On-Board Handling and Preservation of Frozen Troll-Caught Albacore, *Thunnus alalunga*

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Introduction

There has been a steady decline in the cannery market demand for U.S.-caught albacore, *Thunnus alalunga*, in the past few years due to a shift from domestic to overseas canneries (Herrick and Koplin[1], King and Bateman[2], Talley[3]). With the reduction of local cannery market orders, the U.S. west coast albacore fishery is forced to seek alternative markets. This has led to an emphasis on fresh marketing and to an increased demand for high quality standards for both the fresh and frozen product (Pleschner[4]). It is important to the development of new markets that the product delivered to the consumers be of a high and consistent quality.

Bleeding and evisceration of fish is essential in the U.S. salmon fishery to maximize fish flesh quality (Melvin et al., 1983), and is required in the foreign tuna-sashimi market (Gibson, 1984).

Although studies have suggested that bleeding and evisceration is necessary for a high quality product (Amos, 1981, Merritt, 1969; Reay and Shewan, 1960), the effects of bleeding and evisceration on the quality of frozen albacore has not been shown.

The objective of this study was to compare the effects of three different handling methods and four different freezing systems on the quality of frozen albacore. Quality was quantitatively compared using bacterial, sodium, and moisture analyses. Selected qualitative, physical, and sensory changes that occur over time while held in standard fresh market storage conditions were evaluated by sensory panel judging.

Methods and Materials

Albacore were collected aboard commercial jig boats in the eastern Pacific Ocean off central California. A total of 57 albacore, ranging from 4.2 to 10.5 kg, were collected.

The body temperature of each albacore was measured immediately after capture using 4-inch probe thermometers that were calibrated with a mercury thermometer at the beginning of each fishing trip. Temperatures were taken deep in the lateral muscle behind the pectoral fin, where the highest body temperature is found (Carey and Teal, 1966).

Handling methods investigated were: 1) Traditional—these fish were whole, neither bled nor eviscerated; 2) Bled—these fish were bled immediately after first temperature measurement by cutting the afferent branchial artery at the bottom of the gills; and 3) Bled, gilled, and eviscerated—these fish were bled, as above, then gilled and eviscerated after bleeding was completed. Gills were severed at their points of attachment. Then, the membrane behind the gills was severed and the viscera were all pulled out attached to the gills. Evisceration without cutting the belly open minimizes contamination and maintains the external appearance of these fish. The fish were then washed, and any remaining kidney, loose membranes, or tendons were removed.

Deep-body temperatures were measured after bleeding and again after evisceration. Temperatures were then measured at 1-hour intervals for 2 hours, after which the fish were frozen. Body temperature decreases over time were analyzed for significance using the one-way analysis of variance test (Zar, 1974).

Four methods of freezing were investigated. These, and their temperature ranges, were: 1) Spray brine (−7.8 to −6.7°C); 2) coil refrigeration (−4.4 to −3.3°C); 3) chilled brine (−17.8 to −15.0°C) until frozen (3-6 hours), then

[1]Herrick, S. F., Jr., and S. J. Koplin. 1985. U.S. tuna trade summary, 1984. NMFS Admin. Rep. SWR-85-6:1-24.
[2]King, D. M., and H. A. Bateman. 1985. The economic impact of recent changes in the U.S. tuna industry. Calif. Sea Grant Coll. Program Work. Pap. P-T-47:1-30.
[3]Talley, K. 1985. Tuna update. Pac. Fish. VI(3):35.

[4]Pleshner, D. B. 1985. Pacific albacore, handle with pride. Pac. Fish. VI(7):28-36.

ABSTRACT—Techniques of bleeding, eviscerating, and shipboard freezing of albacore, Thunnus alalunga, *immediately after landing, to enhance the quality of the frozen product were investigated. Analytical tests used to evaluate the quality of the fish were aerobic plate counts and sodium and moisture analyses. Sensory changes that occur over time while held in standard fresh market storage conditions were evaluated by a sensory panel. The body temperatures of both bled and eviscerated fish decreased faster than nonbled fish. Brine immersion followed by transfer to coil refrigeration resulted in the lowest bacterial growth for all handling methods. Neither handling treatments nor preservation methods had any significant effect on sodium or moisture concentrations. Sensory judging found little difference between handling methods. Discoloration due to oxidation of the oils was the major objection to acceptability of quality.*

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transfer to coil refrigeration (−4.4 to −3.3°C); and 4) air blast (−17.8 to −15.0°C).

