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A COMPARATIVE STUDY USING MULTIPLE INDICES TO MEASURE CHANGES IN QUALITY OF PINK AND COHO SALMON DURING FRESH AND FROZEN STORAGE

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ABSTRACT

During the summer of 1986, the Utilization Research Division of the Northwest Fisheries Science Center entered into a cooperative agreement with the Alaska Seafood Marketing Institute (ASMI) to study how time and temperature affect the quality and acceptability of pink and coho salmon (*Oncorhynchus gorbuscha* and *O. kisutch,* respectively) held on ice and in frozen storage. Changes in the quality of the salmon were determined by chemical, microbiological, and physical analyses which were correlated with results of sensory evaluations made by an experienced taste panel familiar with salmon.

Special emphasis was given to determining the maximum period that both species of salmon could be held refrigerated on ice before losing those characteristics typically associated with premium quality and to follow changes in the quality of those salmon during subsequent frozen storage. Results from these studies were compared to analytical and sensory results from a corresponding study to follow changes in the quality of pink and coho salmon frozen shortly after harvest.

Results of sensory analyses of the iced salmon indicated that both the pink and coho salmon retained their prime quality characteristics for about 8 days postharvest.

Multiple chemical indicators were used in this study to determine freshness or lack of freshness. Inosine monophosphate (IMP) levels in premium quality iced pink salmon ranged between 3.5 and 5.0 micromoles per gram, hypoxanthine (Hx) content ranged between 0.2 and 0.7 micromoles per gram, and trimethylamine (TMA) content was less than 0.4 mg nitrogen per 100 gram. IMP content in premium quality iced coho salmon ranged between 2.5 and 4.0 micromoles per gram, and less than 1.0 micromole per gram of Hx was detected. Premium quality coho salmon contained less than 1.0 mg per 100 grams of TMA.

The chemical indicator for oxidative rancidity (thiobarbituric acid number) in premium grade iced pink and coho salmon did not exceed 2.5 micromoles malonaldehyde per 100 grams in this study.

Premium quality iced salmon were characterized by low bacterial count (i.e., 2.8 to 6.7 x 10^3 no. per cm^2).

After 3 months in frozen storage at -23°C, the sensory scores for the pink salmon stored on ice prior to frozen storage or frozen immediately on landing indicated the fish were of acceptable, but less than premium quality because of rancidity. The quality of the pink salmon reference stored at -29°C was considered organoleptically and chemically premium grade through 9 months of storage.

Overall, the subjective quality of both the coho salmon frozen at point of landing or held on ice prior to frozen storage at -23°C remained premium grade for 6 months. The quality of the reference coho salmon after I year at -29°C was superior to that of the coho salmon stored at -23°C.

Tests for chemical rancidity generally reflected the organoleptic condition of the frozen pink and coho salmon in this study.

Results of cook-drip analyses showed that both species of salmon were affected by both storage on ice and by time in frozen storage, but cook drip was not greatly influenced by differences in storage temperature.

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INTRODUCTION

Acceptability of fishery products is normally based on the consumer's perception of the overall appearance of the product. Perception is generally conditioned on the consumer's reaction to visual stimuli such as color, presence of bruises, loss of scales, or other obvious defects, and to the odor of the raw product as well as to the odor, flavor, color, and texture of the cooked product. Other factors involving physical characteristics such as free (thaw) and cook drip can also affect the consumer's attitude toward the product. Chemical and biological changes, which begin immediately after fish are harvested, also affect the quality of the product. In their initial stages, however, these changes may be very subtle and the consumer is usually unaware of their impact on quality. Whether organoleptic, physical, chemical, or microbiological, all of these factors are collectively affected by time and temperature.

To explain how time and temperature ultimately affect the quality (and thus acceptability) of fresh and frozen pink and coho salmon (*Oncorhynchus gorbuscha* and *O. kisutch , respectively*), a cooperative storage experiment between the Utilization Research Division (URD) of the Northwest Fisheries Science Center (NWFSC) and the Alaska Seafood Marketing Institute (ASMI) was initiated during the summer of 1986. The objective was to follow changes in quality that occur in both fresh and frozen pink and coho salmon during typical conditions of preservation and storage. Changes in salmon quality were periodically determined by making chemical, physical, and microbiological analyses and sensory evaluations of the salmon during iced storage and by chemical and physical analyses and sensory evaluations of the frozen fish. The results of these analyses and evaluations were used to determine which quality attributes have major influences on acceptability. Once identified, both the objective and subjective characteristics of the various test parameters were used to describe the salmon products in terms of quality grades, that is, premium, good, or poor quality.

FISH SAMPLE PREPARATION AND PROCEDURES

Fresh Salmon

Fresh gillnet-caught pink salmon and troll-caught coho salmon were purchased from a salmon processor in Ketchikan, Alaska. The fish were selected for this project by representatives from the ASMI and the URD between 24 and 48 hours postharvest. Selection was made on the basis of the ASMI Premium Quality Program standards (ASMI 1986). Forty-eight fish of each species were packed using conventional commercial packaging (poly-lined Wet-Lok[1] containers refrigerated by gel-ice packs) and air shipped to the NWFSC Montlake Laboratory in Seattle. At the laboratory, the salmon were iced in separate totes, according to species, and stored in a refrigerated room at 2°C. The fish were frequently evaluated for organoleptic, microbiological, chemical, and physical (cook-drip) changes until spoilage was obvious.

Of particular interest in this study was the determination of the maximum period of time that the salmon could be held on ice before losing their premium quality sensory and chemical attributes. When this period was reached (confirmed by subjective and objective means), a representative sample of salmon of both species was removed from the ice and frozen. The frozen fish were glazed with chilled fresh water and placed in poly-lined Wet-Lok cartons and stored at -23°C to simulate commercial storage conditions. Periodically, about every 2 to 4 days for the iced fish and every 2 to 3 months for the frozen fish, several fish of both species were removed from storage and examined chemically, physically, and organoleptically to assess the combined effects of iced and frozen storage on their overall quality.

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[1]Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Frozen Salmon

Salmon of both species selected for frozen storage studies were, like the iced fish, chosen on the basis of ASMI's premium quality standards. After the salmon were frozen at the processing plant, they were packed in poly-lined Wet-Lok containers and shipped to the LTRD laboratory at Montlake. On arrival at the laboratory, the frozen salmon were glazed with chilled fresh water and repacked in Wet-Lok containers. One lot was selected as a reference or control sample and the other lot was subjected to simulated commercial conditions. The reference samples were stored at -29°C and the salmon handled under commercial conditions were stored at -23°C. Reference samples of both species served as the standard for quality in both the fresh (iced) and the frozen storage studies. The frozen salmon were analyzed chemically and physically and evaluated organoleptically at 3-month intervals for 1 year.

Microbiological Methods

At each examination period, three fish of each species were removed from iced storage and evaluated for overall appearance. The skin of each fish was then sampled in duplicate for total aerobic plate counts (APCS) using the swab method described by Tretsven (1963). Serial dilutions and plate counts were made by the methods described by Pelroy and Eklund (1966).

Sensory Evaluations

At each evaluation, the iced salmon were subjectively examined for loss of scale from the skin, texture by digital pressure, and for color and odor. A section of nape, enough to give about 150 g of flesh, was then removed from each fish for making chemical analyses (described below). To facilitate taste panel evaluations, two to three 1-inch thick steaks were removed from near the midsection of each fish sampled. Individual steaks were then placed in a special, double pouch, boil-in-a-bag in which the

bottom of the inner pouch was perforated to allow cooked juices to drain from the fish during heating (Conrad et al. 1985). Cooking was accomplished by suspending the bags of fish in a circulating water bath heated to 76°C for 15 minutes to an internal temperature of 70°C. The cooked fish were served warm to a taste panel consisting of eight members of the URD staff experienced in sensory evaluation of fish. The fresh fish were evaluated for odor, flavor, texture, and sensory rancidity to determine their overall quality using a 9-point hedonic scale where a score of 9 represents excellent and a score of 3 or below indicates unacceptable quality. Rancidity scores were based on a value of 1 indicating no rancidity, 5 moderate rancidity, and 9 strong rancidity. The results of both the subjective and objective sensory tests were then used to arbitrarily assign the equivalent market quality grades used in Tables 1 and 2. Taste panel evaluations were also made on frozen salmon using the same methods for cooking and tasting as described above. In addition to the four basic sensory parameters used to judge the cooked samples, the frozen salmon were also rated for acceptability based on the 9-point scale.

Chemical Methods

Samples of fresh fish taken prior to making the sensory tests were prepared for chemical analysis by removing skin and bones and homogenizing the raw flesh. The samples were then analyzed for freshness or spoilage and for oxidative rancidity. Freshness tests included analyses for nucleotides (inosine monophosphate (IMP) and hypoxanthine (Hx)) and estimation of spoilage was determined by trimethylamine (TMA) analysis. Nucleotides were determined by the methods described by Jones et al. (1964) and modified by Spinelli and Koury[2]. Trimethylamine was determined by methods described by Dyer (1945) and Tozawa et al. (1971). Analysis of nucleotides

[2]Barbara Koury, Research Chemist, URD,NWFSC, National Marine Fisheries Service, 2725 Montlake Blvd. East, Seattle, WA 98112. Pers. commun., January 1988.

was selected for use in this study because their measurement indicates autolytic changes in quality associated with loss of flavor compounds and enhancers that occur very rapidly during fresh or iced storage of fishery products. In very fresh fish (i.e., 1 to 5 days postharvest) these changes are difficult to detect subjectively; thus, analysis for nucleotides is an important tool for assessing early quality changes. Trimethylamine, on the other hand, is a measure of the relative degree of spoilage when associated with microbiological degradation. Because of their relationship to one another, there is usually a strong correlation between TMA content and microbiological growth (Bullard and Collins 1980).

Like TMA, pH is also used as a spoilage indicator in fishery products. In this project, the pH of the fresh salmon was read by placing the tip of the pH probe directly on the surface of the comminuted flesh and taking the reading.

Oxidative rancidity was determined in both fresh and frozen samples using the thiobarbituric acid (TBA) test described by Lemon (1975). Results are referred to as TBA numbers or values. Analyses were made on the homogenized flesh, including belly flap tissue, from two 1-inch thick steaks taken from near the mid-section of each fish sampled. The TBA test is a good empirical method for detecting lipid oxidation in fishery products and, as an objective test, is frequently used to correlate with sensory tests.

Cook-Drip Analysis

Although freezing is the best way to preserve the fresh quality of fish, the proc can alter the water-binding capacity of the fish protein, causing drip when the fish is thawed and cooked. The effects of this process also may affect texture, cause loss of protein through denaturation, and can be visually unattractive (Miyauchi et al. 1962).

Cook-drip analyses were carried out in conjunction with the sensory tests previously described. Individual salmon steaks were placed in the inner bag of the

double pouch arrangement, identified, and weighed. After cooking, the steak samples were reweighed (sans cook drip) in the inner pouch and the difference in weights calculated as loss of cook drip.

Statistical Analysis

AR statistics were calculated with a Texas Instrument Programmable 58C calculator. The statistical program used for determination of means, standard deviation, t-statistics, analysis of variance (ANOVA), and correlation coefficients was the TI Applied Statistics Solid State Program. The Newman-Keuls test (Zar 1984) was used to determine differences between means. Statistical significance was tested at the 5% level of significance in this study.

RESULTS AND DISCUSSION - ICED FISH STUDY

Microbiological Measurement

Pink Salmon

Results of the total aerobic bacterial plate counts made on the iced pink salmon are shown in Figure 1. Total aerobic counts made from samplings of the pink salmon skin were generally low through the first 8 or 9 days of storage. Counts ranged between 1.1 and 5.7 x 10^3 org per cm^2 during this time (Appendix Table 1). Between days 9 and 14, the last days of iced storage, there was a significant increase ($P = 0.95$, t-test) in bacterial numbers to 3 x 10^6 org per cm^2. In marine fishes, a count of 106 usually indicates significant bacterial spoilage. The fish had a poor overall appearance and spoilage odor. They were between 15 and 16 days postharvest at this time.

