. D., editors. Tuna: physiology, ecology, and evolution. San Deigo: Academic Press. p. 312-344.

Bekhit AED & Faustman C. 2005. Metmyoglobin reducing activity. Meat Science 71(3):407-439.

Bernard J & Vouille D, inventors; Saupiquet SA PAA: Saupiquet, 44200 Nantes, France, assignee. 1999 19980409. Method for processing of red muscle of tuna, to prepare a food-grade product. EP; European-Patent-Application patent EP 0 948 906 A1; (EP0948906A1).

Bertoldi FC, Sant'Anna ES & Beirfo LH. 2004. Reducing the bitterness of tuna (*Euthynnuspelamis*) dark meat with *Lactobacillus casei* subsp. casei ATCC 393. Food Technology and Biotechnology 42(1):41-45.

Birch EE, Castaneda YS, Wheaton DH, Birch DG, Uauy RD & Hoffman DR. 2005. Visual maturation of term infants fed long-chain polyunsaturated fatty acid-supplemented or control formula for 12 mo1-3. American Journal of Clinical Nutrition 81(4):871-879.

Boddeke R, Slijper EJ & Stelt Avd. 1959. Histological characteristics of the body musculature of fishes in connection with their mode of life. Proceedings of the Koninklijke Nederlandse. Akademie Van Wetenschappen Series C Biological and Medical Sciences 62:576-588.

Buss D & Mellentin J. 2004. FDA gives the go-ahead for long-awaited omega-3 health claim. New Nutrition Business 10(1):1, 8.

Carey FG. 1981. Warm fish. In: Taylor, C. R., Johansen, K. & Bolis, L., editors. A companion to animal physiology. Cambridge: Cambridge University Press. p. 216-233.

Chia Ling J & Wen Ching K. 2000. Effect of enzyme treatment upon hydrolysis of proteins from the cooking juice of tuna. Food Science and Agricultural Chemistry 2(4):226-232.

Chia Ling J & Wen Ching K. 2001. Antioxidative properties of protein hydrolysates from tuna cooking juice. Taiwanese Journal of Agricultural Chemistry and Food Science 39(5):363-369.

Chia Ling J & Wen Ching K. 2002. 1,1-Diphenyl-2-picrylhydrazyl (DPPH) radical scavenging by protein hydrolyzates from tuna cooking juice. Fisheries Science 68(2):430-435.

Chinnamma G. 1975. Biochemical differences between the red and white meat of tuna and changes in quality during freezing and storage. Fishery-Technology 12(1):70-74.

Choudhury GS & Bublitz CG. 1996. Computer-based controls in fish processing industry. In: Mittal, G. S., editor). Computerized Control Systems in the Food Industry. New York: Marcel Dekker. p. 513-538.

Choudhury GS & Gogoi BK. 1995. Extrusion processing of fish muscle. Journal of Aquatic Food Product Technology 4(4):37-67.

Collette BB & Nauen CE. 1983. Scombrids of the world. An annotated and illustrated cataloque of tunas, mackereks, bonitos and related species known to date. Rome: Food and Agriculture Organization of the United Nations.

Delgado CL, Wada N, Rosegrant MW, Meijer S & Ahmed M. 2003. Fish to 2020: supply and demand in changing global markets. Washington, DC.: International Food Policy Research Institute (IFPRI).

FAO Fisheries Department. 2004. The state of world fisheries and aquaculture 2004. Rome: Food and Agriculture Organization of the United Nations.

Food Market Exchange. 2003. Recovery yield issue. Tuna production. Phayathai, Bangkok: Food Market Exchange.

Gibbs RH & Collette BB. 1967. Comparative anatomy and systematics of the tunas, genus Thunnus. U.S. Fish Wildlife and Service Fishery Bulletin 66(1):65-130.

Graham JB. 1975. Heat exchange in the yellow-fin tuna, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*, and the adaptive significant of elevated body temperatures in scombroid fishes. Fishery Bulletin of the Fish and Wildlife Service 73:219-229.

Hilliam M. 2001. Heart healthy foods. Opportunities for foods & beverages aimed at heart health abound. World of Food Ingredients (Oct./Nov.):98, 100-101, 103.

