UTILIZATION OF PACIFIC HAKE (*Merluccius productus*) IN THERMALLY PROCESSED PRODUCTS

by

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ABSTRACT

The potential of Pacific hake (Merluccius productus), which occur in Pacific north east waters, for human consumption is of interest because the biomass of the fish is known to be of significant size. However, this resource has not been fully exploited by the local fishing industry. The presence of Myxosporean parasite spores in the fish muscle is thought to cause a soft cooked fish texture, thus giving rise to problems in processing and affecting the marketability of the fish product.

Studies were conducted on the textural properties of Pacific hake from two different fishing areas with different postharvest handling treatments. Fish samples from the Strait of Georgia and from offshore waters west of Vancouver Island were obtained from commercial sources. The west coast offshore hake samples were obtained in frozen form. They were thawed, filleted, vacuum-packed in barrier bags and refrozen for storage at -29°C. Two batches of fish chilled in refrigerated sea water were available from Georgia Strait. One of these batches was frozen immediately when received and subsequently processed similar to the west coast samples, whereas the other batch was chilled in ice for 1-3 days after landing while the fish were progressively processed into fillets for frozen storage at -29°C.

The presence and types of species of Myxosporean parasite spores in fish fillets were determined by light and scanning electron microscopy. The fillets were grouped according to the level of infection in terms of the numbers of parasite spores determined by wet mount microscopic examination.

Fillets of fish samples with light and medium parasite infection levels were used for investigation of cooked fish texture in thermal processing. The fish were processed in three types of container: half-pound and quarter-pound salmon cans and quarter dingley cans, at retort temperatures of 115, 120 and 130°C. The cooked fish texture was evaluated for its cohesiveness and firmness as measured from the force-distance curve obtained instrumentally using a Kramer shear-compression cell of diminished capacity. Weight loss of the fish during cooking was also determined. Similarly, cooked texture was also evaluated upon cooking by baking, steaming and microwave heating.

It was found that Pacific hake from west coast offshore waters and the Strait of Georgia could produce canned products of acceptable textural quality in all three types of container. Less liquid exuded from fish processed in quarter dingley cans as compared with the cylindrical cans. Higher scores for cohesiveness and firmness measurements were observed in fish cooked at 130°C as compared with those processed at 115 and 120°C. Immediate freezing of Pacific hake upon landing gave a significant improvement in cooked texture.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

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INTRODUCTION

With the introduction of 200 mile exclusive economic zones (EEZ), the pattern of world fish production has changed dramatically during the past decade. Foreign fleets have been operating in the offshore waters of British Columbia, Canada, for Pacific hake (Merluccius productus) since 1967. A recorded high catch for hake of 52.8 thousand tonnes was harvested in 1969. Following the establishment of EEZ in 1977, Canada had the obligation to continue providing access by foreign vessels to fish stocks which were considered surplus to the harvesting capacity of the Canadian fishing vessels. In addition, if the potential catch of the stock exceeded the processing and marketing capacity of the local fishing industry, direct sales of fish to foreign vessels were permitted by government regulations.

The above describes the present situation of offshore Pacific hake fishery in British Columbia waters where a certain quota of the catch has been allocated to foreign and joint fishing operations. The co-operative fishing arrangement with foreign countries was initiated in 1978 by the Hake Consortium of British Columbia which represented the local fishing industry in negotiations with foreign fishing partners (Buechler and Proverbs, 1983). However, the Canadian interest in the co-operative fishing arrangements has been confined primarily to catching operations and direct sales. Although the potential for Pacific hake fishing by the Canadian fleet has been proven by an increasing volume of

catch under this joint operation, participation of the local fishery industry in hake processing and marketing has not been encouraging.

It is generally recognized that development of a fishery for under-utilized species would help to decrease fishing pressure on the declining traditional fish stocks. To develop a fishery for under-utilized Pacific hake, it is necessary to define the physical and technological characteristics of the fish. Biological studies on stock size and distribution of Pacific hake in the Strait of Georgia and offshore waters west of Vancouver Island were carried out in recent years by the Department of Fisheries and Oceans. Quality problems due to infection of the fish muscle by protozoan parasites were also investigated.

If a fishery for under-utilized species is to be developed for human consumption, its viability will be determined by factors which include marketing opportunities for the fish products and their suitability for human food. Domestic landings of Pacific hake have been minimal as compared to the total catch. They have not been marketed locally although some were processed and marketed in the USA as a traditional white fish product in frozen dressed form, by a Canadian fishing company (Knott, 1984).

Pacific hake in Canadian waters are known to be infected with two species of Myxosporean protozoan parasites: Kudoa thyrsitis and Kudoa paniformis. Kudoa thyrsitis has been found in hake harvested in offshore waters west of Vancouver Island and Georgia

Strait; however, Kudoa paniformis was present only in the offshore fish (Kabata and Whitaker, 1981). Mushiness in cooked texture of Pacific hake was considered to be associated with Kudoa paniformis infection (Tsuyuki et al., 1982). Acceptable cooked texture quality is critical if Pacific hake is to be utilized for human consumption in order to fully exploit the resource in Canadian waters. It was therefore the purpose of this investigation to study the textural properties of thermally processed Pacific hake from fish caught in two different fishing areas in British Columbia. A secondary objective of this study was to review the relative importance of Pacific hake in the world hake fishery.

REVIEW OF LITERATURE

The fisheries industry is an integrated activity with the goal of food production. According to statistics compiled by the Food and Agriculture Organization of the United Nations (FAO, 1983), the total world production of fish was 74.5 million tonnes in 1981. Of the total catch, some 50 million tonnes were used directly for human consumption and the rest was reduced to fish meal for animal feed. Establishment of the 200 mile offshore fishery zone in the mid 1970's was generally viewed as a move to conserve fishery resources and increase the opportunity for coastal states to manage and develop their fisheries. At the same time, the declining situation of some traditional fishery resources has generated interest in underutilized fish stock and attention to development of technologies which would make their full exploitation possible.

Nomenclature

Pacific hake (Merluccius productus) is the main object for study in this investigation. It is a white flesh and mild flavor demersal fish, which is a member of the Merlucciidae family under the order Gadiformes. Unlike the meat industry, the seafood industry produces a tremendous number of species and products in the marketplace. Confusion in marketing underutilized species because of using unfamiliar and inappropriate names does happen (Martin et al., 1983). A problem with the nomenclature of hake

and hake-like species was discussed by Brooker (1978), Ryan (1979) and Cohen (1980). It is necessary to comprehend this problem before going on further as this will help when interpreting or comparing views and experimental results of different workers. Table 1 shows the species of three families in the Gadiforms order. It can be seen that common names such as hake, whiting and cod are used among fish of different families. Furthermore, Ryan (1979) reported that the American Fisheries Society included Merluccius productus (Pacific hake) and M. bilinearis (silver hake) in the cod family, Gadidae, but the European ichthyologists separated the hakes and cods due to differences in the structure of the skull and ribs. The U.S. Food and Drug Administration (FDA) has approved the designation of five Merluccius species as whiting, i.e. M. bilinearis, M. productus, M. capensis, M. gayi and M. hubbsi (Cohen, 1980). The FAO/WHO Codex Alimentarius Commission (1978) recommended that the standard for quick frozen fillets of hake on the international market include fish of the genera Merluccius and Urophycis. Martin et al. (1983) reported that a name change from Pacific hake to Pacific whiting was considered by the FDA and U.S. Department of Commerce in 1977. Today, Merluccius productus is known commonly as Pacific hake in Canada but as Pacific whiting if it is to be marketed in the United States.

World Catch

For the purpose of this review, the statistics presented regarding hake will refer to fish belonging to the genus Merluc-

Table 1. Classification of Some Gadoid (Cod-like) Fish

Order: Gadiformes	
Family: Merluccidae	
Merluccius bilinearis	Silver hake/whiting
M. productus	Pacific hake/whiting
M. capensis	Cape hake, stock fish
M. paradoxus	Cape hake, stock fish
M. gayi	Chilean hake
M. hubbsi	Argentine hake
M. merluccius	European hake
M. polli	Benguela hake
M. polylepis	Patagonian hake
Macruronus magellanicus	Patagonian grenadier
Macrurohus novaezealandiae	Blue grenadier
Family: Gadidae	
Gadus morhua	Atlantic cod
Gadus macrocephalus	Pacific cod, true cod
Urophycis chuss	Red hake
Urophycis tenuis	White hake
Melanogrammus aeglefinus	Haddock
Theragra chalcogrammus	Alaska pollack, whiting
Micromesistius poutassou	Blue whiting
Merlangius merlangus	Whiting
Phycis chesteri	Longfinned hake
Family: Moridae	
Lotella rhacina	Southern hake, rock cod
Antimora rostrata	Blue hake

cius. World production of hake increased at a rate of nearly 8% per year during 1971-76 reaching 2.1 million tonnes in 1976 with the USSR contributing 32-55% of the world catch (Whitaker, 1980). With the establishment of the EEZ, the catch of hake by the USSR declined drastically from 1.07 million tonnes in 1972 to 95 thousand tonnes in 1981. After the peak in world hake production in 1976, landings dropped to 1.14 million tonnes in 1981 (Table 2). Replacing the USSR, Argentina, Spain and South Africa have become leading producers of hake. Hake production in North and South America was the highest as compared to other regions from 1978 to 1981. Of the total hake production in 1981, 331 thousand tonnes (29%) were Argentine hake and 319 thousand tonnes (28%) were Cape hake. Pacific hake ranked third with 120 thousand tonnes harvested mainly by the USA and Poland in the Pacific north-east region (Table 3).

Resources

Pacific hake occur along the Pacific coast of North America from the Gulf of Alaska to the Gulf of California. Nelson and Larkins (1970) reported genetic studies which suggested that a single population inhabits the offshore region between British Columbia and Mexico. The hake in Puget Sound of Washington have a much slower growth rate than offshore fish and form a genetically distinct population. A separate and smaller stock which has a slower growth rate also occurs in the Strait of Georgia in British Columbia (Stocker, 1981). A survey carried out by the Inter-

Table 2. World Hake (Merluccius sp.) Production by Year (x 1000 tonnes)

	Fish[3]	1979	1980	1981
Africa	1, 8, 9	156.6	154.6	146.4
Asia	1, 2, 5, 8	27.8	14.1	11.5
Europe[1]	1-6, 8, 9	602.3	397.0	440.5
N. and S. America				
Canada	2	...[2]	0.1	...
Cuba	2, 3, 6, 8	5.1	2.4	1.4
USA	2, 5	29.9	21.5	64.2
Argentina	4	369.6	277.4	228.7
Brazil	4	20.8	19.4	20.5
Chile	3, 7	76.0	68.3	71.5
Mexico	2, 5	0.1	...	-
Peru	3	93.0	159.4	70.7
Uruguay	4	57.0	62.3	81.8
		651.5	610.8	538.8
	GRAND TOTAL	1,435.8	1,176.2	1,142.0

[1]including USSR

[2]... less than 100 tonnes

[3]1- Europoean hake
2- Silver hake
3- Chilean hake
4- Argentine hake
5- Pacific hake
6- Benguela hake
7- Patagonian hake
8- Cape hake
9- Senegalese hake

SOURCE: Compiled from the 1981 Yearbook of fishery statistics, catches and landings. Vol. 52. Food and Agriculture Organization of the United Nations, Jan., 1983.

Table 3. Nominal Catch of North Pacific Hake by Countries and Fishing Area (tonnes)

	1979	1980	1981
Pacific North East			
Bulgaria	-	-	6,756
Japan	3,638	817	132
Poland	22,966	50,816	64,179
USSR	101,070	-	311
USA	13,925	5,438	48,649
Area total	141,599	57,071	120,027
Pacific Eastern Central			
USA	23	15	2
Area total	23	15	2

SOURCE: Compiled from the 1981 Yearbook of fishery statistics, catches and landings. Vol. 52. Food and Agriculture Organization of the United Nations, Jan., 1983.

national North Pacific Fisheries Commission (INPFC) in 1977 indicated that the total Pacific hake biomass was 1.2 million tonnes (Dark et al., 1980). The biomass was distributed evenly in three INPFC statistical areas, 350 thousand tonnes in Vancouver (north of latitude 47°30'), 349 thousand tonnes in Columbia (43°00'-47°30'), 370 thousand tonnes in Eureka (40°30'-43°00') and small quantities in Monterey and Conception areas.

According to reports by Nelson and Larkins (1970) and Swanson and Ridenhour (1978), Pacific hake spawn once a year during December to April in offshore areas of southern California and Baja California. The pelagic eggs hatch in about three days after drifting with ocean currents and the larvae continue to drift before northward migration. Adult hake migrate northward annually in the spring and summer and southward in the beginning of fall. Hake migrating into the Canadian offshore waters were predominantly females of larger body size and old age, exhibiting what is known as latitudinal stratification of age (Stocker, 1981). The impact of old fish age on textural quality in terms of the parasite-host relationship is unknown. Another interesting characteristic of Pacific hake is daily vertical migration which is associated with feeding behavior (Grinols and Tillman, 1970). The fish are found usually in long narrow bands at a constant depth of 183 m (100 fathoms) from the surface and positioned over the edge of the continental shelf. They begin to rise toward the surface in the evening and become dispersed within the water at night. As

a result, midwater trawling is more efficient during day-time operation.

Canadian Hake Fishery

The Pacific hake fishing activities take place in two separate regions in British Columbia, Georgia Strait and vicinity (Area 4B) and South West Vancouver Island (3C) (Buechler and Proverbs, 1983), as shown in Figure 1. The hake fishing operations in the Strait of Georgia take place between February and May when the fish aggregate to spawn in the deep water between Halibut Bank and Gabriola Island. Based on a biological study in 1979, the biomass estimated in Georgia Strait ranged from 10,000 to 38,000 tonnes and a provisional total allowable catch (TAC) of 10,000 tonnes has been recommended since 1980 (Stocker, 1981). Despite the TAC, the landings have been insignificant (Table 4). In 1981 it was reported that two major companies: Pacific Whiting Ltd. and J.S. McMillan Fisheries Ltd., were participating in the fishing operations. Crest Packers Ltd. joined in later in 1982 but Pacific Whiting Ltd. withdrew in the same year. In 1984, it appeared that Crest Packers Ltd. was the only company interested in the hake fishery in Georgia Strait.

The offshore Pacific hake fishery takes place in waters off the west coast of Vancouver Island, from the Amphitrite Point south to the International Boundary and westward from shoreline to the edge of the continental shelf. The offshore TAC has been recommended to be approximately 35,000 to 40,000 tonnes based on

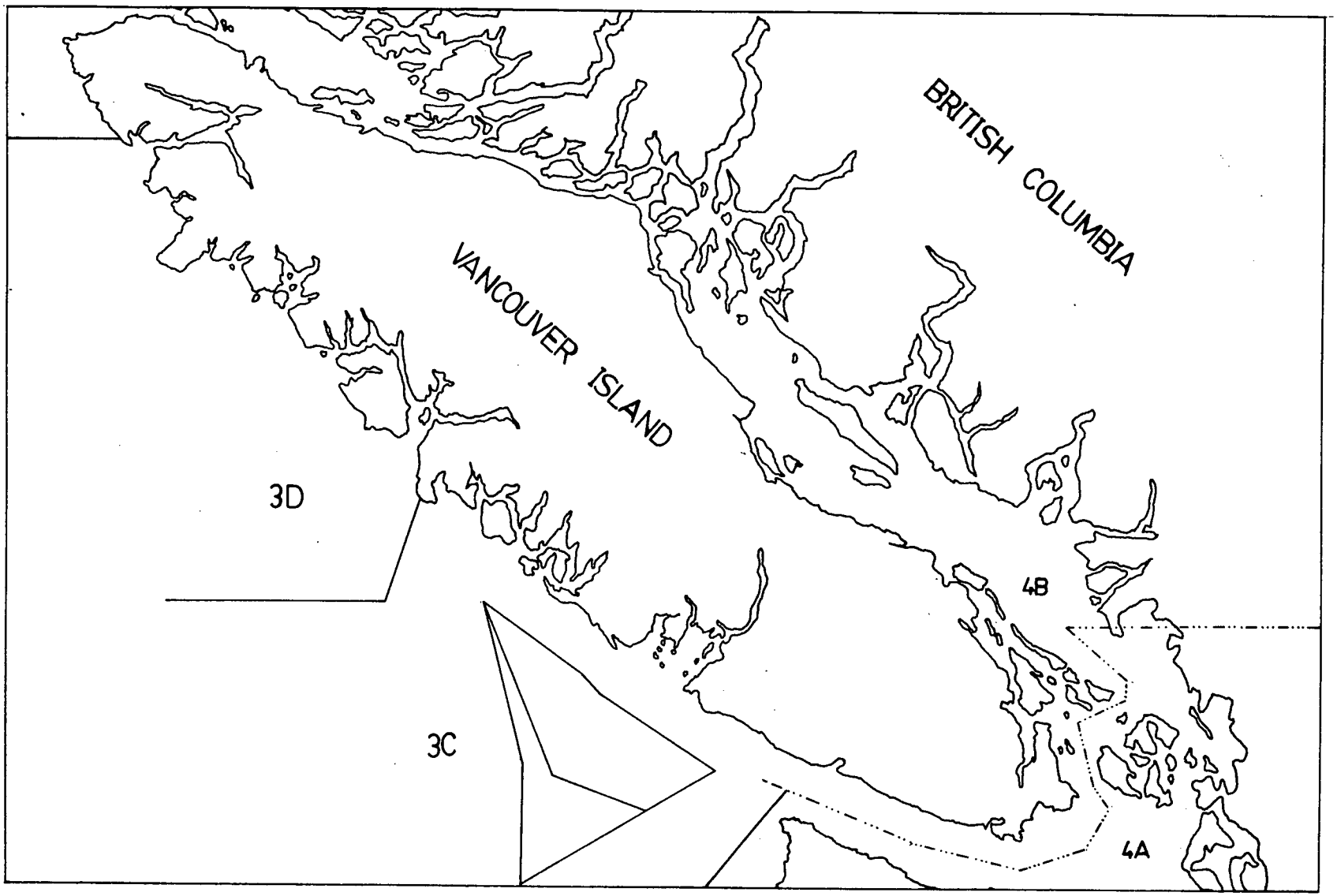

Figure 1. Fishing Areas of Pacific Hake in Waters of British Columbia, Canada

Table 4. Pacific Hake Total Allowable Catch (TAC) and Landings in Canadian Waters (tonnes)

