AN ABSTRACT OF THE THESIS OF

Seong Ook Chang for the degree of Master of Science in Food Science and Technology presented on August 26, 1988

Title: Development of a Product which Simulates Abalone Texture from Alaska Pollock (Theragra chalcogramma) Surimi

Abstract approved _____
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The objective of these studies was to develop an analog from surimi that would resemble abalone. Preliminary studies involved the standardization of batter preparation conditions, such as pH adjustment, optimum moisture content and batter mixing time. The texture of a gelled analog prepared with different protein adjuncts (egg white, gluten and bovine serum albumin) was compared with cooked abalone for hardness, elasticity, and cohesiveness by a trained sensory evaluation panel and by instrumental methods.

Serial levels of sodium carbonate were used to adjust the pH of the sol from pH 6.75 to 7.73. As the pH value rose, the textural strength of kamaboko correspondingly increased. The 0.1% level of sodium carbonate was determined suitable for further use.

The moisture level in kamaboko caused significant variations in hardness ($P<0.001$) and cohesiveness

($P<0.001$). At the lowest level of moisture tested, 73.24%, gel hardness was greatest (127N/g); with a 5% increase in moisture, the gel hardness was lower (52N/g).

Sol mixing time (solubilization of myofibrillar proteins) was a very important factor to significantly affect gel texture for properties of hardness ($P<0.001$), elasticity ($P=0.002$) and cohesiveness ($P<0.001$). To produce a strong, elastic and cohesive gel, 30 minutes mixing was required.

In serial concentrations (0 to 4%), egg white, gluten, and bovine serum albumin, were evaluated for enhancement of textural parameters in order to produce an imitation abalone product. The addition of either egg white or gluten at the two percent level resulted in the greatest hardness and most cohesive gels ($P<0.001$). Two percent added bovine serum albumin significantly improved gel hardness and elasticity ($P=0.003$ and $P=0.0149$, respectively).

A shredded gel containing one of three protein adjuncts was effective in varying the final gel texture when incorporated with a surimi-based carrier. In overall parameters, the trained sensory evaluation panel judged the analog gel containing bovine serum albumin texturized chunks (at a 70:30 ratio to carrier) closest to cooked abalone. The instrumental measurements of textural parameters were slightly less discriminating than the trained sensory panel.

Development of a Product which Simulates Abalone Texture from Alaska Pollock (*Theragra chalcogramma*) Surimi

by

Seong Ook Chang

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed: August 26, 1988
Commencement: June 11, 1989

APPROVED:

Professor of Food Science and Technology
in charge of major

Head of department of Food Science and Technology

Dean of Graduate School

Date thesis is presented August 26, 1988

Typed by Seong Ook Chang

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Lucina E. Lampila for her helpful suggestions and guidance through the cource of this work.

Special appreciation is extended to Dr. Mina R. McDaniel for supporting this research.

With all my thanks to Nancy Chamberlain, Diane Heintz and David Lundahl for their assistance and friendship throughout this work.

The cooperation of all sensory panel members is appreciated.

Finally, I would like to extend my thanks and deep appreciation to my wife, Sun-Kyung, my son, Jin-Young for their patience and understanding during this investigation.

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DEVELOPMENT OF A PRODUCT WHICH SIMULATES ABALONE TEXTURE FROM ALASKA POLLOCK (*Theragra chalcogramma*) SURIMI

INTRODUCTION

Surimi is the Japanese term for mechanically deboned fish flesh that has been washed with water and mixed with cryoprotectants in order to provide extended frozen shelf life (Lee, 1984). It is used as an intermediate product for a variety of fabricated seafoods. With its usefulness in the manufacture of seafood products and the present upsurge in its market share, surimi has recently aroused the interest of the American seafood processors.

Washing not only removes fat and undesirable materials, such as blood, pigments, and other water soluble constituents, e.g., enzymes and low molecular weight nitrogenous compounds, but more importantly, concentrates myofibrillar (actomyosin) proteins (Lee, 1984). Myofibrillar proteins are necessary for gel strength and elasticity, essential properties for currently marketed surimi-based products (Kudo et al., 1973). Freezing of surimi became commercially possible after the discovery of the cryoprotective role of sucrose which prevents muscle protein, particularly actomyosin, from denaturation during frozen storage (Matsumoto, 1978). Also, the adoption of freezing technology allowed for extended holding periods of fish flesh used in kamaboko

(generic term which includes a variety of products prepared from surimi) production, as well as improved market life.

The most notable characteristic of kamaboko is its resilient texture called "ashi". The essential element in the forming of ashi is actomyosin which is present in fish flesh. Preventing denaturation of actomyosin is of great importance as well as is the elimination of the components that may obstruct the forming of ashi (Suzuki, 1981). Ashi of kamaboko is related closely to the fish species, freshness, and processing techniques. The technological goal of kamaboko production is to maximize the ashi of the final product from a given fish or surimi by applying good processing techniques and by using proper ingredients (Okada, 1985).

There are two categories of ingredients used to strengthen and/or improve the gel strength in the commercial production of kamaboko. One includes the chemical ingredients reacting directly with muscle proteins, and the second is gelling substances to strengthen ashi. The formation of good ashi requires both solubilization of myofibrillar proteins from the muscle and the formation of a network structure of the extracted proteins (Okada, 1985). Chemical ingredients may be classified on the basis of their action into either those enhancing the extraction of proteins from the fish muscle,

or those reinforcing the network structure of the extracted proteins. The first step to produce kamaboko is solublization of the myofibrillar or salt-soluble proteins in the fish muscle by adequate grinding with salt. During grinding, the myofibrillar proteins are solubilized, and the fish flesh becomes an extremely viscous sol. In the absence of salt, the proteins are not extracted with grinding and an elastic gel cannot be obtained after heat setting.

Egg white is added to increase glossiness and to enhance the textural strength of kamaboko. As the level of hydrated egg white increases, the textural quality of the end product becomes stronger (Okada, 1985).

Lanier (1986) demonstrated that imitation shellfish products, e.g., shrimp, clams, scallops, crabmeat, which possess textural properties similar to the natural shellfish product can be made from surimi. The successful introduction of crab, shrimp, and scallop analogs made from surimi has rekindled the interests of U.S. processors in minced fish technology (Babbitt, 1986). Recently, the analogs have filled a market niche and provided a substitute for more expensive natural items. With this trend, processors might be interested in producing an abalone-type analog. Abalone is a very expensive shellfish. The retail price is over $35 per pound and may

provide incentive for processors to develop an abalone-type product.

The purpose of this study was to determine the effect of three protein adjuncts (bovine serum albumin, gluten, and egg white) on the gel strength of kamaboko as measured by Texture Profile Analysis using both the Instron Universal Testing Machine and a trained sensory panel. The specific objective was to develop an abalone-like texture from Alaska pollock surimi.