Upon returning to port, specimens were unloaded, bagged, boxed, and stored in a local fish processor's air-blast freezer maintained at −30 ± 4°C until analyses were performed.

Analytical Tests

Muscle tissue samples were aseptically removed from the mid-dorsal loin area at the origin of the first dorsal fin. After removing the skin, samples were drilled from frozen specimens using sterile 1/2-inch diameter, hollow, stainless-steel core bits. Samples included the tissue from just underneath the skin down to the spinal vertebrae. Samples were kept frozen at −12°C until laboratory analysis. Each sample was homogenized before analysis. All analyses were performed by Soil Control Lab[5], Watsonville, Calif.

Aerobic plate counts were done as follows: 10 g of muscle tissue were blended with 10 ml of sterile 0.1 percent peptone water for 2 minutes and spread-plated on Standard Methods Agar with 0.5 percent NaCl added. They were then incubated for 4 days at 20°C. This follows the methodology for marine finfish as suggested by Liston and Matches (1976).

For sodium and moisture analysis, 1 g of tissue sample was dried to constant weight, which provided moisture content data. The sodium content was then measured on a dry weight basis by atomic absorption spectrometry.

The data from the aerobic plate counts and sodium and moisture analyses were analyzed for significance using the Kruskal-Wallis test, a nonparametric two-way analysis of variance (Conover, 1980). For all statistical tests, significance level was set at $\alpha = 0.05$.

Sensory Analysis

Sensory comparisons were made of two handling methods: 1) Traditional (non-bled) fish; and 2) bled, gilled, and eviscerated fish.

Samples were prepared by cutting the frozen specimens into steaks with a meat-cutting bandsaw. The steaks were placed into plastic pouches, labeled and returned to the freezer until needed. Each day one steak from each method was defrosted and placed in a local fish market's cool storage room which was maintained at a temperature of 0.5°C. Steaks were assessed on a total of 12 consecutive days.

Sensory assessments of the steaks were made by a trained panel of six judges. The samples were presented to the panelists in the raw state as one would view them in a fresh fish market. Panel members were trained by observing the spoilage pattern of albacore over its shelf life by the use of labeled samples. The panelists judged duplicate sets of each method. Duplicate sets were made by slicing each steak in half so that each sample contained both dorsal and ventral portions of the steak. This avoided any difference between sets. Each handling method and set was judged separately.

Panelists judged for odor and visual appearance, and were allowed to touch the steaks to feel for oil and moisture content differences. The judges estimated the amount of time each fish steak had been stored under refrigeration and indicated their acceptance or rejection of its quality (Fig. 1). Expressing the quality of

Raw Evaluation - Albacore

Use odor as the primary basis of judgment. Use appearance as a deciding factor in borderline cases only.

Quality descriptors	Your estimate of time sample was refrigerated (1-12 days)	Sample Letter	Acceptance: Would you cook & eat this fish?	
			YES	NO
Sea-fresh, seaweedy, briny, neutral, or little odor. Glossy or translucent appearance.				
Little odor or very slight fishy, stale or musty odor. Little or no glossiness.				
Slight fishy, sour, or acidic odors. Somewhat dull waxy or opaque. Some discoloration.				
Definite fishy, rancid, sour, or acidic odors. Opaque with moderate discoloration.				
Very strong fishy and rancid odors. Opaque, and dry with much discoloration.				

Figure 1.—Sensory evaluation data sheet.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

the product in terms of estimated storage time is an approach developed by Learson and Ronsivalli (1969).

Panelists' duplicate evaluations were compared using scatter plots to check the consistency of their answers and their ability to judge the spoilage pattern of albacore. For statistical analysis, the data were entered into a contingency table and analyzed using the chi-square statistic (Zar, 1974).