	1980		1981		1982	
	TAC	CATCH	TAC	CATCH	TAC	CATCH
Strait of Georgia (4B)						
1. Domestic fishery	10,000	508	10,000	2,668	10,000	3,085
Offshore (3C)						
1. Domestic fishery	8,000	46	6,000	3,783	10,000	-
2. National fishery						
Poland	5,000	4,943	8,000	2,918	10,000	10,357
Japan	6,000	817	5,000	187	2,500	2,237
	11,000	5,760	13,000	3,105	12,500	12,594
3. Co-operative fishery						
USSR	8,000	4,884	8,000	7,487	8,000	9,390
Poland	5,000	4,795	5,000	5,050	10,000	10,222
Greece	6,000	3,530	8,000	4,927	-	-
	19,000	13,209	21,000	17,464	18,000	19,613

SOURCE: Offshore Division, Department of Fisheries and Oceans, Vancouver, B.C.

the maximum sustainable yield of Pacific hake off the west coast of the USA and an estimated proportion of fish migrating into Canadian waters (Buechler and Proverbs, 1983). The TAC in offshore waters was further divided into three categories of fishing operation: domestic, national and co-operative fishery. The west coast offshore hake has not been exploited to any extent by domestic fishing vessels alone; however, the hake co-operative fishery which began in 1978 appears to be promising and is beneficial to the Canadian fishermen. It involves the catching operation by Canadian midwater trawlers which deliver their catch to foreign vessels for processing. It was reported that the number of Canadian trawlers participating in this co-operative venture increased from two in 1978 to seventeen in 1982 with a catch of 19.6 thousand tonnes worth $3.2 million. The great difference in amount of catch between the domestic and co-operative fishery in offshore waters as shown in Table 4 reflects the underlying problems with regard to acceptability and salability of fish encountered in the hake fishery. The resource has not been exploited fully by the local industry because it is generally considered that the species has poor keeping quality and a soft texture problem.

Quality Problems

The interest in hake production for human consumption in the world market began in the 1970's. Before that time, hake was caught and used to a large extent for fish meal production in South America and on a small scale for industrial purposes in

North America (Nelson and Dyer, 1970; Schroeder et al., 1978). Hake began to emerge later as a promising substitute for cod and haddock when the shortage in supplies of the latter in the North Atlantic became severe (Coburn, 1978). With rapid growth of the hake industry in South American countries for export in various frozen forms, the quality of the raw material as a product in the frozen fish market became an important issue and the factors affecting it in postharvest handling and processing were discussed extensively in a technical meeting in 1977 (FAO, 1978). In North America, several research studies were conducted in the 1970's on the characteristics and quality of hake as well as evaluation of its utilization as human food. Patashnik et al. (1970) estimated from edible fish fillets that offshore Pacific hake had an average of 81.5% moisture, 16.5% protein and 1.6% fat, whereas the Puget Sound hake had about the same proximate chemical composition except that fat was 2.5%. Pacific hake is generally considered as a low fat and moderately high protein fish.

The major quality problems with Pacific hake are denaturation of muscle proteins during frozen storage and parasite infestation. It is well accepted that quality of frozen fish is dependent on the quality of the raw material and an extended storage life can be obtained only if good handling practices are observed during harvesting and freezing.

Various species of gadoid fish in North America have been studied for their storage life. Dassow et al. (1970) stated that

a relatively low myofibrillar protein content in Pacific hake was responsible for ineffective water holding capacity and poor freeze-thaw characteristics with regard to drip loss and texture. They also found that unglazed hake portions stored at -18°C deteriorated in quality within two weeks, whereas glazed portions could be stored for up to ten weeks at the same temperature. If the ice glazed portions were stored at -29°C, their storage life could be extended to 24 weeks.

It is generally believed that large quantities of trimethylamine oxide (TMAO) are present in white flesh demersal fish such as hake and other gadoid fish (Hebard et al., 1982). Studying the quality deterioration in the flesh of Pacific hake during storage at -20°C, Babbitt et al. (1972) observed that formaldehyde (FA) and dimethylamine (DMA) were formed due to an enzyme system present in the muscle and other tissue as a result of breakdown of the endogenous TMAO. The FA formed was postulated to involve reactions which gave rise to crosslinking of the myofibrillar protein. The fish flesh was subsequently reduced in extractable protein and water holding capacity. Packaging in vacuum- or air-sealed moisture vapor proof pouches or wrapping in polyethylene seemed to have little effect on the breakdown of TMAO. Similar results were obtained by Dingle (1978) working on silver hake (Merluccius bilinearis) at frozen storage between -5 and -10°C. Gill et al. (1979) studied frozen storage of red hake (Urophycis chuss) fillets at -5 and -17°C over a period of 35 days and showed

that the cooked fish were toughened as indicated by Instron peak heights and slopes. Regenstein et al. (1982) mentioned that the basis for suggesting the participation of FA in the changes is that FA disappeared long before DMA during storage but they also pointed out that malonaldehyde, a breakdown product from the oxidation of free fatty acids, may also react similarly with proteins. On the other hand, Hiltz et al. (1976) studied silver hake stored at -26°C and found that they could be kept up to six months with negligible deterioration. The enzyme responsible for the TMAO breakdown has not been isolated. The enzyme was said to be active down to near -29°C but much more so in the -9.4 to -3.9°C range (Dyer and Hiltz, 1974).

Crawford et al. (1979) investigated the shelf life of Pacific hake fillets and minced fish blocks by comparing their stability and quality with that of true cod (Gadus macrocephalus). The results showed that Pacific hake was acceptable in quality over a 12 month frozen storage period at -26°C and did not deteriorate more rapidly than true cod. Moisture vapor proof film packing was found to be slightly better than ice glazing in protection against deterioration. Howgate (1979) stated that the toughening of frozen fish flesh stored under unsuitable conditions was not contributed by crosslinking of protein molecules. His study by means of electron microscopy and x-ray diffraction did not show changes in average interfilament spacing which was expected if crosslinking took place. He suggested that the sarcoplasmic

reticulum degraded during frozen storage and acted as "a glue to cement the fibrils together," thereby giving rise to tougher texture.

Protozoan parasites belonging to Myxosporea are common in fish. The parasite is responsible for the abnormal appearance in the flesh. Patashnik and Groninger (1964) observed a milky condition which was associated with high proteolytic activity in some Pacific coast fish such as halibut (Hippoglossus stenolepis), sole (Microstomus pacificus) and (Eopsetta jordani), salmon (Oncorhynchus kisutch) and flounder (Platichthys stellatus). Except for salmon, these fish were infected by a Kudoa species closely resembling Chloromyxum thyrsites which was investigated by Willis (1949) in barraconta (Thyrsites atun). Mushiness in canned South African pilchard (Sardinops ocellata) obtained when the fish was caught at the end of spawning season was reported to be infected by a protozoan parasite of the Chloromyxum species (Van Den Broek, 1965). Parasitization by Myxosporean Chloromyxum thyrsites was also found in Argentine hake and Cape hake (Burt, 1974; 1978) and Peruvian hake (Merluccius gayi peruanus) (Okada et al., 1981).

A high incidence of abnormal mushy texture also occurs in the cooked flesh of Pacific hake. Dassow et al. (1970), and Dassow and Beardsley (1974) mentioned that the mushy condition was often associated with the presence of myxosporean parasites of the Kudoa species in the muscle. The infected portion appeared to have proteolysis of tissue with accompanying liquefaction and mushiness. Later studies showed that the parasite existed in two

forms: one in which pseudocysts appeared as white streaks, and others that were black in color (Anon., 1978). In an investigation designed to elucidate the relationship between texture of cooked flesh and the presence or absence of parasite, extensive samples were collected by Tsuyuki and co-workers from the Strait of Georgia and from offshore waters southwest of Vancouver Island. The fish were filleted and the paired fillets were wrapped suitably and held in frozen storage. One fillet was used for flesh quality study (Tsuyuki et al., 1982) and the other for investigation of parasites (Kabata and Whitaker, 1981). It was found the offshore hake were infected by two species of parasites identified as Kudoa thyrsitis and Kudoa paniformis, whereas the hake from the Strait were infected only by Kudoa thyrsitis. The parasites formed pseudocysts within muscle fibers. The infected fiber contained only either one of the species. The infected fibers were slightly distended and white in color. The presence of the black colored infected muscle fibers was the result of gradual deposition of melanin by the host around the infected area, a defence mechanism which would eventually destroy the spores in the pseudocyst.

Flesh quality studied by Tsuyuki et al. (1982) revealed that those fish infected with only Kudoa thyrsitis contained an enzyme in their muscle tissue which had strong proteolytic activity in the acid range. The acid protease was heat labile and did not lead to an unacceptable mushy texture upon cooking. However, muscle tissue of west coast hake which were infected with Kudoa

paniformis alone or together with Kudoa thyrsitis would demonstrate strong proteolytic activity in both the acid and neutral range. Muscle with proteolytic activity in the neutral pH range would become mushy during slow cooking and the enzyme concerned was relatively heat stable with an optimum activity at 50-60°C.

Konagaya (1980) investigated the parasitization of Kudoa species in yellowfish sole (Limanda aspera) and discovered that proteolytic activity was associated with two types of protease. They were designated as proteases A which hydrolyzed hemoglobin at pH 3 and protease B which hydrolyzed casein at pH 6.5. Protease B activity was not always detected in less infected muscles. Investigations by Patashnik et al. (1982) also revealed the presence of two types of Kudoa species in Pacific hake flesh sampled off the west coast of the United States. Their observations concurred with those of Canadian workers in that the black cysts were the older ones, some of which were devoid of spores and no longer proteolytically active, whereas the white cysts were younger and more proteolytically active, causing the textural problem upon cooking. They also reported that the spores per se did not generate proteolytic activity.

The mechanism of abnormal texture development was hypothesized by Willis (1949) to be due to either the trophozoite of the parasite which may induce autolysis of tissue, or it may secrete extra-cellular enzymes. The proteolytic activity is highly localised within the pseudocyst and while living, the host removed the enzyme from the parasitized muscle fibers by blood

circulation. After death of the host, the active proteolytic enzymes diffuse from the cyst to the adjacent muscle fibers and damage the texture of hake flesh. A different view on the cause of mushiness in cooked muscle of parasitized Pacific hake was held by Erickson et al. (1983). They compared the proteolytic activity in the sacroplasmic fluids of parasitized Pacific hake and unparasitized true cod and found that cathepsin B was present in hake but not in cod, and larger amounts of cathepsin C were present in hake. It was explained that an immunological response to the myxosporean spores might be responsible for the secretion of cathepsins from lysosomes in phagocytic cells, therefore cathepsins may be responsible for the accelerated muscle breakdown. However, the workers did not rule out entirely the possibility that the enzymes were produced by the parasite.

Process Developments

It is rather fortunate that there is no evidence that the myxosporean parasites can cause illness or infection in man (Dassow and Beardsley, 1974; Patashnik et al., 1982) and moderate parasitization does not affect the proximate composition of fish (Dassow et al., 1970). Therefore, the primary concern in utilization of Pacific hake is to minimize the occurrence of mushy texture in the cooked product. The extent of damage depends on the severity of parasitization and on how rapidly and properly the fish was chilled, processed, frozen and cooked. Apparently, the parasites are viable during frozen storage of fish and development

of an undesirable textural quality can occur after the frozen fish is thawed and held for long hours.

Miller and Spinelli (1982) treated minced parasitized Pacific hake muscle with protease inhibitors and found that hydrogen peroxide, potassium bromate and dibasic phosphate peroxides could inhibit proteolysis during frozen storage at -20°C for a month. The muscle maintained a desirable texture upon baking for 20 minutes at 162°C. Thermal processing is known to arrest the proteolytic activity readily if rapid heat penetration to the product is achieved. Miyauchi (1977) and Patashnik et al. (1982) found that fast deep frying produced more acceptable texture than slow oven cooking. It was also found that cooking from the frozen state was preferable to thawing before cooking. Although lean white flesh fish such as hake are not usually suitable for canning (Huss and Asenjo, 1976), it has been reported that some could be canned as fish patties and fish balls. Liver of hake is known to be canned in the USSR. Canning hake roe in oil was carried out on an experimental scale in Peru and the product was found to be acceptable (Beumer, 1974). Hake being canned in southern Brazil was reported by Burt (1978). Oettle (1974) reported that Cape hake was processed into canned spiced (curried) fish. The production of canned hake by South Africa was 2,248 tonnes in 1981 (FAO, 1983). Other process developments being studied, using hake as the raw material, include salting and drying (Lupin, 1978; Sanchez and Lam,1978) and manufacturing of surimi-based fish products (Kudo, et al., 1973; Okada, 1978).

MATERIALS AND METHODS

Fish Sample Preparations

Pacific hake (Merluccius productus) used in this investigation were obtained from two different sources. One sample consisting of 281 fish (W) was obtained from a fishing area off the west coast of Vancouver Island. These fish were caught by a Polish midwater trawler, m/v "Pollux", on 29th September, 1983 at a depth of 140 m by haul No. 192 trawling from 49°15'N, 126°53'W to 49°13'N, 126°60'W. The fish were received on the 20th of October, 1983 when the vessel called at Vancouver. They were transported to the Technology Service Branch, Technology Research Laboratory, Department of Fisheries and Oceans in Vancouver for storage at -29°C.

All the west coast offshore samples were frozen whole fish. The fish were packed in paperboard cartons each containing three 11 kg blocks of frozen whole fish. Each frozen block was 90 cm x 30 cm x 6 cm consisting of one layer of fish twelve to fifteen in number and each block was sealed in a polyethylene bag. The fish were separated by defrosting the block in running tap water mixed with flaked ice. Each fish was cut along perpendicular lines behind the pectoral fin and in front of the tail fin to remove the head and tail. The viscera and peritoneum were also removed from the body cavity. Each fish was filleted on both sides of the body. The paired fillets were cleaned, placed into Barrier Bags (Cryovac Division, W.R. Grace & Co. of Canada Ltd.) and vacuum-

packed with a Multivac vacuum sealing machine to improve product quality and shelf life (Anderson, 1983). Each bag was numbered and the weights of the whole fish and the paired fillets produced from it were measured. The yield for each individual fish was determined as the body weight of paired fillets compared to the original weight. The temperature of the fillets was kept as low as possible throughout the procedure. The vacuum packed fillets were rapidly re-frozen and stored at -29°C until further processing.

Fish from the Strait of Georgia were harvested by the mid-water trawler, m/v "Sea Crest", operating in the fishing area south of Halibut Bank at a depth of 120 m. The fish were stored in refrigerated seawater tanks at -1.1 °C on board the vessel for two to three days before landing. The first batch of 152 fish (SF) caught in the Strait was received on the 25th of March, 1984. They were transported to the fisheries laboratory with flaked ice in insulated plastic containers. In the laboratory, they were placed into large polyethylene bags with ten to fifteen fish per bag and were stored immediately at -29°C. The fish were defrosted and filleted within ten days by the procedure described for the west coast samples. Each vacuum-packed bag containing the paired fillets of a fish was numbered.

The second batch of 211 fish (SC) was received on the 26th of April, 1984. After being transported to the laboratory with flaked ice in insulated containers, the fish were stored in that way in a cold room at 0°C. The fish were filleted starting twelve

hours later with the work continuing until filleting was completed within three days. Similarly, the paired fillets were vacuum-packed, numbered and frozen for storage at -29°C. The yield for each individual fish was also determined. Again, the temperature of the fish was kept as low as possible throughout the handling procedure.

Microscopic Examination of Parasites in Fish Flesh

A previous study of musculature parasitization of Pacific hake sampled from Georgia Strait and offshore waters west of Vancouver Island showed that the two species of myxosporean parasites could be identified by differences in the shape and size of their spores (Kabata and Whitaker, 1981). These workers also divided the fillet length of each fish into six areas to investigate the distribution of parasites and found that the anterior portions of the fish body contained the most pseudocysts formed by the parasites, whereas the incidence decreased gradually towards the posterior end. Okada et al. (1981) studied myxosporean infestation of Peruvian hake and also found that the anterior part of the fillet was the most severely infested.

In this study, the occurrence and severity of parasitic infection were evaluated by wet mount microscopic examination of the fish muscle tissue. A piece of tissue 0.5 cm x 0.5 cm x 0.5 cm was dissected from the anterio-dorsal portion of the right hand side fillet. It was teased apart on a glass microscope slide (Corning, 3" x 1" plain). With addition of four drops of water, the teased tissue sample was covered by a cover glass (22 mm

square) and examined by a light microscope (E. Leitz Wetzler) under phase contrast illumination at a magnification of x400. By observing the morphology of the spores, it could be determined whether the fish had a mixed infection by both Kudoa thyrsitis and Kudoa paniformis or a single infection by either one of the parasite species. The parasite spore intensity was evaluated by counting the number of spores in a randomly selected field. The counting was repeated in three randomly selected fields and the total was averaged. Severity of parasitization was determined by arbitrarily categorizing the spore intensity into four levels: i.e., fewer than 5 spores per field was considered as light infection, between 6 and 19 spores per field as medium infection, between 20 and 29 spores per field as heavy infection, and 30 or more per field as very heavy infection. If the fish had a mixed infection by two Kudoa species, then the severity was based on counting the number of Kudoa paniformis spores. The rationale for this was based on the findings of Tsuyuki et al. (1982) that Pacific hake infected with Kudoa paniformis would develop unacceptable cooked mushy texture while those with Kudoa thyrsitis only would not. Microscopic wet mount examination was carried out for all 644 fish samples obtained both from offshore waters west of Vancouver Island and the Strait of Georgia.

