AN ABSTRACT OF THE THESIS OF

Sena C. Wheeler for the degree of Master of Science in Food Science and Technology presented on October 2, 2002.

Title: Intrinsic and Extrinsic Quality of West Coast Albacore Tuna (*Thunnus alalunga*).

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Michael T. Morrissey

The purpose of this study is to identify the intrinsic and extrinsic quality characteristics of West Coast albacore tuna (*Thunnus alalunga*). Albacore tuna were troll caught off the Oregon coast and transferred to the Oregon State University Seafood laboratory in Astoria, Oregon. Core samples were extracted from six designated body zones of 16 fish and analyzed for lipid, moisture, protein, ash, and fatty acid distribution. Proximate distribution was constant throughout the body zones. Protein and ash made up 25% of the composition, lipid and moisture made up the remaining 75%. The lipid content ranged from 3.9 ± 0.2 to 36.3 ± 1.1%, with a distribution of higher lipid towards the head and lower lipid towards the tail. Total omega-3 content averaged 40% of the identified fatty acids for each body zone, with omega-3 (g/100g tissue) ranging from 2.1 ± 0.5 to 3.5 ± 0.4.

Furthermore, an inverse correlation (R^2= -0.95) was found for lipid and moisture content, enabling a faster estimate of lipid content derived from moisture content. Onboard handling techniques for West Coast albacore tuna were evaluated using sensory and analytical methods. Chilling (immediately and after 3 h), spiking, and bleeding at the throat and gills were evaluated by a sensory panel for overall quality, color, smell, texture and flavor. 2-Thiobarbituric acid-reactive substances (TBARS) and pH were also compared. Rapid chilling significantly and positively influenced overall quality, color, texture, and flavor; and significantly reduced oxidative rancidity. Bleeding at the throat significantly and positively influenced all sensory attributes tested, but did not significantly influence TBARS or pH. Neither spiking nor bleeding at the gills significantly affected sensory attributes.

Intrinsic and Extrinsic Quality of West Coast Albacore Tuna (*Thunnus alalunga*)

by
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APPROVED:

Major Professor, representing Food Science and Technology

Chair of the Department of Food Science and Technology

Dean of the Graduate School

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Sena C. Wheeler, Author

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INTRODUCTION

Tuna have been fished worldwide for thousands of years (Powell 2000). The tuna trade has evolved into an enormous international industry, presently making it the world's most lucrative fishery (FAO 2002a). The global catch of tuna and tuna-like species has increased from less than 0.6 million metric tons (mt) in 1950 to 5.5 million mt in 1998 (FAO 2002a). In 2000, albacore tuna (*Thunnus alalunga*) accounted for 7% of world tuna catch by weight, or about 225,000 mt per year (aTuna.com 2002). The largest fraction of the world's albacore (67%) is caught in the Pacific basin. Albacore form two separate Pacific stocks, one north and one south of the equator. Forty percent of the world albacore catch comes from the northern Pacific stock, 27% from the southern Pacific stock (IATTC 2002). Presently, U.S. West Coast catch accounts for about 15-20% of the total North Pacific harvest (PFMC 2001).

Tuna fisheries include both low-value high-volume fisheries that supply the canneries, and high-value low-volume fisheries that specialize in high quality fresh and frozen tuna. In recent years, the wholesale price paid at landing for fresh sashimi-quality tuna has reached more than $500 per kg. Only very small

quantities sell at these high prices. The wholesale price paid at landing for cannery-grade tuna can be less than $1 per kg (FAO 2002a). Albacore is the source of high-value canned "white tuna", which sells for up to twice as much per pound as "light tuna", which is yellowfin or skipjack (WFOA 2002). In the U.S., canned albacore is widely available. Smaller amounts of albacore are available fresh, frozen, or as sashimi (aTuna.com 2002).

In the past, U.S. tuna canneries purchased about 80% of the West Coast albacore tuna catch. Recently, however, this percentage has dropped to 30%, with the majority of the albacore transshipped to other countries such as Spain (WFOA 2002). With the reduction of cannery market orders, the U.S. West Coast albacore fishery has been forced to seek alternative markets. Problems related to limited market development and consumer awareness as well as product quality and consistency, are concerns that need to be addressed in the development of alternative markets for West Coast albacore tuna.

The intrinsic characteristics of West Coast albacore tuna can be an important aspect of the promotional material used to enhance its image in the marketplace and educate consumers. Intrinsic characteristics that are inherent to the fish include lipid, moisture, protein, ash and fatty acid content of the lipid fraction. While these components have been studied thoroughly in albacore tuna, current information is lacking on West Coast albacore tuna. Dotson (1978) found a high lipid content with variable distribution throughout individual West Coast

albacore tuna. There is a need to confirm these reports and identify the fatty acid content and distribution to form a more complete picture of the unique intrinsic characteristics of West Coast albacore tuna.

Furthermore, Dotson (1978) indicated a need for a rapid measure of lipid content. The inverse relationship between the lipid and moisture content of West Coast albacore tuna needs to be identified so that moisture content can be used to provide a fast estimation of lipid. This information can be very useful for the identification of fish with high and low lipid contents for use in specific products.

To successfully supply alternative markets, the quality and consistency of the catch (extrinsic characteristics) needs to be improved. Historically, alternative markets have been limited because albacore are delicate and bruise easily leading to poor texture quality when not handled and chilled properly. Research suggests that if albacore are properly handled, they can be processed into high-valued fresh, frozen and value-added products. This can be accomplished by improving onboard handling and chilling techniques, and standardizing them throughout the fishery. Studies have recommended a variety of handling methods (Goodrick 1987; Price and Melvin 1994; Williams 1986; Amos 1981; Melvin and others 1983). Few have actually studied their effects with both sensory and chemical methods on West Coast albacore tuna. Currently, there is no industry consensus on the best handling technique or chilling system to produce the highest and most consistent quality product (Price and others 1991).

The purpose of this study was to identify and quantify the intrinsic and extrinsic quality characteristics of West Coast albacore tuna.

Objective 1: Evaluate the proximate distribution. Lipid, moisture, protein, and ash will be quantified and distribution throughout the fish will be compared.

Objective 2: Assess the fatty acid profile of the lipid fraction and quantify the total omega-3 content.

Objective 3: Identify the correlation between lipid and moisture content, as well as the correlation between lipid and total omega-3 content.

Objective 4: Determine the effect on quality of on-board handling and chilling techniques. Sensory and chemical analyses will be used to assess the effects of chilling, spiking, and bleeding.

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CHAPTER 2

QUANTIFICATION AND DISTRIBUTION OF LIPID, MOISTURE, AND FATTY ACIDS OF WEST COAST ALBACORE TUNA (*THUNNUS ALALUNGA)*

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ABSTRACT

The purpose of this study is to identify the intrinsic quality characteristics - lipid, moisture, and fatty acid content - of West Coast albacore tuna (*Thunnus alalunga*). Twelve West Coast albacore tuna were troll caught off the Oregon coast (45° N and 125° W) in September 2000, delivered directly to the Oregon State University Seafood Laboratory, Astoria , Oregon and held at -30°C for one year. Four additional West Coast albacore tuna were troll caught off the Oregon coast (48° N and 127° West) in August 2002, and analyzed fresh for fatty acid content. Core samples were taken from six designated body zones of the sixteen fish. The lipid content ranged from 3.9 ± 0.2 to 36.3 ± 1.1%, with a distribution of higher lipid towards the head and lower lipid towards the tail. Total omega-3 content averaged approximately 40% of the identified fatty acids for each body zone, with average omega-3 (g/100g tissue) ranging from 2.1 ± 0.5 to 3.5 ± 0.4. An inverse correlation (R^2= -0.95) was found for lipid and moisture content. Lipid content was also weakly correlated to weight and length (R^2=0.37), and total omega-3 content (R^2=0.39).

Key Words: Albacore tuna, lipid, fatty acids, omega-3

INTRODUCTION

Albacore tuna (*Thunnus alalunga*) is a common fish found in temperate and tropical seas worldwide. They are a pelagic species, highly adapted for long migrations across entire oceans (Ueyanagi 1975). Several studies have been conducted on lipid content (Sidwell and others 1974; Stansby 1976; Dotson 1978; Gallardo and others 1989; Perez-Villarreal and Pozo 1990) and fatty acid distribution (Aubourg and others 1989, 1990a, 1990b, 1997; Garcias-Arias and others 1994) of albacore tuna, reporting great differences in lipid content depending on catch location.

West Coast albacore tuna are found off the shores of the West Coast of the United States. They are sexually immature (three or four years of age) and have generally migrated across the Pacific Ocean and up the coast from California (Dotson 1978). There are fewer studies focusing on West Coast albacore tuna compared to albacore found in other locations. Dotson's (1978) study is the primary research conducted on the lipid content of West Coast albacore tuna. This study indicated that lipid levels were generally quite high and considerably variable among individual albacore, and at different loci within each fish. Sidwell and others (1974) and Stansby (1976) published papers listing the proximate composition of many fish species including West Coast albacore tuna.

Lipids affect the edible quality of seafood (Kinsella and others 1977) and provide sensory characteristics such as smooth texture, enhanced flavor, and increased overall acceptability (Ackman 1980; Katikou and others 2001). Moreover, fish lipids are gaining even more attention due to their high content of omega-3 polyunsaturated fatty acids (PUFA). Albacore are rich in omega-3 fatty acids, which have numerous health benefits. Studies have shown that an increase of dietary omega-3 fatty acids leads to decreased risk of cancer, heart disease, depression, asthma, obesity, autoimmune disease, diabetes, Alzheimer's, and osteoporosis (Nettleton 1995; Simopoulos and Robinson 1999; Albert 2002).