REVIEW OF LITERATURE

Abalone (*Haliotidae*)

Biology and Life History of Abalone (*Haliotidae*)

The abalone is a marine snail related to oysters, squid, octopus and other mollusks. Its genus, *Haliotis*, comes from Greek and means "sea ear" which refers to the shape of the shell (Cox, 1960). There are about 90 existing species of abalones in the world, of which the distribution is wide, in the Pacific, Atlantic and Indian Oceans (Tanikawa and Yamashita, 1961).

The major west coast abalone fishery is in California and Mexico. There are smaller fisheries in British Columbia and Alaska and a growing interest in Oregon and Washington (Pleschner, 1982). California waters are home to five species of abalone including the large red abalone which often grows up to 14 inches (36 cm) and provides the highest quality steaks (Pleschner, 1982).

Abalone inhabit relatively shallow waters along the coast, staying within the intertidal zone, usually less than 200 feet (62 m) deep. Since they are in shallow waters and cannot move with any speed, abalone are exceptionally easy to catch (Pleschner, 1982).

In abalone, the sexes are separate and may be determined by forcing the foot and mantle away from the

right side of the shell and inspecting the gonad. This is the large, smooth, curved, horn-shaped organ which lies against, and bends partially around, the large muscle attaching the animal to the shell. In males the color of the gonad is cream or beige; in females, dark green (Cox, 1960).

According to Cox (1960), abalone spawn during spring and summer. The eggs and sperm are emitted into the water where fertilization takes places. The fertilized egg develops into a free-swimming larva which lasts one to two weeks. During the latter part of this stage a shell commences to form and as it gradually increases in size and weight, the young abalone sinks to the bottom. There it adheres to rocks and in cracks or crevices where it begins to feed on minute algae growing on the substrate. The food is scraped off by the abalone's file-like tongue or radular.

Growth during the first few years is fairly regular. Most young abalone attain about an inch (2.5 cm) in length by the end of their first year and from three or four inches (7.5 to 10 cm) within four or five years. After the fifth year, growth is considerably slower. Some California species apparently never grow larger than six or seven inches (15 to 18 cm), while others may reach 10 or 11 inches [(25 to 28cm), (Cox, 1960)].

Geographical Distribution

The greatest concentrations, both in numbers of species and populations, are off the coasts of Australia, Japan and western North America. The largest species, Haliotis rufescens, occur on the California coast; mature individuals average between 7 and 9 inches (18 to 23 cm) and some exceed 11 inches (28 cm) in diameter. Other large haliotids live off South Australia, New Zealand and South Africa. On the Pacific coast of North America haliotids are found from Sitka, Alaska, south to Cape San Lucas, Baja, Mexico (Ebert, 1969).

In the eastern hemisphere, the northernmost abalones occur on the outer coast of the Kamchatka Peninsula. From there, they range southward along the Asiatic mainland and are found in the coastal waters of Korea, China, Vietnam, Thailand and the Malay Peninsula (Ebert, 1969).

History of the Abalone Harvest

According to Pleschner (1982), the commercial fishery was begun in the 1870s by Chinese immigrants who were brought into the United States to work on the railroad. Abalone had been harvested for years in Asia and the Chinese were quick to see a potential source of trade with their homeland.

The Chinese were able to gather and export nearly 4 millon pounds (1,818 mt) of abalone each year from shallow coastal waters. Usually the meat was either dried or canned for export (Pleschner, 1982).

The high level of exploitation began to affect the resource. In the 1930s and 1940s, Japanese immigrants perfected the techniques and equipment for hard-hat diving. This allowed the divers to go after abalone in deeper waters, which they did until the outbreak of World War II when the Japanese were transported inland (Pleschner, 1982).

Up until 1929, the center of the abalone fishery was at Monterey, California. During the next ten years the fishery moved down the coast to Morro Bay in search for more abundant grounds. From 1940 until the early 1960's, the fishery inched south from Morro Bay to Los Angeles and then settled at Santa Barbara, where it remains to this day (Pleschner, 1982).

From 1951 to 1968, some 4 million pounds (1,818 mt) of abalone were landed each year in California. Landings dropped off dramatically after 1969. By 1974, only 2.6 million pounds (1,182 mt) were landed in California. The decline has continued since then. In 1981, total landed weight was around 741,000 pounds (337 mt), which has been the average for the last four or five years (Pleschner, 1982).

Recently, it has been reported that abalone production in California has fallen from about 2,700 tons (2,454 mt) in 1969 to less than 450 tons (409 mt) in 1980 (Warne, 1982). Also, the U.S. abalone market has been established around the 15.2 to 17.8 cm (6 to 7 inch) pink and red abalone (Warne, 1982) and is not economically feasible or practical for aquaculture at this time. Generally, it takes about 7 years to grow abalone to market size. Commercial growers are targeting a 5 to 10 cm (2 to 4 inch) product which will be marketed in California restaurants (Warne, 1982).

Catching and Handling

Diving has always been the primary method of gathering abalone (Pleschner, 1982). Usually abalone are caught by divers using artificial breathing apparatus at depths varying from 5 to 40 meters (Olley and Thrower, 1977). Abalone live on rocks, grazing on the algae on the surface, and on free seaweed (Shepherd, 1975). The diver locates the abalone and then inserts a flat, spatula-like "abalone iron" under the foot, taking care not to damage the pedal sole, and quickly removes the animal off the rock (Olley and Thrower, 1977).

Once taken to the surface, the abalone can be either shucked at sea or transported live to the processing factory. Distances from the fishing grounds to the

processing factory are important. Small boats, 3 to 4 meters in length, stay at sea for 10 hours and then land abalone on the beach for truck transport to the factory. Larger, ocean-going heavy displacement vessels, up to 24 meters in length can operate up to 5,000 km from port and stay at sea for periods up to five days. Such vessels are usually equipped with wells filled with recirculating sea water in which the abalone can be stored live (Olley and Thrower, 1977). To keep the animals alive for any length of time the water should be well aerated (Stephenson, 1924).

The Australian Code of Practice for handling of abalone (Anonymous, 1972) advises that shucked abalone shall be held at 6°C and not for more than 72 hours. Storage of abalone in ice results in appreciable increases in weight due to the absorption of water (James and Olley, 1970).

Processing

Most of the catch is frozen or canned, but there is some production of steaks and dried abalone. A limited, but potentially lucrative, market for live abalone also exists in Korea and Japan (James and Olley, 1974). Abalone steak is a very delicate, delicious seafood with appeal in more expensive restaurants.

Before abalone can be processed, the shell and viscera are removed. This is done by inserting a flat spatula under the shell and severing the adductor muscle at its points of attachment to the shell. The mouth parts remain with the foot and must be cleanly removed. Blood pours from the severed main artery of a freshly shucked abalone. After an initial rush, the drainage of blood continues until up to 40% of the original muscle weight may be lost (James and Olley, 1971). Small animals lose less blood in proportion to their size than do larger ones (James and Olley, 1974). A residual volume of blood, which may account for up to 15% of the weight, often remains in the foot after draining, and is lost in subsequent processing (Olley and Thrower, 1977). Generally speaking, shucking, trimming, and peeling reduces an abalone to about one-third its round weight (Ebert, 1969).