Furthermore, photographs of both types of myxosporean spores were taken under a light microscope (Wild, Heerbrugg, Switzerland) with Kodak Ektachrome 160 film (ISO 160/23°, tungsten 3200K). The

samples were prepared by aqueous wet mount as described earlier, and micrographs were taken at various magnifications.

For scanning electron microscopic examination, hake fillets infected heavily with Kudoa species parasites were used. Tissue cubes of 5 mm in size were prepared from frozen fish and fixed using a double fixation procedure. Initially, the cubes were treated with 5% glutaraldehyde, vacuum desiccated and water washed. They were then fixed in 2% aqueous osmium tetroxide in Palades buffer (1:1) for secondary fixation. After that, samples were water washed, dehydrated in increasing concentrations of ethanol and processed in a critical point drier (Bomer SPC 1500) using CO_2 as the critical point fluid. The samples were sputter coated with gold in an Eiko IB-2 evaporator and examined by a Hitachi S500 scanning electron microscope.

Thermal Processing

Canning of Pacific hake

Pacific hake were canned in three different types of commercial metal food containers in this study. They were half-pound salmon (No. 1/2 flat), quarter-pound salmon (No. 1/4 flat) and the quarter dingley cans. Half and quarter pound salmon cans were three-piece tinplate cylindrical cans of size 307 x 200.5 (diameter = 87.3 mm, height = 51.2 mm) and 301 x 106 (diameter = 77.8 mm, height = 34.9 mm) respectively, manufactured and supplied by American Can Company, Vancouver. Quarter dingley cans were thin profile two-piece aluminum cans of size 105 mm x 76 mm x 21.3 mm purchased and imported from Noblikk-Sannem, Norway.

Determination of process schedules by heat penetration

The process time for canning Pacific hake in each type of container was determined by Stumbo's method which takes both heating and cooling lags into consideration (Stumbo, 1973). For the purpose of this investigation, process schedules were worked out separately for retort temperatures at 115°C (239°F), 120°C (248°F) and 130°C (266°F) for each type of container.

A test process of 65 minutes cooking time at 120°C and cooling time of 24 minutes was scheduled for hake packed in half-pound salmon cans processed in a 60 cm diameter pilot scale still vertical steam retort (Patterson Broiler Works Ltd., Vancouver, B.C.). Fish samples of the first batch of hake collected from the Strait of Georgia with light or medium levels of infection in terms of parasite spore intensity, were used in the test process. After being partially thawed in a cold room for one hour, the fillets were cut into container height size. The cutlets were then stuffed into the cans vertically by hand. The can body was fitted with a thermocouple receptacle which held a custom copper/constantan thermocouple (O.F. Ecklund Inc., Cape Coral, FL) so that the junction was on the can axis. The thermocouple measured the temperature history at the coldest point which was assumed to be the geometric center of the can. The tip of the thermocouple was imbedded into a piece of fish cutlet or in between the cutlets. About 175 g of fish were placed in the can. The can was double seamed under a vacuum of 70 kPa by a Rooney semi-automatic

sealer (Rooney Machine Co., Bellingham, WA). Ten test cans were used for each test run and a total of three test runs were carried out.

The test cans were kept in a cold room for 24 h before they were processed. The thermocouple in each can was connected with a 5 m long thermocouple wire (TT-T-24 solid teflon, copper/constantan-duplex-ANSI type T) which passed through the retort wall and connected to a Kaye Ramp II Processor/Scanner data logger. The thermocouple wire was numbered in accordance with the number of the thermocouple placed in the can. The circuit which consisted of the thermocouple and lead wire of the same number was calibrated before it was used for processing. For calibration, the thermocouples were immersed in an oil bath (Haake N3, Fisher Scientific Co., Vancouver, B.C.) heated up to 115, 120 and 130°C separately as measured by an ASTM certified thermometer (immersion type, range 94-136°C, Brooklyn Thermometer, Farmingdale, NY). The readings of temperature by the thermocouples were recorded at one minute intervals by the Kaye data logger continuously for 10 minutes at each oil bath temperature. The corresponding readings from the thermometer were also recorded. The difference between the average of the pairs of readings was obtained and used as the correction factor for each thermocouple. In addition to the ten thermocouples which monitored the product center temperatures, four additional thermocouple wires were used for monitoring the retort temperature in the test process. The sensing junctions of

these thermocouples were held in the center of a spring coil so that they could be placed in between the test cans but not touching the containers. These thermocouples wires were also calibrated in the manner described for the thermocouples used in test cans.

The initial temperature of the product was taken as the average of all the test cans at the start of the process (National Canner's Association, 1976; Bee and Park, 1978). This was maintained close to 5°C in this study. The setting up of the test cans in the retort for the test process was completed as quickly as possible in order to maintain the low initial temperature. The test cans were processed in pure steam. After closing the retort lid, the retort was brought up to the desired processing temperature in five minutes. The temperatures of the retort and test cans were monitored by the Kaye data logger at one minute intervals throughout heating and cooling. The data logger was also hooked up to a digital tape recorder (Model 300 D/110, Columbia Data Products, Inc., Columbia, MD) so that the temperature readings were recorded on a four track magnetic tape.

A test process of 55 minutes cooking time at 120°C and cooling time of 24 minutes was used for hake canned in quarter-pound salmon cans. A similar procedure as described for the previous test process was repeated for the quarter-pound salmon cans with a few exceptions. These cans were stuffed with about 85 g of partially defrosted fish cutlets and closed by a seaming machine without making a vacuum in the can. The quarter-pound salmon cans

were processed in an FMC Model 500W water immersion pilot scale sterilizer with a come-up time of seven minutes. The cans were placed at the center of the retort car on the sixth tray counting from the car bottom. Five empty trays were stacked on top of the cans and a tray cover plate was placed on the top of the car. All the trays and the cover plate were positioned horizontally on top of each other so as to facilitate circulation of water between them. The cans were lined up along the length of the tray to minimize the effects of temperature difference between the ends of the retort car. Four reference thermocouples were placed near the test cans to monitor the retort temperature.

As for the quarter dingley cans, the test process was scheduled for 55 minutes of cooking time at 120°C and 24 minutes of cooling time. About 85 g of partially defrosted fish fillets cut into container size lengths were stuffed into each can. Since no custom thermocouples were available for this type of container, thermocouple wire with the copper and constantan conductors soldered at one end was used as the hot junction for heat penetration measurement. The wire was passed through one end of the can using a brass packing gland so that the hot junction was positioned at the geometric center. The end of the thermocouple wire inside the can was embedded in a slice of fish cutlet. The dingley cans were closed without vacuum and processed in the FMC Model 500W water immersion sterilizer as described for quarter-pound salmon cans.

After the process run, the test cans were opened and checked to ensure that the end of the thermocouple or thermocouple wire was not shifted from the geometric center of the container. The temperature data of the test cans were transferred to an Apple II microcomputer and analyzed by programs developed by Smith and Tung (1983). The transfer was achieved by manual data entry onto a file based on the temperature data printout from the Kaye data logger or by transfering the data from the magnetic tape to a file through a communication link between the Columbia recorder and the microcomputer.

The program was designed to estimate the process time required to achieve a given process lethality for a specific process temperature and initial temperature. For each type of container, heat penetration data of the three test process runs were used in the estimation. The first part of the program involved analysis of the heat penetration curves obtained from each test can in each test run. Other information required and fed into the program for calculation were data such as correction factors of the thermocouples, retort temperature and cooling water temperature. Input of thermocouple correction factors improved accuracy in estimation. Retort temperature of each test process was obtained by averaging the temperature readings of the four reference thermocouples during the last ten minutes of the heating time. Cooling water temperature was the mean of the constant readings of reference thermocouples at the end of the cooling period.

The heating and cooling curves for each test can were separately displayed graphically on the screen of the computer monitor for analysis. The plot of the heating curve showed the logarithmic values of the differences (g) between retort and product center temperatures as a function of heating time in minutes on a linear scale starting with steam-on as zero time. The curve was characterized by an initial lag of the product center temperature followed by a linear relationship between log g and heating time. The data points deviated from the linear relationship as the product center temperature approached the retort temperature at the end of heating. Any error in data entry could be corrected at this point of time before further analysis was carried out. A straight line was drawn graphically on the monitor screen through the data points on the linear portion of the curve by manipulating the joy sticks. The limits of the straight line drawn were selected so that the equation for the chosen line could be derived by means of least squares linear regression analysis. The goodness of fit was indicated by the value of the coefficient of determination (r^2). At the same time, the heating curve parameters were calculated.

The heating rate index, f_h, was defined as the time in minutes required for the linear portion of the curve to traverse one logarithmic cycle. The heating lag factor, j_{ch}, could be calculated from the equation:

$$j_{ch} = \frac{T_r - T_{pih}}{T_r - T_{ih}}$$

where T_r was the retort temperature and T_{ih} was the initial heating temperature. The pseudo-initial heating temperature, T_{pih}, was the temperature indicated at the point on the plot where extension of the linear portion of the heating curve intersected a vertical line drawn from a point on the horizontal axis marking 58% of the come-up time starting from steam-on. Stumbo (1973) believed that 30-50% of the come-up time contributed to the lethal value of the process and 42% is the commonly used figure for the come-up time effectiveness in the process time calculation.

The cooling curve made use of the relationship between the logarithmic values of m (the difference between temperatures at the product center and the cooling water) and cooling time in minutes. A cooling lag of the product center temperature was shown as the initial curved portion of the cooling curve which was followed by a linear relationship between the two variables. Similarly, the best fitting straight line was obtained by means of least squares linear regression analysis using the data points on the linear portion of the curve. The cooling curve parameters were then calculated. The cooling rate index, f_c, was defined as the time in minutes required for the linear portion of the curve to traverse one logarithmic cycle. The cooling lag factor, j_{cc}, was derived from the equation:

$$j_{cc} = \frac{T_w - T_{pic}}{T_w - T_{ic}}$$

where T_w and T_{ic} were the cooling water and initial cooling temperatures respectively. The pseudo-initial cooling tempera-

ture, T_{pic}, was the product temperature indicated at the point where the extrapolation of the linear portion of the cooling curve intersected the vertical axis at the beginning of the cooling period.

In the second part of the program, the heat penetration parameters, f_h, j_{ch}, f_c and j_{cc} of each test can obtained from the test process were tabulated for estimates of process time for retort temperatures (T_r) separately at 115, 120 and 130°C. The program was designed to calculate the desired process schedules by assigning z = 10C° (18F°) to characterize an organism with respect to its relative resistance to lethal temperatures. The z-value was defined as the number of degrees in temperature required for the thermal destruction curve to traverse one logarithmic cycle. The equation used to calculate the process time, B, in minutes was:

$$B = f_h (\log j_{ch} I_h - \log g_c)$$

where

$$I_h = T_r - T_{ih}$$

and g_c = difference between retort temperature and the maximum temperature of product center at steam-off time.

In order to determine g_c it was necessary to use Stumbo's table of z = 18F° showing the relation of f_h/U and g_c for various values of j_{cc}. The process value $U = F_o F_i$, where F_o = target lethality in minutes and F_i = time at the retort temperature equivalent to 1 minute at 121.1°C. That is, $F_i = \log^{-1}((121.1 - T_r)/10)$.

Since the temperatures used throughout were in degrees Celsius, the g_c values obtained from the Stumbo's table had to be multiplied by 5/9. For this investigation, the initial temperature, T_{ih}, was assumed to be 0°C for process time estimation. It was also decided that a target lethality value of 6 minutes (F_0 = 6 min) was suitable for the process schedules. The operator's process time (P_t) was evaluated by the equation:

$$P_t = B - 0.42\ 1$$

where 1 was the come-up time in minutes.

The estimated values of P_t derived from all test cans for a specific retort temperature were averaged for each type of container to determine the mean and standard deviation. The proposed operator's process time P_t* was derived from the mean of all estimated P_t values plus three standard deviations. That is,

$$P_t^* = \text{mean of estimated } P_t + 3 \text{ S.D. } P_t$$

The last part of the program was designed to confirm whether the proposed process schedule would result in lethality equivalent to or higher than the target lethality chosen. Using the proposed operator's process time, the values of delivered lethality of all test cans were calculated. These values were totalled and their mean was determined which should be equal to or greater than the target lethality, i.e. the mean delivered lethality should be 6 minutes or more in the case of this study.

Canning According to Predetermined Process Schedules

Fish samples obtained from Georgia Strait (SF and SC) and the west coast offshore waters of Vancouver Island (W) were canned in three different types of containers and processed at 115, 120 and 130°C. Only fish with light or medium levels of infection by the parasites were used in canning to ensure homogeneity in raw material quality.

Half pound cans in the vertical steam retort

Fifteen cans were cooked for each process run which was repeated three times per process schedule at 115, 120 and 130°C. Each can was filled with 175 g of partially thawed fish cutlets that were cut to container height size. Five of the cans contained fish from the west coast offshore waters. The rest contained fish samples from Georgia Strait, five each with SF and SC samples. As mentioned before, the Georgia Strait hake collected in the first batch (SF) were frozen before they were partially thawed, filleted and re-frozen during sample preparation, while the second batch (SC) fish were chilled before filleting and frozen storage. In general, the size of the fillets for the west coast offshore fish was large and some could be separated into two portions for stuffing into two cans. On the other hand, the fillets of the Georgia Strait fish were sufficient to fill only one container, and often, fillets of two fish samples were pooled together to make up the fill weight. Each can was labelled and the fish sample in the can was identified by the number assigned to it earlier during sample preparation. The cans were

vacuum closed at 70 kPa and then kept in the cold room for 24 h before processing. Three of the five containers with SF samples were fitted with thermocouples in the manner described for the test process. Four reference thermocouples were also placed among the cans in the retort. The product center and retort temperatures were monitored throughout the whole process run at one minute intervals using the Kaye data logger.

Quarter pound cans in the FMC water immersion sterilizer

The design of the process runs regarding number of runs and number of containers per run for this subject was similar to that of half pound salmon cans with a few exceptions. The fill weight of the can was 85 g and the cans were closed without vacuum. Since a smaller fill weight was required for each container, the size of hake from the Georgia Strait was sufficient to fill two cans. The two cans containing the cutlets of the same fish sample were cooked by different process schedules. As for the west coast offshore fish, fillets of each fish sample were sufficient to fill three cans. Cans containing cutlets of the same west coast fish sample were cooked by different process schedules. Similarly, the product center and retort temperatures were monitored throughout each process run at one minute intervals.

Quarter dingley cans in the FMC water immersion sterilizer

The design of process runs and the procedure in carrying out the cooking was the same as that described for quarter pound salmon cans. The fill weight of the can was 85 g, and the fish

samples were prepared in the same manner as for quarter pound salmon cans. The product center and retort temperature were monitored throughout all process runs at one minute intervals.

Other Cooking Methods

The hake samples were cooked by baking and steaming methods developed by the Technology Research Laboratory of the Department of Fisheries and Oceans. Frozen fillets of each fish sample were thawed in a polyethylene bag immersed in 20°C (68°F) water for one hour. They were then cut into portions of 5 cm x 5 cm and wrapped by a sheet of aluminum foil. For baking, the oven (Westinghouse) was pre-heated at 177°C (350°F) for 15 minutes and then the wrapped samples were placed in it for 25 minutes. For steaming, the wrapped samples were placed above boiling water on a rack in a covered Dutch oven and cooked for 10 minutes. The fish were also cooked in a microwave oven (Hot Point, RK 9300, Camco, Inc., Toronto, Ont.; max. power output = 625 W). The thawed fish sample was wrapped by a sheet of paper towel and placed on a styrofoam tray in the oven. Cooking was done by setting the oven to autocook for approximately two minutes followed by one more minute of manual cook until the fish muscle could be flaked easily.

Five samples of hake fillets from fish of west coast offshore waters were cooked by canning, baking and steaming. Each sample was divided into three portions for the treatments. For canning, the fish was processed in quarter dingley cans at 130°C retort temperature according to the schedule determined earlier. The

temperature histories within the fillets during baking and steaming were measured by inserting calibrated thermocouples into the fish meat and monitoring temperatures with the Kaye data logger at one minute intervals. These experiments were carried out with three replications.

For each batch of hake harvested from the Georgia Strait, three samples were cooked by steaming and baking. Fillets of each fish sample were divided into two portions for the treatments. The experiment was repeated three times.

Determination of Weight Loss During Cooking and Textural Properties of Cooked Fish Samples

The loss of weight by the canned fish samples was determined. The partially defrosted fish cutlets were weighed before stuffing into the can for processing. After cooking, the cans were checked for leakage and physical damage. The liquid exuded from fish flesh during cooking was drained from the can for two minutes by pouring the cooked fish into a sieve (No. 10 mesh size, 2.0 mm). The drained weight of the cooked fish was then measured. The weight loss due to fluid was determined as the difference between fill weight and drained weight of fish and expressed as a percentage of fill weight. The weight loss was also determined for each fish sample cooked by baking, steaming and microwave heating.