Knowledge of lipid content is crucial for different markets for albacore tuna. The major tuna canneries prefer albacore with lower lipid content for commercial canning operations. This facilitates the processing of the tuna and also prevents the formation of lipid layers in the can after processing and sterilization. The Spanish market prefers albacore in the range of 6-12% lipid (Gomez 2002). Albacore low in lipids will be too dry for several of their products while high lipid albacore produces a lower yield for their cannery operations.

As the market value of albacore tuna varies in direct proportion to its fat content, Dotson (1978) indicated a need for rapid lipid analysis to improve the economics of the fishery. Lipid content is inversely proportional to moisture content in most pelagic species (Love 1997). If this inverse correlation can be found in West Coast albacore tuna, then regression analysis can be used to develop a mathematical relationship between lipid and moisture. Therefore, a rapid method

of moisture testing could potentially provide a fast estimation of lipid content in West Coast albacore tuna.

The objectives of this study are 1) to compare the proximate distribution across six designated body zones, 2) to assess the fatty acid profile and total omega-3 content, and 3) to determine the correlations between lipids and moisture and omega-3 content of West Coast albacore tuna.

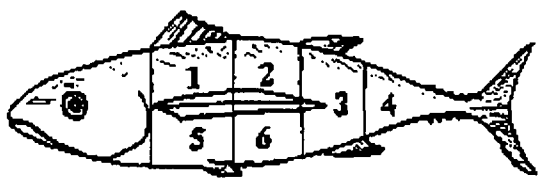
MATERIALS AND METHODS

Sample Preparation

Twelve albacore tuna were troll caught off the Oregon coast (45° N and 125° W) between August 31 and September 6, 2000 (F/V Aquavit). The whole fish were blast frozen (-20°C) at sea and transferred to the Oregon State University Seafood Laboratory, Astoria, Oregon where they were held at -30°C. After 12 to 18 months of frozen storage, the lipid and moisture contents were measured on twelve fish; protein and ash were also measured on four of the fish. Four additional fish were troll caught off the Oregon coast (28° N and 127° W) August of 2002 (F/V Cold Stream). These fish were transferred to the Oregon State University Seafood Laboratory, Astoria, Oregon and immediately analyzed for lipid, moisture and fatty acid content. From each of the 16 fish, ten to twelve core samples (1.8 cm dia, 4.5 cm length) were removed from each of the six designated

body zones (Fig. 2.1). Approximately 100 g of white muscle meat was collected from each body zone and homogenized separately using a blender at low speed.

Figure 2.1 Six designated body zones of West Coast albacore tuna.



Lipid Extraction

The lipid was extracted according to the method of Lee and others (1996). Homogenized paste weighing 5 g was placed in a jar and 50 ml solvent (2:1, chloroform: methanol) was added. The mixture was blended for 1.5 min at moderate speed. The homogenate was filtered through Whatman no.1, 5.5 cm filter paper and funneled into a 100 ml glass-stoppered graduated cylinder. To separate the filtrate into 2 phases (methanol-water and chloroform), 20 ml 0.5% NaCl was added. The mixture was shaken gently by tilting the graduated cylinder 4 times and then allowed to stand until a clear separation was visible. A 5 ml aliquot of the chloroform layer was removed, transferred to a pre-weighed 10 ml beaker, and evaporated for 30 min on a hot plate. Samples were analyzed in replicates of three.

Proximate Analysis

The moisture, protein, and ash contents were determined by standard Association of Official Analytical Chemists (AOAC) methods. Moisture content was found by measuring the mass of a sample before and after drying overnight in an oven (AOAC 1990). Ash content was derived by measuring the mass of a dried sample before and after heating in a muffle furnace (AOAC 1995). Total nitrogen was determined by the Kjeldahl procedure (AOAC 1995) and converted to crude protein by multiplying by 6.25. Samples were analyzed in replicates of three.

Fatty Acid Quantification

Methyl esters were derived from the extracted lipid (Lee and others 1996), according to the AOAC (1995) method. Analysis of the fatty acid methyl esters was performed on a Hewlett Packard Series II 5890 gas chromatograph (Palo Alto, CA) equipped with a capillary column (EC-wax, 30 m x 0.25 mm ID; split ratio, 100:1; Alltech, Deerfield, IL). The temperatures of the injector and detector were held at 250°C and 270°C, respectively. The column started at 50°C and heated up to 180°C at a rate of 5°C per min, then slowed to a rate of 0.8°C per min until it reached 220°C. Individual components were identified based on their retention times as compared to the standard (Supelco 37 Component Fatty Acid Methyl Ester (FAME) Mix, Supelco, Park, Bellfonte, PA). Samples were analyzed in replicates of three.

RESULTS AND DISCUSSION

Proximates

Figure 2.2 shows the proximate distribution of ash, protein, moisture and lipid content across the six designated body zones of West Coast albacore tuna. Ash and protein values remained fairly constant throughout the body zones, with averages of 1.7 ± 0.3 and 24.6 ± 0.5%, respectively. Body zone 5, which contained the highest lipid content, also contained the least amount of protein, with an average of 21.7 ± 0.9%. Sidwell and others (1974) reported similar values for ash and protein of albacore tuna, 1.3 and 24.2%, respectively. Stansby (1976) also reported similar values for ash and protein of West Coast albacore tuna, 1.26 and 25.0%, respectively. He considered the high protein content of albacore tuna to be unique, as it is almost 50% higher than most other species (Stansby 1976).

Together, lipid and moisture constituted the remaining 75% of the proximate distribution for West Coast albacore tuna. This result is consistent with Sidwell and others (1974) who stated that moisture and lipid comprise 80% of most fish, however, in scombroids the percentage is usually 75% due to their high protein content. Aursand and others (1994) found that the moisture content of Atlantic salmon varied with the lipid content, the sum of these two constituents ranged from 78-84%

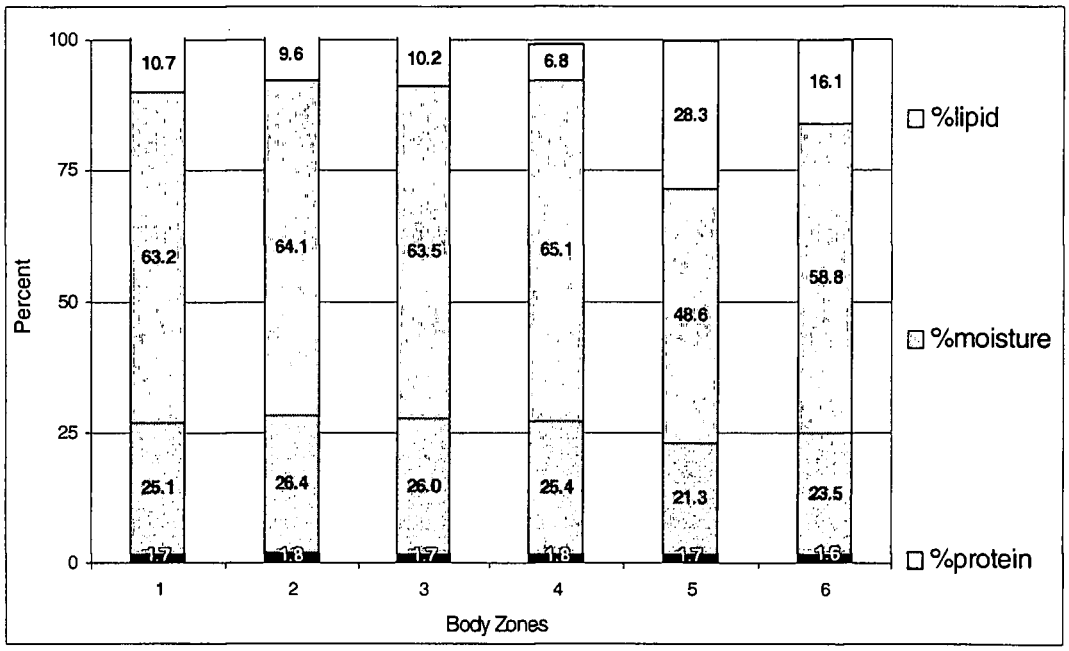


Figure 2.2 Proximate composition across the body zones of 4 West Coast albacore tuna.

The lipid content of the six body zones of West Coast albacore tuna is shown in Fig. 2.3. Considerable variation existed between as well as within individual fish. Each fish exhibited a general trend of higher lipid towards the head and lower lipid towards the tail. Body zone 1 contained an average of 12.6 ± 0.4% lipid, with a range of 8.2 ± 0.3 to 17.1 ± 0.8% lipid. Body zone 2 contained an average of 10.8 ± 0.3% lipid, with a range of 5.7 ± 0.1 to 16.2 ± 0.6% lipid. Body zone 3 contained an average of 11.2 ± 0.4% lipid, with a range of 6.2 ± 0.3 to 17.7 ± 0.8% lipid. Body zone 4 contained an average of 8.1 ± 0.2% lipid, with a range of 3.9 ± 0.2 to 13.0 ± 0.3% lipid. Body zone 5 contained an average of 22.7 ± 0.5% lipid, with a range of 13.9 ± 0.3 to 36.3 ± 1.1% lipid. Body zone 6 contained an average of 15.6 ± 0.4% lipid, with a range of 8.2 ± 0.3 to 20.1 ± 0.2% lipid.