Almost the entire processing operation is done by hand so it is necessary to recover a maximum of saleable meat from each abalone. People working in trimming and peeling must be skillful to keep waste at a minimum and assure the processor of a profit for the product.

Production Methods

Freezing. Shucked abalone, frozen for export, is usually washed and packed in 20 or 40 lb (10 to 20 kg) blocks in polyethylene lined flat cartons (James and Olley, 1974). Ideally, abalone should be frozen rapidly (as soon as possible after shucking), stored at the lowest possible temperature (at least -18° C); and thawed at chill (2 to 5°C) temperatures. Poor freezing and thawing practices can increase the overall loss of drip fluid (James and Olley, 1974). James and Olley (1974) noted that there is always a residual volume of blood in the foot. If this volume is high due to inadequate draining, sheets of ice may form in the blocks. Upon thawing, this may result in excessive drip loss and disagreement over net weight. It is difficult to generalize on the effects of freezing abalone, as Japanese and Australian experience would indicate that it is easy to freeze abalone before rigor (Olley and Thrower, 1977). Shucked abalone was frozen at either -7°C or -18°C for 17 and 5 hours, respectively (Olley and Thrower, 1977). Moisture content and pH were monitored after thawing in water at 20°C for 2 hours; in air at 12°C, overnight; or in air at 0.5°C, overnight. The results indicated that moisture content and pH

increased the colder the thawing conditions; each parameter benefitting the final product quality.

Canning. The unsightly black pigment on the epipodium and foot must be removed before canning. In material which has been frozen for storage, it can easily be washed off with water at 49°C but in fresh material it is difficult to remove (James and Olley, 1974). Abalone are canned either in water or in a four percent NaCl brine (Olley and Thrower, 1977). The processor must guarantee drained weight, as labelled. This is difficult with a product like abalone which loses a great amount of weight between shucking and final equilibration with the canned liquor after retorting (James and Olley, 1974). According to James and Olley (1971), the two main causes of weight loss, in addition to the inevitable bleeding before cooking, are loss of water and loss of solids. The water-holding capacity after cooking depends on the pH and freshness of the raw material. Solids are lost from the muscle by conversion of collagen, which is present in large quantities (3 to 20%), into gelatin which diffuses out into the cannned brine. Texture and final yield depend on the extent of hydration of the protein which is correlated with pH and degree of salt penetration caused by brining (James and Olley, 1974).

Drying. The characteristics required in a high-quality semidried product for the Hawaiian trade have been described by Young et al. (1973). The abalone should have a translucent amber color, clearly showing the dark markings of the pedal arteries, veins, and sinuses. Dark-colored opaque products are popular in Japan (Tanikawa, 1971). The slices of abalone should stretch elastically when pulled from the margins. Flavor, color, and translucence of the product depend on the degree to which browning precusors have been leached out during precooking. The browning precusors will be leached during long cooking. This leaching causes a tasteless product. The product should have a slightly salty flavor and may be lightly smoked to add a characteristic tang. The flavor of the semi-dried product when cooked in oil is reminiscent of bacon (Olley and Thrower, 1977).

Tenderizing. The adductor muscle of freshly shucked abalone is steaked and frozen for marketing. After resolution of rigor, all the pigmented parts and tough outside surface of the pedal sole are trimmed off. The remaining muscle is cut into horizontal slices about 1 cm thick and pounded with a wooden mallet to soften the tough texture (James and Olley, 1974). This operation calls for skill; the slices

must be struck hard enough to break their muscle fibers but not so hard that tissues are crushed and the slices shattered (Ebert, 1969). Some abalone is tenderized with a "cubing" machine. If this is not done, the meat retains its extremely tough consistency, making chewing difficult.

Composition of Abalone

There are three major parts of an abalone. The weights average 30% for the shell, 20% for the internal organs and 50% for the edible portion (Song, 1973). The main components of abalone muscle, as reported by various authors, are listed in Table 1. Seasonal variation affects the chemical composition of abalone flesh. Tanikawa and Yamashita (1961) noted that the moisture of abalone flesh decreased from June to August (72.1%) and gradually increased to a high of 77.9% by October. Similar fluctuations occured with ash content. During the same period, the levels of nonprotein nitrogen gradually increased. These changes corresponded directly with gonadal development prior to spawning.

Table 1. Proximate Composition of Abalone Muscle

Species	Water (%)	Protein (%)	Total N (%)	CHO[a] (%)	Fat (%)	Ash (%)
Japan						
H. gigantea[b]	76	-	20.1	2.3	0.4	1.5
H. discus hannai[c]	72-78	8-13	13-19	0.1-0.5	1-2	1.2-2
United States						
H. cracherodii[d] Pacific Coast	68-72	18-23	-	1.5-7.5	0.8-3	-
Australia						
N. ruber[e]	74-78	-	-	-	-	-
Top of adductor muscle		-	16-20	-	-	-
Pedal sole	-	-	16-18	-	-	-
Epipodium	-	-	9-13	-	-	-
Korea						
H. gigantea nordatis[f]	76	20	-	0.4	0.4	2.8

[a] Carbohydrate
[b] U.S. Department of Health, Education and Welfare (1972)
[c] Tanikawa and Yamashita (1961)
[d] Webber (1970)
[e] Olley et al., 1969-1973 (unpublished results) as cited by Olley and Thrower (1977).
[f] Song (1973)

Texture

The texture of abalone meat is related to the distribution of collagen within the foot (Olley and Thrower, 1977) and its structural arrangement (Lampila et al., 1988). In raw abalone the epipodium and pedal sole, being rich in collagen, are noticeably tough, whereas the adductor muscle is markedly softer (James and Olley 1971). Cooking converts the collagen of abalone to gelatin. The extent of conversion varies with the anatomical origin of the tissue considered. Overall, after one hour boiling, the conversion is about 40%. However, almost all the collagen is gelatinized and the pattern of the texture is reversed on canning; the epipodium and pedal sole become soft and succulent, while the adductor muscle becomes tougher (Olley and Thrower, 1977).

The structure of the adductor muscle is grouped in bands that are arranged orthogonally. That is, the bands are arranged in such a manner that longitudinal and cross-sectional bands occur simultaneously. There is a radical band (cross-sectional) and a circumferential band (longitudinal). These bands lie atop one another in such a manner to form the structural muscle. Fibers oriented in such a manner cause the tissue to form the overall "cup" conformation of the abalone muscle within the shell and extreme toughness of the flesh (Lampila et al., 1988).