The texture of canned fish was evaluated within two weeks after processing. Fish samples cooked by baking, steaming and

microwave heating were assessed immediately after cooking and cooling the cooked fish to room temperature. As soon as the exuded liquid from the fish was drained away, white muscle of the cooked fish sample was separated from skin, bones, dark muscle and blood vessels using a pair of scalpels. Texture measurement was carried out on 25 g of white muscle. The muscle was flaked in a cup using the scalpels and then placed into the standard Kramer Shear-Compression cell with diminished capacity. The number of blades of the test cell was reduced from 10 to 4 and the stationary metal box was modified with two aluminum adaptors to retain only 4 slots for the blades to drive through. The flaked muscle was packed evenly at the cell bottom by tapping it with the broad end of a cork attached to a scalpel and tested immediately. The cell was driven by an Instron Universal Testing Instrument (Model 1122, Instron Corporation, Canton, MA) equipped with a 500 kg load cell. The blades were driven at crosshead speed of 50 mm/min. The chart speed for recording the force curve was set at 100 mm/min and the full scale load on the chart was 100 kg. The compression cycle was terminated immediately after the blades emerged from the bottom of the stationary metal box. Duplicate texture measurements were made for each cooked fish sample. Each force curve was examined by measuring the peak height to provide an index of cohesiveness and the slope of the linear portion indicated firmness of the cooked fish texture.

Statistical Analyses

As described before in the heat penetration history study, linear regression analysis, which is part of the computer program, was applied to determine the best fitting straight line to the linear portion of the heating and cooling curves.

The raw data for each attribute obtained from the texture measurements of cooked fish samples were tested for normality by the rank procedure of SAS packaged program (Ray, 1982) using the UBC mainframe computer (Amdahl 470/V6-II). They were later analyzed by an analysis of variance program, UBC MFAV, and an F-test was performed at $p < 0.01$ to determine whether there was a difference between treatment means. Duncan's multiple range test was also available in the same program to further compare the treatment means at $p < 0.05$ to test for statistical significance of the difference among treatment means.

Computer Graphic Analyses

The printouts of heating and cooling curves by the Apple II microcomputer during the study of heat penetration history in the test process were relatively small and made on poor quality thermal print paper. For the purpose of illustration, representative heating curves for the heat penetration history of each type of container were drawn with the aid of the mainframe computer using a packaged program, UBC Plot Subroutines and Programs. The representative cooling curves of each type of container were drawn by an interactive program, Ace: Graph developed by the UBC

Department of Civil Engineering. Both heating and cooling curves were plotted by a graphic package, QMSPLOT, using a QMS Laser-grafix 1200 printer.

RESULTS AND DISCUSSION

The raw fish materials for this study were obtained from commercial sources. Their availability was limited by a number of factors such as fishing seasons and fishing activities. It has to be noted that under such constraints, the quality of the raw materials for this study could not be controlled by the experimenter until the fish were delivered to the laboratory. Since the suitability of using Pacific hake harvested in Canadian waters for thermal processing was under investigation, the use of raw fish materials from commercial sources would be of value from a practical point of view. Understanding the commercial practices in postharvest handling of Pacific hake would be necessary for optimizing quality of the fish for further processing into value added products by shore based facilities such as canning.

Handling of Pacific Hake After Harvest

Fish harvested in the west coast offshore waters and the Strait of Georgia were handled differently. The fishing operation in the offshore waters was either carried out alone by foreign fishing vessel or jointly by foreign and Canadian fishing vessels under a co-operative arrangement. During co-operative fishing operations, fishing was carried out by a Canadian midwater trawler. After a trawl run, the cod end of the trawl net which contained the catch was released to the sea and attached to some floats. The foreign vessel waiting nearby retrieved the cod end

later. The period that the catch remained in the seawater varied, but it was minimized to prevent quality deterioration of fish. After hauling up the catch to the deck, the fish were dumped into refrigerated seawater (RSW) tanks. Again, the holding time for fish in the RSW tanks also varied and it depended on the efficiency of the processing line. Hake was processed into one of varieties of product form such as frozen blocks of headed/gutted fish, dressed fish or fillets. The processed fish were packed in aluminum trays and rapidly frozen in contact plate freezers. After glazing, the blocks were placed in a polyethylene bag, packed in a paperboard carton and stored at a temperature between -20 and -40°C. The west coast offshore Pacific hake samples for this study were obtained from a Polish vessel and only incomplete information was available regarding how the fish were treated on the foreign vessel. It was presumed that they were handled with the same procedure described above, except that they were frozen into whole fish blocks directly. Figures 2 to 7 show a co-operative fishing operation in the offshore waters and hake processing on board the foreign fishing vessel.

The Canadian midwater trawler was smaller in size as compared to the foreign vessel. Apparently, the vessel, m/v "Sea Crest" which provided the fish for this study was one of two vessels fishing during the spring of 1984 in the Strait of Georgia. The vessel was about 100 gross tonnage equipped with six RSW tanks for

Figure 2. Co-operative Fishing in West Coast Offshore Waters

Figure 3. Retrieving Cod-end of Trawl Net by Foreign Fishing Vessel

Figure 4. Dumping Catch into Opening on Deck for Holding in RSW Tanks

Figure 5. Heading and Gutting of Hake

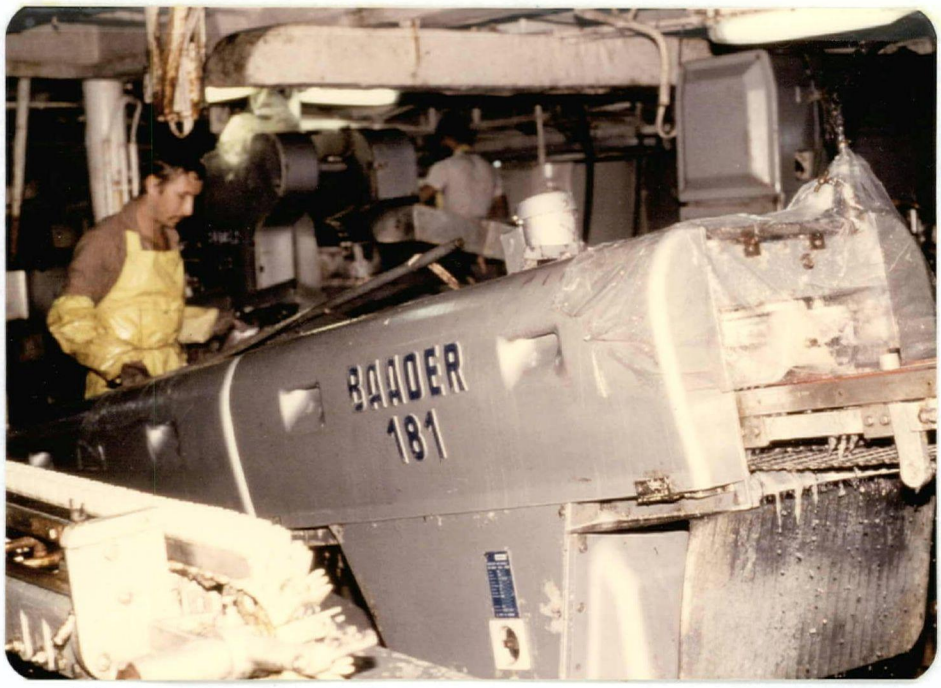

Figure 6. Combined Heading and Filleting Machine Used in Processing Line

Figure 7. Packing Hake Fillets in Trays for Contact Plate Freezing

a total storage capacity of 90 tonnes. It was operating a Polish rope midwater trawl net. After each trawl run, the net was emptied and the fish were stored in RSW tanks at -1.1°C (30°F) without further processing. The duration of the fishing trip depended on the quantity of catch as it might take two to three days to fill up all the RSW tanks. The catch was unloaded at Steveston, B.C. during the night time when the atmospheric temperature was low for better quality of fish. Fish were transferred from vessel to pier by a fish pump (Transvac MKI, Innovac Technology Inc., Vancouver, B.C.) and packed in a large polyethylene lined plywood box. Flaked ice was placed only at the bottom and on top of the box. Pacific hake caught in Georgia Strait was not marketed in Canada but transported to the USA for processing into frozen dressed fish. Post harvest handling of hake caught in Georgia Strait is shown in Figures 8 to 11.

Some of the advantages in using RSW for storing fresh fish are greater speed of cooling, less textural damage due to reduced pressure upon the fish and low holding temperature (Licciardello, 1980). Hiltz et al. (1976) compared holding summer caught silver hake in ice and RSW and found that fish held in RSW still maintained a firm texture after 5 days while those held in ice had very soft texture.

Biological Characteristics

Morphological characteristics of Pacific hake were described in detail by Hart (1973). In general, the fish is elongated in

Figure 8. Trawling in Strait of Georgia Using Polish Rope Midwater Trawl Net

Figure 9. Releasing Catch into RSW Tank

Figure 10. Pumping Hake from RSW Tank on Board Vessel to Pier

Figure 11. Packing Fish in Boxes with Flaked Ice for Transportation

shape, tapering to a fine caudal peduncle from about one-third of its length from the anterior end. It has a large head with a protruding lower jaw that does not possess a chin barbel. The fish can be distinguished by having two dorsal fins, the first one short and triangular and the second one similar to the anal fin which is long and deeply notched. Figure 12 shows the external features of Pacific hake. Pacific hake harvested in the west coast offshore waters and Georgia Strait were somewhat different. The average size of the offshore hake was 783.0 g (n = 281) whereas it was 396.2 g (n = 363) for those from Georgia Strait. These observations were smaller than the previous report stating that average size of offshore hake was 1,080 g as compared to 580 g of the Strait hake (Buechler and Proverbs, 1983).

The yield of production of Pacific hake processed by hand filleting was studied. It was reported by Heen and Karsti (1965) that there were no difficulties in filleting defrosted fish and the yield was at least as high as when iced fish was used. Skin-on fillets provided yields of 44.9% and 45.7%, respectively for offshore and Georgia Strait hake. Yields of 41 to 46% for skin-on fillets processed by hand from cape hake were reported by Burt (1974). Sanchez and Lam (1978) studied Chilean hake and found that the edible portion averaged 47.5% of the fish weight. Swanson and Ridenhour (1978) reported fillet yields ranging between 26 to 31% of the round weight of hake and commented that they were not too soft to be handled by filleters in the industry. Dassow

Figure 12. External Appearance of Pacific Hake (Merluccius productus)

and Beardsley (1974) reported the fillet yield of hake in one commercial trial with fish of an average weight of 1.1 kg was about 25%, an acceptable commercial yield.

Observation of Parasites Spores

Observation of the myxosporean spores in Pacific hake muscle tissue was reported in a study on fish samples caught off the Washington and Oregon coast by Patashnik et al. (1982). They observed two types of myxosporean spore, one being 4-6 um and containing four oval-shaped polar capsules and the other 8-18 um in size, containing four subequal-sized elongated capsules encapsulated in a starlike four-pointed sheath. The small spores were typically found in Pacific hake while the larger ones were seen only in about 30% of the samples together with the small ones. The description of myxosporean spores by Kabata and Whitaker (1981) was more detailed. They observed two species of Myxosporea belonging to the genus Kudoa in the muscle of hake obtained in Canadian waters. They identified one of them, the larger sized ones, as Kudoa thyrsitis and suggested naming the other Kudoa paniformis. Identification of Kudoa thyrsitis was based on shapes of the tips of valves, the anterior end of spores, the posterior end of spores, and the length of the spore. According to these authors, the spores were stellate with valves of unequal sizes. Valves tapered distally in polar view. The polar capsules were pyriform and large with one capsule larger than the other three. The spores of K. paniformis were described as subquadrangular in

polar view, with rounded tips of valves. Their polar capsules were pyriform and subequal in size.

Two types of spores were observed in this study with morphological characteristics similar to the descriptions above. Two types of myxosporean spores were observed under the light microscope as shown in Figures 13 and 14. Scanning electron microscopy of the spores provided greater detail as illustrated Figures 15 and 16. Both Kudoa species formed pseudocysts within the muscle fibers in which the spores were densely packed as thick masses (Figures 17 and 18). The spores were released if the infected muscle fibers were ruptured.

Occurrence and Severity of Parasitization

Microscopic examination of the tissue samples of Pacific hake revealed that fish harvested in the west coast offshore waters were infected by two species of Myxosporea, Kudoa thyrsitis and Kudoa paniformis, whereas those from Georgia Strait were infected only by Kudoa thyrsitis. These observations were similar to the report by Kabata and Whitaker (1981). Among the offshore hake (n = 281), 42.3% had mixed infection, 35.6% were infected by K. paniformis, 14.9% by K. thyrsitis and 7.1% were non-infected. The severity of parasitization is shown in Table 5A in terms of parasite spore intensity. Kabata and Whitaker (1981) examined 322 offshore hake and found that both species of parasite occurred in 18.3% of fish, K. paniformis in 38.8%, K. thyrsitis in 32.2 % and 10.5% were free of infection. The two sets of results were ana-

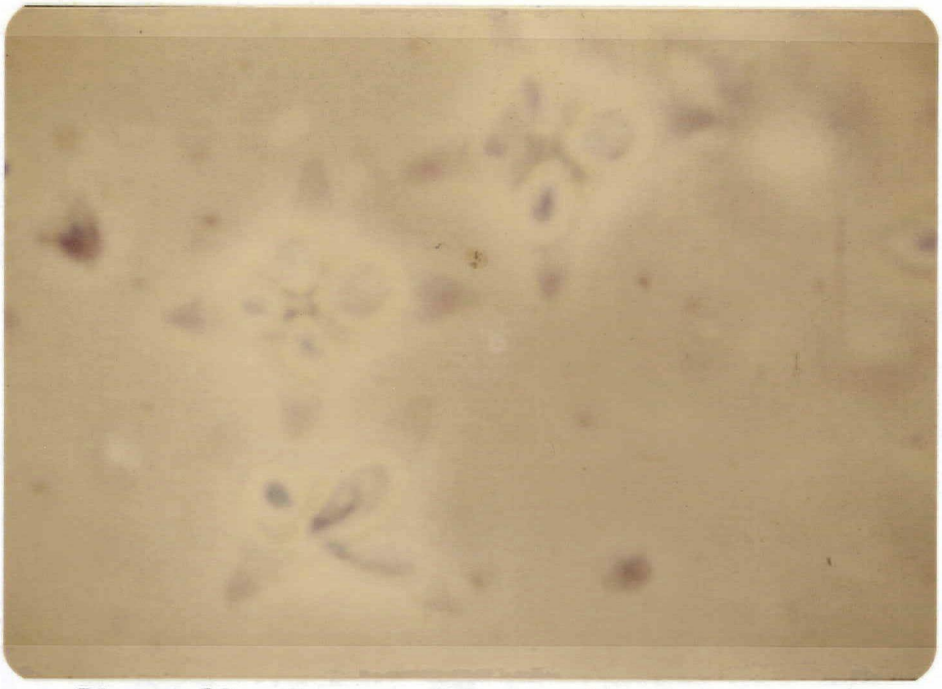

Figure 13. Spores of Kudoa thyrsitis as Seen in Aqueous Wet Mount (1000x)

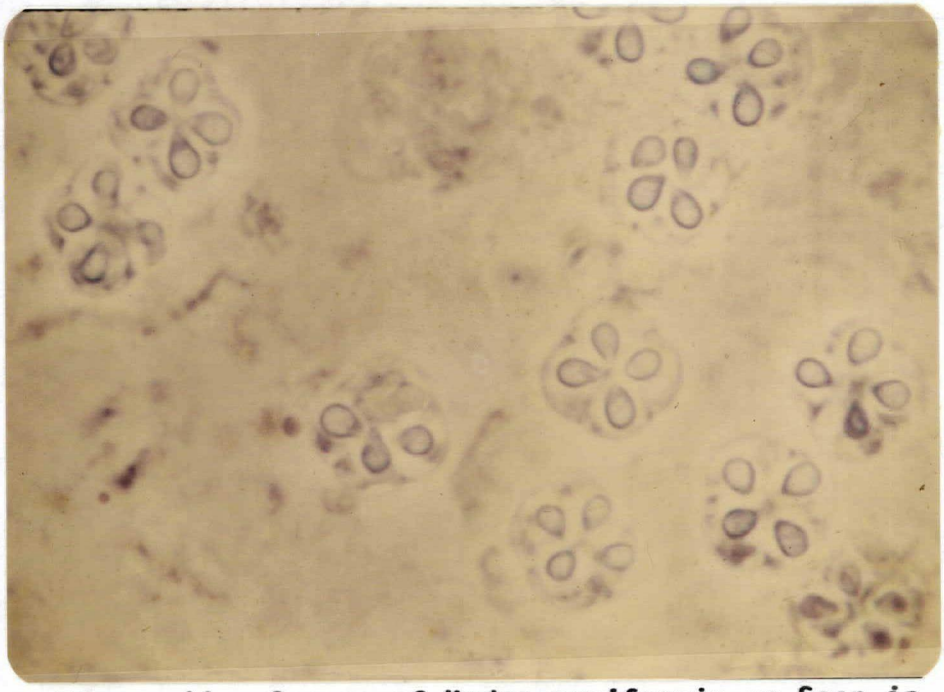

Figure 14. Spores of Kudoa paniformis as Seen in Aqueous Wet Mount (1000x)