Coho Salmon

Although the numbers were higher, APCs made on the iced coho salmon followed a growth pattern similar to that of those measured in the iced pink salmon (Fig. 1). Initial APCS, starting in the 10^4 org per cm^2 range (Appendix Table 1), show that

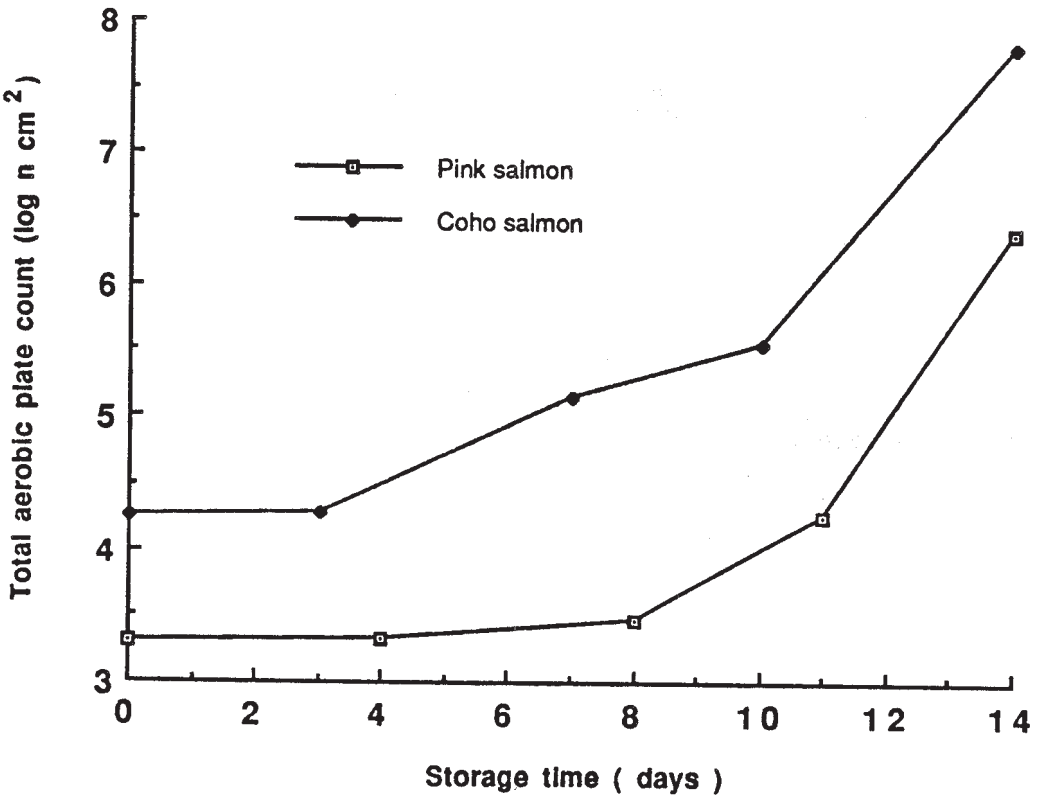

Figure 1.--Total anaerobic plate counts of microbial flora from the skin of pink and coho salmon held on ice for various periods.

after what appears to be the end of a very short lag phase (at 3 days), there occurred a steady but significant growth (P = 0.95, t-test) in bacteria until day 14 of the storage study. At this point, bacterial numbers reached 10^8 org per cm^2. About 15 to 16 days postharvest, the iced coho were characterized by overt spoilage odors and a generally poor appearance.

Sensory Evaluations

Raw Pink Salmon

Overall, the subjective quality of the iced pink salmon in terms of appearance, odor, and texture was considered to be excellent (premium) through the first 7 days of storage (Table 1). About 9 days into the experiment, the pink salmon showed loss of quality which was distinguished by a softening of texture and mild rancid or fishy odors primarily in the dark flesh along the mid-line of the fish and in the belly cavity. These odors were not observed in every fish examined, however. After 11 days on ice, the pink salmon developed odors best described as stale, fruity and sour, and rancid, mainly from the belly cavities. The flesh was moderately soft but there were no exposed rib bones. Discoloration of the belly lining, which appeared as random yellowish-brown patches, was apparent at this time. The patches appeared to be related to the rancid odors. Bacterial slime, which was sticky, was apparent in the belly as well as on the skin. After 14 days, the pink salmon were uniformly of poor quality. Discoloration of the visceral cavity was evident in all of the fish as was the presence of strong spoilage and rancid odors. Spoilage odors corresponded to the relatively high bacterial counts (Fig. 1). Degradation in fish quality was also manifested by uniformly soft texture brought about by biochemical and microbiological changes.

Table 1.--Summary of sensory[a] evaluations of pink salmon held on ice in refrigerated storage at 2°C and equivalent market quality grades.

Time on ice (days)	Sample treatment	Mean[b] sensory scores for cooked pink salmon				Subjective sensory evaluation of raw pink salmon	Equivalent market quality grades
		Odor	Flavor	Texture	Rancidity[c]		
0	Reference	8.0 ± 0.90[d]	8.4 ± 0.90[d]	8.6 ± 0.50[d]	1.2 ± 0.7[d]	Bright skin color, minimal loss of scales, belly cavity free of off-odors, flesh normal color, no blemishes, firm textured.	Excellent (premium).
4	Reference	8.4 ± 0.70[d]	8.3 ± 0.70[d]	8.2 ± 0.80[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	8.2 ± 0.80[d]	8.1 ± 1.20[d]	8.3 ± 0.70[d]	1.1 ± 0.3[d]	Same as reference at 0 days.	Excellent.
7	Reference	8.3 ± 0.80[d]	8.6 ± 0.50[d]	7.8 ± 0.70[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	8.3 ± 0.50[d]	7.6 ± 0.50[d]	7.4 ± 1.00[d]	1.0 ± 0[d]	Loss of fresh odor, good appearance, color, and texture.	Excellent.
9	Reference	8.1 ± 0.60[d]	8.3 ± 0.70[d]	8.0 ± 0.90[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	7.3 ± 0.70[d]	6.4 ± 1.50[d]	7.4 ± 1.30[d]	2.7 ± 1.70[d]	Loss of fresh odor, good appearance, color, and texture.	Good.
11	Reference	7.5 ± 1.10[d]	8.0 ± 0.50[d]	8.0 ± 0.90[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	5.9 ± 1.40[d]	4.8 ± 2.30[e]	7.1 ± 1.40[d]	4.2 ± 2.50[e]	Fair appearance, loss of scales (10 to 15%), off-odors present, softening of texture, flat odor.	Marginal.
14	Reference	7.8 ± 1.50[d]	8.3 ± 0.80[d]	8.3 ± 1.20[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	4.8 ± 2.60[e]	3.3 ± 1.60[e]	6.5 ± 1.60[e]	5.7 ± 2.80[e]	Rancid odors, slight softening of flesh, 20 to 30% loss of scales, loss of normal color.	Poor, unacceptable quality.

[a] Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, 9 is excellent (premium).
[b] Each value represents the mean of 8 samples ± the standard deviation.
[c] Rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is moderate, 9 is strong.
[d] Means in the same column with a common superscript letter are not significantly different (P>0.05).
[e] Significantly different from the reference at the 5% level of significance.

Raw Coho Salmon

The quality of the iced coho salmon was considered excellent through the first 7 days of the study (Table 2). Overall appearance was very good with bright, shiny skin and no noticeable loss of scales or color of meat. The flesh was firm.

After 9 days on ice, slight but distinct stale or fruity off-odors were detected in the visceral (belly) cavity of the fish. The odors were attributed to bacterial activity. The fish were slightly soft to the touch but were otherwise of acceptable quality.

Generally poor appearance in the form of a pink blush on the skin, soft texture, and a sticky feeling produced by bacteria characterized the fish after 13 days. The presence of ammonia or putrefactive odors in the belly cavity was associated with bacterial decomposition (Fig. 1). By the end of the study, the iced coho salmon were uniformly soft textured, had strong spoilage odors present both on the skin and in the visceral cavity, and generally had a poor overall appearance.

Cooked Pink Salmon

Results of sensory analyses of the cooked iced pink salmon are given in Table 1. For the first 4 days of the storage study, there was essentially no difference between mean sensory scores for the variables measured in the iced pink salmon and their corresponding reference**.** Mean scores ranged between 7 and 8 with the exception of sensory rancidity which averaged 1.0 (no rancid flavor). By the end of 7 days, slight changes ($P = 0.98$, t-test) were noted in the various sensory attributes of the iced pink salmon compared to the same attributes in the frozen reference. These fish were subjectively considered excellent quality. Between 7 and 9 days, significant changes ($P = 0.97$, t-test) in flavor (suspected as rancidity) were detected in the iced pink salmon, dropping them from excellent to good quality. The effect of rancidity, however, was not confirmed until after 11 days of storage when mean odor, flavor, and rancidity scores for the iced pink salmon were significantly lower ($P = 0.97$, t-test) than the same

Table 2.--Summary of sensory[a] evaluations of coho salmon held on ice in refrigerated storage at 2°C and equivalent market quality grades.

Time on ice (days)	Sample treatment	Mean[b] sensory scores for cooked coho salmon				Subjective sensory evaluation of raw coho salmon	Equivalent market quality grades
		Odor	Flavor	Texture	Rancidity[c]		
0	Reference	8.9 ± 0.35[d]	8.9 ± 0.35[d]	8.9 ± 0.35[d]	1.0 ± 0[d]	Bright skin color, minimal loss of scales, belly cavity free of off-odors, flesh normal color, no blemishes, firm textured.	Excellent (premium).
3	Reference	8.5 ± 0.6[d]	8.7 ± 0.50[d]	8.8 ± 0.50[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	8.7 ± 0.50[d]	8.5 ± 0.50[d]	8.7 ± 0.70[d]	1.0 ± 0[d]	Same as reference at 0 days.	Excellent.
7	Reference	8.2 ± 0.80[d]	8.2 ± 0.80[d]	8.1 ± 0.70[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	8.0 ± 0.80[d]	8.4 ± 0.50[d]	8.1± 0.50[d]	1.4 ± 0.8[d]	Good appearance, 10% loss of scales, no off-odors, firm texture.	Excellent.
9	Reference	8.5 ± 0.76[d]	8.5 ± 0.53[d]	8.6 ± 0.52[d]	1.2 ± 0.71[d]	Not evaluated.	
	Iced	5.7 ± 1.8[e]	6.7 ± 1.4[d]	7.4 ± 1.30[d]	2.6 ± 1.50[d]	Distinct loss of fresh odor, natural flesh color , no exposed rib bones, slight softening of texture.	Good.
13	Reference	7.7 ± 1.30[d]	7.9 ± 0.70[d]	8.0 ± 0.80[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	6.1 ± 1.90[e]	6.6 ± 1.20[e]	7.1 ± 0.60[d]	1.5 ± 1.10[d]	Slightly fruity off odors in belly cavity, rib bones intact, slightly soft texture,20% scale loss,fair skin and flesh color.	Average to fair.
15	Reference	7.3 ± 1.10[d]	7.4 ± 0.80[d]	7.3 ± 1.10[d]	1.0 ± 0[d]	Not evaluated.	
	Iced	4.1 ± 1.70[e]	4.0 ± 1.70[e]	6.4 ± 1.20[e]	2.0 ± 1.40[d]	Dull skin color, 25 to 35% loss of scales, off odors predominate, heavy slime on skin, soft texture.	Borderline to poor.

a Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, 9 is excellent (premium).

b Each value represents the mean of 8 samples ± the standard deviation.

c Rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is moderate, 9 is strong.

d Means in the same column with a common superscript letter are not significantly different (P>0.05).

e Significantly different from the reference at the 5% level of significance.

sensory attributes for the control. By the end of the storage test, the raw fish were subjectively judged to be unacceptable on the basis of odor and appearance; taste panel scores reflected the results of the microbiological changes (Fig. 1). Mean odor and flavor scores in Table 1 indicate the quality of the cooked fish was of borderline acceptability.

Cooked Coho Salmon

Changes followed in the sensory characteristics of the iced coho salmon (Table 2) were similar to the sensory changes observed in the iced pink salmon. Mean odor, flavor, texture, and sensory rancidity scores for the iced coho salmon were not significantly different ($P>0.05$) after the first 7 days of storage from scores for the same attributes measured in the reference sample. Lower mean odor and flavor scores at day 9 were attributed to the combined effects of autolytic changes and microbial growth, reducing their status from excellent to good quality. By the 13th day of storage, significant changes ($P = 0.97$, t-test) were noted in the various sensory attributes as compared to those of the corresponding reference sample. The quality of the iced fish before cooking was generally considered fair. However, after cooking, their acceptability seemed improved. This apparent contradiction is explained by the fact that early chemical and bacteriological products of spoilage (odor, slime, sticky feel, etc.) are sometimes transient, frequently disappearing when the fish is washed and cooked. Odors observed in the early stages of spoilage are often volatilized when the fish is cooked. Thus, the changes are not always apparent during taste testing. This phenomenon, however, does not occur in the latter stages of spoilage. The effects of spoilage are seen in the results of the sensory analysis (Table 2) of the coho salmon held on ice for 15 days. Although on average they were marginally acceptable as a cooked product, some fish were not acceptable because they had lost much of their normal odor and flavor characteristics by this time. There also appeared to be some loss of texture

quality during iced storage but the change was not significant (P>0.05). Rancidity was not an obvious organoleptic problem in the iced coho salmon.

pH Measurements

Pink Salmon

Results of surface pH determinations made on the pink salmon held on ice are shown in Figure 2. Although there was a slight increase in pH values with time (Appendix Table 2), the differences between the initial and final pH of the pink salmon after 14 days on ice were not significant (P>0.05).