Table 1.—Decrease of body temperature over time of freshly caught albacore handled three different ways. Ten fish were measured for each handling method.

	Mean temperature loss (°C ± S.D.) and Time elapsed since fish landed		
Handling method	15 min.	1 hour	2 hours
Traditional		2.9±1.92	3.7±1.92
Bled	1.3±0.87	3.5±1.15	5.6±1.45
Bled, gilled & evisc.	1.5±0.83	3.6±1.06	5.1±1.29

Results

The mean deep-body temperature losses of 10 specimens from each handling treatment (N = 30) were higher for bled, and bled, gilled, and eviscerated fish than traditionally handled fish, but not in a statistically significant way (Table 1). By 2 hours after bleeding, the differences were higher but were not significant ($P = 0.06$).

Analytical Tests

Aerobic plate counts ranged from less than 1.0×10^3 to 1.8×10^5 colony-forming units/g (Table 2). Significant differences were found among both handling methods and freezing systems ($P = 0.02$). The brine tank/coils freezing treatment consistently resulted in the lowest bacterial growth for all three handling methods. The only significant difference between handling methods for any one freezing system was in air blast where the traditional fish had significantly lower bacterial counts than the bled, gilled, and eviscerated fish, but the meaning of this result is unclear due to the large differences in variances in the two treatments. The counts for the traditional treatment exhibited very low variability while those for the other two treatments were quite variable.

Every albacore sampled had relatively low bacterial counts. The count on the raw material can be expected to be between 10^4 and 10^6 bacteria/g on arrival at the processing plant. Counts on good quality material held under good conditions range from 10^4 to 10^5 bacteria/g (Liston and Matches, 1976).

Neither handling treatments nor preservation methods had any significant effect on sodium concentrations (Table 3). The values ranged from 875 to 3400 ppm. There were no consistent trends.

Similarly, handling treatments and freezing methods had no significant effect on moisture content (Table 4). Values ranged from 57.8 to 77.2 percent. Although not significantly so, fish frozen

Table 2.—Aerobic plate counts of albacore dorsal muscle tissue for 3 different handling methods and 4 different freezing systems; mean values are for colony forming units per gram[1].

	Mean APC values			
Handling method	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	8.0×10^{4}**	3.2×10^{3}*	4.5×10^{4}	2.5×10^{3}*
Bled	2.3×10^{4}	4.2×10^{3}*	1.1×10^{4}	6.4×10^{4}**
Bled, gilled & eviscerated	4.5×10^{4}**	1.0×10^{3}*	1.9×10^{4}	4.2×10^{4}

[1]Means within the same horizontal row followed by * have significantly lower bacterial counts than those followed by **

Table 3.—Sodium content (dry-weight basis) in the dorsal muscle of albacore; mean values are expressed as parts per million/g.

	Sodium content			
Handling method	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	1,630 ± 314	1,409 ± 580	1,930 ± 676	2,140 ± 723
Bled	1,680 ± 498	2,202 ± 811	2,258 ± 741	1,948 ± 466
Bled, gilled & eviscerated	2,463 ± 783	2,032 ± 241	2,036 ± 509	2,144 ± 532

Table 4.—Moisture content (%) in the dorsal muscle tissue of albacore for 3 different handling methods and 4 different freezing systems. Values given are means followed by standard deviations.

	Moisture content			
Handling method	Spray brine	Brine tank/coils	Coils only	Air blast
Traditional	68.5 ± 0.3	66.5 ± 2.1	70.1 ± 1.9	66.1 ± 5.1
Bled	66.7 ± 0.6	66.9 ± 2.0	70.8 ± 4.7	67.2 ± 6.3
Bled, gilled & eviscerated	66.3 ± 1.5	67.1 ± 4.4	69.3 ± 4.4	68.2 ± 4.0