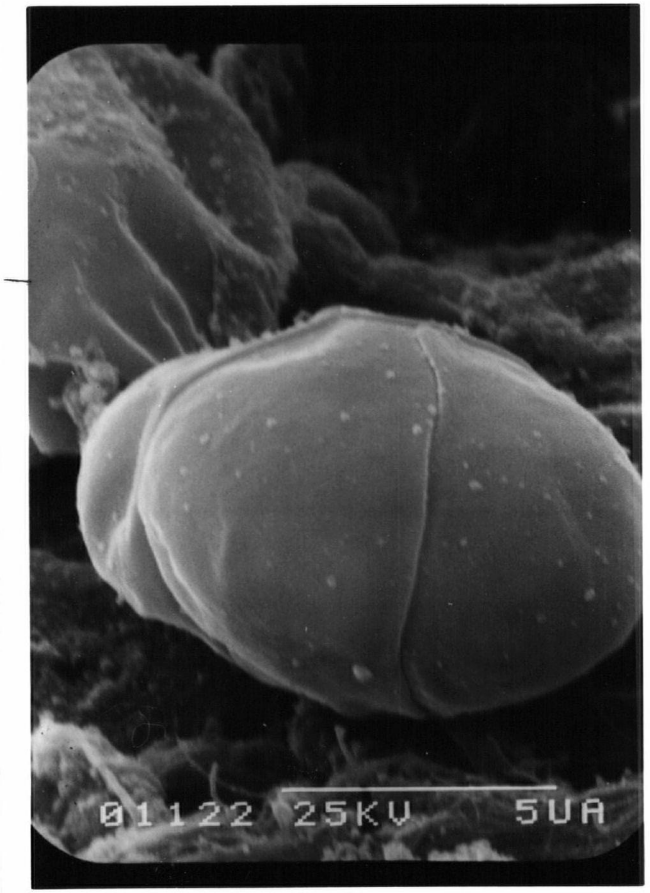

Figure 15. Scanning Electron Microscope Enlargement of Kudoa paniformis Spore

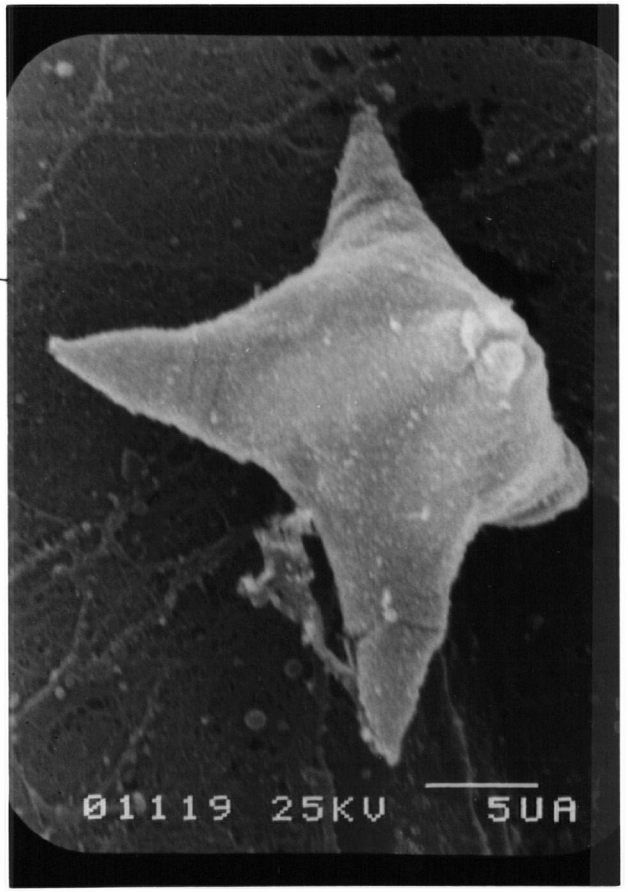

Figure 16. Scanning Electron Microscope Enlargement of Kudoa thyrsitis Spore

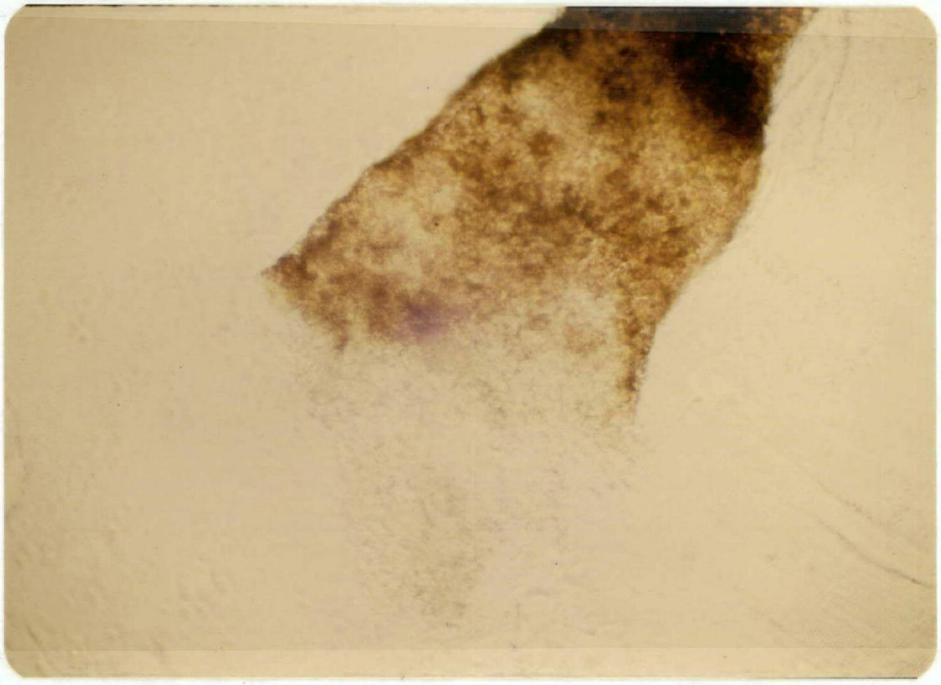

Figure 17. A Pseudocyst Condensely Packed with Parasite Spores. Brown Colour Mass is Melanin Deposition by Host (100x)

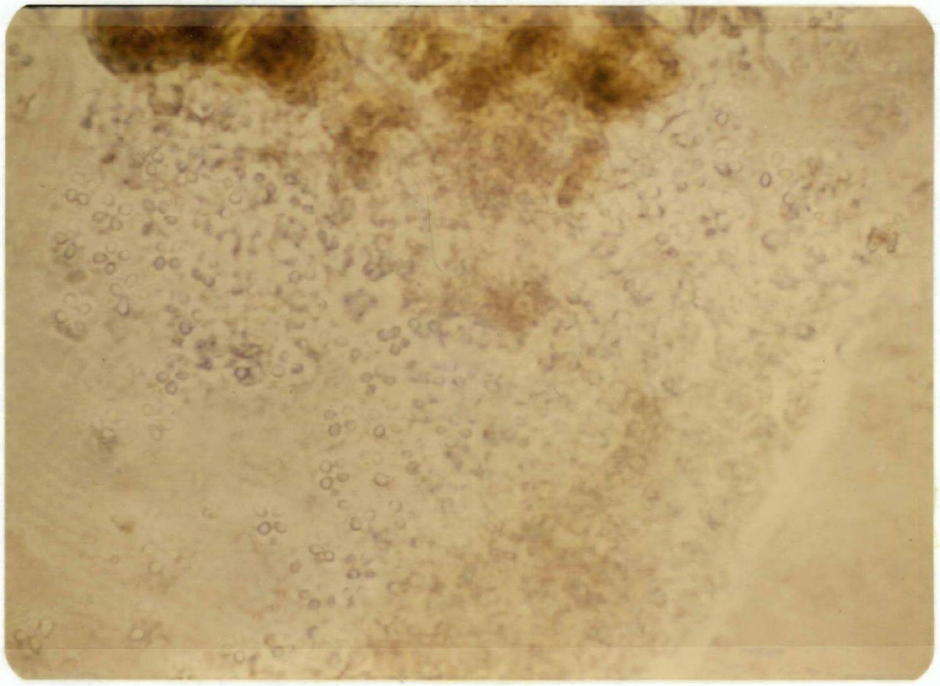

Figure 18. *Kudoa paniformis* Spores Released From Teased Pseudocyst (400x)

Table 5. Occurrence and Severity of Parasitization of Pacific Hake Harvested in Offshore Waters West of Vancouver Island and Georgia Strait

A. Fish samples from offshore waters west of Vancouver Island (n=281)

Parasite Spore Intensity[a]	Types of Parasitization			
	Single		Mixed[b]	Total
	K. thyrsitis	*K. Paniformis*		
None	-	-	-	20
Light (L)	42	60	67	169
Medium (M)	-	15	30	45
Heavy (H)	-	8	7	15
Very Heavy (VH)	-	17	15	32
	42	100	119	281

B. Fish samples from Georgia Strait (n=363)

Parasite Spore Intensity[a]	Types of Parasitization			
	Single		Mixed[b]	Total
	K. thyrsitis	*K. Paniformis*		
None	-	-	-	83
Light (L)	265	-	-	265
Medium (M)	14	-	-	14
Heavy (H)	1	-	-	1
Very Heavy (VH)	-	-	-	-
	279	-	-	363

[a] L: $\leq$5, M: 6-19, H:20-29, VH: $\geq$30

[b]Parasite spore intensity based on counting of *K. Paniformis* spores.

lysed by chi-square test ($\alpha = 0.01$) which indicated that the composition of types of infection is dependent of fish sampling. A higher incidence of mixed infection and a lower incidence of infection solely by K. thyrsitis were found in this study. In most of the mixed infection cases, both parasites had low spore intensities and very often, the number of spores observed in a selected field under the microscope was only one or two. Although it was convenient to examine the sample at x400 magnification, the possibility of observing spores of two different species in a field was quite remote. The tissue sample had to be examined repeatedly in order to confirm mixed infection. As shown in Table 5A, all those fish parasitized only with K. thyrsitis were light in infection. Among fish which had mixed infection, the intensity of K. thyrsitis spore was light except for one sample having medium infection (data not tabulated). Of the 363 fish sampled from Georgia Strait, 76.9% were parasitized only by K. thyrsitis and the rest were free from infection. None of the Georgia Strait fish was parasitized with K. paniformis. The percentage of infected fish from Georgia Strait in this study was lower than the observation by Kabata and Whitaker (1981) that 99 of 100 fish examined were infected by K. thyrsitis.

This study did not intend to draw a relationship between parasite spore intensity and the prevalence of infected muscle fibers or visually apparent hair-like pseudocysts in the fillet muscle. However, those heavily infected fish with a high spore intensity could usually be singled out without difficulty due to

the presence of infected muscle fibers which varied in color from yellowish white to dark brown or black (Figure 19). The variation in color of the infected muscle fiber was thought to be due to a defensive mechanism of the fish in which melanin granules were deposited around the infected fibers to different degrees (Kabata and Whitaker, 1981). Occasionally the presence of black pseudocysts did not coincide with a high spore intensity in the same tissue sample as it was observed that most of the spores were deformed probably due to melanin deposition and confined within the pseudocysts. Patashnik et al. (1982) observed that some black pseudocysts were devoid of spores and no longer proteolytically active. Among the west coast offshore fish, fillets of high parasite spore intensity tended to show softness in texture and the muscle could be easily teased apart when the tissue sample was prepared for microscopic examination.

Design of Process Schedules for Canning of Pacific Hake

Canning would seem to be one of the processing methods to moderate if not overcome the problem of soft texture in cooked hake since rapid heat penetration into the product could inactivate proteolytic enzymes early in the cooking process. Securing raw materials is the first step in the fish canning operation and good fish handling practices have to be observed to ensure good raw material quality. The use of frozen fish as raw material in the canning industry was reported by Heen and Karsti (1965) in many countries to enhance final quality and circumvent quality

Figure 19. Comparison of Parasitized (Left) and Unparasitized (Right) Pacific Hake Fillets

changes inevitably taking place in chilled fish. For the purpose of this study, fish with light and medium levels of infection in terms of parasite spore intensity were used since the majority of the fish were grouped under these two categories.

Three-piece tinplate half and quarter pound salmon cans were chosen in this study because of their local availability and because they are commonly used in the fish canning industry in British Columbia. Quarter dingley aluminum cans were used as their thin profile was expected to enhance heat penetration during processing. Though not common for fish canning in the Canadian West, quarter dingley cans are used for canning mackerel fillets in vegetable oil or tomato sauce by Empaquete P. Janes & Sons Ltd, Newfoundland. Therefore, the canning materials utilized in this investigation are readily available in Canada.

Recommended process times have been outlined for salmon and tuna processing in still retorts using pure saturated steam for half and quarter pound salmon cans to achieve commercial sterility (National Canners Association, 1976). As for quarter dingley cans, the recommended heat processing time for sardines was 60 minutes at 112°C (224°F) using a water cook retort in the Norwegian canning industry (Stenstrom, 1965; Skramstad, 1977). However, the rate of heating of food products in the containers is not only a function of the geometry and heat transfer characteristics of the container but also the physical properties of the food product (Pflug and Esselen, 1980). Studies on heat penetration

history for hake canning were therefore necessary for designing the process schedules.

Vacuum-closed half pound salmon cans were processed in pure steam which is assumed to have an infinitely high heat transfer rate at the surface (Adams et al., 1983). The quarter pound salmon cans and quarter dingley cans which were closed without vacuum were processed in hot water with overriding pressure to balance the pressure inside the cans to maintain their integrity. The heat transfer rate to the container during the water cook was assumed to be greater than the heat transfer rate through the product to the center, therefore this method of processing was adopted for this study. An alternative method of processing with an overpressure would be to use a mixture of steam and air. Nevertheless, Skramstad (1977) found that heat transfer into the center of cans was good whether quarter dingley cans were processed in water-filled or steam-air filled retorts. Wilson (1980) compared processing of rigid cans and retort pouches and commented that the effect of the heating medium on time required to process rigid cans was minor.

Since the majority of the can volume was filled with fish cutlets which were solid, the heat during thermal processing would transfer by conduction through contact points between the can wall and cutlets. A considerable amount of water was exuding out from the fish meat into the can during cooking. This cook-out liquid allowed good contact between the can wall and the product, resul-

ting in heat transfer being a combination of conduction and convection (Wilson, 1980). There are no canned foods that transfer heat purely by conduction or purely by convection as pointed out by Stumbo (1973). Since the fish cutlets virtually did not move inside the can during heating and cooking, the mechanism of heat transfer in this instance was considered to be mainly by conduction.

The process schedules were designed by computer calculation of process time for different retort temperatures. The calculation based on heat penetration data of 30 test cans from three separate retort runs was considered more reliable than the traditional method of using the heating rate of the slowest heating package of the test group (Tung and Garland, 1978). Variation in the heat penetration parameters were observed among test cans in the temperature history study for each type of container. The mean value and standard deviation of f_h, f_c, j_{ch} and j_{cc} for the containers are presented in Table 6. These parameters were derived from heating and cooling curves of each test can and curves typically representing each type of container are shown in Figures 20 and 21. The product exhibited simple straight line semi-logarithmic heating and cooling curves after the initial lag.

It can be noted from the heating parameters for each type of container in Table 6 that the magnitudes of f_h and f_c are different and the mean value of j_{cc} does not equal 1.41. The assumptions of $f_h = f_c$ and $j_{cc} = 1.41$ in Ball's formula

Table 6. Heat Penetration Parameters for Pacific Hake in Three Types of Container Thermally Processed at 120°C

Container type	Mean values (standard deviations)			
	f_h min	f_c min	j_{ch}	j_{cc}
Half pound salmon	20.34 (2.08)	33.96 (2.51)	2.65 (0.77)	1.23 (0.08)
Quarter pound salmon	16.67 (1.68)	17.71 (1.42)	1.72 (0.43)	1.38 (0.11)
Quarter dingley	9.03 (1.18)	7.10 (1.71)	0.79 (0.24)	1.07 (0.20)