Coho Salmon

Mean surface pH measurements for coho salmon held on ice (Fig. 2, Appendix Table 2) also show a gradual increase in values with time. The trend (increase in pH) appeared to coincide with increases in APC; however, the difference between initial pHs and those made with time was not significant (P>0.05).

Chemical Analysis

Pink Salmon

Data for nucleotide and TMA analyses made on iced pink salmon are given in Appendix Table 3. Initial IMP values represented as zero time in Figure 3 were determined from fish that were estimated to be between 2 and 3 days post harvest at the time of analysis. Overall, there was a progressive and significant loss (P = 0.97, t-test) of IMP during storage. Spinelli and Koury (pers. commun.) observed a higher starting level of IMP in iced pink salmon flesh (7-0 micromoles per g) than the starting level found in this study. The results of their work, however, were based on pink salmon that were less than 24 hours postharvest when analyzed. The decrease of IMP in the iced pink salmon with time appeared to coincide with the general loss of organoleptic

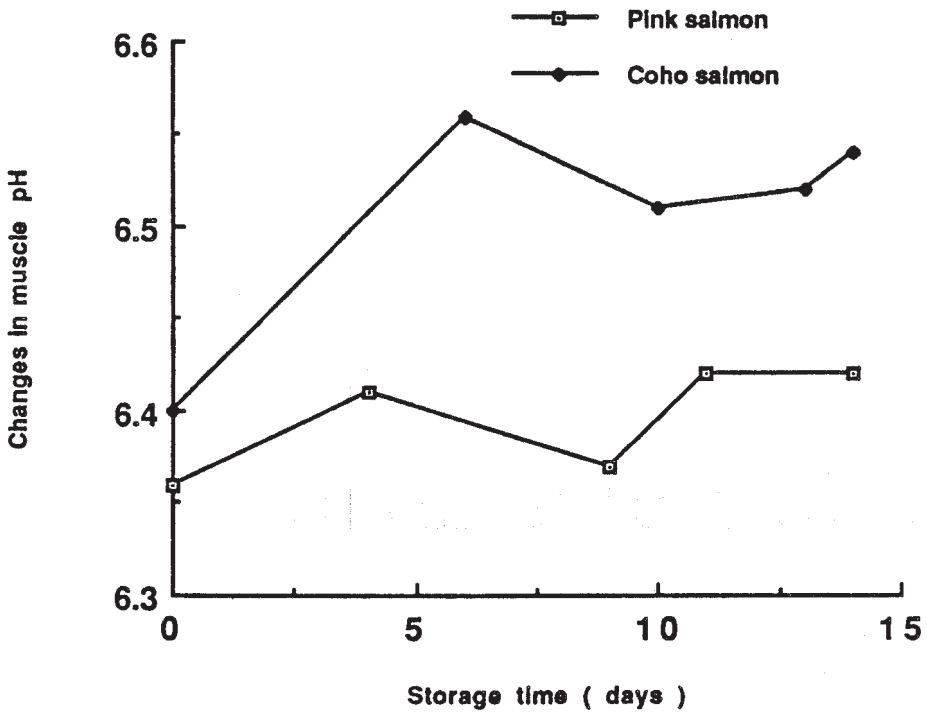

Figure 2.--Changes in muscle pH of pink and coho salmon as function of time in iced storage at 2°C.

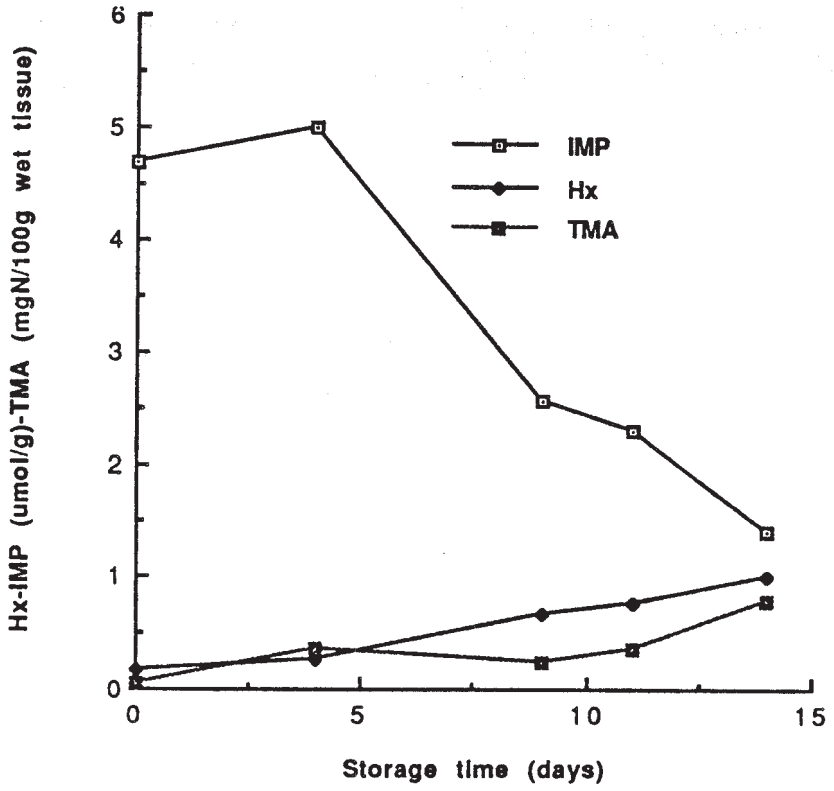

Figure 3.--Nucleotide and trimethylamine content expressed in mg N/100 g in pink and coho salmon held on ice in refrigerated storage at 2°C for various periods.

quality, as previously noted. The correlation (r = 0.87) between sensory flavor scores and EMP values (Table 3) was good.

Simultaneous with the decrease in IMP, there was a significant increase (P = 0.97, t-test) in hypoxanthine (Hx) in the iced pink salmon. Although not large, the change in the concentration of Hx, like IMP, coincided with loss of organoleptic quality. Similarly, as with IMP, there was a very good correlation (r = 0.97) between sensory flavor scores and Hx concentration (Table 3).

Results of analysis for the development of TMA in the iced pink salmon were in general agreement with APC estimations (Fig. 3). A slight increase in TMA concentrations through 11 days of storage coincided with low bacterial activity (Fig. 1). However, after 14 days on ice, the TMA content had risen significantly (P = 0.97, t-test). This increase corresponded to the APCs and general observations on quality (Table 1). Also, changes in TMA concentration over time correlated well (r = 0.91 in Table 3) with sensory flavor scores for the pink salmon.

Changes in rancidity values (TBA number) for pink salmon held on ice are shown in Figure 4. For the first 9 days of storage, the TBA test results (Appendix Table 4) did not indicate significant oxidative rancidity. This was confirmed by our taste panel (Table 1) which indicated a slight change in the level of sensory rancidity in the cooked product. Between 9 and 11 days, there was a significant increase (P = 0.97, t-test) in TBA numbers, indicating that the additional time on ice created a window of susceptibility that permitted increased oxidation of fatty acids in the oils of the pink salmon. This change was also detected by the taste panel. External signs of rancidity (odor and color) were also observed in the raw fish during this time. Mean flavor scores (Table 1) and corresponding mean TBA numbers for the iced pink salmon correlated well (r = 0.87) suggesting that rancidity had as much to do with loss of quality as microbial spoilage and chemical degradation.

Table 3.--Correlation coefficient between sensory flavor scores and nucleotides, TMA, and TBA numbers for iced salmon.

Chemical index	Correlation coefficient	Significance
IMP (pink)	0.87	0.005
IMP (coho)	0.79	0.05
Hx (pink)	-0.97	0.001
Hx (coho)	-0.90	0.005
TMA (pink)	-0.91	0.01
TMA (coho)	-0.99	0.001
TBA (pink)	-0.87	0.02
TBA (coho)	-0.17	N.S.

N.S. = Not significant.

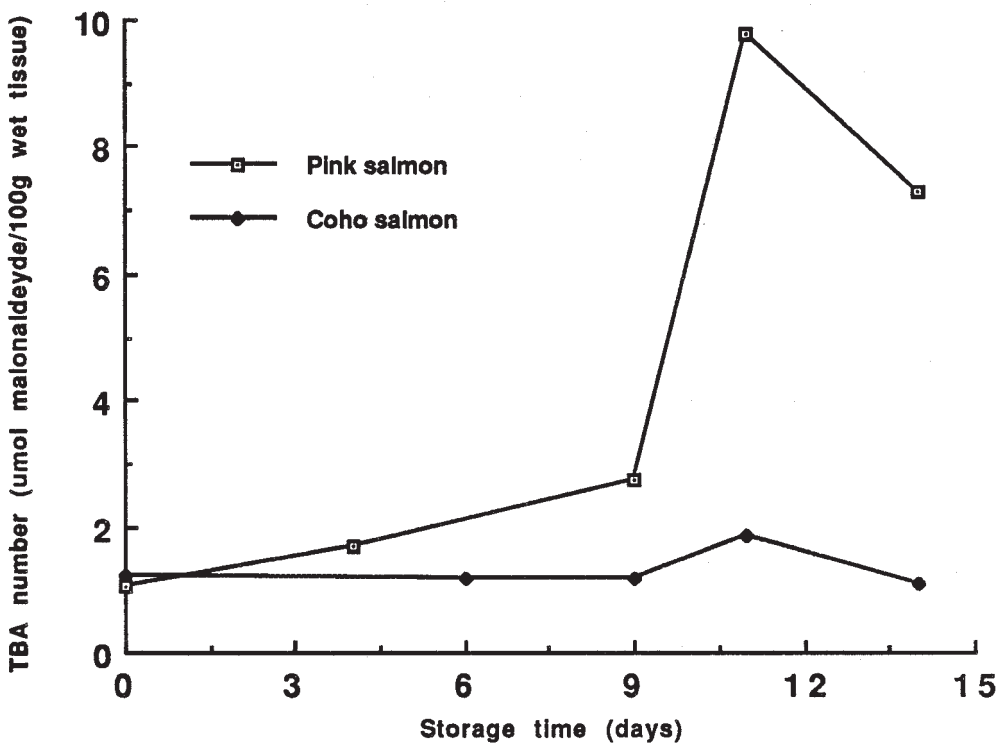

Figure 4.--Results of thiobarbituric acid analyses showing the effect of time in iced storage at 2°C on the development of oxidative rancidity in pink and coho salmon.

Coho Salmon

Changes in nucleotide and TMA content in coho salmon held on ice are shown in Figure 5 (Appendix Table 5). The initial (zero time) concentration of IMP in this study is based on coho salmon analyzed about 2-3 days postharvest. In work done by Spinelli and Koury (pers. commun.), the IMP concentration in very fresh coho salmon (analyzed less than 24 hours postharvest) was greater than 7.0 micromoles per g. The difference in initial IMP content between the two studies is attributed to the rapid degradation of IMP in fish after death. As expected, there was a sustained, significant reduction ($P < 0.05$) in IMP content in the coho salmon during storage, followed by a corresponding increase in hypoxanthine. After 9 days in storage, the changes in nucleotides appeared to affect the organoleptic attributes of the iced salmon in such a way as to cause loss of normal cooked odor and flavor characteristics (Table 2) normally associated with high quality. These changes were significant ($P = 0.97$, t-test) after 13 days in storage. Correlation coefficients (Table 3) between flavor scores and IN4P and hypoxanthine concentrations were $r = 0.79$ and $r = 0.90$, respectively.

Development of TMA (Fig. 5) in the coho salmon closely correlated to the increase in APCS. The correlation coefficient ($r = 0.99$) between flavor scores and TMA content (Table 3) strongly suggests that after 9 days in iced storage (about 11 days postharvest), the loss of quality in the fresh product was influenced as much by bacterial activity as through the breakdown of chemical components, that is, degradation of nucleotides. In comparing results between the work reported here and the studies of Spinelli and Koury (pers. commun.), the concentration of TMA at 11 days (total time postharvest) was essentially identical in both studies at about 1.8 mg nitrogen per 100 g. At this time, the quality of the product in both experiments was considered acceptable but only fair. The coho salmon were of borderline acceptability after 15 days on ice.

