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).

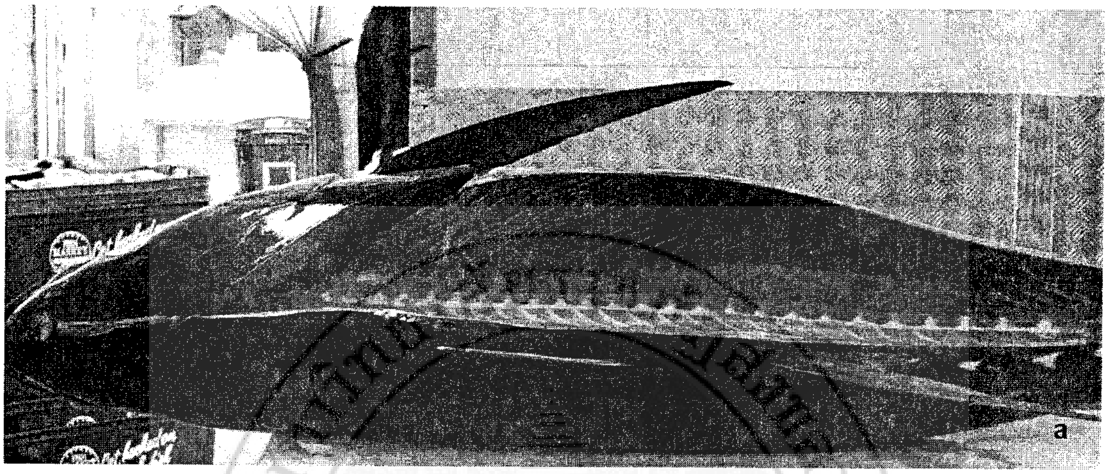

Figure 1 Dark meat of yellowfin tuna located along side of backbone

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

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[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.

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