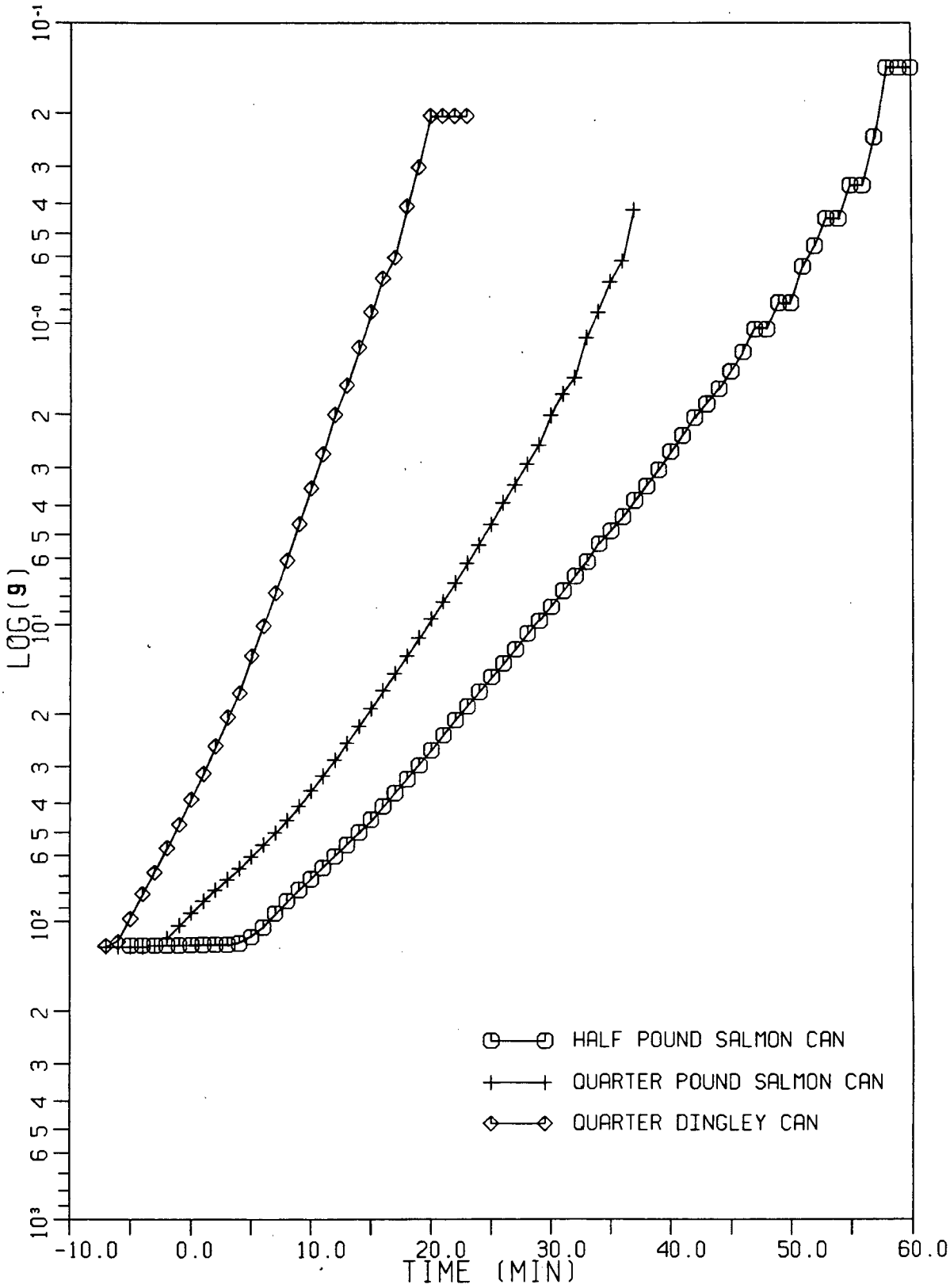

Figure 20. Typical Heating Curves of Three Types of Container

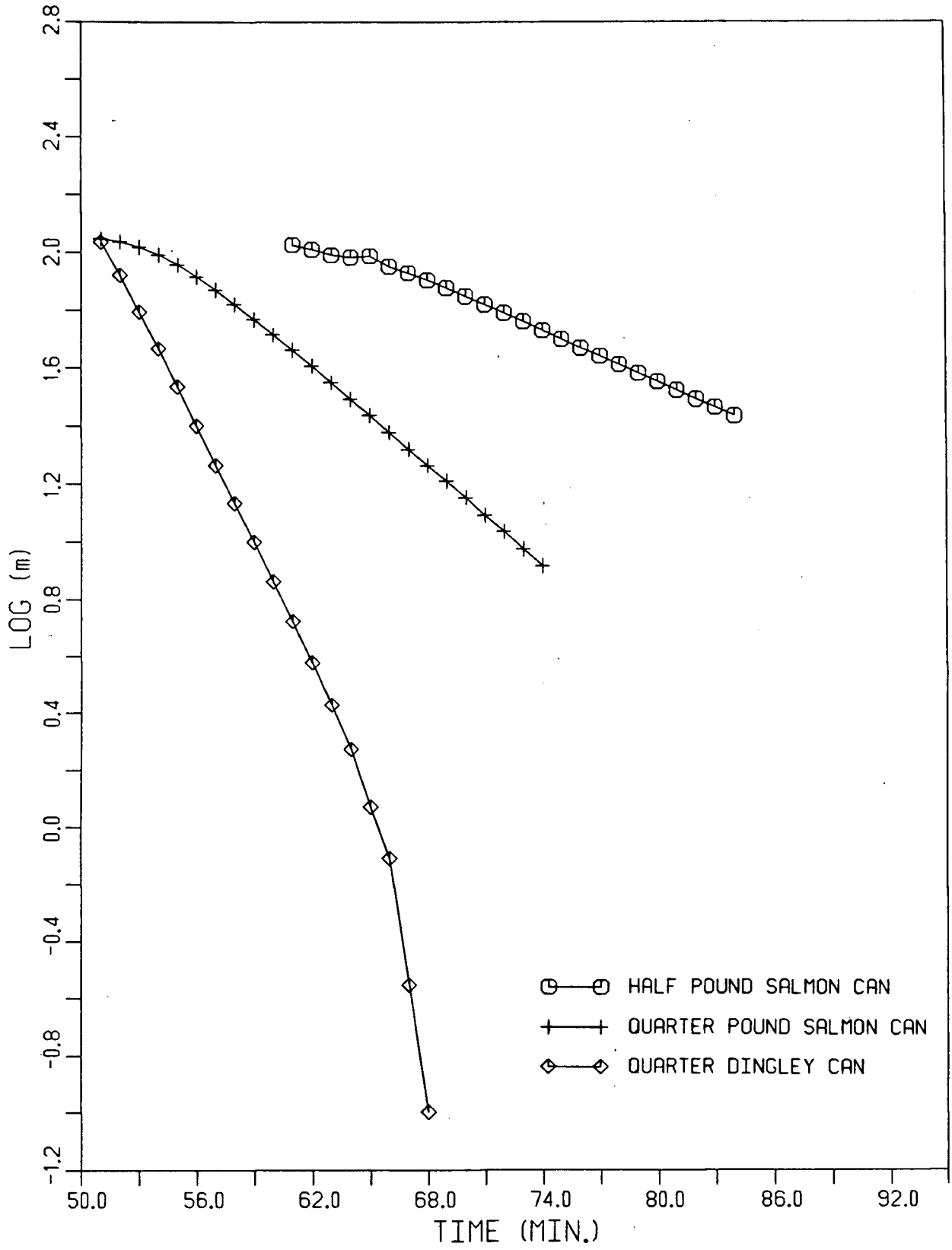

Figure 21. Typical Cooling Curves of Three Types of Container

method of thermal process time calculation has drawn criticism from researchers working on this subject and were viewed to be invalid by Hayakawa (1978) and Merson, et al. (1978). Hayakawa (1978) commented that the assumption of $j_{cc} = 1.41$ by Ball's method overestimates the sterilizing values of heat process when $j_{cc} < 1.41$ and underestimates when $j_{cc} > 1.41$. Stumbo's formula method, which was used in calculation in this study, allows j_{cc} to be a variable but the assumption of $f_h = f_c$ remains (Stumbo, 1973). Smith and Tung (1982) commented that Stumbo's method gave the best estimates of process lethality when compared with other formula methods. Tung and Garland (1978) used Stumbo's method in calculation and mentioned that when $f_c > f_h$ the method will provide an additional small margin of safety in the estimated process and this margin of safety would be reversed when $f_c < f_h$.

Table 6 shows that the mean j_{ch} value for the quarter dingley can was less than unity which was different from that of the other two cylindrical cans. This can be explained by the shape of the heating curves for the quarter dingley can which had a short lag or no lag at the start of heating typically shown in Figure 20. Stumbo (1973) mentioned that when there is no lag in heating, i.e. when the semilog heating curve is straight from the beginning of process, then $T_{pih} = T_{ih}$. However, in the computer calculation of this study, it appeared that when the lag was short or did not occur, T_{pih} was greater than T_{ih}, resulting

in j_{ch} being less than 1. Comparing the parameters among the types of container, it is obvious that heat penetration was more rapid in quarter dingley cans as compared to the other two types of container. This was indicated by small heating and cooling rate indices in Table 6 and the steeper slopes of heating and cooling curves shown in Figures 20 and 21.

Similar to other canned fish, Pacific hake is considered a low acid food which includes products with pH values greater than 4.5. Pacific hake and other related species were known to have an ultimate pH of 6.2-6.6 at maximum rigor as reported by Bramsnaes (1965). Pflug and Odlang (1978) reviewed z and F values used to ensure the safety of low acid canned food and suggested a process using an F_0 value of 3.0 minutes with a z value of 10C° (18F°) as a realistic minimum cook for low acid foods that will be free from Clostridium botulinum. Skramstad (1977) reported that in the Norwegian canning industry, an F_0 value of 6.0 minutes and z value of 10C° is a practical value for sardine processing. The use of F_0 = 6.0 minutes and z = 10C° was considered to be a reasonable target process in this study.

The process schedules for different container types at different retort temperatures are listed in Table 7. Although the initial temperature (T_{ih}) of the product varied in the order of 5°C, the process schedules were designed by assuming the initial temperature to be 0°C as a safety margin. In fact, the effect of this assumption on process time calculation was small. Comparing

Table 7. Process Schedules of Pacific Hake Canned in Different Containers and Processed at Different Retort Temperatures

Container type	Process time (minutes)		
	Retort temperature (°C)		
	115	120	130
Half pound salmon	76.1	56.5	41.4
Quarter pound salmon	57.9	39.4	25.8
Quarter dingley	40.4	23.5	13.0

Table 8. Confirmation of Process Schedules - Mean Delivered Lethality of Thermal Process for Different Types of Container at Different Retort Temperatures

Container type	Mean Delivered Lethality, F_o(minutes)		
	Retort temperature (°C)		
	115	120	130
Half pound salmon	9.39	14.47	46.19
Quarter pound salmon	7.73	10.19	21.14
Quarter dingley	7.80	10.10	26.66

processes at different retort temperatures, the greatest difference in estimated process times required to cook half pound salmon cans with initial product temperatures of 0°C or 5°C was only 0.4 minutes. That is, for a retort temperature of 115°C, the estimated process time was 76.1 minutes for T_{ih} = 0°C and 75.7 minutes for T_{ih} = 5°C. The difference was even smaller with quarter pound salmon cans and quarter dingley cans for which the differences were 0.3 and 0.1 minutes, respectively.

Table 8 presents the mean delivered lethalities calculated by computer to confirm the process schedules designed for different types of containers. They exceeded the target of F_0 = 6.0 minutes chosen in this study. The minimum delivered lethality was found to be 6.72 minutes for a quarter pound salmon test can calculated for a retort temperature of 115°C. It is obvious from the table that for each type of container, the mean delivered lethality was greater at higher retort temperatures.

The method of thermal process calculation applied in this study slightly overestimated the required process times as compared to the method suggested by Tung and Garland (1978). For instance, the process time estimated for half pound salmon cans thermally processed at 130°C was 41.4 minutes (Table 7). Using the calculation procedures by Tung and Garland (1978), the estimated process time would have been 39.7 minutes. The disparity between the two methods was that f_h* (the mean f_h + 3 S.D. f_h) and $\overline{j_{ch}}$ (the mean j_{ch}) were used in their calculation for

the required process time while in this study, process times, P_t were calculated for each test can based on various pairs of f_h and j_{ch} values and finally P_t^* (the mean P_t + 3 S.D. P_t) was obtained as the required process time. However, it was not the purpose of this study to decide which method gave better process time estimations.

Measurement of Textural Properties of Cooked Pacific Hake

Unlike textural studies on meat of warm blooded animals, methods for objective evaluations of fish muscle texture have not been extensively documented. Mechanical properties of raw and cooked fish flesh were studied by Johnson et al. (1980; 1982) who attempted to characterize the qualitative rheological behavior of fish flesh. It has been generally considered that objective study of fish texture is not easy due to nonuniformity of fish muscle structure and difficulties in test specimen preparation. The descriptions of fish muscle structure by Howgate (1979), Dunajski (1979) and Suzuki (1980) could be applied to Pacific hake. Briefly, the muscles of the fish body have a metameric structure where the muscles are divided into segments called myotomes by transverse sheets of connective tissue called myocommata. The shape of the myotomes depends largely on the species of fish and its size varies along the length of the body. The muscle cells or fibers lie parallel to the long axis of the body. Length and diameter of muscle cells differ among species and within individuals according to their location in the body. The muscle can

be divided into two types, dark and white muscles, whose proportion varies along the body length. Dark muscle, which lies along the side of the body under the skin, has more connective tissue around the muscle cells and it also contains less protein and more lipid as compared to white muscle.

Sutton and Main (1969) considered that the texture of cooked fish muscle could be largely defined in terms of two parameters, hardness and succulence, and hardness could be measured instrumentally. They constructed a fish texturometer to measure hardness of cooked fish muscle by driving a plunger into mashed cooked fish muscle placed in a cup. The force required to deform the sample through a fixed distance was considered as hardness. They claimed that a good correlation was obtained between the instrument and sensory panel assessment of hardness, although there were difficulties in obtaining uniform packing of sample. Borderias et al. (1983) however, did not find significant correlations between results of instrumental analyses and that of sensory evaluation for cooked and raw fish fillets when using different kinds of cell attachments to an Instron tester. Dunajski (1979) reviewed the use of instrumental methods to assess the texture of fish and commented that those devices applicable to testing red meat were not suitable for cooked fish. He explained that fish muscle has a relatively low content of connective tissue which disintegrates during heating and the muscle falls apart easily.

The choice of method for texture measurement of cooked hake in this study was considered after reviewing the experiments of

previous workers. Voisey (1972) conducted an exploratory investigation using eight different test cells for measuring the texture of canned herring with an Ottawa Texture Measuring System (OTMS). He concluded that both Kramer shear-compression cell (CS-1 or CS-2) and OTMS 15cm^2 4-wire grid cell could detect differences between samples of soft and firm texture and that the latter gave more satisfactory results. In his study, the test sample quantity in the Kramer shear-compression cell was 45 g and the crosshead and chart speeds were set at 100 and 200 mm/min, respectively. Bilinski et al. (1977) who also studied texture of canned herring using a standard Kramer shear-compression cell of diminished capacity (4 blades) mounted in an OTMS. He used a sample quantity of 15 g for each determination and the speed of the crosshead and chart were speed 30 on the dial and 15 mm/min, respectively. Dunajski (1979) recommended that the quantity of test sample be limited to a minimum of 10-15 g to ensure reproducibility of measurements in a thin blade Kramer shear-compression cell (CS-1). Gill et al. (1979) commented that both the 10 cm^2 OTMS wire shear cell and the Kramer shear-compression cell with diminished capacity (4 blades) could be used for evaluating fish texture, but the latter was chosen for their study on red hake and haddock. Crosshead and recorder speeds of 100 and 200 mm/min were chosen, respectively.

It appears that there is no standard way to measure cooked fish texture and selection of testing conditions and test cell

would depend on the experience and preference of the worker. In this study, a standard Kramer shear-compression cell of diminished capacity (4 blades) mounted on an Instron Universal Testing Instrument was available and found convenient in texture measurement of cooked Pacific hake. Testing conditions such as test sample size, crosshead and chart speeds were selected after preliminary trials to ensure that a complete history of the changes in the measured variables could be graphically recorded. It was observed that reproducibility of measurements in this study depended on several factors. The white muscle collected for the test sample had to be free from other tissues. The drip resulting from cooking should be poured off but drying of fish muscle due to delays in measuring must be avoided. Thorough flaking of fish muscles was important as it improved the homogeneity of the test sample and increased the randomness of fibers orientation with respect to the shearing blades. This view was shared by Bilinski et al. (1977) and Dunajski (1979) but it seemed that instead of flaking, cutting the test sample into 1 cm^3 pieces for testing was also workable (Gill et al., 1979). Even packing of flaked fish muscle at the bottom of the box of the test cell was found to improve smoothness of the force curve.