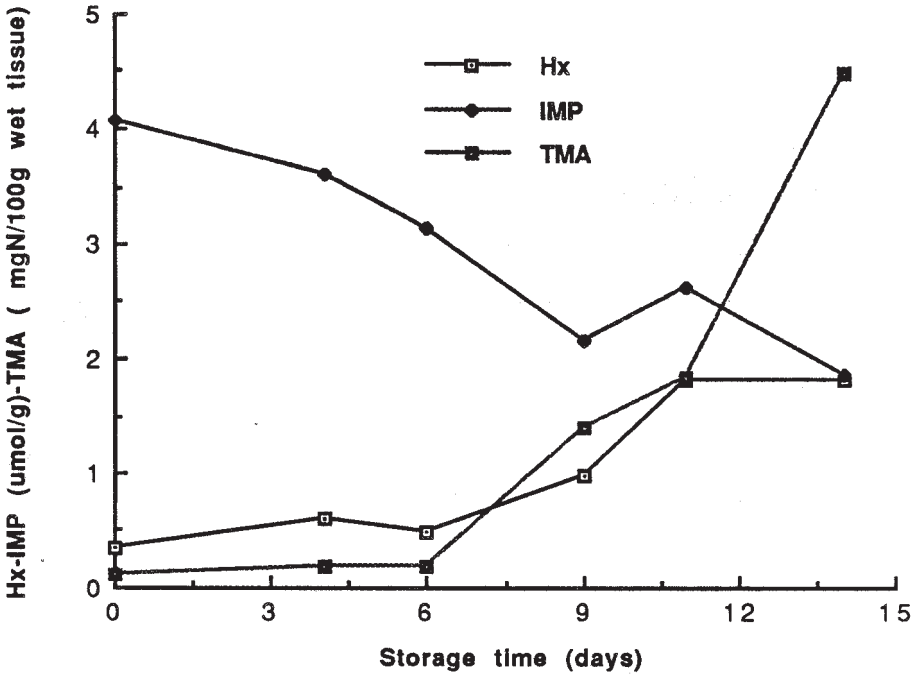

Figure 5.--Nucleotide and trimethylamine content expressed in mg N/100 g in pink and coho salmon held on ice in refrigerated storage at 2°C for various periods.

Results of analysis for rancidity in the iced coho salmon (Fig. 4) show no significant change (P>0.05) in TBA numbers during the storage test. Low TBA numbers (Appendix Table 4) found in the coho salmon indicated that, as expected, oxidation of lipids was not as much of a problem as it was with the pink salmon. This was verified by our taste panel evaluations which indicated no organoleptic rancidity. There was almost no correlation (Table 3) between flavor and TBA numbers in the coho salmon.

RESULTS AND DISCUSSION-FROZEN FISH STUDY

Sensory Evaluations

Cooked Pink Salmon Frozen Immediately on Landing

Results of the cooked sensory analyses of pink salmon that were frozen immediately upon landing are given in Table 4. Sensory scores indicate that, after 1 month in frozen storage, the general quality of both the reference samples stored at -29°C and the pink salmon stored at -23°C was moderately diminished compared to initial sensory findings. Storage temperature appeared to have less effect on loss of quality in the reference samples than loss of quality in the pink salmon stored at -23°C. However, because of the variability between and within samples, differences in the various sensory attributes were not statistically significant (P = 0.025, F-test). Based on acceptability scores in Table 4, the average quality of the frozen pink salmon was considered excellent. By the end of 3 months in frozen storage, obvious changes were detected in the quality of the pink salmon stored at -23°C. Although not statistically different (P>0.05) from the 3-month reference sample, mean odor, flavor, texture, and rancidity scores for the samples stored at -23°C were significantly different from the initial mean sensory scores for the same attributes. The mean sensory rancidity score for the pink salmon stored at -23°C was higher (2.5) than the mean rancidity score for the corresponding reference (1.1) indicating that rancidity influenced flavor and odor

Table 4.--Summary of sensory[a] evaluations of pink salmon frozen immediately after landing and held in frozen storage for various periods to simulate commercial storage compared to a frozen reference (Ref).

Time in frozen storage (months)	Storage temp (°C)	Mean[b] sensory scores for pink salmon				
		Odor	Flavor	Texture	Sensory[c] rancidity	Acceptability
		Mean	Mean	Mean	Mean	Mean
0	-29 (Ref)	8.4 ± 0.7[d]	8.3 ± 0.7[d]	8.3 ± 0.7[d]	1.0 ± 0[d]	8.4 ± 0.7[d]
1	-29 (Ref)	7.1 ± 1.8[d]	7.2 ± 1.4[d]	7.2 ± 1.0[d]	1.2 ± 0.3[d]	7.1 ± 1.1[d]
	-23	6.7 ± 2.0d	6.7 ± 1.5[d]	6.9 ± 1.7[d]	1.6 ± 1.0[d]	6.6 ± 2.0[d]
3	-29 (Ref)	7.3 ± 0.5[de]	7.6 ± 0.7[de]	7.0 ± 1.1[de]	1.1 ± 0.7[d]	7.5 ± 1.4[e]
	-23	6.3 ± 2.3[e]	6.0 ± 2.4[e]	6.1 ± 1.5[e]	2.5 ± 2.0[d]	5.6 ± 2.1[e]
6	-29 (Ref)	7.9 ± 0.7[d]	7.7 ± 0.5[d]	7.4 ± 0.8[d]	1.3 ± 0.8[d]	7.6 ± 0.5[d]
	-23	7.7 ± 0.5[d]	6.6 ± 1.0[d]	6.6 ± 0.8[d]	1.6 ± 1.0[d]	6.7 ± 0.9[d]
9	-29 (Ref)	6.7 ± 2.0[d]	6.6 ± 1.8[de]	6.2 ± 1.5[e]	2.5 ± 2.0[d]	6.5 ± 1.5[de]
	-23	6.7 ± 1.7[d]	6.0 ± 1.4[e]	6.0 ± 1.1[e]	2.2 ± 0.7[d]	6.1 ± 1.0[e]
12	-29 (Ref)	6.7 ± 1.4[de]	7.0 ± 1.4[d]	6.9 ± 1.3[d]	2.1 ± 1.1[de]	6.9 ± 1.3[d]
	-23	5.4 ± 1.7[e]	5.1 ± 1.1	6.6 ± 1.1[d]	3.9 ± 2.2[e]	5.0 ± 0.8

a Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, and 9 is excellent.

b Each value represents the mean of 8 samples ± the standard deviation.

c Sensory rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is slight, and 9 is strong.

d Means in the same column with a common superscript letter are not significantly different (P>0.05).

e Means in the same row and column with a common superscript letter are not significantly different (P>0.05).

scores. However, other factors (such as drip loss) can also affect flavor and texture. By this time (3 months), the quality of the salmon stored at -23°C could only be considered as fair. By comparison**,** the quality of the reference was rated as good. The relationship in quality between the two sample groups remained about the same: fair vs. good through 9 months of storage. The aberration in mean sensory scores for the pink salmon stored at -23°C for 6 months was not an improvement in quality, but probably the result of random sampling procedures used in this study, variability in the quality of the frozen salmon, and some lack of discrimination by taste judges. Beyond 9 months of storage at -23°C, there was a progressive deterioration in the general quality of the pink salmon. After 12 months of storage, their quality was significantly lower ($P = 0.025$, F-test) than the overall quality of the corresponding reference. The factor which most affected the quality of the fish stored at -23°C was the presence of oxidative rancidity. Generally, mean sensory scores for the samples at 12 months indicated that they were of acceptable quality; however, because of variability in quality, some samples were found to be organoleptically unacceptable.

Cooked Pink Salmon Held on Ice Prior to Frozen Storage

The results of sensory analyses of cooked pink salmon held on ice for 7 days prior to frozen storage for I year are shown in Table 5. The mean sensory scores generally indicated that after 3 months in frozen storage, the reference and pink salmon samples held on ice were subjectively considered premium and good quality, respectively. Rancidity in the iced salmon appeared to be the major influencing factor contributing to the difference in quality between the two sets of samples and, except for texture, also contributed to the rather high level of variability (large standard deviations) in the sensory parameters evaluated.

There were essentially no changes in the quality condition of the fish from either sample group between 3 and 6 months of storage.

Table 5.--Summary of sensory[a] evaluations of pink salmon held on ice in refrigerated storage (2°C) prior to frozen storage compared to a frozen reference (Ref).

Time in frozen storage (months)	Time on ice (days)	Storage temp (°C)	Mean[a] sensory scores for cooked pink salmon				
			Odor	Flavor	Texture	Sensory[c] rancidity	Acceptability
			Mean	Mean	Mean	Mean	Mean
2	0 (Ref)	-29	8.4 ± 0.7	8.3 ± 0.7	8.1 ± 0.8	1.0 ± 0	8.3 ± 0.7
3	0 (Ref)	-29	7.4 ± 0.5	7.6 ± 0.7	7.0 ± 1.1	1.0 ± 1.0	7.5 ± 0.9
	7	-23	6.7 ± 1.3	6.2 ± 1.2	6.9 ± 1.1	2.2 ± 1.7	6.5 ± 1
6	0 (Ref)	-29	7.6 ± 0.7	8.1 ± 0.6	7.8 ± 0.6	1.2 ± 0.7	7.9 ± 0.6
	7	-23	7.6 ± 0.5	7.4 ± 1.3	7.4 ± 0.5	1.2 ± 0.7	7.1 ± 1.1
12	0 (Ref)	-29	6.7 ± 1.4	7.0 ± 1.4	6.9 ± 1.3	2.1 ± 1.1	6.9 ± 1.3
	7	-23	4.4 ± 0.9[d]	4.4 ± 1.1[d]	5.4 ± 1.7[d]	5.4 ± 1.5[d]	4.4 ± 1.1[d]

a Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, and 9 is excellent.

b Each value represents the mean of 8 samples ± the standard deviation.

c Sensory rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is slight, and 9 is strong.

d Means in the same column without a superscript letter are not significantly different (P>0.05).

By the end of 12 months of storage, a significant loss ($P = 0.025$, F-test) of normal sensory characteristics occurred in the iced salmon sufficient to render them of below average quality. The mean sensory texture scores also indicate that the iced pink salmon experienced a significant loss of normal texture characteristics (i.e., moistness and firmness). The texture of the iced samples could best be described as fibrous, dry (lack of moistness), and chewy.

Cooked Coho Salmon Frozen Immediately on Landing

Taste panel results for coho salmon frozen at the time of landing are given in Table 6. After 1 month of storage, there were no observed differences ($P>0.05$) in the various sensory parameters measured for the reference salmon and coho salmon stored at -23°C. The quality of these products was excellent.

After 3 months in storage, some organoleptic changes were detected in the salmon stored at the higher (-23°C) temperature. Lower flavor and acceptability scores appeared to be related to the significant increase ($P = 0.97$, t-test) in mean sensory rancidity scores. Because of rancid flavors, the overall acceptability of these fish was rated at better than average but less than premium. By comparison, the reference sample was considered premium quality. The relationship in quality remained unchanged through 9 months of frozen storage.

Mean sensory scores in Table 6 show that after 12 months in storage the overall quality of the coho reference was good. As expected, however, coho salmon held at -23°C experienced a greater loss of quality than the comparative reference. Overall, their quality was considered fair. Because of natural variation, some of the fish stored at -23°C were considered borderline quality due to their higher oxidative rancidity levels and loss of normal texture characteristics.

Table 6.--Summary of sensory[a] evaluations of coho salmon frozen immediately after landing and held in frozen storage for various periods to simulate commercial storage compared to a frozen reference (Ref).