According to Love et al. (1974), there is difficulty in distinguishing between alterations in texture of fish caused by interplay between different moisture, protein contents and pH values. The textural changes are extremely obvious even to an untrained sensory panel tasting abalone for the first time (James and Olley, 1970).

Developing Field

Abalone steak is one of the most delicate and delicious seafoods harvested from West coast waters. It is probably the most expensive with a retail price between $35 and $39 per pound. Even Alaska King crab takes a back seat to both the taste and cost of abalone (Pleschner, 1982).

Since 1969, abalone landings have dropped off dramatically. By 1974, only 2.6 million pounds (1,182 mt) were landed in California. The decline has continued since then. Total landed weight was around 700,000 pounds (318 mt) in 1981. As a result, many food scientists and processors are encouraged to find a substitute for the limited and expensive natural abalone steak.

Alaska Pollock (*Theragra chalcograma*)

Resources and Distribution

Alaska pollock is one of the twenty five species of fish in the cod family, Gadidae (Miller and Lea, 1972). Average weight and size of pollock are 16 inches (40 cm) and 1.1 lbs [(500 g) (AFDF, 1987)]. Their color ranges from olive green to brown on the dorsal surface, frequently blotched or mottled and silverly on the sides (Hart, 1973).

Alaska pollock feeds on plankton, the abundant microscopic plants and animals that support all marine ecosystems. The fish grows relatively quickly, attaining a harvestable size by about three years of age. Sexual maturity is reached at the age of three or four years, with a prolific yield of roe per spawning. The pollock schools are found at all levels in the water column between the sea floor and the surface (Sonu, 1986).

The ideal place for Alaska pollock is along the continental shelf where the underwater geographic layout causes upwelling (AFDF, 1987). Upwelling causes cold, dense water to rise to the surface, generating a density of nutrients. This explains why nearly one-third of the world's pollock resource, estimated at 8-10 million metric tons worldwide, is to be found along the Pacific continental shelf from the Gulf of Alaska, along the

Aleutian archipelago, in an arc across the Bering Sea, around the Kamchatka Peninsula in the western Pacific, and into the Sea of Japan. The estimated annual harvest of pollock in Alaska is approximately 1.3 million metric tons.

World Production

Alaska pollock has been exploited commercially since the early 1900s. In the pre-World War II era, Korea dominated the fishery, landing over 250,000 mt annually. However, the early Korean fishery is dwarfed by the tremendous expansion that occurred in catches during the 1960's and 1970's. The trend in the world catch of Alaska pollock by major harvesting nations for the period 1970-1979 is shown in Figure 1. Catches increased rapidly from about 500,000 mt in the early 1960's to over 1,000,000 mt by the middle of the decade. A peak production of approximately 5,500,000 mt was attained in the mid-1970's and has subsequently declined to about 4,500,000 mt (Natural Resources Consultants, 1973).

In terms of weight, Alaska pollock is currently the most important single species in the world fish catch. Alaska pollock has constituted about eight percent of the world harvest of marine fishes and shellfish and about nine percent of the worldwide finfish in recent years (Natural Resources Consultants, 1983). Its importance as

a resource in the northeast Pacific which compares pollock potential with estimated total bottomfish potential over several areas (Figure 2).

Figure 1. Alaska pollock catch by major nations, 1970-1979 (Natural Resources Consultants, 1983).

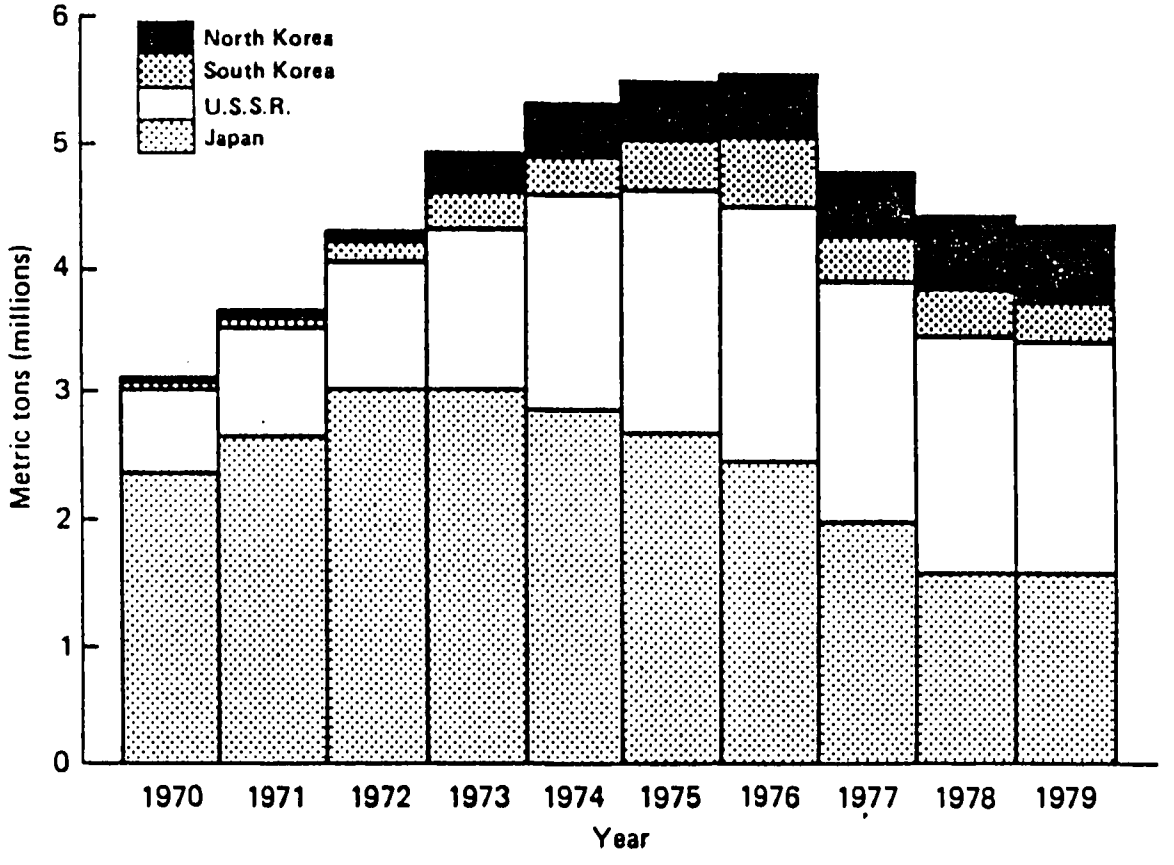
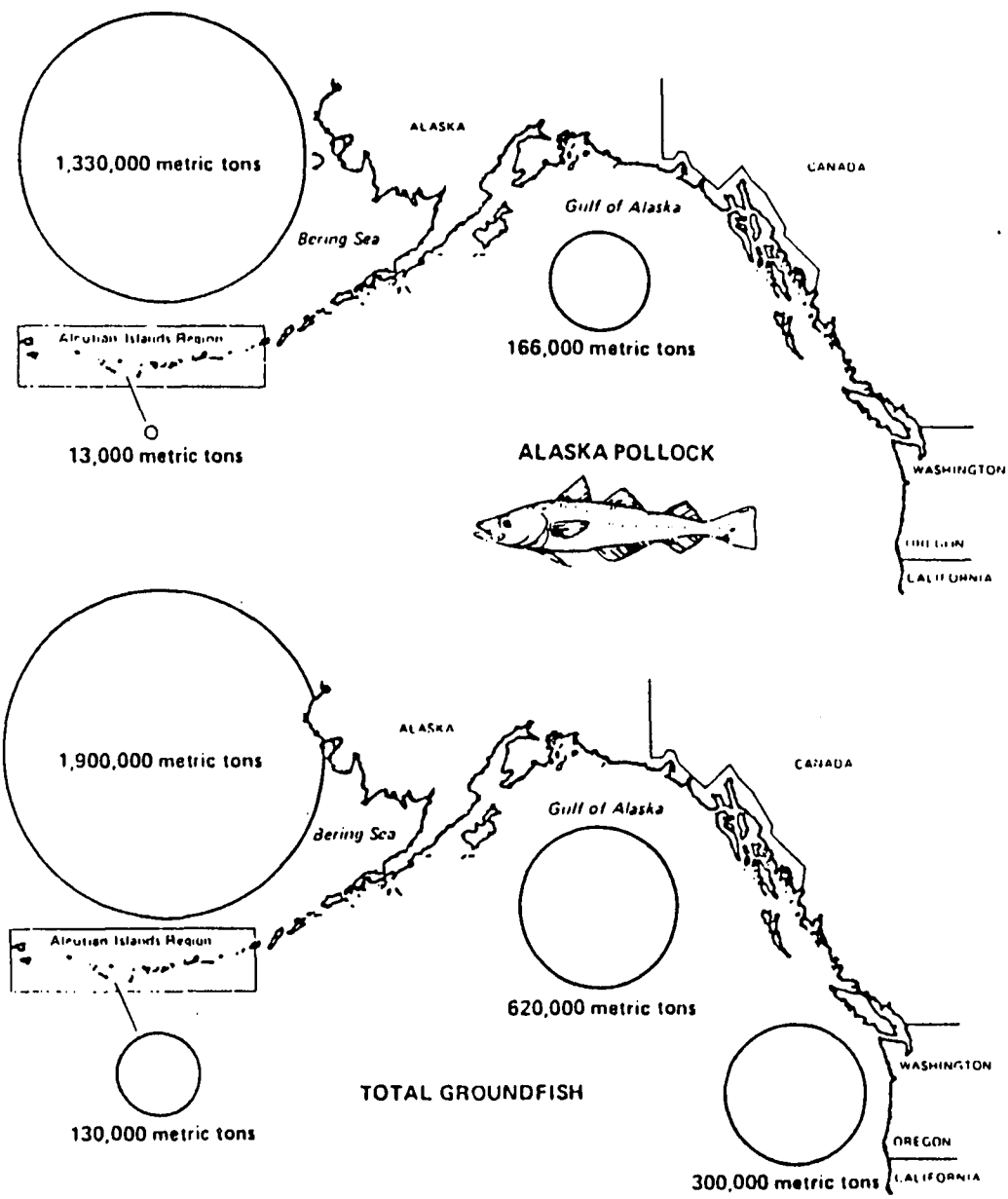