A composite of different forces was thought to be acting on the test sample during measurement, as it might involve shear, compression, extrusion and friction (Szczesniak et al., 1970; Dunajski, 1979). Typical force-distance curves for cooked Pacific

hake muscle are shown in Figures 22-24 representing various textural properties indicated by differences in magnitudes of peak force and slope. The curves presented in the same figure are duplicate measurements of one test sample indicating good reproducibility of each determination. The curves reveal that force increased non-linearly when the blades initially contacted the sample until uniform contact was established between the sample and the blades. The force then increased linearly with crosshead movement. The slope of this portion represents a compression phase and provides an index of firmness which is a common term for hardness defined by Szczesniak (1963) as the force necessary to attain a given deformation. Gill et al. (1979) interpreted the slope as a measurement of chewiness since it monitored resistance to compression alone. The compression was possibly caused by the slanted bottom edges of the flexible blades of the cell (Szczesniak et al. 1970). The maximum force value at the main peak coincided with initiation of sample shearing (Voisey, 1972) and it provides an index of cohesiveness which was defined by Szczesniak (1963) as the strength of the internal bonds making up the body of the product. According to Szczesniak et al. (1970), the shoulder after the main peak is when the shear blades mesh with slits in the bottom of the cell and is apparently due to friction contributed by food debris. A flattening of the peak exhibits extrusion (Bourne and Moyer, 1968). This was observed in samples which were mushy and pasty as demonstrated in typical force curves shown in

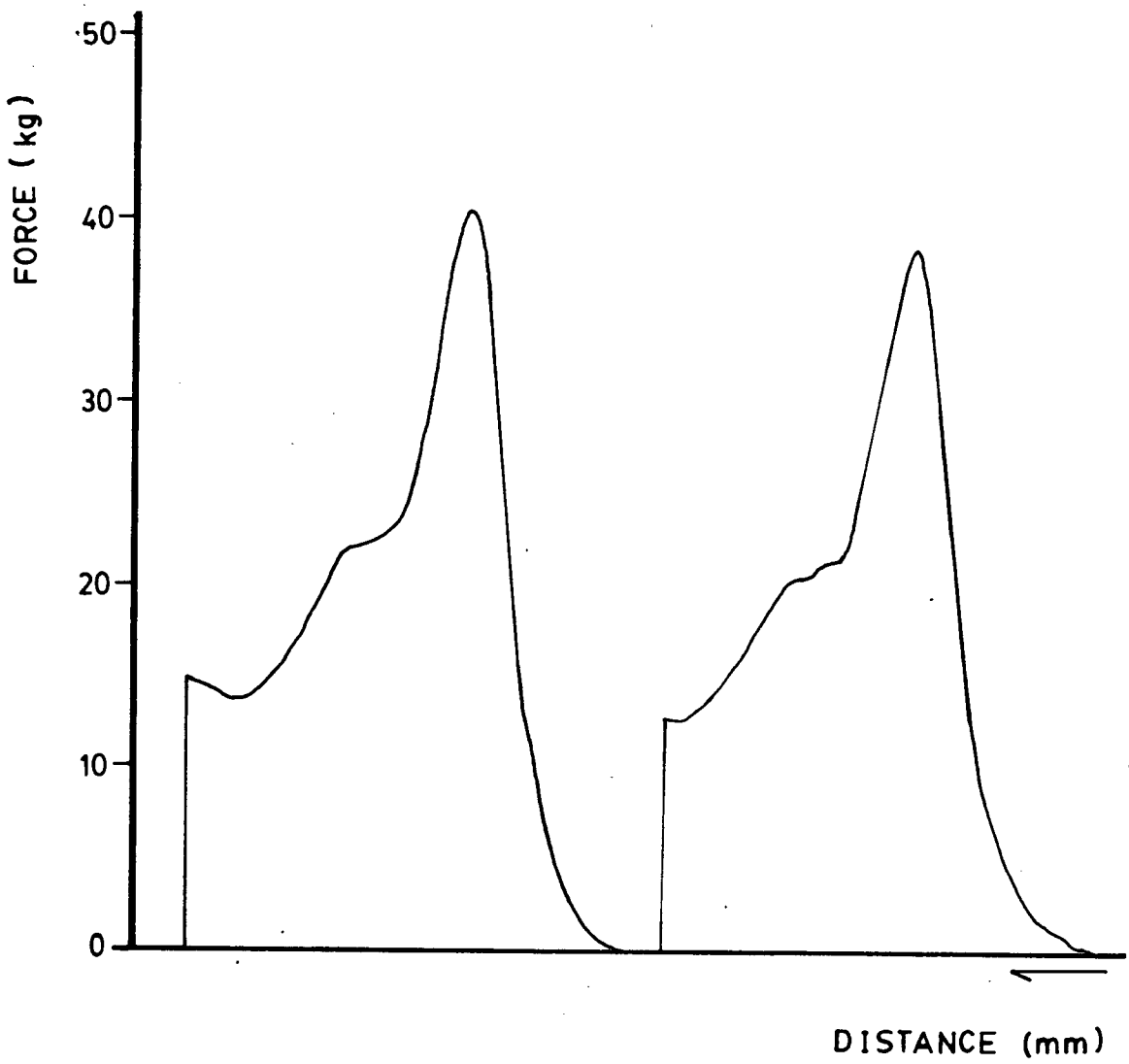

Figure 22. Typical Force-distance Curves of Cooked Hake Muscle of Firm Texture

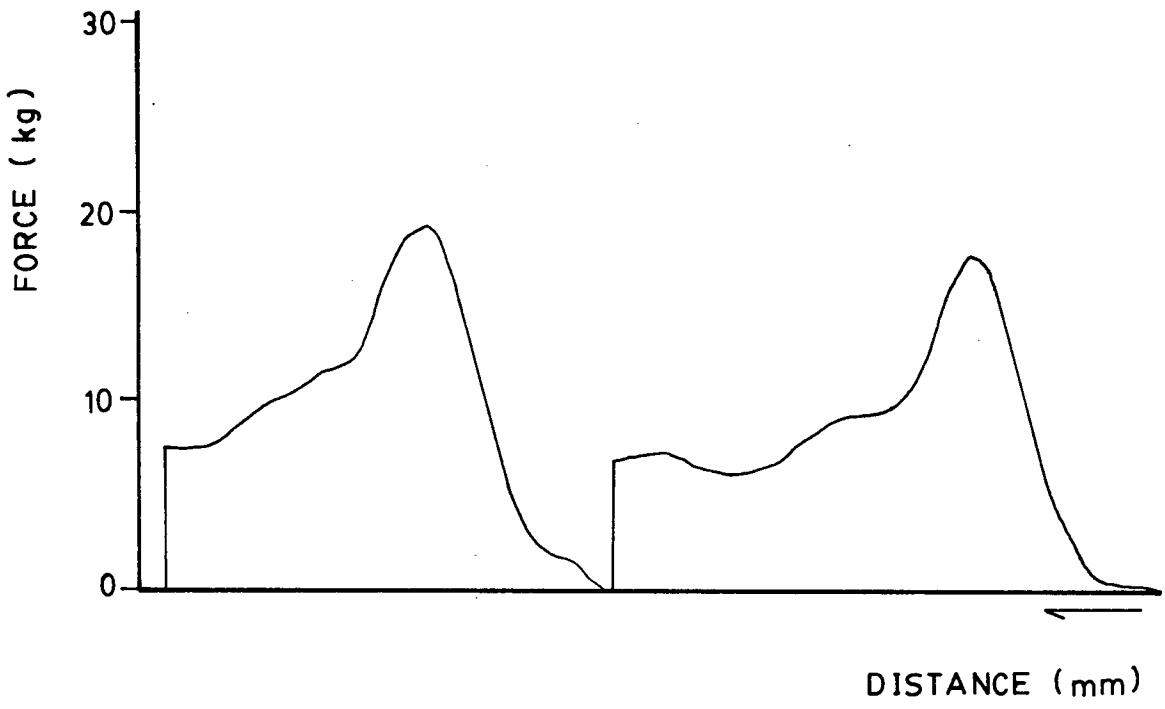

Figure 23. Typical Force-distance Curves of Cooked Hake Muscle of Soft Texture

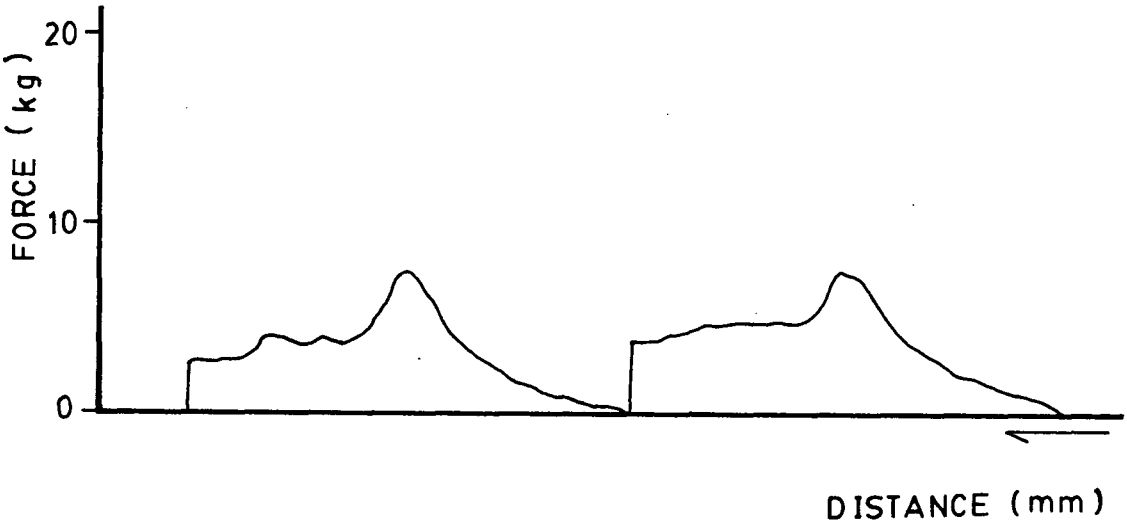

Figure 24. Typical Force-distance Curves of Cooked Hake Muscle of Mushy Texture

Figure 24. The measurement of area under the force curve which reports the energy to complete the test was viewed to give no advantage because energy is proportional to force where samples of the same size are deformed over the same stroke (Voisey, 1976). It is incorrect to report the data as force per unit sample weight since the relationship between maximum force and sample weight was found not to be linear (Szczesniak et al., 1970).

Non-destructive indirect physical methods of texture measurement in canned products involve determination of the drained weight. Drained weight could sometimes be used as an index of textural damage caused by processing as it reflects fluid retention (Szczesniak, 1973). As for canned fish products, excessive water exuded from fish is undesirable. If the fish is canned with sauces or oil, this water will dilute or mix with the ingredients and shrinking of the cooked fish may result in damage due to movement of fish in the container (Van Den Broek, 1965).

Texture of Canned Pacific Hake

The textural properties of Pacific hake processed in three different types of containers according to different process schedules are discussed in this section.

Processing in half pound salmon cans

Bilinski et al. (1977) advised that pooling flesh from several fish must be avoided during texture measurement because dif-

ferences could occur among individual fish. However, this could not be achieved for hake from Georgia Strait as the size of fillets from one fish was too small, therefore flesh of more than one fish was required to fill the can. This has to be noted when interpreting the results of texture measurement. Table 9 shows that textural properties of the Strait frozen (SF), Strait chilled (SC) and west coast (W) fish samples were not affected significantly by different retort processing temperatures for the range used in this study ($p > 0.05$). However, analysis of variance in Table 10 indicates that fish type had a significant effect on the textural properties with F values significant at $p < 0.01$ for mean cohesiveness and firmness and $p < 0.05$ for mean percent weight loss. The W fish samples had the highest mean scores in cooked fish cohesiveness and firmness measurements as compared to that of the two Strait fish samples, SF and SC. Cooking processes of different retort temperature seemed to have no effect on the textural properties except for percent weight loss where processing at 130°C caused a higher weight loss from the cooked fish. There was no significant interaction between fish type and retort temperature on overall textural properties.

Processing in quarter pound salmon cans

The mean cohesiveness score of SF fish processed at 115°C was significantly lower than those obtained at 120 and 130°C ($p < 0.05$). The textural properties of SC fish were not affected at all by retort temperature. As for the W fish samples, processing

Table 9. Textural Properties of Pacific Hake Processed in Half Pound Salmon Cans

Fish Sample	Retort temp. (°C)	Textural Properties[1] Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Strait, Frozen (SF)	115	25.83(2.84)[a2]	2.27(0.31)[a]	27.47(2.62)
	120	26.42(3.96)[a]	2.29(0.39)[a]	27.26(1.98)
	130	25.73(5.26)[a]	2.28(0.51)[a]	29.31(2.44)
Strait, Chilled (SC)	115	19.05(2.65)[c]	1.67(0.33)[c]	26.95(2.80)
	120	18.95(2.48)[c]	1.60(0.21)[c]	27.02(2.05)
	130	19.03(4.10)[c]	1.70(0.31)[c]	27.73(2.03)
West coast offshore (W)	115	30.04(6.02)[b]	3.11(0.84)[b]	25.73(3.06)
	120	31.32(4.97)[b]	3.40(0.68)[b]	25.84(2.53)
	130	31.65(5.53)[b]	3.39(0.74)[b]	28.36(2.46)

[1]Data expressed as mean (standard deviation), n = 15.
[2]Data in a column followed by same letter do not differ ($p > 0.05$).

Table 10. Analysis of Variance of Textural Properties of Pacific Hake Processed in Half Pound Salmon Cans

Test	Source	DF	Mean Sq.	F-Value
Cohesiveness	Fish Type (F)	2	1,632.30	84.96*[1]
	Retort Temp (T)	2	4.54	0.27 n.s.[2]
	FT	4	4.19	0.22 n.s.
	Error	126	19.21	
	Total	134		
Firmness	Fish Type (F)	2	31.15	113.82*
	Retort Temp (T)	2	0.14	0.51 n.s.
	FT	4	0.15	0.53 n.s.
	Error	126	0.27	
	Total	134		
Weight loss	Fish Type (F)	2	21.33	3.51**[3]
	Retort Temp (T)	2	46.23	7.60*
	FT	4	4.43	0.73 n.s.
	Error	126	6.08	
	Total	134		

[1]* Significant at $p < 0.01$
[2]n.s. = not significant ($p > 0.05$)
[3]** Significant at $p < 0.05$

at 130°C resulted in fish texture which was more cohesive and firmer than those cooked at 115 and 120°C (Table 11). It has to be remembered that for the west coast offshore fish, the fish muscle samples in each temperature treatment belonged to the same lot of fish as the fillets of one fish were large enough to fill three containers to be processed at different retort temperatures. Analysis of variance results in Table 12 show that mean weight loss was not affected by the factors, fish type and retort temperature. However, these two factors influenced the mean cohesiveness and firmness of cooked fish texture indicated by F values significant at $p < 0.01$. Similar to the results obtained from processing in half pound salmon cans, the W cooked fish texture had higher overall mean scores in cohesiveness and firmness as compared to the SF and SC fish samples. Retort temperature had a similar effect on cohesiveness and firmness of cooked fish with the result that fish processed at 130°C had the highest mean score in both measurements. There was no significant interaction between fish type and retort temperature on overall textural properties of cooked fish.

Processing in quarter dingley cans

The cohesiveness and firmness of SC fish samples were not affected significantly ($p > 0.05$) by processing at different retort temperatures (Table 13). Again, the same note has to be taken for comparing the W fish muscle samples in different temperature treatments since they were from the same lot of fish. The

Table 11. Textural Properties of Pacific Hake Processed in Quarter Pound Salmon Can

Fish Sample	Retort temp. (°C)	Textural Properties[1] Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Strait, Frozen (SF)	115	24.61(1.89)^{a2}	2.22(0.22)^{a}	21.52(2.70)
	120	27.98(3.19)^{b}	2.35(0.25)^{ab}	20.46(1.99)
	130	30.32(3.51)^{bc}	2.57(0.30)^{b}	22.07(2.23)
Strait, Chilled (SC)	115	18.35(2.96)^{d}	1.46(0.24)^{d}	22.72(3.05)
	120	18.41(2.79)^{d}	1.60(0.33)^{d}	20.61(3.52)
	130	19.93(3.68)^{d}	1.67(0.39)^{d}	20.13(2.12)
West coast offshore (W)	115	29.09(3.20)^{bc}	2.97(0.44)^{c}	20.87(1.99)
	120	30.70(4.11)^{c}	3.07(0.46)^{c}	21.53(3.03)
	130	33.59(3.80)^{e}	3.48(0.53)^{e}	20.98(2.37)

[1]Data expressed as mean (standard deviation), n = 15.
[2]Data in a column followed by same letter do not differ ($p > 0.05$).

Table 12. Analysis of Variance of Textural Properties of Pacific Hake Processed in Quarter Pound Salmon Cans

Test	Source	DF	Mean Sq.	F-Value
Cohesiveness	Fish Type (F)	2	1,788.10	164.65*[1]
	Retort Temp (T)	2	175.00	16.11*
	FT	4	19.18	1.77n.s.[2]
	Error	126	10.86	
	Total	134		
Firmness	Fish Type (F)	2	28.71	214.18*
	Retort Temp (T)	2	1.44	10.78*
	FT	4	0.13	0.98 n.s.
	Error	126	0.13	
	Total	134		
Weight loss	Fish Type (F)	2	0.68	0.10 n.s.
	Retort Temp (T)	2	8.72	1.28 n.s.
	FT	4	15.93	2.34 n.s.
	Error	126	6.79	
	Total	134		

[1]* Significant at $p < 0.01$
[2]n.s. = not significant ($p > 0.05$)

Table 13. Textural Properties of Pacific Hake Processed in Quarter Dingley Cans

Fish Sample	Retort temp. (°C)	Textural Properties[1] Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Strait, Frozen (SF)	115	24.36(2.10)^{a2}	2.03(0.23)^{a}	19.86(1.85)
	120	28.15(4.84)^{bc}	2.40(0.56)^{ab}	18.97(2.33)
	130	31.48(7.81)^{c}	2.68(0.75)^{bc}	20.67(2.85)
Strait, Chilled (SC)	115	18.10(1.46)^{d}	1.35(0.13)^{d}	20.04(1.73)
	120	18.31(1.97)^{d}	1.36(0.19)^{d}	18.57(2.69)
	130	18.61(1.72)^{d}	1.42(0.19)^{d}	19.91(2.30)
West coast offshore (W)	115	26.13(5.74)^{ab}	2.38(0.65)^{ab}	20.87(1.99)
	120	29.09(6.06)^{bc}	2.64(0.64)^{bc}	20.94(3.39)
	130	30.70(5.76)^{c}	2.91(0.72)^{c}	18.88(3.56)

[1]Data expressed as mean (standard deviation), n = 15.
[2]Data in a column followed by same letter do not differ ($p > 0.05$).

SF fish resulted in lower mean cohesiveness scores when processed at 115°C as compared to the other two retort temperatures ($p < 0.05$). Analysis of variance in Table 14 shows that cohesiveness and firmness of fish were significantly affected by fish type and retort temperature as indicated by F values significant at $p < 0.01$. The SF and W fish samples were more cohesive and firmer in cooked texture as compared to SC fish. Fish processed at 120 and 130°C had higher overall mean scores in cohesiveness and firmness measurement as compared to those cooked at 115°C. There was no significant interaction between fish type and retort temperature on overall textural properties of cooked fish. Mean weight loss was not significantly affected by the two factors, fish type and retort temperature.