Time in frozen storage (months)	Storage temp (°C)	Mean[b] sensory scores for pink salmon				
		Odor	Flavor	Texture	Sensory[c] rancidity	Acceptability
		Mean	Mean	Mean	Mean	Mean
0	-29 (Ref)	8.2 ± 0.8[d]	8.6 ± 0.7[d]	8.7 ± 0.7[d]	1 ± 0[d]	8.7 ± 0.5[d]
1	-29 (Ref)	7.7 ± 1.4[d]	7.9 ± 0.7[d]	8.0 ± 1.0[d]	1.0 ± 0[d]	7.8 ± 0.7[d]
	-23	7.1 ± 1.0[d]	6.9 ± 0.9[d]	7.3 ± 0.5[d]	1.6 ± 1.1[d]	6.7 ± 0.7[d]
3	-29 (Ref)	7.5 ± 0.5[d]	7.7 ± 0.5[d]	7.3 ± 1.0[d]	1.1 ± 0.3[d]	7.5 ± 0.5[de]
	-23	7.0 ± 1.6[d]	6.9 ± 1.6[d]	7.0 ± 1.3[d]	3.5 ± 1.8	6.5 ± 1.4[e]
6	-29 (Ref)	7.9 ± 0.6[d]	7.6 ± 1.1[de]	7.7 ± 0.9[de]	1.1 ± 0.3[d]	7.7 ± 1.1[de]
	-23	7.9 ± 0.6[d]	6.9 ± 1.0[e]	6.6 ± 1.4[e]	1.5 ± 0.9[d]	7.0 ± 0.9[e]
9	-29 (Ref)	7.1 ± 1.8[d]	7.5 ± 1.4[d]	6.5 ± 1.1[e]	2.5 ± 1.8[d]	7.0 ± 1.4[e]
	-23	7.2 ± 1.8[d]	7.6 ± 1.5[d]	7.2 ± 1.2[de]	2.0 ± 2.6[d]	7.5 ± 1.4[de]
12	-29 (Ref)	6.6 ± 1.0[e]	7.1 ± 1.2[de]	7.3 ± 1.5[de]	3.0 ± 1.1[d]	7.0 ± 1.0[de]
	-23	6.6 ± 2.1[de]	6.0 ± 2.2[e]	6.0 ± 1.5[e]	2.9 ± 1.7[d]	6.0 ± 1.6[e]

a Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, and 9 is excellent.
b Each value represents the mean of 8 samples ± the standard deviation.
c Sensory rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is slight, and 9 is strong.
d Means in the same column with a common superscript letter are not significantly different (P>0.05).
e Means in the same row and column with a common superscript letter are not significantly different (P>0.05).

Cooked Coho Salmon Held on Ice Prior to Frozen Storage.

Taste panel results in Table 7 show that after 6 months of storage at -23°C the overall quality of the coho salmon held on ice for up to 7 days before freezing was considered premium grade when compared to the reference samples of the same quality.

By the end of 12 months in frozen storage, both the reference fish and those stored at -23°C showed a significant loss ($P < 0.05$) in quality. Data in Table 7 show a general reduction in mean sensory scores for all parameters measured as well as an increase in the level of sensory rancidity. Loss of quality was attributed to moderately rancid flavors and odors and to the negative effects of prolonged frozen storage on the texture of the fish. Interestingly, storage temperature did not significantly affect the sensory properties of the fish from either study group enough to make a qualitative difference. Both the reference fish and those held on ice were rated on the high side of average quality by the end of the storage study.

Chemical Analysis

Pink Salmon Frozen Immediately on Landing

Results of analyses for oxidative rancidity in the pink salmon frozen upon landing are shown in Figure 6. The significant increase ($P = 0.97$, t-test) in TBA values (Appendix Table 6) in the pink salmon stored at -23°C, between zero-time sampling and 3 months, corresponded to the increase in sensory rancidity values and subsequent decrease in odor and flavor scores (Table 4). Although low, the correlation coefficient ($r = 0.43$) between TBA values and flavor scores in Table 8 indicates a relationship between the two parameters.

The significant decrease ($P < 0.05$) in TBA values between 3 and 6 months, in both the reference samples and the pink salmon samples stored at -23°C, is probably the result of the reaction of aldehydes formed from precursor peroxides and hydroperoxides

Table 7.--Summary of sensory[a] evaluations of coho salmon held on ice in refrigerated storage (2°C) prior to frozen storage compared to a frozen reference (Ref).

Time in frozen storage (months)	Time on ice (days)	Storage temp (°C)	Mean[b] sensory scores for cooked pink salmon				
			Odor Mean	Flavor Mean	Texture Mean	Sensory[c] rancidity Mean	Acceptability Mean
0	0 (Ref)	-29	8.2 ± 0.8	8.6 ± 0.7	8.7 ± 0.7	1.0 ± 0	8.7 ± 0.5
3	0 (Ref)	-29	7.7 ± 1.0	8.0 ± 0.6	7.7 ± 0.9	1.1 ± 0.3	8.0 ± 0.8
	7	-23	7.6 ± 1.1	8.0 ± 0.9	7.2 ± 1.0	1.5 ± 0.8	7.9 ± 0.8
6	0 (Ref)	-29	7.5 ± 1.2	7.7 ± 0.7	7.9 ± 0.8	1.5 ± 0.3	7.9 ± 0.6
	7	-23	7.6 ± 0.7	7.1 ± 1.7	7.9 ± 0.8	1.4 ± 0.8	7.4 ± 1.9
12	0 (Ref)	-29	7.0 ± 1.0[d]	6.7 ± 1.6[d]	7.0 ± 1.4[d]	2.6 ± 1.5[d]	6.9 ± 1.5[d]
	7	-23	6.9 ± 1.1[d]	6.6 ± 1.1[d]	6.4 ± 1.3[d]	2.3 ± 1.1[d]	6.4 ± 1.3[d]

a Sensory scores are based on a 9-point hedonic scale where 1 is poor, 3 is borderline, and 9 is excellent.

b Each value represents the mean of 8 samples ± the standard deviation.

c Sensory rancidity scores are based on a 9-point hedonic scale where 1 is none, 5 is slight, and 9 is strong.

d Means in the same row and column with a common superscript letter are not significantly different (P>0.05).

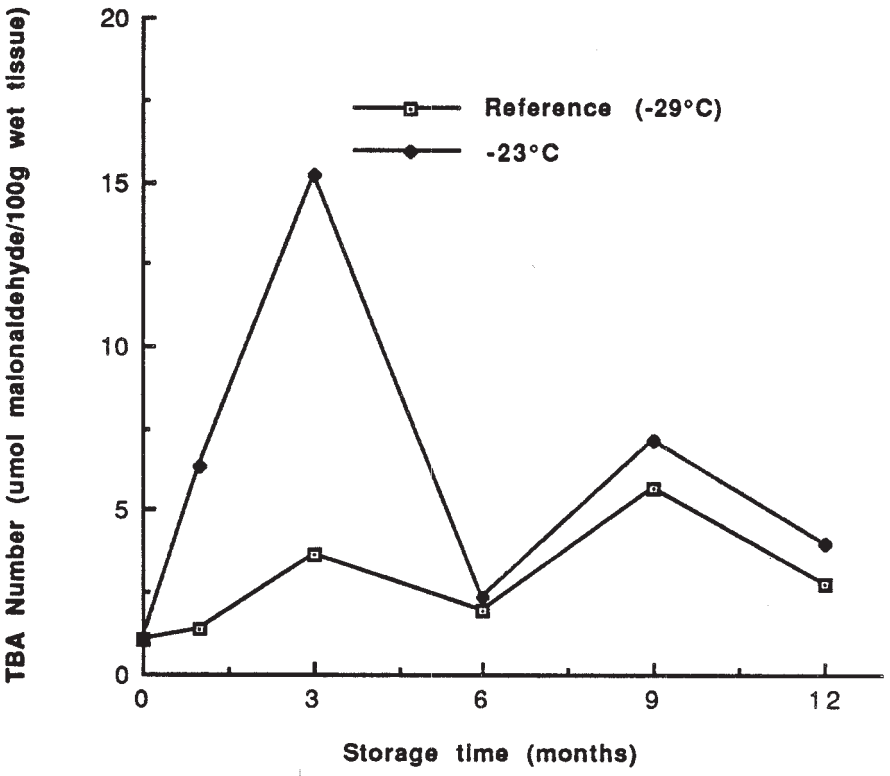

Figure 6.--Results of thiobarbituric acid analyses showing the effect of immediate freezing on landing followed by frozen storage on the development of oxidative rancidity in pink salmon.

Table 8.--Correlation coefficient between sensory flavor scores and TBA numbers for frozen salmon.

Chemical index	Correlation coefficient	Significance
TBA (pink -29°C)	-0.76	0.05
TBA (pink -23°C)	0.43	0.15
TBA (coho -29°C)	-0.87	N.S.
TBA (coho -23°C)	-0.17	0.20

N.S. = Not significant.

that react with thliobarbituric acid (TBA) to give the characteristic red chromogen**.** Aldehydes react with other compounds to form products that do not react with TBA. Thus a reduction in TBA values was observed. This should not be interpreted to mean that there is no rancidity, however. Mean sensory rancidity scores in Table 4 corresponded to the changes in TBA values.

The increase in TBA values in both groups of fish at 9 months was followed by a decrease in TBAs by the end of the storage study. Mean sensory rancidity scores for the pink salmon stored at -23°C, however, rose during this period indicating a perceptible increase in organoleptic rancidity. As explained previously, the apparent contradiction between TBA values and sensory scores is attributed to the decomposition of reactive aldehydes, the production of peroxides, or both; in any case, neither are measured by the TBA test.

Pink Salmon Held on Ice Prior to Frozen Storage

After 3 months in frozen storage, mean TBA values (Appendix Table 7, Fig. 7) for both the pink salmon held on ice before freezing and their reference were not ,significantly different (P = 0.05, F test). However, the fish held on ice before freezing had lower mean odor and flavor scores and a correspondingly higher sensory rancidity score than the reference samples (Table 5), suggesting the presence of oxidative rancidity. Although the mean sensory scores for the iced pink salmon were not significantly different from the reference samples, the large standard deviations indicate a high degree of variability in the iced samples and indicate that some fish were rancid and that others were not. The relationship between TBA values and sensory scores persisted for the remainder of the study and, although sensory rancidity was a problem in the pink salmon stored on ice, this difference was not clearly indicated by the results of the TBA analyses.

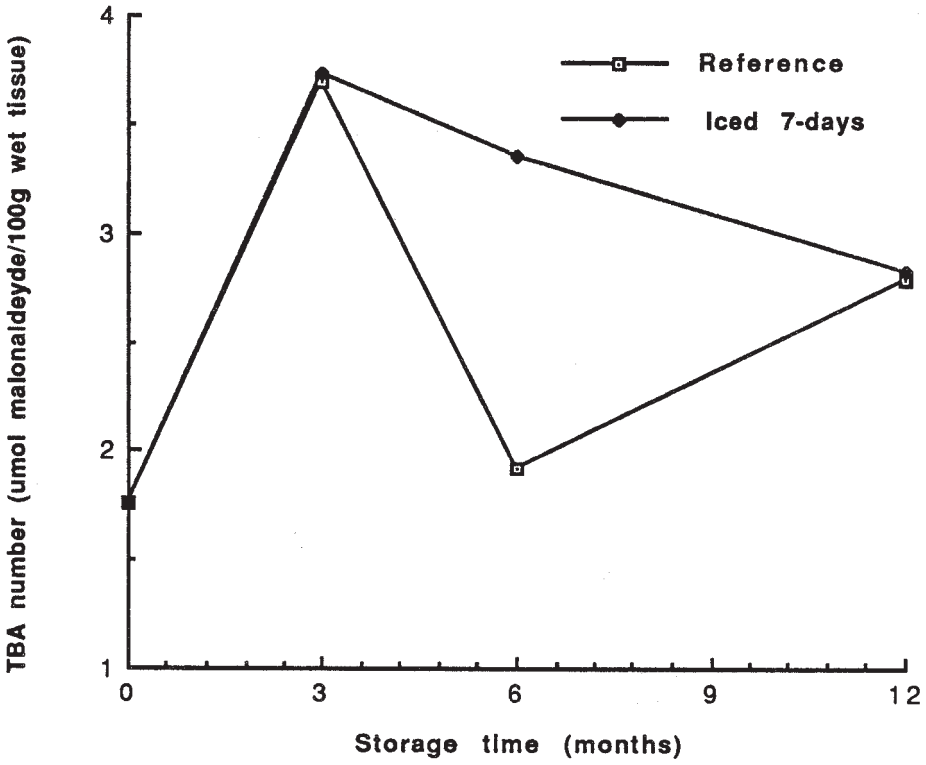

Figure 7.--Results of thiobarbituric acid analyses showing the effect of holding on ice at 2°C for 7 days before frozen storage on the development of oxidative rancidity in pink salmon.

Coho Salmon Frozen Immediately on Landing

Results of chemical analyses for rancidity in the coho salmon frozen immediately upon landing at the processing plant are shown in Figure 8. TBA values (Appendix Table 6) for both the reference fish and the coho salmon stored at -23°C remained low during the first month of storage. Between the first and third months of storage, TBA values increased significantly ($P = 0.97$, t-test) in both groups of fish, but there was no significant difference between the two groups. Although the increase in TBA was significant, the level of sensory rancidity was not, and as a result, our taste panel found only slightly rancid off-flavors in some of the salmon stored at -23°C. Correlation coefficient values in Table 8 suggest that the results of our taste panel evaluations were valid. Between the third month and the end of the study, TBA values for both the reference fish and those stored at -23°C went through several typical induction-propagation-termination cycles producing the typical fluctuating increase/ decrease pattern in TBA values. Differences in TBA values between the two groups during this time were not significant ($P>0.05$). Final TBA values in Figure 8 indicate relatively low levels of oxidative rancidity in both sample groups by the end of the storage experiment.