Figure 2. Alaska pollock and total groundfish availability within the U.S. Fishery Conservation Zone from Alaska to California (Natural Resources Consultants, 1983).



Products

Pollock is used in the manufacture of a variety of products depending on the country involved, national preferences, historical use patterns and available technology. In the pre-World War II period, most pollock was headed, gutted and dried while smaller catches were eaten fresh (Natural Resources Consultants, 1983). Dried pollock was a traditional product in Korea. In the post-World War II period, Korea again began to use pollock in the dried form, but with the advent of improved preservation methods greater amounts were consumed fresh, particularly in South Korea and Northern Japan (AFDF, 1987).

The greatest variety of pollock product is manufactured by Japan, where a highly sophisticated and technologically advanced industry has developed, based on making commercial products from fish paste (surimi). Most of the surimi produced in the past few years in Japan is made from pollock, although small amounts of other species are also used.

Surimi

History

Traditionally, Japanese surimi was prepared from fresh fish and immediately processed into kamaboko which is a generic term for a variety of products prepared from surimi. The technique for making kamaboko products from minced and washed fish evolved around 1100 A.D., when Japanese fishermen discovered that they could keep the product longer if washed minced fish was mixed with salt, ground, and cooked (Lee, 1984).

For several centuries, surimi production was run on a day-to-day basis, depending on the supply of fresh fish available from days catch, until Japanese scientists discovered a technique to stabilize frozen surimi (Matsumoto, 1978). This technique was based on the use of a cryoprotectant (sucrose) which kept the surimi stable from denaturation during frozen storage (Lee, 1984).

In recent years, about half of the Japanese frozen surimi has been processed on board ships and the other half by land-based operations (Okada, 1985). Processing frozen surimi on board has a superior quality to that prepared in shore plants, due to immediate handling (on the same day of harvest) that ensures a good quality product. Shore plants process fish that have been harvested one to five days prior to handling, depending on

the distance of the fishing ground to the plants (Suzuki, 1981; Okada, 1985).

Surimi is prepared from over 60 fish species such as Alaska pollock, mackerel, croaker and shark (Suzuki, 1981). Each species requires slightly different processing techniques (Lee, 1984). Most companies now entering the surimi production business in the U.S. are focusing on Alaska pollock as the raw material (AFDF, 1987).

Recently, many countries have been interested in Japanese kamaboko products and have tried to adopt the surimi technology to optimally utilize their fish resources (Okada, 1985). Introduction of a variety of new, improved equipment and machinery increased initial production of 8,000 mt of frozen surimi by factory ships in 1965 up to the record of 218,000 mt in 1973. The expanding marketing opportunities increased the demand for surimi and accelerated the growth of surimi technology. In 1987, twenty countries were either investigating or commercially producing surimi. World surimi production for 1987 was estimated between 350,000 and 400,000 mt made from numerous species (AFDF, 1987).

Processing

Surimi is a bland, white, gelatinous fish paste with an exceptionally long frozen shelf life due primarily to the addition of cryoprotectants. Though surimi can successfully be made from many species, including blue whiting, mackerel, menhaden and hoki, Alaska pollock has been identified as one of the most attractive raw materials for surimi. There are seven basic steps of surimi production (AFDF, 1987).

Heading and Gutting. Viscera and the majority of the backbone are removed. It is extremely important to remove most of the backbone at the heading/gutting stage because neural fluids in the backbone break down proteins in the flesh and degrade the surimi. The kidney, intestines, parts of the stomach and the liver contain enzymes that severely damage the integrity of the protein if allowed to mix with the flesh.