Hu FB, Bronner L, Willett WC, Stampfer MJ, Rexrode KM, Albert CM, Hunter D & Manson JE. 2002. Fish and omega-3 fatty acid intake and risk of coronary heart disease in women. Journal of the American Medical Association 287(14):1815-1821.

Hu FB & Willett WC. 2002. Optimal diets for prevention of coronary heart disease. Journal of the American Medical Association 288(20):2569-2578.

Huss HH. 1988. Fresh fish - quality and quality changes. Rome: Food and Agriculture Organization of the United Nations, Danish International Development Agency (DNIDA).

Je JY, Park PJ, Jung WK & Kim SK. 2005. Isolation of angiotensin I converting enzyme (ACE) inhibitor from fermented oyster sauce, *Crassostrea gigas*. Food Chemistry 90(4):809-814.

Jeon YJ & Kim SK. 2002. Antitumor activity of chitosan oligosaccharides produced in ultrafiltration membrance reactor system. Journal of Microbiology and Biotechnology 12(3):503-507.

Kang CH, Jung HY, Lee DH, Park JK, Ha JU, Lee SC & Hwang YI. 2000. Analysis of chemical compounds on tuna processing by-products. Journal of the Korean Society of Food Science and Nutrition 29(6):981-986.

Kanoh S, Suzuki T, Maeyama K, Takewa T, Watabe S & Hashimoto K. 1986. Comparative studies on ordinary and dark muscles of tuna fish. Bulletin of the Japanese Society of Scientific Fisheries 52:1807-1716.

Katz SL. 2002. Design of heterothermic muscle in fish. Journal of Experimental Biology 205(15):2251-2266.

Kim SK, Kim YT, Byun HG, Nam KS, Joo DS & Shahidi F. 2001. Isolation and characterization of antioxidative peptides from gelatin hydrolysate of Alaska pollack skin. Journal of Agricultural and Food Chemistry 49(4):1984-1989.

Kim SK & Mendis E. 2006. Bioactive compounds from marine processing byproducts - A review. Food Research International 39(4):383-393.

Kropf DH, Hunt MC & Piske D. 1986. Color formation and retention in fresh meat. Proceedings of the Meat Industry Research Conference. p. 62-66.

Lock AL & Bauman DE. 2004. Modifying milk fat composition of dairy cows to enhance fatty acids beneficial to human health. Lipids 39(12):1197-1206.

Love RM. 1978. Dark color in white fish. Edinburgh: Her Majesty's Stationary Office (HMSO) Press.

McLennan P. 2004. Omega-3 polyunsaturated fatty acid prevention of cardiac arrhythmia and sudden death: cellular or circulating? Current Topics in Nutraceutical Research 2(2):101-111.

Mori TA, Vandongen R, Beilin LJ, Burke V, Morris J & Ritchie J. 1994. Effects of varying dietary fat, fish, and fish oils on blood lipids in a randomized controlled trial in men at risk of heart disease. American Journal of Clinical Nutrition 59(5):1060-1068.

Mukundan MK, Arul James M, Radhakrishnan AG & Antony PD. 1979. Red and white meats of tuna (*Euthynnus affinis*); their biochemical role and nutritional quality. Fishery Technology 16(2):77-82.

Nettleton JA. 2005. Polyunsaturated fatty acids and brain function. Ingredients, Health & Nutrition 0(1):12-13.

Neutze JM & Starling MB. 1986. Fish oils and coronary heart disease. New Zealand Medical Journal 99(807):581-583.

Nichos P, Mooney B, Virtue P & Elliott N. 1998. Nutritional value of Australian Fish: oil, fatty acid and cholesterol of edible species. Final report, August 1998. FRDC Project 95/122. Report prepared for the Fisheries Research and Development Corporation. Hobart: CSIRO Division of Marine Research.

Ohr LM. 2003. Wellness for women. Food Technology 57(10):71-72, 74, 77.

Parkinson AJ, Cruz AL, Heyward WL, Bulkow LR, Hall D, Barstaed L & Connor WE. 1994. Elevated concentrations of plasma omega-3 polyunsaturated fatty acids among Alaskan Eskimos. American Journal of Clinical Nutrition 59(2):384-388.