These results are similar to previously reported values for West Coast albacore tuna. Dotson (1978) found an average lipid content of 21.1% in the belly flaps, and 5.3 and 4.2% in the anterior and posterior portion, respectively. Karrick and Thurston (1968) reported an average lipid content for West Coast albacore of 9 to 17%, with 36% lipid in the belly flaps. Stansby (1976) recorded average fat contents from 28 West Coast albacore tuna, ranging from 5.1 to 16.1% with an average of 10.3%. He described the fat content for West Coast albacore tuna as unusually high for tuna, as other varieties usually contained less than 5% fat. The reported lipid contents for skipjack and yellowfin tuna are 0.78 ± 0.22 and 0.57 ± 0.04%, respectively (Medina and others 1995).

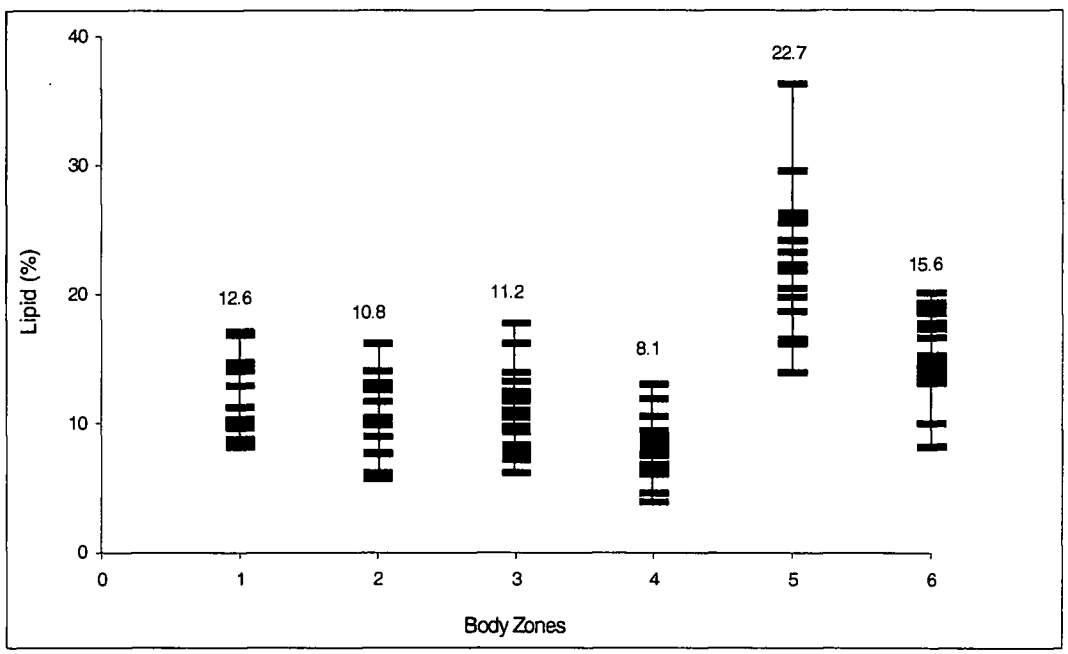


Figure 2.3 Lipid distribution across the body zones of 16 West Coast albacore tuna. Mean values for each body zone are listed.

Gallardo and others (1989) measured albacore tuna caught in the Atlantic Ocean and found a similar trend of higher lipid content in the belly flaps, with 18.5% lipid found there and 5.8% lipid in the back muscle. Various species of freshwater finfish (Kinsella and others 1977) and salmon (Aursand and others 1994; Bell and others 1998; Katikou and others 2001) were also found to be lipid rich in the anterior sections, especially in the belly flap area, compared to the posterior tail region. Ackman (1980) stated that belly flaps of many fish are much higher in lipid, with 29% lipid found in mackerel belly flaps.

The lipid content of body zone 5 (belly flaps) was, on average, 3.1 ± 1.3 times higher than the lipid content of body zone 4 (tail section). Lipid may be stored first in the belly region before it is deposited in white muscle regions (Dotson 1978). The tail region may have lower lipid content because that area is used for extensive swimming. This region is apt to have a considerably lower lipid content than less active muscles toward the head (Stansby 1976). Furthermore, the lipid was found to vary considerably from one fish to another, even when caught in the same location at the same time. Dotson (1978) explained that fish species that migrate extensively, like tuna, have a greater variation in lipid content between fish because lipid is used as an energy source between areas of abundant food. Some fish may have been recently feeding when harvested, while others may have just traveled through an area of scarce food, thus depleting their lipid stores. This variation in lipid content between and within individual fish can pose a problem for

processors, as tuna low in lipids are more suited for certain products while others require tuna high in lipid content.

Fatty Acids

Table 2.1 shows the total fatty acid composition of the lipids for the six body zones of West Coast albacore tuna. Although lipid content of the six body zones was found to be highly variable, the fatty acid distribution was relatively constant across the body zones. The major fatty acids for all six body zones were 16:0, 18:1ω9, 20:5ω3 and 22:6ω3. These four fatty acids were found to be the most abundant in other studies on albacore tuna as well (Aubourg and others 1989, 1997; Medina and others 1992; Garcia-Arias and others 1994; Murase and Saito 1996). Palmitic acid (C16:0) was present in an average concentration of 20.4 ± 3.7%. Values reported in the literature for albacore tuna were similar, ranging from 16.6% (Murase and Saito 1996) to 21.4% (Garcia-Arias and others 1994). Oleic acid (C18:1n9) averaged 16.2 ± 1.6%, while values in the literature ranged from 13.3% (Medina and others 1992) to 18.9% (Aubourg and others 1989). Eicosapentaenoic acid (EPA) averaged 11.6 ± 1.4%, while values in the literature were lower, ranging from 4.4% (Murase and Saito 1996) to 8.3% (Garcia-Arias and others 1994). Docosahexaenoic acid (DHA) was present in an average concentration of 26.7 ± 3.9%. Literature values were variable, ranging from 20.6% (Aubourg and others 1989) to 31.3% (Aubourg and others 1997).

Table 2.1 Fatty acid composition (%) of the lipids of six body zones of West Coast albacore tuna

	Body Zones[a]						
	1	2	3	4	5	6	average
Lipid[b]	**14.7 ± 0.5**	**14.0 ± 0.4**	**13.2 ± 0.6**	**9.7 ± 0.4**	**22.7 ± 0.8**	**17.9 ± 0.6**	**15.4 ± 0.5**
Fatty Acid[c]							
c14:0	3.7 ± 0.3[d]	3.9 ± 0.5	3.9 ± 0.5	3.5 ± 0.4	3.6 ± 0.4	3.6 ± 0.4	3.7 ± 0.4
c15:0	0.8 ± 0.1	0.9 ± 0.2	0.9 ± 0.2	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1
c16:0	19.4 ± 3.0	21.4 ± 4.2	21.4 ± 5.6	18.5 ± 3.0	20.1 ± 3.2	21.7 ± 3.2	20.4 ± 3.7
c17:0	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.2	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1
c18:0	5.2 ± 0.7	5.8 ± 1.2	5.9 ± 1.5	5.1 ± 0.9	5.3 ± 0.6	6.1 ± 1.0	5.6 ± 1.0
c20:0	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
ΣSFA	**30.2 ± 5.5**	**33.3 ± 2.6**	**33.2 ± 1.4**	**29.0 ± 3.5**	**31.0 ± 5.1**	**33.5 ± 12.1**	**31.7 ± 5.0**
c16:1	5.4 ± 0.5	5.1 ± 0.5	5.7 ± 1.0	5.9 ± 0.8	4.9 ± 0.2	4.6 ± 0.4	5.3 ± 0.6
c18:1ω9	16.6 ± 1.2	15.4 ± 1.2	17.0 ± 3.0	17.7 ± 2.4	15.6 ± 0.8	14.9 ± 1.0	16.2 ± 1.6
c20:1ω9	2.2 ± 0.2	2.1 ± 0.2	2.1 ± 0.5	2.4 ± 0.3	2.1 ± 0.2	2.0 ± 0.2	2.2 ± 0.3
c22:1ω9	0.4 ± 0.0	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.0	0.4 ± 0.1	0.4 ± 0.1
c24:1ω9	0.6 ± 0.1	0.7 ± 0.2	0.7 ± 0.2	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.2	0.7 ± 0.2
ΣMUFA	**25.3 ± 2.4**	**23.7 ± 1.9**	**25.9 ± 2.6**	**27.6 ± 4.7**	**23.8 ± 1.9**	**22.7 ± 0.9**	**24.8 ± 2.4**
c18:2ω6	2.0 ± 0.1	1.8 ± 0.1	2.0 ± 0.3	2.2 ± 0.3	1.8 ± 0.1	1.7 ± 0.1	1.9 ± 0.2
c18:3ω3	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.2	1.1 ± 0.1	0.9 ± 0.0	0.9 ± 0.1	1.0 ± 0.1
c18:3ω6	0.3 ± 0.0	0.2 ± 0.1	0.3 ± 0.0	0.3 ± 0.1	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.0
c20:2	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.0
c20:3ω3	1.2 ± 0.1	1.1 ± 0.2	1.2 ± 0.3	1.4 ± 0.2	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.2
c20:3ω6	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
c20:4ω6	0.3 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0
c20:5ω3	11.7 ± 0.9	11.0 ± 1.0	11.5 ± 3.1	13.3 ± 1.9	11.4 ± 0.7	10.9 ± 0.8	11.6 ± 1.4
c22:6ω3	27.5 ± 1.8	27.2 ± 3.2	24.1 ± 6.2	24.2 ± 6.3	29.0 ± 2.9	28.3 ± 3.0	26.7 ± 3.9
ΣPUFA	**44.6 ± 5.3**	**43.1 ± 4.0**	**41.0 ± 2.4**	**43.4 ± 7.3**	**45.3 ± 6.7**	**43.9 ± 12.1**	**43.5 ± 6.3**
Σ n3 %	41.5 ± 2.8	40.2 ± 4.5	37.8 ± 5.8	40.0 ± 5.3	42.4 ± 3.7	41.2 ± 3.9	40.5 ± 4.3
Σ n3 g/100g	2.5 ± 0.2	3.0 ± 0.4	2.2 ± 0.4	2.1 ± 0.5	3.5 ± 0.4	3.1 ± 0.6	2.8 ± 0.5