Mincing. Muscle tissue is separated from skin and bones of the fish by a belt-drum-type deboner. The minced tissue falls out of the end of the drum, and the rejected skin and bone falls into a chute for disposal.

Washing/Rinsing. The mince is mixed with fresh water in a ratio tank. The tank is given this name because it is important to maintain the water/mince ratio at such a level that the mince begins to mix with water. Washing the fish mince in fresh water removes some water soluble proteins and fats, increasing the concentration of functional myofibrillar proteins. Some enzymes or undesirable components such as alkaline protease (Lanier et al., 1981), blood and pigments are also rinsed away at this stage. Washing is done in a three or four stage series of tanks, with partial dewatering between stages.

Refining. After the final rinsing, the washed mince falls down a chute into the refiner where most of remaining imperfections are removed from the flesh. The refiner is a high-speed rotating spiral surrounded by a screen with holes measuring 1.2 mm to 3.2 mm in diameter. The soft, yielding flesh is forced through the screen; material with imperfections such as skin, bone, and connective tissue can not be pushed through the holes and is discarded through the reject end of the drum. It is important to monitor the speed and temperature of the flesh as it spins to ensure that the material is not damaged by heat generated friction in the refiner.

Dehydrating. The remaining water is squeezed out of the mince at this stage. A screw press is usually employed. As the screw rotates, it pushes the flesh down the length of the drum. Since the screw gradually increases in diameter, the increasing pressure squeezes the remaining moisture out of the mince through the small holes in the screen.

Mixing. The material at this stage is a paste and about the consistency of mashed potatoes. It is mixed with four percent each of sucrose and sorbitol. These cryoprotective ingredients stabilize the surimi proteins from denaturation in the frozen stage. Prevention of protein denaturation by sugars can be explained by their ability to increase the surface tension of water (Arakawa and Timasheff, 1982) as well as the amount of bound water, which prevents withdrawal of the water molecule from the protein, thus stabilizing the protein (Sun and Wang, 1984). The addition of sucrose and sorbitol also adds a sweetness to the surimi that some U.S. consumers find undesirable. Work is now progressing to replace these ingredients with other nonsweetening cryoprotectants.

Filling/Freezing. After mixing, the surimi is extruded onto metal trays lined with polyethylene bags using a hydraulically-driven filler. The surimi must be quickly frozen to temperatures at least as low as -4° F (-20°C). Freezing can be done in contact plate freezers or air blast freezers.

Surimi-Based Products

Surimi-based food products, primarily shellfish analogs, are the most exciting new seafood products to hit the American market since the introduction of fish sticks 30 years ago. According to Sabella (1985) and Hasselback (1984), simulated crab has represented 90% of the surimi market, but other shellfish analogs (scallops, shrimp and lobster) are just becoming available. The quantity of surimi-based foods is doubling annually. The crab product is available in a number of forms including, legs, chunks or flakes, and is presented in many brand names, such as Sea Legs, King Krab, Ocean Magic, and etc. (Hasselback, 1984; Anonymous 1982).

Simulation of texture is achieved not only by a mechanical texturization process, but also by textural modification through formulation with added ingredients. The commercial formulas for simulated shellfish products differ not only with the type of products but also with manufacturers (Lee and Kim, 1985).

Primarily, Alaska pollock is used in the manufacture of surimi-based shellfish products. Other low priced species may be used, such as, fresh water catfish, gulf croaker, menhaden and red hake (Hasselback, 1984; Anonymous, 1984). Domestic production of surimi-based products could provide utilization for the giant Alaska pollock resource; Pacific whiting from Washington, Oregon and California waters; Atlantic gulf croaker; and red and silver hake from New England. Undoubtedly, Alaska pollock will be the leader in surimi production, which alone could generate one billion pounds (454,454 mt) of surimi annually (Babbitt, 1986).

Surimi could provide a use for the bulk of the now underutilized species and give seafood protein a secure and substantial role in the diet of the United States consumers (Sabella, 1985). The development of surimi technology has just begun in the U.S., while Japan has been improving this technology for several hundred years. The commercial success of the United States surimi industry will depend greatly upon how quickly it can absorb the existing technology and how new products developed by domestic processors can compete with Japanese products (Lee, 1984).

Kamaboko

Gel Formation

Kamaboko is the heat-set gel prepared from salt solubilized, refined, fish flesh (Niscolo and Frank, 1966). The distinguishing characteristic of kamaboko is its texture called "ashi". Actomyosin (myofibrillar protein) in fish meat is the essential element to form ashi. Kamaboko with good "ashi" is produced from fish muscle containing the greatest quantity of salt extractable myofibrillar protein (Okada et al., 1973).

Study by Fukazawa et al. (1961) shows that among the myofibrillar proteins, myosin is shown to be the primary agent for gel formation. Complete solubilization of the myofibrillar protein is necessary for gel formation. Sodium chloride is used for solubilizing myofibrillar protein. According to Suzuki (1981), the main component of salt-solubilized protein is actomyosin which is an essential component for gel formation. Optimal gelling properties in surimi are obtained with the addition of 2.5-3.0% NaCl (Lanier et al., 1985). The sodium chloride ions are bound to the acidic and basic amino acid residues, therefore intermolecular ionic bonds are ruptured, and as a result the proteins are dispersed in the water or solubilized. Ionic bonds and hydrogen bonds are not thermo stable and are ruptured on heating. On the

contrary, disulfide bonds and hydrophobic bonds are thermostable and their formation, is promoted by heating which results in a three dimensional gel network (Niwa, 1985).

Jiang et al. (1986) demonstrated the important role that disulfide bonds play in the formation of minced fish gels. The low gel forming ability of frozen fish was attributed to the loss of reactive sulfhydryl groups during frozen storage. Sulfhydryl groups were recovered by adding reductants as the fish was ground. The pH of the minced fish was neutralized and oxidants were added during processing into the final product to induce the reformation of disulfide bonds which reinforced the protein network structure of the gel.

A different kind of sol-gel phenomenon has been identified as setting (Makinodan and Ikeda, 1971). Translucent gels are formed when protein sols are subjected to a low temperature setting (holding near 0°C for 12-24 hours) and high temperature setting (near 40°C, one hour) (Wu et al., 1985a). Lanier et al., (1981) have shown that fish protein that has been set prior to cook gelation will possess stronger textural properties than if cooked directly from the raw state.

However, Wu et al. (1985b), have shown that a high temperature setting may consist of thermal denaturation (unfolding) of particular regions of myosin with

subsequent formation of a network structure through aggregation of unfolded molecules. Thus intermolecular hydrophobic interactions rather than disulfide bonding were responsible for gel formation at high temperature. This may show that there is a wide variation in the gel forming ability of muscle proteins among different fish species (Makinodan and Ikeda, 1971).