Sensory evaluations measure the accumulative effects of storage. The sensory rancidity scores in Table 6 indicate the presence of low levels of rancidity in both sets of samples by the end of the study. Thus, the overall results of the sensory tests generally agree with the results of our chemical analyses.

Coho Salmon Held on Ice Prior to Frozen Storage

Results of analyses for chemical rancidity occurring in coho salmon stored on ice for 8 days prior to frozen storage of up to 1 year are shown in Figure 9. The significant rise ($P < 0.05$) in the TBA values (Appendix Table 7) in the reference sample at 3 months is unexplained, but the results of our taste panel evaluations (Table 7) did not

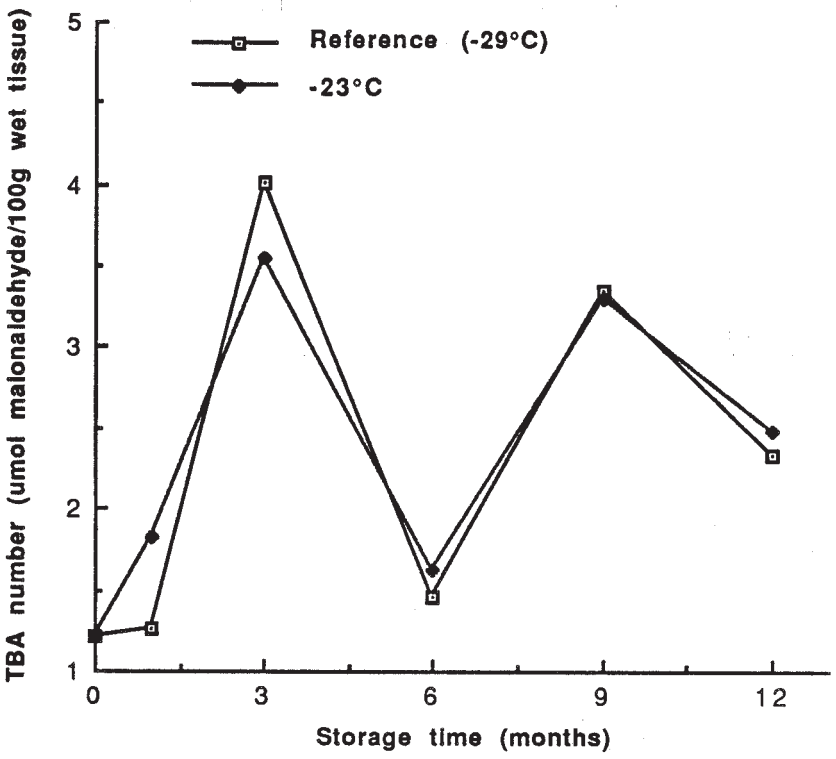

Figure 8.--Results of thiobarbituric acid showing the effect of immediate freezing on landing followed by frozen storage on the development of oxidative rancidity in coho salmon.

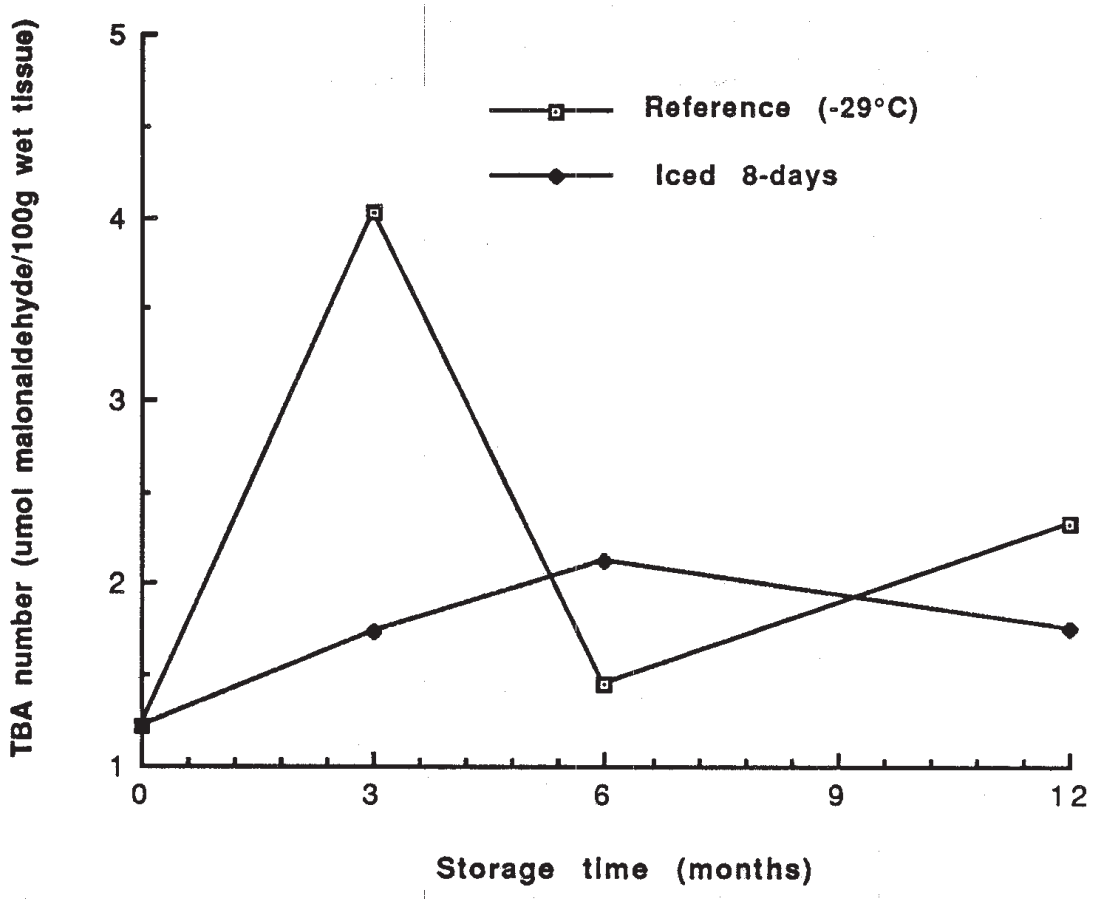

Figure 9.--Results of thiobarbituric acid analyses showing the effect of holding coho salmon on ice at 2°C for 8 days before frozen storage on the development of oxidative rancidity.

indicate the presence of rancid flavors. Except for the increase (P = 0.025, F-test) in the TBA value for the reference sample at 3 months, chemical rancidity in the reference sample and the coho salmon held on ice appeared to be relatively low through 1 year of frozen storage.

Cook-Drip Analysis

Pink Salmon Frozen Immediatelv on Landing

Figure 10 shows a general increase in the loss of cook-drip values (Appendix Table 8) from the pink salmon reference fish and pink salmon frozen immediately on landing and stored at -23°C for the first 9 months of storage. Concurrently, there was a general loss of sensory texture (Table 4) quality in both sample groups during this period, indicating a possible cause-and-effect relationship between loss of moisture and texture. The reduction in cook-drip loss between 9 and 12 months of storage is not understood. Although the loss of cook-drip from the reference sample stored at -29°C was slightly lower than the cook-drip loss from the pink salmon stored at -23°C, the difference was not statistically significant.

Pink Salmon Held on Ice Prior to Frozen Storage

The trend in cook-drip values (Fig. 11) for pink salmon held on ice before frozen storage was similar to the cook-drip results for the pink salmon frozen immediately on landing (i.e., a general increase in cook-drip followed by an unexplained decrease). The cook-drip loss from the pink salmon held on ice was higher (Appendix Table 9) than from the reference sample, possibly because of the difference in storage temperatures. Absorption of melt water coming into contact with the fish during storage on ice could explain the increased loss in drip. In a study to determine the effect of various factors on thaw drip formation, Bilinski et al. (1977) found that storing Pacific salmon on ice or in refrigerated seawater for up to 10 days prior to freezing resulted in a higher thawdrip loss than freezing alone. The results of the cook-drip analyses in that study generally

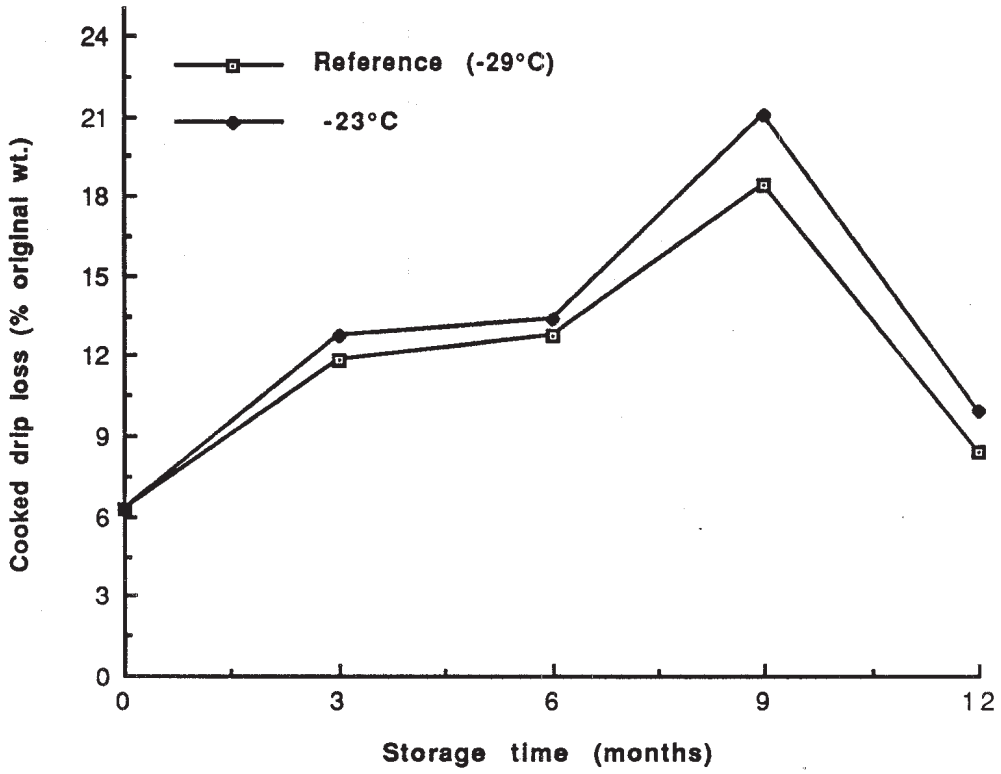

Figure 10.--Results of physical analyses showing the effect of immediate freezing on landing followed by frozen storage on cook drip loss (based on original weight) from pink salmon.

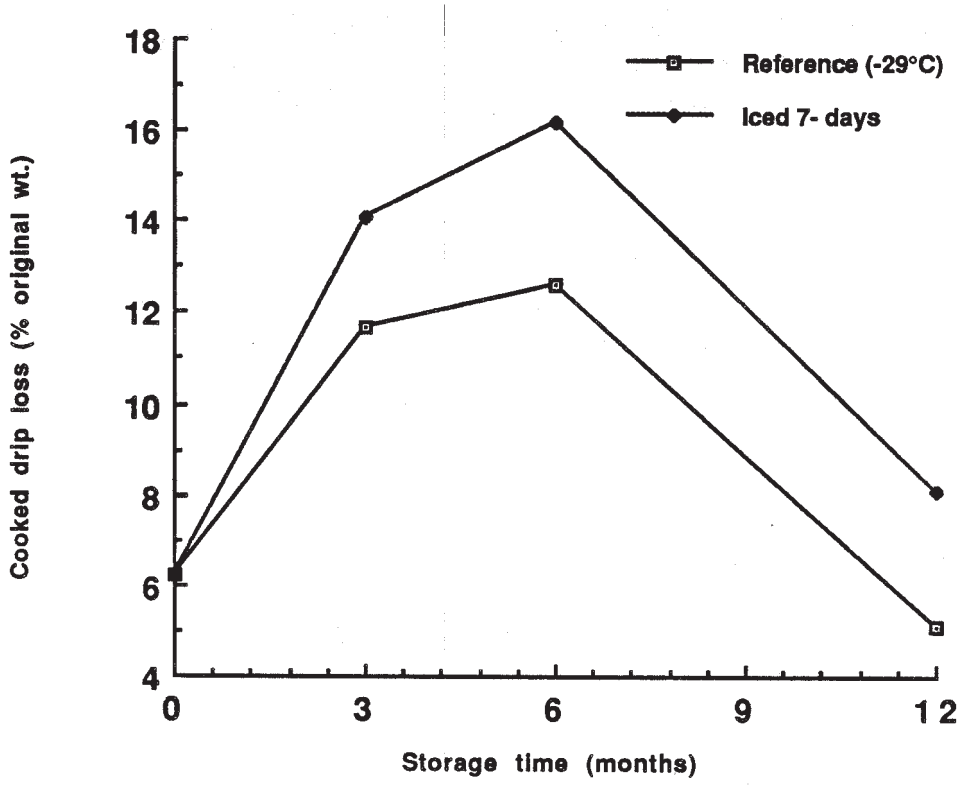

Figure 11. Results of physical analyses showing the effect of holding on ice at 2°C for 7 days before frozen storage on cook drip loss (based on original weight) from pink salmon.

agreed with the cooked sensory texture results in Table 5. That is, the texture of the reference, which had the lowest loss of cook-drip, was generally considered more tender (juicy) than the texture of the pink salmon held on ice.