[a] Body zones as indicated in Figure 1, from 4 fresh West Coast albacore tuna.
[b] Lipid (% w/w) of wet tissue.
[c] Fatty acid (%) of identified peaks
[d] Mean ± standard deviation

Polyunsaturated acids such as EPA and DHA are important for highly migratory fish, such as West Coast albacore tuna (Bell and others 1986). This is shown by an active use of saturated and monounsaturated fatty acids as an energy source during fasting and the storage of unsaturated fatty acids such as DHA (Watanabe and others 1989). It has been reported that the DHA content of tuna is high compared to other fish species (Aubourg and others 1989; Watanabe and others 1995; Murase and Saito 1996; Saito and others 1997). The DHA content found in West Coast albacore tuna was at least twice that reported for other seafood (Wander and Patton 1991; Aursand and others 1994; Jonsson and others 1997; Sargent 1997). Atlantic salmon, anchovies and herring contain 12.2, 9.0 and 6.0% DHA, respectively (Jonsson and others 1997; Sargent 1997). This high DHA content for tuna could be related to cooler water temperatures influencing accumulation of subcutaneous fat, as well as feeding on prey that have higher DHA content than species who live in warmer waters (Saito and others 1997). Murase and Saito (1996) found that the DHA content of albacore caught off the coast of Japan was similar to that of their prey fish, whose DHA contents are higher than other fish species. Because high DHA contents have been recorded for many migratory tuna species such as bluefin, yellowfin, skipjack and albacore, it has also been suggested that DHA is gradually accumulated during extensive migration (Saito 1996). However, high levels of DHA in juvenile skipjack and bluefin tuna, have indicated a species-specific biochemical characteristic of tuna to accumulate DHA from early life stages (Ishihara and Saito 1996; Tanabe and others 1999).

Total omega-3 percentages were very consistent across the six body zones of West Coast albacore tuna, averaging 40.5 ± 6.3%. Other albacore tuna studies report a range of total omega-3 fatty acids from 29.1% (Aubourg 1989) to 43.8% (Medina and others 1992). These results are higher than those reported for salmon, which range from 17.6% (Jonsson and others 1997) to 28% (Sargent 1997).

While omega-3 percentages remained fairly constant across the body zones, total omega-3 content was variable, ranging from 2.1 ± 0.5 g/100g tissue in body zone 4 (low lipid tail section) to 3.5 ± 0.4 g/100g tissue in body zone 5 (high lipid belly flaps). Body zones that contained the highest lipid content consequently had the highest total omega-3 content. Total EPA and DHA content ranged from 0.6 ± 0.0 and 1.4 ± 0.5 g/100g tissue in body zone 4 (low lipid tail section) to 0.9 ± 0.1 and 2.3 ± 0.4 g/100g tissue in body zone 5 (high lipid belly flaps). Total omega-3 content for farmed Atlantic salmon is 1.8 g/100g tissue; values for EPA and DHA are 0.6 and 1.2, respectively (Nettleton 1995).

Correlations

Figure 2.4 shows an inverse correlation between the lipid and moisture content of West Coast albacore tuna (R^2 = -0.95) analyzed in this study. Garcia-Arias and others (1994) also reported an inverse correlation (R^2= -0.95) between lipid and moisture content of albacore tuna caught in the Atlantic Ocean. These results provide further evidence supporting the finding that moisture content of

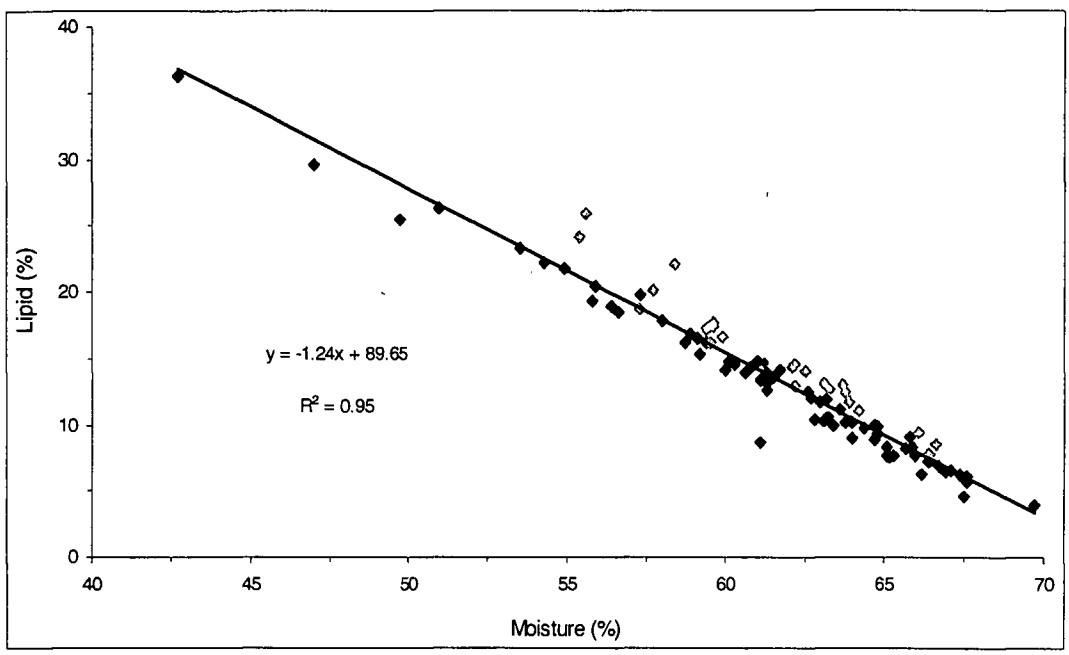


Figure 2.4 Lipid and moisture correlation for 16 West Coast albacore tuna. Six body zones are represented for each fish. Black = fish frozen for over one year. Gray = fresh fish.

pelagic species is related to lipid content (Stansby 1976; Dotson 1978; Perez-Villarreal and Pozo 1990; Katikou and others 2001).

Love (1997) concluded that over 80% of the variation in lipid content correlates inversely and significantly with moisture content. Because lipid content can vary widely through migration, the moisture content also varies. This is a consequence of the fish maintaining a constant density slightly greater than that of water (Perez-Villarreal and Pozo 1990). Given this relationship between lipid and moisture, Kent (1990) stated that a measurement of one serves to determine the other. The equation developed based on the trend line in Fig. 2.4 ($y = -1.24x + 89.65$) would allow the lipid content to be estimated based on the moisture content. The gray points on Fig. 2.4 represent fresh samples that were never frozen. While they are still correlated to moisture with all the previously frozen samples, the moisture content is slightly higher. This shows that whole fish do experience some degree of dehydration after one year of frozen storage at –30°C.

Figure 2.5 shows a weak, positive correlation between lipid content and length and weight of West Coast albacore tuna ($R^2 = 0.37$). Body zone 1 was used to represent the average fat content of the fish. Dotson (1978) found no relationship between fish length and lipid content of West Coast albacore tuna. However, Perez-Villarreal and Pozo (1990) reported a significant interaction between lipid content and size for albacore tuna from the Atlantic Ocean. Craven and others (1997) reported a correlation ($R^2 = 0.23$) between percent lipid and weight for West Coast albacore tuna caught 130 miles offshore.

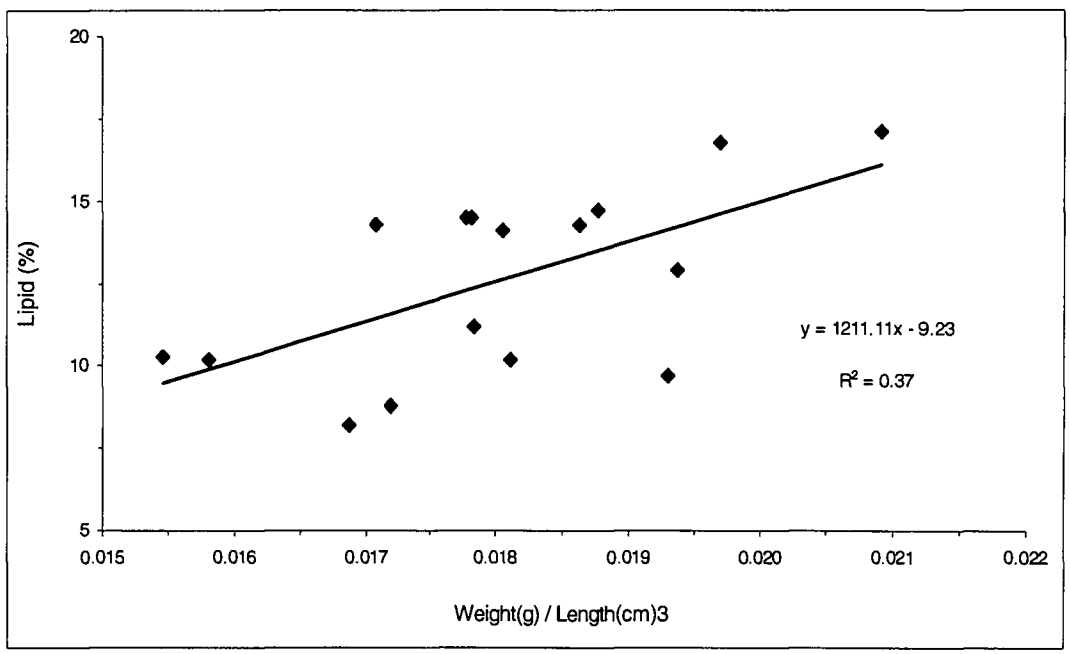


Figure 2.5 Lipid and weight length correlation for 16 West Coast albacore tuna.