Effect of Temperature

The function of the myofibrillar proteins in a comminuted product is their ability to form a continuous gel, and among these proteins myosin is the primary agent in this process (Fukazawa et al., 1961). The quality of gel-forming is dependent on the species, processing conditions and heat treatments.

Lanier, et al. (1981) and Cheng, et al. (1979) have reported both protein changes during heating and the effect on textural parameters. All have demonstrated that gel setting of fish muscle proteins takes place at temperatures above 55°C.

An earlier report (Cheng et al., 1979) noted that the degradation of myosin is related to the textural strength of cooked fish gels. A proteolytic factor in the sarcoplasmic fraction, termed alkaline protease (Iwata et al., 1974; Makinodan and Ikeda, 1971; Makinodan and Ikeda,

1977), was suspected to be responsible for the myosin degradation during thermal processing. As a result, textural firmness was decreased at temperatures approaching the optimum for proteolytic activity (60°C) which was due to proteolytic degradation of the muscle proteins. At temperatures above and below this region, proteolytic activity was decreased, and the textural firmness of gels was much greater. This finding thus suggests that the textural firmness of gels is closely linked with protease activity.

According to Lee (1984), surimi paste gels rapidly upon heating at 80-90°C but slowly at 40-50°C. High temperatures (80 to 90°C) resulted in a stronger gel than cooking without a slow set (40 to 50°C). This led to a new theory of temperature-dependent gel-setting behavior. At a fast (high temperature) heating rate, a tight, cohesive network with a large number of small aggregrates is formed, whereas at a slow heating rate, a loose network with a small number of large aggregates is formed. From this finding, it was determined that the strongest gels could be produced by preincubating the gel at 40°C, followed by cooking at 90°C.

The Effect of Ingredients on Gel Texture

Nonprotein Adjuncts

The pH is the most important single factor influencing texture in fish (Feinstein and Buck, 1984). The gel strength of surimi based products is influenced by pH. The strongest gels were obtained when the pH was maintained between 6.5 and 7.5 (Okada, 1985). The optimum pH range for solubilization of actomyosin was found to be 6.5 - 7.0 (Knipe et al., 1985). Phosphates and/or sodium carbonate is commonly used for adjusting the pH of surimi based products. Also, Shimp (1985) mentioned that polyphosphates are effective in surimi based products because they act by increasing pH and enhancing solubilization of the myofibrillar proteins. This improves water binding and thus enhances gel strength.

Moisture content greatly influences the overall textural characteristics of kamaboko (Lee, 1986). The textural effects of moisture are dependent upon its interaction with other ingredients in the gel product formulation. Lee and Toledo (1979) reported that the strength of cooked gels made from comminuted Spanish mackerel decreased gradually as the moisture level was increased to 79% and dropped drastically with moisture levels in excess of 79%. The results suggested that

products are less cohesive below a critical moisture content.

Bovine Serum Albumin

The proper utilization of gelling substances with surimi may improve the texture of the products, especially in instances when low grade surimi is used. Blood plasma is commonly used in meat products as a functional ingredient mainly because of its gelling properties induced by heat (Hermannson and Lucisano, 1982).

Beef plasma contains over 73% protein, will bind up to 10-12 times its weight in water, emulsifies fats, enhances the texture of cooked sausage products, and it has been demonstrated to provide heat-coagulating and foaming properties similar to natural egg products in cake formulas (Duxbury, 1988). Therefore, when powdered plasma proteins are added to meat products, the water binding properties are enhanced. The texture of products that contain powdered plasma is greatly improved and the "mushiness" factor of a product is lowered.

Egg White

The appearance and texture characteristics of many cooked foods is primarily dependent upon the ability of egg albumen to coagulate and produce a continuous three

dimensional gel network possessing structural rigidity (Shimada and Matsushita, 1980). This functional property could be important in the development of new food products that utilize egg white solely, or in conjunction with other proteins, to provide the textural properties of the product (Buldwin, 1977).

Egg white is added in either raw or frozen form to increase glossiness as well as to enhance the textural strength of kamaboko. Different concentrations are used depending on the fish species and the desired texture of the final product. Several researchers have reported that protein adjuncts had functions like fillers in fish gels. According to Burgarella et al. (1985), the globular proteins (egg white and whey protein concentrate) absorbed water and filled the interstitial spaces of the fish protein gel matrix. The turgidity of the matrix was increased as a direct result of increased solids content and decreased moisture content. Iso et al. (1985) also attributed this same filler mechanism to the increased gel strength and elasticity of surimi gels containing egg white. This may indicate that the additives do not contribute to the network structure of kamaboko but instead perform as filler.

When dry egg white is used, an appropriate amount of water should be added to adjust the moisture content of the finished product (Lee, 1984). A large amount of egg

white, such as, 20%, however, decreases the textural strength, causes brittleness and gives an unpleasant hydrogen sulfide odor to the product (Okada, 1985).

Gluten

Vegetable protein is widely used as an additive to many food products. It can also be used for fish paste products such as boiled kamaboko, fried kamaboko, fish sausage, and etc. (Areche and Fujii, 1979). Gluten, or wheat protein, is added in dry form to enhance the gel strength of kamaboko. Gluten has to be rehydrated before it can be used since the rehydrated proteins move more rapidly and become incorporated into the gel matrix. According to Okada (1985), addition of dry gluten without rehydration markedly increases the textural strength of the end products, but the texture is too tough. With an increase in the amount of gluten added, the color of kamaboko darkens and an unacceptable flavor is detected. Therefore, it is recommended to add less than four percent gluten on a dry basis to surimi (Okada, 1985).

Analysis of Texture

Instron Texture Profile Analysis

The Instron Universal Testing Machine has been used to evaluate texture of meat, meat products, intact poultry muscle (Prusa et al., 1982) and kamaboko (Lanier, 1985). Also, this instrument serves the very useful purpose of quantifying (objectively) quality factors related to textural parameters. According to Kramer (1968), however, an objective method cannot possibly be an improvement in accuracy over a subjective method, since the accuracy of an objective procedure can be determined only by its degree of correlation with the subjective evaluation sought. The precision and accuracy of the objective method, however, can be superior since a physical or chemical procedure should provide closer duplication than a human sensory panel, and by use of references or blanks, objective methods should be more easily calibrated than human judges who are subject to drift. The objective of Instron Universal Testing is to replace sensory evaluation testing, however, although the objective methods can give numbers they fail to answer the key question of product acceptability.

Sensory Evaluation

Humans are the best source for evaluating food texture, since they can simultaneously perceive, analyze, integrate, and interpret a large number of textural sensations (Larmond, 1976), even though the sensory evaluation test is faced with many methodological, psychological and physiological problems. Consumer panels respond to the ultimate criterion of food quality which is product acceptability.