Coho Salmon Frozen Immediately on Landing

Results of the analyses to determine cook-drip loss in the coho salmon frozen on arrival at the processing plant are shown in Figure 12. Although variable, the trend in cook-drip values (Appendix Table 8) for both the reference sample and the salmon stored at -23°C were similar to the results of the cook-drip tests for pink salmon handled and stored under the same conditions. The exception to this trend occurred after 9 months of storage, when the cook-drip loss for the reference samples was about 20% higher than the cook-drip loss from the comparative sample. Differences in the cookdrip loss between the reference and test fish, however, were not statistically different. As observed previously, the decline in cook-drip values for both sets of samples between 9 and 12 months of storage is not fully understood. Sensory texture results in Table 6 indicate that, except for the 9-month examination, the texture of the reference samples was generally more acceptable than the texture of the comparative fish stored at -23°C.

Coho Salmon Held on Ice Prior to Frozen Storage

Results of cook-drip loss analyses for coho salmon stored on ice before freezing are shown in Figure 13. Again, the trend in cook-drip losses for this group of fish was similar to the trend in cook-drip losses observed for the pink salmon stored on ice. Cook-drip losses from the reference sample and iced fish were not significantly different ($P = 0.025$, F-test) from one another at each examination period. However, drip losses from the reference sample were consistently less than cook-drip losses from the iced salmon. Differences were attributed to the low temperature at which the reference sample was stored and to the possibility that the iced fish absorbed water during

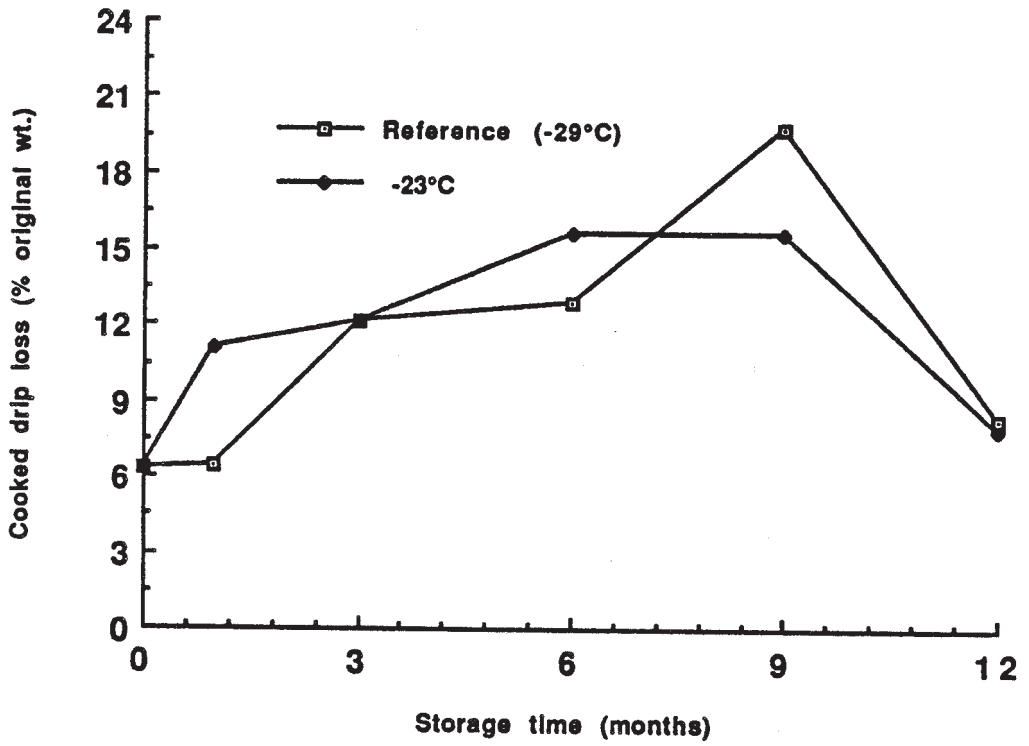

Figure 12.--Results of physical analyses showing the effect of immediate freezing on landing followed by frozen storage on cook drip loss (based on original weight) from coho salmon.

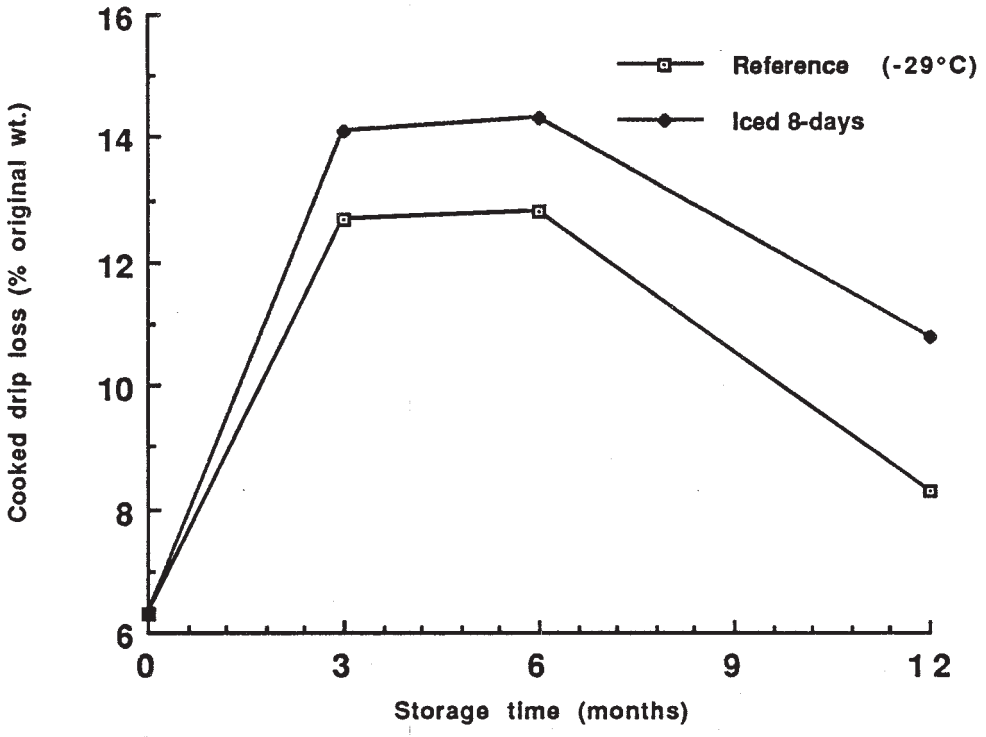

Figure 13.--Results of physical analyses showing the effect of holding on ice at 2°C for 8 days before frozen storage on cook drip loss (based on original weight) from coho salmon.

refrigerated storage. Taste panel results in Table 7 were consistent with cook-drip losses in Figure 13. Sensory texture tended to reflect the treatment of the fish prior to frozen storage with the result that the texture of the reference samples were on average slightly better than the texture of the coho salmon held on ice prior to frozen storage.

CONCLUSIONS

Sensory results for the research reported here show that the postharvest quality of fresh, prime pink salmon can be maintained up to 7 or 8 days on ice when the fish are kept refrigerated at 2°C. Generally, the industry has been unable to consistently achieve acceptable levels of quality, much less prime quality, beyond 7 to 8 days postharvest. After the first 7 days of iced storage in this study, the subjective quality of the iced pink salmon changed from premium (excellent) to average quality for a short period (3-4 days), followed by poor quality.

Similarly, the subjective quality of coho salmon in this study remained at the premium grade for about 7 days on ice (about 9 days postharvest). This was followed by a short period of average sensory quality, becoming borderline after 13 days.

Bacterial growth on both the pink and coho salmon held on ice typically remained low during the first 8 to 9 days of storage. This stage was followed by a rapid growth phase until spoilage occurred at around 16 days postharvest.

Chemical indicators used in this study to determine freshness or loss of freshness due to spoilage in the iced salmon indicated that IMP in premium grade pink salmon ranged from a low concentration of 3.5 micromoles per g to a high of 5.0 micromoles per g. The corresponding Hx levels in the premium grade fish ranged in concentration from 0.2 to 0.7 micromoles per g. Since there is very little trimethylamine oxide (TMAO) in pink salmon, it is difficult to fix a TMA number (produced by the reduction of TMAO) for premium quality fish. However, based on our work and confirmed by the

work of Spinelli and Koury (pers. commun.), a TMA number of 0.4 mg nitrogen per 100 g or less is likely.

On the low end of the quality scale (poor to unacceptable) the IMP content in iced pink salmon ranged between 1.4 and 2.3 micromoles per g and the Hx levels ranged between 0.8 and 1.0 micromoles per g. The concentration of the spoilage indicator TMA ranged between 0.4 and 0.8 mg nitrogen per 100 g.

Results of tests to assess fresh quality of the iced coho salmon indicated that the concentration of IMP in the premium product ranged between 2.5 and 4.0 micromoles per g, while the concentration of Hx was less than 1.0 micromole per g. The maximum concentration of TMA in top quality coho salmon was about 1.0 mg nitrogen per 100 g. Near the end of iced storage, the chemical characteristics of the coho salmon were characterized by an IMP content of about 1.9 micromoles per g and a Hx content of 1.8 micromoles per g. TMA content in the poor quality coho salmon ranged between 3.5 and 4.5 mg nitrogen per 100 g.

Oxidative rancidity significantly affected the fresh quality of the iced pink salmon in this experiment. TBA numbers for premium quality iced pink salmon did not exceed 2.5 micromoles malonaldehyde per 100 g but peaked at 9.8 micromoles malonaldehyde per 100 g in iced pink salmon of low quality. Premium quality iced coho salmon were characterized by a TBA number of 2 micromoles per 100 g or less.

Because of rancid flavors, the organoleptic quality of pink salmon frozen at the point of landing was found acceptable but less than premium grade after 3 months of storage at -23°C. The quality of the reference stored at -29°C was excellent. After 9 months in storage, both the reference samples and comparative pink salmon were subjectively of acceptable quality but less than premium grade.

Similarly, the organoleptic quality of pink salmon stored on ice for 7 days was acceptable but was less than premium grade after 3 months of frozen storage at -23’C. The quality of the reference samples was subjectively considered premium grade.

Beyond 6 months of storage, enough loss of quality had occurred in the reference samples to render them less than premium grade.

Compared to the excellent quality reference sample, the overall quality of the coho salmon frozen at point of landing followed by storage at -23°C was premium grade through 3 months of storage. Between 3 and 6 months, however, small changes in the sensory properties of the fish stored at -23°C rendered them less than premium grade but still of good quality. By the end of 9 months in frozen storage, the reference samples had lost their premium quality status, but were considered a very good product. The quality of the reference samples was generally superior to the quality of the comparative coho salmon after 1 year.

After 3 months in storage at -23°C, the subjective quality of both the coho salmon held on ice for 7 days before freezing and the corresponding reference samples were considered premium grade. This relationship in quality existed, with slight variations, through 6 months of storage. Between 6 and 12 months, a significant decline of normal sensory attributes occurred in both products, sufficient enough to change their premium quality status to fair.

Generally, the results of the objective tests to measure rancidity in frozen pink salmon corresponded to observed trends in our sensory tests. The six-fold increase in TBA values between the initial and 3-month examinations of the pink salmon frozen on landing and stored at -23°C coincided with the first observable sensory rancidity detected by the taste panel and significantly affected their acceptability. A second peak in TBA values was also observed by the taste panel at 9 months. At this time, the increase in TBA rancidity was organoleptically detectable in both the reference and the comparative samples. Although there were no significant differences in TBA values between the reference and the comparative frozen pink salmon at 12 months, the quality of the reference samples was generally considered superior to the quality of the comparative fish.