Figure 2.6 shows a weak correlation between percent fat and total omega-3 content (g/ 100g tissue) for West Coast albacore tuna ($R^2 = 0.39$). A correlation between fat and total omega-3 content for albacore tuna has not been previously reported in the literature. This type of information may become more prevalent as omega-3 fatty acids continue to be studied.

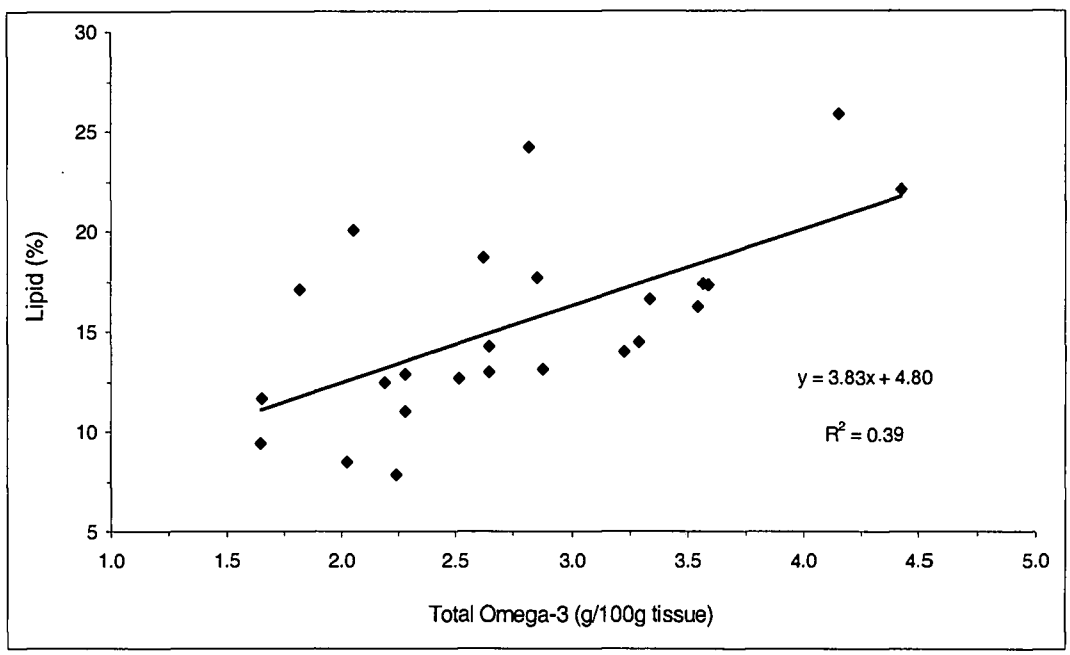


Figure 2.6 Lipid and total omega-3 correlation for 16 West Coast albacore tuna.

CONCLUSIONS

Other studies have evaluated the lipid content and distribution of albacore tuna (Sidwell and others 1974; Stansby 1976; Dotson 1978; Gallardo and others 1989; Perez-Villarreal and Pozo 1990). However, this is one of few studies to evaluate these characteristics of West Coast albacore tuna. Further, this study expanded the evaluation of intrinsic characteristics to also include the proximate and fatty acid composition. The results form a more complete picture of the unique characteristics of West Coast albacore tuna.

Analysis of the proximate composition showed that ash and protein content remained constant throughout the six body zones, comprising 25% of the composition. Together, lipid and moisture constituted the remaining 75%. The lipid contents for each fish were variable, showing a general trend of higher lipid content towards the head, and lower lipid content towards the tail of the tuna; indicating that different parts of the fish may have different intrinsic qualities. Total omega-3 g/100g tissue ranged from 2.1 (low lipid tail section) to 3.5 (high lipid belly flaps).

Over 20 years ago, Dotson (1978) indicated a need for a rapid measure of lipid content in West Coast albacore tuna. This study provides strong evidence of an inverse relationship between the lipid and moisture for West Coast albacore tuna

(R^2 = -0.98). This result indicates that moisture content can be used to provide a fast estimation of lipid. This information can be very useful for the identification of fish with high and low lipid contents for use in specific products.

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CHAPTER 3

EVALUATION OF ONBOARD HANDLING TECHNIQUES FOR ALBACORE TUNA (*THUNNUS ALALUNGA)*

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To be Submitted to Journal of Food Science

ABSTRACT

Onboard handling techniques for West Coast albacore tuna (*Thunnus alalunga*) were evaluated using sensory and analytical methods. The tuna samples were chilled (immediately and after 3 h), spiked, and bled at either the throat or gills and evaluated by a sensory panel for overall quality, color, smell, texture and flavor. 2-Thiobarbituric acid-reactive substances (TBARS) and pH were also compared. Rapid chilling significantly and positively influenced overall quality, color, texture, and flavor; and significantly reduced oxidative rancidity. Bleeding at the throat significantly and positively influenced all sensory attributes tested, but did not significantly influence TBARS or pH. Neither spiking nor bleeding at the gills significantly affected sensory attributes.

Key Words: Albacore tuna, onboard handling, spiking, bleeding, chilling

INTRODUCTION

Cannery demand for U.S. caught albacore tuna (*Thunnus alalunga*) has decreased due to a shift from domestic to overseas markets (Jacoby 1987). In the past, United States tuna canners purchased about 80% of the West Coast albacore tuna catch, however, this amount has decreased to 30% in the past five years (WFOA 2002). More of the West Coast albacore catch is being sold in alternative markets, such as fresh and frozen loins, fresh raw sashimi grade loins, and smoked loins. In 2001, 43% of the catch was exported to European countries, primarily Spain, and 20% was sold as sashimi (WFOA 2002). As the West Coast albacore industry continues to develop alternative markets, an improvement in the quality and consistency of the catch has become increasingly important (Price and others 1991). Improving handling and chilling techniques onboard fishing vessels are ways to address these quality and consistency concerns.

Historically, alternative markets have been limited because albacore tuna is a delicate fish that bruises easily when not handled and chilled properly, leading to poor texture quality. Price and Melvin (1994) described albacore as a unique fish requiring special handling procedures. Current handling procedures range from little or no treatment to bleeding, spiking, or a combination of the two. Chilling times range from immediately after capture to severely delayed. Currently, there is no industry consensus on the best handling techniques or chilling systems to produce the highest and most consistent quality product (Price and others 1991).

Several papers recommend various handling methods (Goodrick 1987; Price and Melvin 1994; Williams 1986; Amos 1981; Melvin and others 1983); however, few have actually studied their effects with both sensory and chemical methods on West Coast albacore tuna. Jacoby (1987) compared the effects of bleeding, gilling, eviscerating and different onboard freezing techniques for albacore tuna. Sensory judges found little difference between handling methods over 12 days of storage. Price and others (1991) used chemical methods to analyze albacore tuna that were spiked, dressed, bled or left round. No significant differences were found among handling procedures for total plate count (TPC), pH, salt, trimethylamine nitrogen (TMA-N), or nucleotide content over 33 days of storage. However, he did find that dressed albacore cooled faster than round or bled albacore.

The purpose of this study was to compare the effects of rapid chilling, spiking and bleeding at the throat and gills on albacore tuna using both sensory analysis and analytical measurements.

MATERIALS AND METHODS

Sample Preparation

Albacore tuna were troll caught onboard F/V Aquavit off the Oregon Coast. The fish were caught November 2001 and delivered directly to the Oregon State University Seafood Laboratory, Astoria, Oregon where they were held at –30 °C for one month. This study used twelve specially handled fish, ranging from 5.5 to 10.9 kg with an average length and circumference of 78.7 and 27.6 cm, respectively. The study design for the handling of the samples is shown in Table 3.1.

Handling methods investigated were: 1) Chilling- fish were either frozen immediately or 3 h after harvest, in a blast freezer at –20 °C; 2) Spiking- if a fish was spiked, the method used was to thrust an ice pick into the soft spot above the eyes at a 30 degree angle and moved from side to side to destroy the brain; 3) Bleeding- fish were bled at the throat, at the gills, or not bled. Bleeding at the throat was accomplished by cutting the afferent bronchial artery at the nape of the neck between the heart and gills. Bleeding at the gills was accomplished by inserting a knife behind the gill, through the gill membrane, and cutting up toward the spine; severing the blood vessels at the top of the gills. To take advantage of the pumping action of the heart, bleeding was done immediately after the fish were landed.

Table 3.1 Onboard handling experiment for albacore tuna

	Handling Techniques		
1	Chilled (0)	Spiked (Yes)	Bled (Th)
2	Chilled (0)	Spiked (Yes)	Bled (Gill)
3	Chilled (0)	Spiked (Yes)	Bled (No)
4	Chilled (0)	Spiked (No)	Bled (Th)
5	Chilled (0)	Spiked (No)	Bled (Gill)
6	Chilled (0)	Spiked (No)	Bled (No)
7	Chilled (3)	Spiked (Yes)	Bled (Th)
8	Chilled (3)	Spiked (Yes)	Bled (Gill)
9	Chilled (3)	Spiked (Yes)	Bled (No)
10	Chilled (3)	Spiked (No)	Bled (Th)
11	Chilled (3)	Spiked (No)	Bled (Gill)
12	Chilled (3)	Spiked (No)	Bled (No)

Sensory Analysis

The twelve samples were thawed for 24 h at 1.5 °C and loined. The anterior and posterior section of the right and left loin were removed and saved for chemical analyses. The remaining middle sections were divided into ten 1.5 inch slices and five one inch slices. The ten 1.5 inch slices were used as raw samples.
The five one inch slices were cooked for seven min at 350 °C in a commercial convection oven. Dyer and others (1964) reported better discrimination between quality levels when samples were baked. After cooling for 10 min the slices were vertically divided, resulting in ten cooked samples. Both raw and cooked samples were evaluated within the following hour and a half.