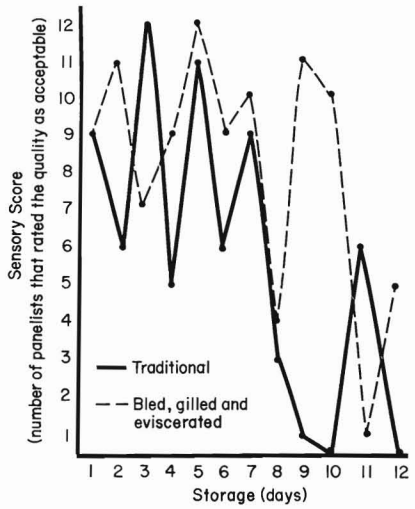

Figure 2.—Sensory evaluation of albacore steaks.

by the "coils only" method had a higher moisture content than the other freezing methods, regardless of handling method.

Sensory Analysis

There were no statistically significant differences between the two handling treatments in the sensory analysis. However, bled, gilled, and eviscerated fish generally had higher acceptability counts and were acceptable for a longer period of time than traditionally handled fish (Fig. 2). Discoloration—browning of the flesh—started by day 6 and was well developed by day 8. Even though discoloration had begun, there was a lag time of several days before the off-odors associated with spoilage occurred. Moisture loss also contributed to rejected acceptability starting at day 8.

Discussion

Fish spoils mainly through bacterial decomposition. Enyzmes also play a part in decomposition, either directly or by providing the bacteria with readily assimilable nutrients. It has been shown that temperature is the most important single factor affecting spoilage rate (Reay and Shewan, 1960). Research on raw albacore kept at temperatures above freezing has shown that bacterial growth is dependent on the storage temperature (Farber and Lerke, 1961).

The marine bacteria responsible for spoiling marine fish are of the psychrotrophic variety, which exhibit their most rapid population increases between 20° and 24°C (Reay and Shewan, 1960; Liston and Matches, 1976). All varieties of bacteria build up populations more slowly the lower the temperature is below optimum, but marine bacteria continue to multiply under chill conditions. Some remain active, even in frozen fish. The temperature must be below −10°C before bacteria cease to grow and multiply (Amos, 1981).

Enzymes, the compounds responsible for digestion and cell metabolism, will remain active even in dead fish. These chemical reactions are slowed down by chilling the fish. However, an increase in chemical activity will occur just below the point at which freezing of the flesh begins, in the region of −1° to −5°C (Merritt, 1969). This is caused by the fresh water in the fish flesh freezing, thereby concentrating the enzymes. The more slowly the fish are frozen the larger the ice crystal formation will be, and large ice crystal formation causes the membranes in the fish flesh to break, providing greater potential for enzymatic decay and texture loss. Keeping the fish below −5°C causes the chemical activity to slow down dramatically. However, the fish would have to be chilled to −30°C to bring a halt to chemical spoilage (Amos, 1981).

Albacore are a warm-bodied fish, capable of achieving muscle tissue temperatures that are 12°-14°C warmer than the ambient surface water temperature (Carey et al., 1971; Konagaya et al., 1969). This is due to a countercurrent heat exchange system consisting of a rete of closely packed arteries and veins located in the vascular system of the lateral muscle. This rete provides a thermal barrier preventing heat generated by metabolism from being lost to the colder, surrounding water, when the blood passes through the gills (Carey and Teal, 1966). The high temperature of albacore when landed (26°-30°C) increases the initial rate of chemical reaction and enzymatic activity and as a result starts the decrease of the flesh quality before it is subjected to refrigeration and during the substantial amount of time it takes to freeze these large fish. Laurs et al. (1978) estimated that the total blood volume of albacore comprised 8.2-19.7 percent of the body weight of the fish. I had hoped to show that bleeding was an effective way to immediately decrease body temperature and perhaps with more samples it would have. Although bleeding did not prove to be statistically significant, it is considered a good practice since it removes heme compounds which accelerate oxidative rancidity (Ronsivalli, 1982), and results in a lighter colored flesh (Amos, 1981; Ronsivalli, 1982).