General observations in hake canning

Different mean weight loss in fish processed in different container types were 27.30, 21.21 and 19.73% observed for half and quarter pound salmon and quarter dingley cans, respectively. Larger quantities of fluid exuded from fish when processed in half pound and quarter pound salmon cans could have resulted from combined effects of heat penetration and time in cooking and was accompanied by shrinkage of the cooked fish in the container. Textural properties such as cohesiveness and firmness differed significantly ($p < 0.01$) between SF and SC canned fish. This shows that although both fish samples were obtained from the Strait of Georgia and infected only with the myxosporean parasite,

Table 14. Analysis of Variance of Textural Properties of Pacific Hake Processed in Quarter Dingley Cans

Test	Source	DF	Mean Sq	F-Value
Cohesiveness	Fish Type (F)	2	1,498.70	67.28*[1]
	Retort Temp (T)	2	187.05	8.40*
	FT	4	42.37	1.90 n.s.
	Error	126	22.28	
	Total	134		
Firmness	Fish Type (F)	2	19.95	78.67*
	Retort Temp (T)	2	1.93	7.61*
	FT	4	0.35	1.40 n.s.
	Error	126	0.25	
	Total	134		
weight loss	Fish Type (F)	2	1.64	0.21 n.s.[2]
	Retort Temp (T)	2	1.86	0.24 n.s.
	FT	4	17.49	2.21 n.s.
	Error	126	7.91	
	Total	134		

[1]* Significant at $p < 0.01$
[2]n.s. = not significant ($p > 0.05$)

K. thyrsitis, different postharvest handling methods could affect the textural quality of the final product. Immediate freezing as in the case of handling SF samples resulted in higher mean scores in cohesiveness and firmness measurements of the canned fish texture of peak force shear value of 27.21 kg and slope value of 2.35 kg/mm, respectively. In comparison, the SC samples, which were chilled for 1-3 days after unloading from fishing vessels, had canned fish texture of mean peak force shear value of 18.75 kg and mean slope value of 1.54 kg/mm. The canned SC fish texture was considered soft and tender but not mushy if tested organoleptically and it demonstrated typical force-distance curves as shown in Figure 23. The texture of canned SF fish produced force-distance curves similar to the typical one shown in Figure 22. Texture of fish muscle could change in quality if the fish were harvested during spawning season (Dunajski, 1979). It was reported that spawning of Pacific hake began in March and peak spawning occurred in April or May in Strait of Georgia although the stocks exhibited variation in spawning times (Foucher and Beamish, 1980). The difference in cooked fish texture between SF and SC fish which were sampled at different times during the spawning season may have resulted from the variable state of maturity of the fish.

As compared to SF fish, the west coast offshore (W) fish had significantly higher mean scores in cohesiveness and firmness with a peak force shear value of 30.26 kg and slope value of 3.04

kg/mm, respectively. The west coast fish samples used for canning were parasitized with K. paniformis alone or together with K. thyrsitis and the level of infection was either light or medium in terms of K. paniformis spore intensity. Apparently, the presence of K. paniformis did not cause mushiness in the cooked texture of canned west coast offshore hake. The muscle protease(s) which had an optimum activity near neutrality and associated with Pacific hake muscle tissue infected with K. paniformis was relatively heat stable with an activity optimum at 55°-60°C (Tsuyuki et al., 1982) 1982). Evidently, the heating rates were so rapid in all three types of container as shown in Figure 20 that the duration of the temperature range, 55-60°C, during heating was a fraction of a minute. Rapid heating to a higher temperature would probably arrest the enzyme activity during thermal processing. Similar views were held in many studies of cooking temperature effect on muscle alkaline protease activity in fish, particularly minced fish product (Makinodan and Ideda, 1971; Lanier et al., 1978; Cheng et al., 1979; and Deng, 1981). Patashnik et al. (1982) found that the enzyme(s) was completely inactivated by heating at 70°C for 10 minutes, suggesting rapidly heating Pacific hake to achieve an internal temperature higher than 70°C would inactivate the enzyme during cooking.

Cooked Texture of Hake Processed by Other Methods

Pacific hake samples from west coast offshore waters and Georgia Strait were further tested for their textural properties

upon cooking by steaming, baking and microwave heating. Patashnik et al. (1982) pointed out that one of the difficult problems in studying the abnormal texture of Pacific hake was the wide variance between fish in the treatment groups. This problem was considered in designing the experiment on hake canning. But, due to restraints of fish size and fill weights of containers, only variance between fish was minimized for canning the west coast offshore hake samples in half pound salmon cans and quarter dingley cans by using the same lot of fish for different treatments. To avoid the problem in studying the cooked texture when processed by other methods, each fish was separated into equal portions for different treatments in each experiment.

Table 15 shows the textural properties of Pacific hake harvested from Georgia Strait and cooked by steaming, baking and microwave heating. In experiments I and II, cohesiveness and firmness for cooked texture of SF and SC fish were not significantly affected by cooking methods. Analysis of variance (data not shown) indicated that higher mean scores in cohesiveness and firmness measurements were obtained for SF fish as compared to SC fish.

As compared to canning and steaming, baking (oven heating) is considered a slow cooking method since air has lower heat transfer capacity as compared to that of boiling water or condensing steam. The increase in temperature within test fish samples during steaming and baking is shown in Figure 25. Each data point

Table 15. Comparison of Textural Properties of Georgia Strait Pacific Hake Processed by Different Cooking Methods

Experiment I

Cooking Methods	Textural Properties[1]		
Strait, frozen	Cohesiveness[1] (kg)	Firmness (kg/mm)	Weight loss (%)
Steaming	31.76(4.95)^{a2}	2.47(0.40)^{a}	18.56(2.48)^{a}
Baking	32.21(3.42)^{a}	2.52(0.45)^{a}	23.53(1.93)^{b}
Strait, chilled			
Steaming	21.60(1.44)^{x}	1.69(0.17)^{x}	15.93(2.54)^{x}
Baking	22.90(1.51)^{x}	1.67(0.16)^{x}	19.78(1.81)^{y}

Experiment II

Cooking Methods	Textural Properties[1]		
Strait, frozen	Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Microwave heating	30.58(2.41)^{m}	2.30(0.42)^{m}	16.22(2.87)^{m}
Baking	31.59(2.71)^{m}	2.48(0.42)^{m}	23.64(1.98)^{n}
Strait, chilled			
Microwave heating	20.89(2.12)^{p}	1.88(0.23)^{p}	16.96(3.37)^{p}
Baking	21.82(2.40)^{p}	1.77(0.12)^{p}	18.88(1.83)^{p}

[1]Data expressed as mean (standard deviation), n = 9
[2]Data in a column followed by same letter do not differ ($p > 0.05$).

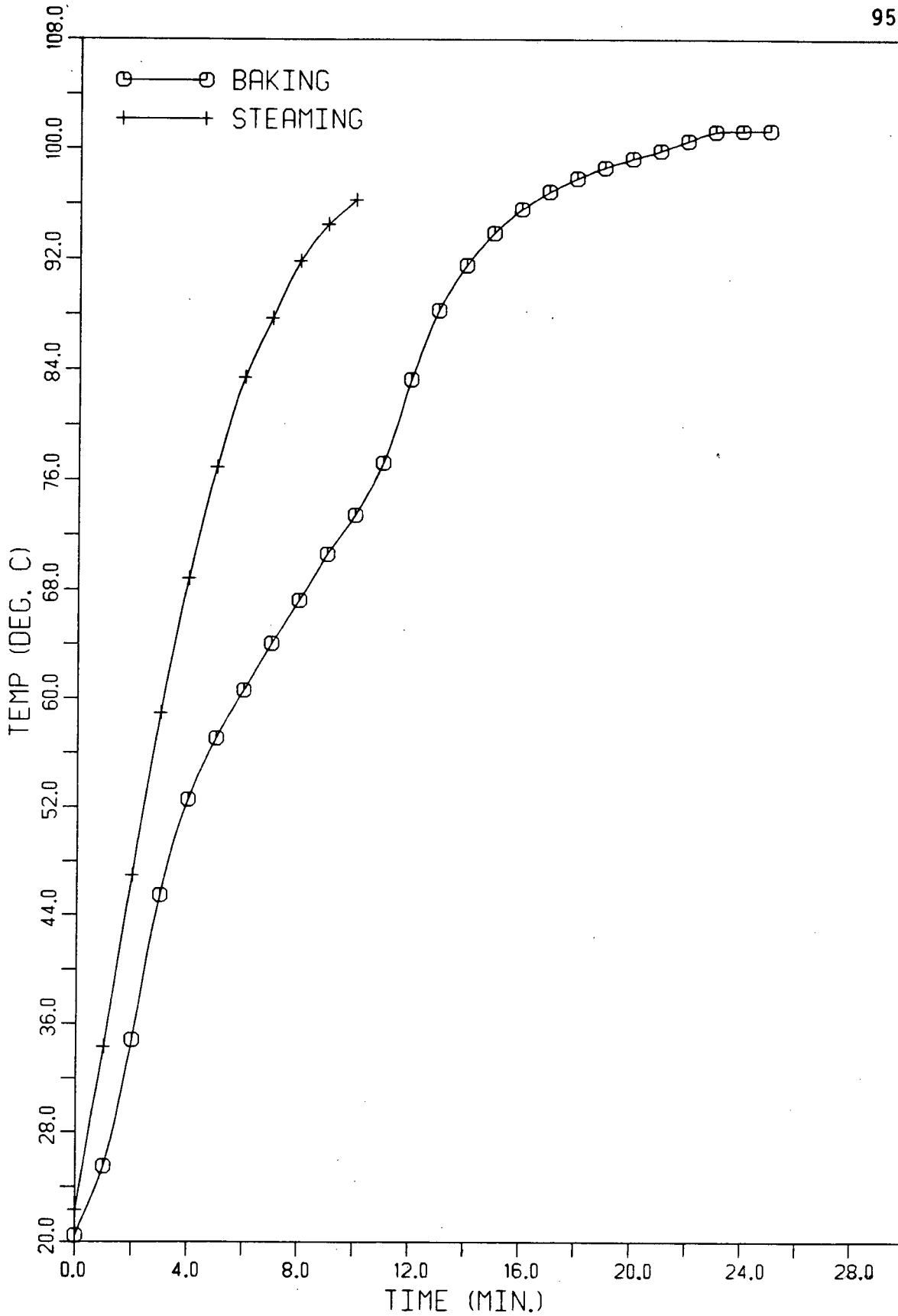

Figure 25. Development of Temperature in Hake Fillet Samples Cooked by Baking and Steaming

represents a mean of 16 and 20 determinations for baking and steaming, respectively. It can be observed that during baking, the internal temperature of the fish sample remained in the 55-60°C range for more than four minutes.

Table 16 shows the textural properties of west coast offshore hake cooked by canning, steaming, baking and microwave heating. In experiment I, the mean values of cohesiveness of cooked texture were not significantly different among cooking methods ($p > 0.05$) although baking resulted in the lowest mean cohesiveness score. The canned west coast hake had a significantly higher mean firmness score ($p < 0.05$) than those cooked by baking. Apparently, the west coast offshore hake samples used for baking in this study produced acceptable cooked texture comparable to canned and steamed products.

Miyauchi (1977) reported that 18.5% of 189 frozen hake fillets, baked at 350°F for 20 minutes were unacceptably mushy. He further demonstrated that the occurrence of mushiness during cooking depended not only on the cooking method but also on post-harvest handling of fish and concluded that rapid chilling, filleting and freezing of hake immediately after harvest would maintain the texture of flesh at a desirable level. Patashnik et al. (1982) studied the relationship between cooked texture and variability in severity of parasitization of Pacific hake fillets and found that only severely parasitized hake resulted in consistently poor texture ratings if they were oven cooked or their thawed

Table 16. Comparison of Textural Properties of West Coast Offshore Pacific Hake Processed by Different Cooking Methods

Experiment I

Cooking Methods	Textural Properties[1]		
	Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Canning	26.80(3.53)^{a2}	2.75(0.49)^{a}	18.43(3.40)^{a}
Steaming	28.51(7.84)^{a}	2.28(0.82)^{ab}	19.66(2.77)^{ab}
Baking	26.43(7.23)^{a}	2.18(0.78)^{b}	21.99(5.00)^{b}

Experiment II

Cooking Methods	Textural Properties[1]		
	Cohesiveness (kg)	Firmness (kg/mm)	Weight loss (%)
Microwave heating	17.89(6.68)^{x}	1.34(0.73)^{x}	16.29(2.11)^{x}
Baking	28.71(9.32)^{y}	2.56(0.98)^{y}	23.84(4.65)^{y}

[1]Data expressed as mean (standard deviation), n = 15.
[2]Data in a column followed by same letter do not differ ($p > 0.05$).

fillet portion was held for a period and refrozen before cooking. They concluded that severely parasitized hake were highly prone to proteolytic softening but not all severely parasitized hake were equally affected. Slightly parasitized hake were insignificantly affected by the treatments.

Observations in this study indicate that not all of the west coast offshore hake would produce unacceptable cooked texture if the fish was properly handled. It has to be remembered that heavily parasitized fish samples in terms of high counts of K. paniformis spores were not used in this study. This group of fish accounted for 16.7% of the west coast fish samples collected (Table 5A) and their fillets, as mentioned before, tended to show softness in texture. If the assumption that all these heavily parasitized fish would produce poor cooked texture is true, then the frequency of occurrence of unacceptable cooked fish texture among west coast offshore fish can be predicted from the percentage of heavily parasitized fish. On the other hand, the offshore Pacific hake which were slightly parasitized ranging from none to medium in terms of spore intensity, could produce acceptable cooked texture when thermally processed by canning, steaming or baking.

Experiment II in Table 16 shows a significant difference between mean scores of textural properties of west coast fish cooked by microwave heating and baking ($p < 0.05$). Of the 15 determinations of the microwave cooked samples, 6 samples had

cohesiveness value of less than 15 kg and had firmness value less than 1 kg/mm. In comparison, only 1 test sample of the baked fish had a cohesiveness value of less than 15 kg and a firmness value equal to or less than 1 kg/mm. Those samples with low values in texture measurements demonstrated typical force-distance curves, as shown in Figure 24. The reason for the development of mushy texture among west coast offshore fish upon microwave heating is unknown. Microwave cooking of Pacific hake was carried out by Patashnik et al. (1982) but their work was briefly described. Their results showed that parasitized 3-day iced fillets were normal in texture when rapidly microwave cooked. Madeira and Penfield (1985) compared microwave and oven cooking of turbot fillet sections. The microwave heated turbot samples were rated softer and had lower Kramer shear values in texture measurement. Further study has to be carried out on microwave heating of fish before any valid conclusion can be drawn as to its effect on cooked fish texture.

CONCLUSIONS

Parasitization with two kinds of Myxosporean parasite, Kudoa thyrsitis and Kudoa paniformis in Pacific hake (Merluccius productus) harvested from two fishing areas, Strait of Georgia and offshore waters along the west coast of Vancouver Island was observed in this investigation. Hake samples from the Strait of Georgia were found to be infected only with K. thyrsitis, 76.9% with light and medium levels of infection in terms of spore intensity and 22.9% not infected. Among the fish samples studied from west coast offshore waters, none was infected alone with K. thyrsitis, 7.1% of them were free from parasitization and 76.2% were infected with K. paniformis alone or together with K. thyrsitis at light and medium levels of infection in terms of K. paniformis spore counts. The heavily parasitized Pacific hake fillets exhibited the presence of visibly abundant melanin deposited pseudocysts in fish muscle and could be culled without much difficulty. The raw heavily parasitized fillets tended to show softness in texture. From a practical point of view, they should and could be eliminated from others during the preparation of raw fish material for further processing. It was therefore considered to be more practical if fish with light and medium levels of infection were used in the thermal processing studies as the majority of fish samples showed these conditions and the effect of parasitization on cooked textural quality was the basis of this investigation.

Canned Pacific hake was shown to exhibit simple straight line semi-logarithmic heating and cooling curves during retorting. The process times estimated from heat penetration studies indicated that shorter times were required to achieve a specified lethality at a given retort temperature for canned hake in thin profile aluminum quarter dingley cans as compared to the cylindrical three-piece tinplate cans, half and quarter pound salmon cans. For each type of container, the process time estimated was shorter if the cans were cooked at higher retort temperature to achieve an equal lethality.

Evaluation of cooked Pacific hake textural properties such as cohesiveness and firmness could be achieved conveniently using Kramer multi-blade shear-compression cell of diminished capacity. Replication in texture determinations of fish sample resulted in good reproducibility if the test muscle tissue samples were prepared properly. Variation in textural properties between individual fish samples within one treatment group was observed.

Pacific hake from west coast offshore waters (W) and the Strait of Georgia (SF) with light and medium infection levels produced acceptable cooked textural quality after thermally processed in all three types of containers studied. There was no indication that the presence of K. paniformis in west coast offshore hake would cause undesirable cooked texture as was thought in the beginning. Presumably, the enzyme activity in fish muscle which was associated with parasitization was arrested by rapid

heat penetration during retorting. However, postharvest handling of fish was shown to influence the cooked Pacific hake textural properties. Cooked fish texture of fish from the Strait of Georgia frozen immediately after landing (SF) was significantly different from those chilled for 1-3 days and then frozen (SC), as the latter showed decreased scores of cohesiveness and firmness. In general, weight loss due to liquid exuded from fish during cooking was lower for fish processed in quarter dingley cans, possibly as a result of the combined effect of processing time and heat penetration. Fish canned and cooked at 130°C tended to produce more cohesive and firmer cooked muscle texture.

In the studies of cooked fish texture by other cooking methods, steaming and baking did not result in significant differences in cohesiveness and firmness for each fish type. When cooked by microwave heating, cohesiveness and firmness of cooked fish from Georgia Strait did not differ significantly from baking. However, as compared to baking, mushiness of cooked texture of some west coast offshore hake fillet samples was observed when cooking by microwave heating for some unknown reasons.

It can be concluded that Pacific hake harvested from Canadian waters could produce acceptable canned texture provided that heavily parasitized fish are eliminated from the raw material and good postharvest handling practices were observed. Further studies are necessary to establish optimum process schedules for

each container type based on other quality attributes such as color, flavor and appearance of the final product.

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