Pong CH-YU, Chiou TZ-KU, Ho MI-LA & Jiang SH-TZ. 2000. Effect of polyethylene package on the metmyoglobin reductase activity and color of tuna muscle during low temperature storage. Fisheries Science 66(2):384-389.

Prichard BNC, Smith CCT, Ling KLE & Betteridge DJ. 1995. Fish oils and cardiovascular disease. British Medical Journal 310(6983):819-820.

Rice R. 2004. Essential oils. Food Technology International:47-49.

Ruxton CHS, Reed SC, Simpson MJA & Millington KJ. 2004. The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence. Journal of Human Nutrition and Dietetics 17(5):449-459.

Sheard NF. 1998. Fish consumption and risk of sudden cardiac death. Nutrition Reviews 56(6): 177-179.

Simopoulos AP. 1991. Omega-3 fatty acids in health and disease and in growth and development. American Journal of Clinical Nutrition 54(no. 3):438-463.

Simopoulos AP. 1997. Essential fatty acids in health and chronic disease. Food Reviews International 13(4):623-631.

Sinclair A & O'Dea K. 1984. Australian fish may protect against heart disease. Australian Fisheries 43(4):22-23.

Sinclair AJ. 1993. The nutritional significance of omega 3 polyunsaturated fatty acids for humans. ASEAN Food Journal 8(1):3-13.

Singer P & Wirth M. 2003. Omega-3 fatty acids reduce blood pressure, plasma thromboxane B2 and stress response in patients with essential hypertension. Ernaehrungs Umschau 50(2): 40-44.

Sloan AE. 2000. The top ten functional food trends. Food Technology 54(4):33-34, 36, 38, 40, 42, 44, 46, 48, 50-52, 54, 56, 58, 60, 62.

Thankamma R, Lekshmy-Nair A, Vasanth-Shenoy A & Gopakumar K. 1985. Suitability of tuna red meat for preparation of wafers. Fishery Technology 22(1):45-47.

U.S. Department of Agriculture. 2005. USDA Nutrient Database for Standard Reference,Release18. Nutrient Data Laboratory Home Page. In: Service, A. R., editor).

Vannuccini S. 2003. Overview of fish production, utilization, consumption and trade based on 2001 data. Rome, Italy: Food and Agriculture Organization of the United Nations.

Verlengia R, Gorjao R, Kanunfre CC, Bordin S, Martins de Lima T, Fernandes Martins E, Newsholme P & Curi R. 2004. Effects of EPA and DHA on proliferation, cytokine production, and gene expression on Raji cells. Lipids 39(9):857-864.

Videler JJ. 1993. Fish swimming. London: Chapman and Hall.Wade MA. 2005a. A foray into fatty acids. Prepared Foods 174(3):Nutra Solutions Supplement, NS17-NS18, NS21, NS23.

Wade MA. 2005b. 'School's in' for omega-3. Prepared Foods 174(1):145-146, 148, 151-152.

Ward CM & Trenerry VC. 1997. The determination of niacin in cereals, meat and selected foods by capillary electrophoresis and high performance liquid chromatography. Food chemistry 60(no. 4):667-674.

Ward OP. 1995. Microbial production of long-chain PUFAs. Inform 6(no. 6):683, 685-688.

Watanabe T, Sugii K, Yamada J & Kinumaki T. 1989. Useful lipids in tuna heads. Bulletin of the Tokai Regional Fisheries Research Laboratory [Tokai ku Suisan Kenkyusho Kenkyu Hokoku] 124:69-80.

Westneat MW & Wainwright SA. 2001. Mechanical design for swimming: muscle, tendon, and bone. In: Block, B. A. & Stevens, E. D., editors. Tuna: Physiology, Ecology, and Evolution. San Diego: Academic Press. p. 271-311.

Wikipedia contributors. 2006. Tuna. Wikipedia, The Free Encyclopedia.

Williams CM. 2000. Dietary fatty acids and human health. Annales de Zootechnie 49(no. 3): 165-180.