Frozen albacore varies in sodium content because of harvesting and processing practices. The two methods of preservation that contribute most to variable sodium content in albacore are brine freezing, either by continuous spray-brine or the immersion in chilled brine before transfer to the coil freezer. Brine freezing is the most commonly used method of preservation in the tuna fishery (Wekell et al., 1983). Since fish are hypo-osmotic to the brine solution, they will tend to take up salt or sodium into their tissues. The amount of sodium incorporated depends on storage time, temperature of the brine, the size of the fish, and the amount of time it takes to freeeze them (Farber, 1955; Roach et al., 1967; Tomlinson and Geiger, 1963). During the freezing process, penetration of sodium into the outer 3/8-inch of flesh can be quite high, but is insignificant into the inner layers of the flesh (Roach et al., 1967; Tomlinson and Geiger, 1963; Tomlinson et al.[6]). This is why each sample was homogenized before analysis.

Fish are added to the fish holds on an "as caught basis" and since this increases the temperature of the hold at least temporarily, sodium penetration to each fish is erratic. Other factors to take into consideration are the capacity and reliability of the refrigeration system, and the location of the fish in the fish hold. Where two fish freeze close together, salt penetration will be greater in the sides exposed to the brine than in the sides touching each other. It has been shown that low temperatures must be used, (ideally −18°C), to prevent any appreciable salt penetration into the flesh during freezing and storage in strong brine solutions (Farber, 1955).

Although there has been much recent discussion of the suitability of spray-brined fish for the fresh and frozen market, I found no significant quality degradation in the spray-brined fish. However, Ronsivalli and Baker (1981) reported that absorption of salt has a catalytic effect in oxidative deterioration of the quality of the fish during subsequent storage. It should also be mentioned that the fish in this study were stored from only 2 days to 2 weeks in the freezers aboard the fishing vessels. This is an unusually short time and could account for the variability in the data and the similarity among freezing systems.

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[6]Tomlinson, N., S. E. Geiger, and E. Roberts. 1962. Frozen albacore tuna: the influence of storage conditions prior to freezing. Fish. Res. Board Can., Pac. Coast Sta. Prog. Rep. 114:

In oily fish such as albacore, the oxidation of the oil can contribute significantly to spoilage. Fish oils of the unsaturated type readily combine with atmospheric oxygen, with the assistance of catalysts in the flesh, which causes rancid odors and flavor and color changes (Reay and Shewan, 1960). It was mainly the browning of the flesh that caused sensory judges to reject samples. This would not have been as apparent had the samples been cooked, although the cooking procedure (baking, steaming, frying) chosen for panel testing can affect the results (Dyer et al., 1964).

Conclusion

This study has shown that albacore preserves as well with a minimum of handling and is amenable to any short-term freezing technique that ensures consistent temperatures below freezing. The fish that were obtained for this study were of a consistently high quality. This could be attributed to the fact that the fishermen who volunteered their time and effort to collect the specimens and record temperature and handling data were already very quality-conscious. It should also be noted that due to the nature and amount of work involved in on-board sampling, the project fish were collected on slow fishing days when time was available and the freezer systems were not stressed. Perhaps the absence of any significant differences between handling treatments indicated that the quality of troll-caught albacore is a result of effort on the part of the fishermen along with adequate refrigeration equipment, rather than any specific handling technique or refrigeration technology.

It is recommended that the fish should be frozen as rapidly as possible and that once frozen they not undergo large temperature fluctuations which lead to periods of thawing and refreezing.

Acknowledgments

This work is a result of research funded with Saltonstall-Kennedy funds administered by the National Marine Fisheries Service under grant number NA-84-ABH-00044.

I would like to thank the fishermen of the port of Moss Landing, Calif.; especially the owner/operators of the fishing vessels *Beticia*, *Captain Banjo*, *Flagship*, *Hornet*, *Judy S* , *Lady Lou*, and *Tradewind*.

Valuable comments and manuscript review were provided by Gregor M. Cailliet (Moss Landing Marine Laboratories), Robert Price (California Sea Grant Marine Advisory Program, Food Science & Technology Extension, University of California, Davis), and Ralph J. Larson (San Francisco State University).

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