Nine panelists participated in the sensory analysis. Each panelist was screened for whether they consumed seafood three times a month and their availability during the training (two days, prior to testing) and testing dates. Each fish was evaluated by the panelists in both the raw and cooked state. Samples were coded with 3-digit numbers and individually presented to the panelists in a completely randomized block design. Panelists used a 9-point anchored scale to evaluate overall quality, color, smell, texture and flavor. Flavor was assessed only for cooked samples.

Chemical Analysis

The anterior sections of the right and left loin for each fish were vacuum-sealed and frozen at –30 °C until analysis, one week later. The sections were homogenized separately and measured in triplicate.

Lipid oxidation was determined by the 2-thiobarbituric acid-reactive substances (TBARS) method described by Sinnhuber and Yu (1977). Antioxidant solution, TBA solution and Trichloroacetic acid (TCA) solution were added to 250 mg of sample and flushed with nitrogen. After heating for 30 min and cooling, samples were centrifuged for 10 min at 3,000 RPM. A part of the clear solution was transferred into a 1 cm cuvet for absorbency measurement at 525 mμ using a Beckman spectrophotometer DU 640 (Beckman Instrument, Inc, Redmond, Wash, U.S.A.). The absorbance multiplied by the factor 46 was reported as the TBARS value, or mg of malonaldehyde per 1000 g sample.

Tissue pH was determined for the homogenous mixtures of fish and distilled water (1:5, w:v) using a Corning pH meter, model 240.

The lipids were extracted following the method of Lee and others (1996). Homogenized paste weighing 5g was placed in a jar and 50 ml 2:1 chloroform-methanol solvent was added. The mixture was blended for 1.5 min at moderate speed. The homogenate was filtered through Whatman no.1, 5.5cm filter paper and funneled into a 100 ml glass-stoppered graduated cylinder. To separate the filtrate into two phases (methanol-water and chloroform), 20 ml 0.5% NaCl was added. The mixture was shaken gently by tilting the graduated cylinder four times and then

allowed to stand until a clear separation was visible. To determine the amount of lipid extracted, a 5ml aliquot of the chloroform layer was removed, transferred to a pre-weighed 10 ml beaker, and evaporated for 30 min on a hot plate.

Statistical Analysis

The data from sensory scores and analytical measurements were analyzed using multiple regression analysis with SAS software package (SAS Institute Inc, Cary, N.C., U.S.A.). Significance level was set at $p<.05$.

RESULTS

Sensory Analysis

As seen in Table 3.2, overall quality scores for raw and cooked samples averaged 7.28 and 7.05, respectively; together the mean was 7.16. Overall quality was significantly increased by rapid chilling and bleeding at the throat (Table 3.3). Color scores for raw and cooked samples averaged 7.43 and 7.42, respectively; together the mean was 7.42. Color was positively and significantly influenced by rapid chilling and bleeding at the throat. Smell scores for raw and cooked samples averaged 7.70 and 7.29, respectively; together the mean was 7.49. Smell was positively and significantly affected by bleeding at the throat. Texture scores for raw and cooked samples averaged 7.06 and 7.43, respectively; together the mean

Table 3.2 Weighted summary statistics for the independent and dependent variables

Variable	Measurement	Mean	St.dev
Sensory			
Overall quality (raw)	1= low quality; 9= high quality	7.28	1.37
Overall quality (cooked)	1= low quality; 9= high quality	7.05	1.37
Color (raw)	1= green, liquefied; 9= pale pink, shiny	7.43	1.45
Color (cooked)	1= brown, molted; 9= ivory, uniform	7.42	1.20
Smell (raw)	1= putrid; 9= fresh	7.70	1.55
Smell (cooked)	1= rancid; 9= neutral	7.29	1.28
Texture (raw)	1= mushy; 9= springy	7.06	1.52
Texture (cooked)	1= very dry, grainy; 9= firm, moist	7.43	1.51
Flavor (cooked)	1= rancid; 9= light chicken	7.24	1.46
Chemical			
TBARS	mg malonaldehyde per 1000g of sample	1.81	0.80
pH		5.91	0.10
Handling			
Chilled	0= after 3 hours; 1= immediately	0.50	0.50
Spiked	0= not spiked; 1= spiked	0.50	0.50
Bled throat	0= not bled; 1= bled throat	0.33	0.47
Bled gill	0= not bled; 1= bled gill	0.33	0.47

was 7.24. Texture was significantly increased by rapid chilling and bleeding at the throat. Flavor was evaluated for cooked samples only; the mean score was 7.24. Flavor was positively and significantly influenced by rapid chilling and bleeding at the throat.

Chemical Analysis

The TBARS value is used as a measure of oxidative rancidity in fats. TBARS values ranged from 0.41 to 3.00, with an average of 1.81 (Table 3.2). TBARS was significantly reduced by immediate chilling, and significantly increased by both spiking and bleeding at the gills (Table 3.3). The pH of samples ranged from 5.76 to 6.16 with an average of 5.91; and was significantly reduced by immediate chilling and significantly increased by bleeding at the gills.

DISCUSSION

Chilling

Rapidly chilling the albacore tuna rather than leaving them on deck for 3 h post-harvest significantly improved sensory evaluation of overall quality and color. Since overall quality is mainly influenced by color (Barrett and others 1965), quality and color will be discussed together. It has been well documented that tuna should be chilled as quickly and efficiently as possible after capture to maximize

Table 3.3 Estimates and p values for sensory and chemical measurements of albacore tuna

	Dependent Variables						
Independent Variables	**Overall**	**Color**	**Smell**	**Texture**	**Flavor**	**TBARS**	**pH**
Chilled	0.45	0.64	0.32	0.44	0.61	-0.26	-1.78
	(0.01)	(0.0005)	(0.1)	(0.05)	(0.05)	(0.005)	(0.0001)
Spiked	0.12	0.20	0.28	0.15	-0.16	0.17	0.11
	(0.5)	(0.5)	(0.1)	(0.5)	(1.0)	(0.05)	(1.0)
Bled throat	0.74	0.86	0.54	0.62	0.82	-0.16	-0.73
	(0.005)	(0.0001)	(0.05)	(0.05)	(0.05)	(0.1)	(0.1)
Bled gills	0.31	0.29	0.22	0.49	0.65	0.72	3.77
	(0.5)	(0.5)	(0.5)	(0.1)	(0.1)	(0.0001)	(0.0001)
Preparation	0.23	0.01	0.42	-0.36			
	(0.5)	(1.0)	(0.05)	(0.1)			
adj. R-sq	0.06	0.12	0.04	0.04	0.06	0.37	0.45

[a] Estimate

[b] P value

quality (Crawford and Finch 1968; Wilson 1982; Williams 1986; Goodrick 1987; Jacoby 1987; Price and others 1991; Price and Melvin 1994; Goblirsch 2002). Albacore tuna are warm-blooded fish, core temperatures can be as high as 26 – 30 °C when landed. Removing their body heat as soon as possible is vital for slowing down the rate of both autolytic reactions and bacterial growth (Carey and Teal 1966; Haard 1992a). Price and Melvin (1994) suggested chilling albacore tuna within 15 min of capture to ensure a high quality product without histamine. The consumption of fish containing histamine can lead to scombroid poisoning. The best way to prevent scombroid poisoning is rapid chilling on the vessel; therefore, FDA regulations recommend fish be rapidly chilled to 4 °C (Price and Melvin 1994). Craven and others (1997) also reported a relationship between sensory scores and the time tuna spent on deck post harvest; quality significantly decreased as time between capture and chilling increased. The lower the body temperatures before fish go into rigor mortis the higher the quality of the meat (Jerret 1984). Additionally, the shelf life of the fish is significantly compromised when product temperature is not rapidly dropped to near freezing (FDA/CFSAN 2002). Fish rapidly cooled to 0 °C had 14 days of safe shelf life, while delayed cooling to 0 °C decreased shelf life to 8 days (FDA/CFSAN 2002). As a general rule, one day of shelf-life is lost each h an albacore is left on deck (Price and Melvin 1994)

Rapidly chilled fish received significantly higher texture scores from the sensory panel. This is in agreement with MacDonald and others (1997), who found

that rapid chilling of freshly caught fish slowed down the onset, duration, and relaxation stages of rigor mortis resulting in better fish texture. Haard (1992a) reported extensive autolysis of collagen and loss of muscle integrity in rockfish that experienced short-term temperature abuse.

It has been shown that temperature is the single most important factor affecting spoilage rate of fish (Reay and Shewan 1960). Price and others (1991) found that albacore left on deck cooled slowly and remained above 24 °C for over 2 h, thus increasing bacterial growth and the chemical breakdown of the flesh. This decrease in bacterial growth and chemical breakdown could be responsible for the significant increase in flavor of rapidly chilled albacore tuna.