Tests for chemical rancidity in the pink salmon held on ice prior to freezing indicated that the longer the fish were held on ice, the greater the potential for increased oxidative rancidity during storage. Although TBA values for pink salmon held on ice for 7 days were not significantly different from those of the reference at any time during the frozen storage study, the iced fish were considered organoleptically rancid and of unacceptable quality by the end of the study.

Low TBA values for the coho salmon frozen on landing and stored at -23°C correlated with results from the sensory evaluations, indicating that the presence of low levels of chemical rancidity did not greatly influence the overall quality of the coho salmon in this experiment.

As in the case of the pink salmon, TBA test results from the analysis of coho salmon held on ice before freezing indicated that the longer the fish were stored on ice, the more influence oxidative rancidity had on overall acceptability.

Results of physical analyses of the pink salmon frozen at point of landing indicated that cook-drip loss increased with time in frozen storage, but that the difference in storage temperatures did not appear to significantly affect drip formation. The length of time that pink salmon were held on ice before frozen storage also affected the formation of cook-drip loss. With some variation, results of the cook-drip analyses made on the two coho salmon treatment groups (frozen on landing and stored on ice) were similar to the results of cook-drip analyses made on the pink salmon.

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APPENDIX

Appendix Table 1.--Total aerobic plate counts (APCs) of microbial flora from the skin of pink and coho salmon held on ice for various periods.

Time on ice (days)	Total aerobic plate counts (number/cm^2)	
	Pink salmon	Coho salmon
	Mean[a]	Mean
0	$6.36 \pm 2.8 \times 10^3$	$2.8 \pm 3.2 \times 10^3$
3	Not tested	$3.3 \pm 0.2 \times 10^4$
4	$2.70 \pm 1.0 \times 10^3$	Not tested
6	Not tested	$1.3 \pm 4.0 \times 10^5$
9	$4.5 \pm 2.2 \times 10^3$	Not tested
10	Not tested	$5.6 \pm 2.7 \times 10^5$
11	$2.7 \pm 2.6 \times 10^4$	Not tested
12	Not tested	$8.8 \pm 3.2 \times 10^{7b}$
14	$3.7 \pm 0.4 \times 10^{6b}$	$7.8 \pm 3.2 \times 10^{7b}$

[a] Each value represents the mean of 3 fish samples analyzed in duplicate ± the standard deviation.

[b] Significantly different from the initial APC at the 5% level of significance.

Appendix Table 2.--Changes in muscle pH of pink and coho salmon as a function of time in iced storage at 2°C.

Time on ice (days)	pH measurements	
	Pink salmon Mean[a]	Coho salmon Mean
0	6.36 ± 0.04[b]	6.40 ± 0.09[b]
4	6.41 ± 0.02[b]	Not tested
6	Not tested	6.56 ± 0.03[b]
9	6.37 ± 0.07[b]	Not tested
10	Not tested	6.51 ± 0.13[b]
11	6.42 ± 0.04[b]	Not tested
13	Not tested	6.52 ± 0.03[b]
14	6.42 ± 0.03[b]	6.54 ± 0.07[b]

[a] Each value represents the mean of 6 samples ± the standard deviation.

[b] Means in the same column with a common superscript letter are not significantly different (P>0.05).

Appendix Table 3.--Nucleotide[a] and trimethylamine content in pink salmon held on ice in refrigerated storage at 2°C for various periods

Time on ice (days)	Hypoxanthine content (µmoles/g)	IMP content (µmoles/g)	TMA content (mg N/100 g)
	Mean[b]	Mean	Mean
0	0.17 ± 0.09[c]	4.70 ± 0.79[c]	0.05 ± 0.04[c]
4	0.26 ± 0.76[c]	5.00 ± 0.76[c]	0.34 ± 0.15[c]
9	0.66 ± 0.16[d]	2.58 ± 0.53[d]	1.23 ± 1.11[c]
11	0.76 ± 0.11[d]	2.31 ± 0.50[d]	1.36 ± 0.21[c]
14	1.01 ± 0.17[d]	1.40 ± 0.1[d]	0.79 ± 0.10[d]

a Hypoxanthine and inosine monophosphate.

b Each value represents the mean of 6 samples ± the standard deviation.

c Means in the same column with a common superscript letter are not significantly different (P>0.05).

d Significantly different from the zero time (0) and 4-day mean at the 5% level of significance.

Appendix Table 4.--Results of TBA analyses to determine the effect of time in iced storage at 2°C for various periods on the development of oxidative rancidity in pink and coho salmon.

Time on ice (days)	Sample	TBA number (μmoles malonaldehyde/100 g)	
		Pink salmon	Coho salmon
		Mean[a]	Mean
0	Reference	1.04 ± 0.30[b]	1.22 ± 0.47[b]
4	Iced	1.67 ± 0.55[b]	Not tested
6	Iced	Not tested	1.18 ± 0.47[b]
9	Iced	2.75 ± 1.43[c]	1.20 ± 0.51[b]
11	Iced	9.80 ± 5.19[c]	1.86 ± 0.54[b]
14	Iced	7.31 ± 3.10[c]	1.09 ± 0.39[b]

[a] Each value represents the mean of 6 samples ± the standard deviation.

[b] Means in the same column with a common superscript letter are not significantly different (P>0.05).

[c] Significantly different from the reference at the 5% level of significance.

Appendix Table 5.--Nucleotide[a] and trimethylamine content in coho salmon held on ice in refrigerated storage at 2°C for various periods.

Time on ice (days)	Hypoxanthine content (µmoles /g) Mean[b]	IMP content (µmoles /g) Mean	TMA content (mg N/100 g) Mean
0	0.36 ± 0.12[c]	4.10 ± 0.60[c]	0.12 ± 0.0[c]
4	0.61 ± 0.13[c]	3.61 ± 0.48	0.19 ± 0.12[c]
6	0.48 ± 0.10[c]	3.14 ± 0.61[c]	0.19 ± 0.09[c]
9	0.97 ± 0.57[d]	2.17± 0.24[d]	1.39 ± 1.54[c]
11	1.82 ± 0.60[d]	2.62 ± 0.42[d]	1.83 ± 0.23[d]
14	1.82 ± 0.56[d]	1.87 ± 0.72[d]	4.48 ± 1.30[d]

a Hypoxanthine and inosine monophosphate.

b Each value represents the mean of 6 samples ± the standard deviation.

c Means in the same column with a common superscript letter are not significantly different (P>0.05).

d Significantly different from the zero time (0) and 4-day mean at the 5% level of significance.

Appendix Table 6.--Results of TBA analyses of pink and coho salmon to determine the effect of freezing on landing followed by frozen storage at -23°C for the various periods on the development of oxidative rancidity. Reference (Ref) samples stored at -29°C.

Time in frozen storage (months)	Storage temp (°C)	TBA number (µmoles malonaldehyde/100 g)	
		Pink salmon Mean[a]	Coho salmon Mean
0	Ref. (-29)	1.04 ± 0.30[b]	1.22 ± 0.47[b]
1	Ref. (-29)	1.40 ± 0.10[b]	1.27 ± 0.10[b]
	(-23)	6.37 ± 2.84[b]	1.83 ± 0.23[b]
3	Ref. (-29)	3.69 ± 0.18	4.02 ± 0.0
	(-23)	15.24 ± 1.72[d]	3.55 ± 0.03[d]
6	Ref. (-29)	1.92 ± 0.03[b]	1.46 ± 0.17[b]
	(-23)	2.93 ± 0.39[b]	1.62 ± 0.74[b]
9	Ref. (-29)	5.73 ± 3.34[c]	3.35± 0.25[c]
	(-23)	7.17 ± 0.34[c]	3.30 ± 0.54[c]
12	Ref. (-29)	2.79 ± 0.52[c]	2.33 ± 0.54[b]
	(-23)	4.00 ± 1.42[c]	2.48 ± 0.32[c]

[a] Each value represents the mean of 6 samples ± the standard deviation.

[b] Means in the same column with a common superscript letter are not significantly different (P>0.05).

[c] Means in the same column for the same month with a common superscript letter are not significantly different (P>0.05).

[d] Significantly different from the reference at the 5% level of significance.

Appendix Table 7.--Results of TBA analyses of pink and coho salmon to determine the effect of iced storage prior to frozen storage at -23°C on the development of oxidative rancidity. Reference samples (Ref) stored at -29°C.

Time in frozen storage (month)	Time on ice (days)	Storage temperature (°C)	TBA number (μM malonaldehyde/100 g)	
			Pink salmon	Coho salmon
			Mean[ab]	Mean
0	0	Ref (-29)	1.76 ± 1.0[ac]	1.22 ± 0.47[ac]
3	0	Ref (-29)	3.69 ± 0.18[bd]	4.02 ± 0[b]
	7	(-23)	3.73 ± 0.04[bd]	Not tested
	8	(-23)	Not tested	1.74 ± 0.04[bc]
6	0	Ref (-29)	1.92 ± 0.04[bc]	1.46 ± 0.17[bcd]
	7	(-23)	3.35 ± 0.22[b]	Not tested
	8	(-23)	Not tested	2.13 ± 0.74
12	0	Ref (-29)	2.79 ± 0.52[bd]	2.33 ± 0.54[bd]
	7	(-23)	2.83 ± 1.55[bd]	Not tested
	8	(-23)	Not tested	1.76 ± 0.33[bd]

a Each value represents the mean of 6 samples ± the standard deviation.

b Each value represents the means of 3 samples ± the standard deviation.

c Means in the same column with a common superscript letter are not significantly different (P>0.05).

d Means in the same column for the same month with a common superscript letter are not significantly different (P>0.05).

Appendix Table 8.--Results of physical analyses of pink and coho salmon to determine the effect of freezing on landing followed by frozen storage for various periods on cook-drip loss.

Time in frozen storage (months)	Storage temp (°C)	Cook-drip loss (%)	
		Pink salmon	Coho salmon
		Mean[a]	Mean
0	Ref. (-29)	9.1 ± 2.13[ac]	6.3 ± 1.22.8[ac]
1	Ref. (-29)	6.3 ± 1.2[a]	6.9 ± 1.1[ac]
	(-23)	12.8 ± 1.2[ae]	11.4 ± 1.6[ae]
3	Ref. (-29)	11.8 ± 0.8[bd]	12.9 ± 1.9[bd]
	(-23)	12.8 ± 0.5[bd]	12.7 ± 0.5[bd]
6	Ref. (-29)	12.8 ± 1.2[bd]	14.1 ± 1.7[b]
	(-23)	13.4 ± 0.6[bd]	15.6 ± 1.5[bde]
9	Ref. (-29)	18.4 ± 1.1[b]	19.8 ± 1.7[bde]
	(-23)	21.1 ± 1.5[be]	15.6 ± 1.6[be]
12	Ref. (-29)	8.4 ± 0.9[ad]	8.4 ± 0.9[ad]
	(-23)	9.9 ± 1.5[acd]	7.9 ± 2.2[acd]

a Each value represents the mean of 6 samples ± the standard deviation.

b Each value represents the means of 3 samples ± the standard deviation.

c Means in the same column with a common superscript letter are not significantly different (P>0.05).

d Means in the same column for the same month with a common superscript letter are not significantly different (P>0.05).

e Significantly different from the reference for the same month at the 5% level of significance.

Appendix Table 9.--Results of physical analyses of pink and coho salmon to determine the effect of iced storage prior to frozen storage on cook-drip loss

Time in frozen storage (months)	Time on ice (days)	Storage temperature (°C)	Cook-drip loss (%)	
			Pink salmon	Coho salmon
			Mean[ab]	Mean
0	0	Ref (-29)	6.3 ± 1.2[ac]	6.4 ± 1.5[ac]
3	0	Ref (-29)	11.8 ± 0.8[bd]	12.9 ± 1.9[bd]
	7	(-23)	14.1 ± 0.5[bd]	Not tested
	8	(-23)	Not tested	14.2 ± 0.9[bd]
6	0	Ref (-29)	12.8 ± 1.1[bd]	12.9 ± 1.9[bd]
	7	(-23)	16.2 ± 2.3[bd]	Not tested
	8	(-23)	Not tested	14.3 ± 0.6[bd]
12	0	Ref (-29)	5.4 ± 1.6[ac]	7.9 ± 2.27[c]
	7	(-23)	7.9 ± 1.7[ac]	Not tested
	8	(-23)	Not tested	10.5 ± 1.4[ac]

[a] Each value represents the mean of 6 samples ± the standard deviation.

[b] Each value represents the means of 3 samples ± the standard deviation.

[c] Means in the same column with a common superscript letter are not significantly different (P>0.05).

[d] Means in the same column for the same month with a common superscript letter are not significantly different (P>0.05).