Spiking

Spiking did not significantly influence any of the sensory attributes tested. Spiking is said to disrupt the medulla oblongata, severing the spinal column from the higher neuron centers; resulting in a delayed onset of rigor mortis, decrease in temperature and lactic acid, better retention of skin color and flesh translucency, and extension of prime quality (Wilson 1982; Boyd and others 1984; Haard 1992a; Price and Melvin 1994). However, there is some debate over spiking methods and their effectiveness. Howgate (2002) reports that positive effects are found when the process of spiking includes inserting a wire into the spinal column to destroy the spinal cord, also called pithing. The method of spiking used in this study is one commonly used in the fishing industry, essentially destroying the brain by passing a

spike through it without the use of a wire to destroy the central nervous system. This renders the fish unconscious so that it does not struggle, but muscle activity may still continue. Goodrick (1987) suggested that killing by a blow to the head or a spike to the brain does not ensure a decrease in muscle temperature. Potsompong and others (1991) found no differences in quality between spiked and non-spiked fish based on sensory evaluations of sea bass after 24 hours storage.

Bleeding

Bleeding albacore tuna at the throat had a positive and significant effect on overall quality. Albacore are a warm-blooded fish, often warmer than the ambient surface water temperature. A counter current heat exchange system consisting of closely packed arteries and veins provides a thermal barrier preventing heat generated by metabolism from being lost to the colder, surrounding water (Carey and Teal, 1966). The total blood volume of albacore has been estimated to comprise 8.2-19.7% of the body weight, therefore bleeding is an effective way to immediately decrease body temperature, increasing overall quality (Laurs and others 1978; Haard 1992b). Jacoby (1987) reported greater (not significant) mean deep-body temperature losses and higher acceptability scores for bled albacore and bled, gilled and eviscerated albacore than non-bled albacore. Price and Melvin (1994) claimed that bleeding helped to reduce fish temperature on deck, as well as improve the appearance of uncooked tuna loins.

This decrease in body temperature may be responsible for the significantly higher texture scores received by albacore tuna bled at the throat, as entering rigor mortis at a higher temperature increases toughness and gaping of the flesh (Amos 1981).

Albacore tuna bled at the throat received significantly higher color scores. This is in agreement with a statement by the FAO (2002) that effective bleeding reduces discoloration of the flesh. Bleeding removes heme compounds, which results in a lighter colored flesh (Amos, 1981; Ronsivalli, 1981). Other researches have also reported an increase in color attributes as a result of bleeding. Amos (1981) claimed that bleeding produced a clean white product that was more acceptable to the processors and consumers. In comparing a* values, Terayama and Yamanaka (2000) found that bled skipjack tuna received the highest scores. Barrett and others (1965) reported improved color quality for bled yellowfin tuna.

Albacore tuna bled at the throat also received significantly higher scores for flavor and smell. Williams (1986) claimed that unbled tuna meat sours more quickly than bled meat. After death, albacore can no longer regulate body temperature or flesh pH. If the temperature of unbled fish remains high, enzymes break down ATP to compounds that are associated with off-flavors in "stale" fish (Price and Melvin 1994). Furthermore, consumers highly evaluated bled skipjack tuna, claiming it did not have a fishy smell (Terayama and Yamanaka 2000).

Albacore tuna bled at the gills, did not receive significant scores for any of the sensory attributes tested. It is apparent, therefore, that bleeding at the throat is a

more efficient bleeding method. This is in contrast with the belief that all methods of bleeding are essentially equal (Price and Melvin 1994). Furthermore, a throat-cut is easy to physically observe in frozen albacore while a gill-cut fish must be first thawed to observe the gills and thus more difficult to verify as bled.

TBARS

The TBARS procedure has been widely accepted as a sensitive method for the measurement of malonaldehyde in foods and the results can be correlated with the development of off-odors and flavors (Sinnhuber and Yu 1977). In this study, rapidly chilled fish had significantly lower TBARS values. Fish that were bled at the throat also had lower, however not significant, TBARS values. Both these groups received significantly higher sensory scores for overall quality and flavor; samples bled at the throat also received significantly higher scores for smell. Fish that were spiked and fish that were bled at the gills had significantly higher TBARS values. These samples showed no significance in sensory scores for overall quality, smell, or flavor. Therefore, a relationship was observed between TBARS values and sensory scores for overall quality, smell, and flavor.

Rapidly chilled samples received lower TBARS values because oxidative rancidity is slowed at lower temperatures. Significantly higher TBARS values for fish bled at the gills further prove that it is an inefficient bleeding method, for heme compounds found in blood are known to accelerate oxidative rancidity (Ronsivalli 1981).

pH

The pH response was not consistent with sensory or TBARS scores. Fish that were rapidly chilled had significantly lower pH values, while fish that were bled at the throat had insignificantly lower pH values. Meanwhile, fish that were bled at the gills had significantly higher pH values, while fish that were spiked had insignificantly higher pH values. According to the literature, the lowering of pH may be due to lactic or pyruvic acid formation caused by ATP hydrolysis during the death struggles of the fish, and can be associated with poor overall quality, texture, color, and flavor (Barrett and others 1965; Mills 1975; Konagaya and Konagaya 1979; Haard 1992a; Price and Melvin 1994). However, Cramer and others (1981) also found they could not correlate lower pH with poor quality tuna flesh in all cases. It is important to note that while significant reductions and increases in pH where found in this study, pH values were very consistent with a range of 5.76 to 6.16.

CONCLUSIONS

As a higher percentage of albacore are being sold in alternative markets, onboard handling and chilling techniques are becoming the keys to a successful industry. It is strongly recommended that albacore tuna be first bled at the throat and then rapidly chilled to increase overall quality, color, smell, texture and flavor.

These two handling techniques are very simple to do, and yet they make a remarkable difference in the quality of the tuna. If every albacore tuna is bled at the throat and rapidly chilled, a high quality product can be consistently supplied to alternative markets.

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CONCLUSIONS

The purpose of this study was to identify and quantify the intrinsic and extrinsic quality characteristics of West Coast albacore tuna. The first objective was to evaluate the proximate distribution throughout the fish. The proximate composition of West Coast albacore tuna showed that ash and protein content remained constant throughout the six body zones and comprised 25% of the composition. Together, fat and moisture made up the remaining 75%. The lipid content was variable between and within individual fish, showing a general trend of a higher lipid towards the head, and a lower lipid towards the tail of the tuna.

The second objective was to assess the fatty acid profile of the lipid fraction and quantify the total omega-3 content. Fatty acid distribution was consistent with the values reported in the literature, and was not diverse across the body zones. Total omega-3 percentages were very consistent across the six body, averaging 40.5 ± 6.3%. Total omega-3 g/100g tissue ranged from 2.1 (low lipid tail section) to 3.5 (high lipid belly flaps).

The third objective was to identify the correlation between lipid and moisture content as well as the correlation between lipid and total omega-3 content. The inverse relationship between fat and moisture content produced a correlation of –0.98. This result indicates that moisture content can be used to provide a fast

estimation of lipid. This information can be very useful for the identification of fish with high and low lipid contents for use in specific products.

The final objective was to determine the effect on quality of on-board handling and chilling techniques. Immediate chilling and bleeding at the throat significantly and positively influenced every parameter tested except for pH. Immediate chilling significantly and positively influenced overall quality, color, texture, and flavor; and significantly reduced TBARS. Bleeding at the throat significantly and positively influenced overall quality, color, smell, texture, and flavor; but did not significantly influence TBARS or pH. Because of the numerous significant benefits of both, it is recommended that albacore tuna be bled at the throat and immediately chilled on ice. These handling procedures should provide a consistently high quality product.

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APPENDIX

INFRARED MOISTURE ANALYSIS

INTRODUCTION

An important component of the marketing of West Coast albacore tuna (*Thunnus alalunga*) can be based on the high lipid content and associated health benefits (Simopoulos and Robinson 1999). However, the inherent variability of lipid content makes it difficult to quantify for marketing purposes. The fat content of West Coast albacore tuna can vary tremendously from fish to fish, within areas of a single fish, and at different times of the year (Dotson 1978). This high variability in lipid content also effects the production of West Coast albacore tuna, as different markets demand fish of different lipid content. For example, the export markets in Japan and Spain prefer a higher lipid fish for their products. Domestic markets preferences can be different, ranging from lower lipid content for home canning use to medium lipid content for value-added products such as loins for restaurant or retail markets.

As the alternative market demand for west coast albacore tuna rises, knowledge of the lipid content and distribution is becoming increasingly important. Traditional lipid determination is time consuming, expensive, and requires destructive sampling. It is a laborious process that must be conducted in a laboratory with toxic chemicals. Lipid content is inversely proportional to moisture content in most pelagic species, as over 80% if the variation in fat content correlates with moisture content (Love, 1997). If this inverse correlation can be found for west coast albacore tuna, then regression analysis can be used to develop

a mathematical relationship between fat and moisture. A rapid method of moisture testing could potentially be used to provide fast estimation of lipid content for tuna.

The objective of this study is to investigate infrared technology as a means of providing a rapid method of lipid estimation for West Coast albacore tuna.

MATERIALS AND METHODS

Sample preparation

Four albacore tuna were troll caught off the Oregon coast (28° N and 127° W) August of 2002 (F/V Cold Stream). These fish were transferred to the Oregon State University Seafood Laboratory, Astoria, Oregon and immediately analyzed for lipid and moisture content. Ten to twelve core samples (1.8 cm dia, 4.5 cm length) were removed from each of the six designated body zones. Approximately 100 g of white muscle meat was collected from each body zone and homogenized separately using a blender at low speed.

Lipid Extraction

The lipid was extracted according to the method of Lee and others (1996). Homogenized paste weighing 5 g was placed in a jar and 50 ml solvent (2:1, chloroform: methanol) was added. The mixture was blended for 1.5 min at moderate speed. The homogenate was filtered through Whatman no.1, 5.5 cm filter

paper and funneled into a 100 ml glass-stoppered graduated cylinder. To separate the filtrate into 2 phases (methanol-water and chloroform), 20 ml 0.5% NaCl was added. The mixture was shaken gently by tilting the graduated cylinder 4 times and then allowed to stand until a clear separation was visible. A 5 ml aliquot of the chloroform layer was removed, transferred to a pre-weighed 10 ml beaker, and evaporated for 30 min on a hot plate. Samples were analyzed in replicates of three.

Moisture Quantification (AOAC)

The moisture content was determined using the Convection Gravity method (AOAC 1990). A disposable aluminum weighing dish was pre-dried, cooled in a desiccator, and weighed to the nearest mg. Seven grams of homogenized sample were spread evenly over the bottom of the weighing dish. Samples were placed in a preheated drying oven (103 °C) overnight. Samples were cooled in desiccator for at least 30 min and weighed again to the nearest mg. Samples were analyzed in replicates of three.

Moisture Quantification (Infrared)

The moisture content was determined using Infrared analysis. The appropriate time and temperature for moisture quantification of West Coast albacore tuna was first determined. This was accomplished using a single sample with a known lipid and moisture (AOAC) content. Five-gram samples were heated

for 4 to 24 min at 120°C to 170°C. The most efficient heating combination was determined to be 15 min at 155°C (Fig. 1.1). Samples were analyzed in replicates of three.

RESULTS AND DISCUSSION

Figure 1.2 shows a positive correlation ($R^2 = 0.83$) between moisture content determined using the infrared and AOAC methods. This indicates that moisture content of West Coast albacore tuna can be measured using the infrared method.

Figure 1.3 shows an inverse correlation ($R^2 = -0.78$) between lipid content and moisture content using the infrared method. This indicates that lipid content of West Coast albacore tuna can be estimated from infrared measurements of moisture content using the equation $Y = -1.77 + 121.12$.

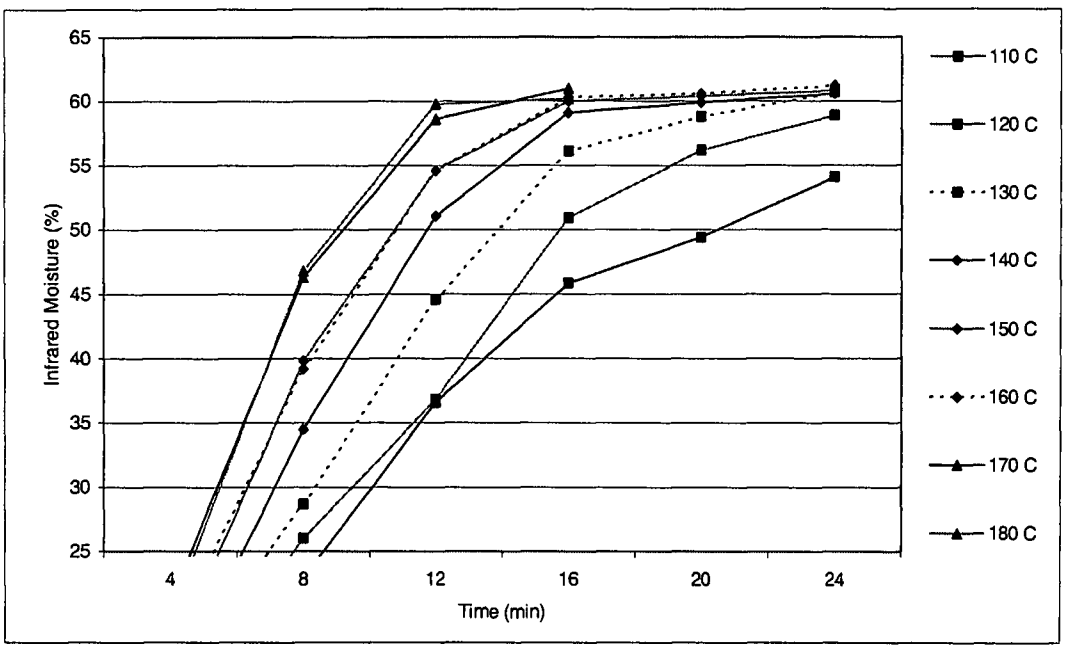

Figure 1.1 Infrared moisture content of West Coast albacore tuna heated at various times and temperatures.

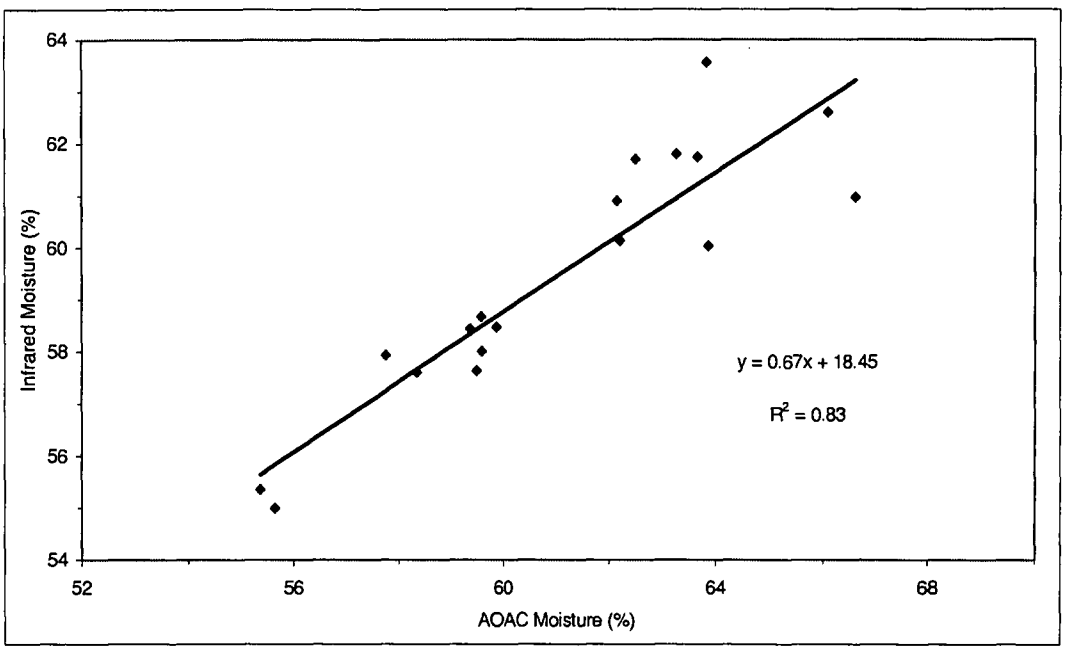

Figure 1.2 Moisture correlation for West Coast albacore tuna using infrared and AOAC methods.

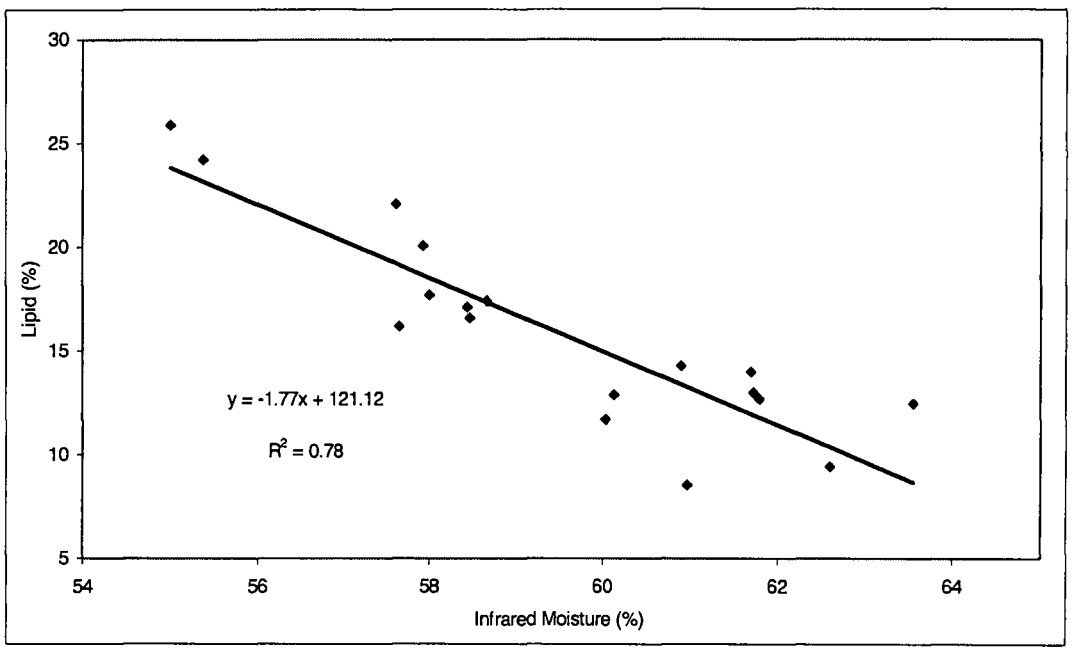

Figure 1.3 Lipid and moisture correlation for West Coast albacore tuna.

CONCLUSIONS

Infrared measurements of the moisture content of West Coast albacore tuna can potentially be used to provide an estimation of lipid content. This method is rapid, inexpensive, and only requires a small sample. Furthermore, neither a laboratory nor toxic chemicals are required for analysis, enabling a fast estimation of lipid content to be preformed right at the docks or processing plant. This information can be very useful for the identification of fish with high and low lipid contents for use in specific products.

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