Disadvantages include the expense and time associated with sensory texture profiling and have led to investigations of instrumental procedures to provide descriptions of the textural attributes of a product. Instrumental texture profile analysis can be extremely useful in evaluating the textural quality of foods; however, since texture is by definition a sensory characteristic (Szczesniak, 1963), the usefulness of any procedure is limited by its relationship to sensory assessment.

Sensory evaluation could be too subjective. Correct panel methods and training, however, can greatly improve the reliability and validity of sensory tests (Abbott, 1972). Therefore, both Instron Texture Profile Analysis and trained sensory evaluation panels would seem to be necessary to evaluate food texture.

MATERIALS AND METHODS

Materials

Frozen Alaska pollock surimi made by North Pacific Seafoods (Kodiak, AK), was used for these studies. The surimi was composed of Alaska pollock, 91.7%; sucrose, 4.0%; sorbitol, 4.0% and sodium tripolyphosphate, 0.3%. The surimi was supplied courtesy of the Alaska Fisheries Develpoment Foundation (Anchorage, AK).

Preliminary work involved the evaluation of pH, moisture, mixing time and concentration and type of protein adjunct (binding agent) and their effect on gel texture. The results of these evaluations were used to establish protocol and formulations for development of the analog.

Adjustment of pH

Sodium carbonate (J.T. Baker, Phillipsburg, N.J.) was used at five levels ranging from 0 to 0.2% to adjust the pH of the batter to 6.65 to 7.73. A slightly alkaline pH generally enhances muscle water binding capacity.

Moisture Content

Numerous investigations have focused on batter formulations that are isonitrogenous. This may be a poor control since water binding in formulations with

comminuted muscle is largely dependent upon the concentration of myofibrillar proteins which compete for available water. Varying moisture levels may affect gel texture, e.g., higher moisture may lead to softer gels. Moisture content was adjusted with ice water at five levels ranging from 73% to 78% for these experiments.

Sol Mixing Time

Different theories exist relating to the time needed to solubilize the myofibrillar proteins in the presence of salts. Four different mixing times (10 to 40 mins.) were tested. Additionally, batter temperature was checked during mixing.

Type and Concentration of Protein Adjuncts

Egg white (Milton G. Waldbaum Corp., Wakefield, NB), bovine serum albumin (American Meat Protein Corp., Ames, IA) and gluten (Sigma Chemical Corp., St. Louis, MO) were added to batter formulations at the 0, 1, 2, 3, and 4% levels. Moisture content was adjusted to 75.0$\pm$1%.

Batter Preparation, Packaging and Thermal Processing

Frozen surimi was tempered for 16 hours at 2-4°C. The sols were prepared by blending surimi, 2% Nacl, sodium carbonate and ice water at low speed with a Kitchen Aid

mixer (Hobart, Troy, OH) for 20 min at room temperature (22°C.).

A sample of each sol (ca., 250 g) was transferred to a 10.5 cm x 13.0 cm x 2.4 cm, i.d. plastic tray (Gage Industries, Inc., Lake Oswego, OR) bagged, and vacuum sealed (ca., 74 cm Hg, Cryovac Model 6250-B, W.R. Grace & Co., Duncan, SC). The packaged sols were heat-set in a water bath at 40°C for 30 min, followed by heating at 90°C for an additional 30 min. Upon completion of heating, the gels were immediately cooled in ice water. The packages were wiped dry and held overnight at 2-4°C.

Development of Analog

Textured Chunk Production

Frozen surimi was tempered for 16 hours at 2-4°C. Sols were prepared by blending surimi, 2% Nacl, 0.1% sodium carbonate and ice water at low speed with a Kitchen Aid mixer (Hobart, Troy, OH) for 20 min at room temperature (22°C). Final moisture content was adjusted to 75%$\pm$1%. One of three protein adjuncts including egg white (Milton G. Waldbaum Corp., Wakefield, NB); gluten (Sigma Chemical Corp., St. Louis, MO); or bovine serum albumin (American Meat Protein Corp., Ames, IA) equal to 2% of the final product formulation was added and mixed for an additional 10 min. Gluten was rehydrated before

being added (gluten:water, 1:3 w/w). Sols were packaged and thermally processed as previously described.

Gel Grating

After cooling, the gel was grated manually with a cheese grater (diameter, 6.5 mm) and called the texturized chunk (CH). The shredded gel product was formulated with hardness and elastic properties that would differ from the carrier. The objective of this procedure was to develop a varied and irregular texture that would simulate tenderized abalone when the texturized chunks were incorporated into a carrier.

Carrier Production

A sol [carrier, (CA)] was prepared by mixing 89.8% surimi, 2% salt, and 8.2% ice water for 20 min at room temperature (22°C). The final moisture content was 76%±1%. The texturized chunks (CH) were added to the carrrier at different ratios (ratio of CH to CA: 70/30, 50/50 and 30/70) and mixed for an additional 10 min. The sol was transferred to a 10.5 cm x 13.0 cm x 2.4 cm (i.d.) plastic tray (Gage Industries, Inc., Lake Oswego, OR) and vacuum sealed (ca., 74 cm Hg). The sol was heat-set in a water bath at 40°C for 30 min, and held at 90°C for an additional 30 min. After completion of heating, the gel was immediately cooled in ice water and held for 16 hours

at 2-4°C. Trays were removed from refrigeration (2-4°C) and allowed to temper at ca., 22°C for 1 hour. Gels were evaluated by Instron Texture Profile Analysis and a trained sensory evaluation panel.

Preparation of Abalone

Raw Material

Five pounds of tenderized, frozen abalone was purchased from Pacific Seafood Co. (Clackamas, OR) at $36.97 per pound. The abalone was a product of Mexico and identified as Haliotis rufescens. The steaks had been mechanically tenderized by a "cuber" or a mechanical (cube) tenderizer.

Thermal Processing

Raw abalone (ca., 10 cm x 10 cm x 0.5 cm) was sealed in a vacuum bag with a vacuum sealer (ca., 74 cm Hg, Cryovac Model 6250-B, W.R. Grace & Co. Duncan, SC) and cooked in a water bath at 90°C for 10 mins. After heating, the abalone was immediately cooled in ice water and held for 1 hour at 2-4°C.

Instron Texture Profile Analyses (ITPA)

Analysis of Gel Strength

Gels were removed from refrigeration and allowed to temper at ca. 22°C, for 1 hr. Cylinders, 1.4 cm diameter, were cut from the heat-set gels with a brass cork bore. Material from each end of the cylinder was cut to achieve appropriate length (1 cm) and to eliminate dried and case hardened surfaces. Cylinders were selected with a minimum of air pockets.

Double bite compression measurements were performed using the Instron Universal Testing Machine (Instron Corp., Los Alamitos, CA) on three representative cylinders from each gel using the following conditions: crosshead speed, 10 cm/min; chart speed, 100 cm/min; gage length, 1.5 cm; return length, 0.2 cm (80% compression). Each sample was weighed to the nearest 0.01 g and compressed twice using automatic return. Determinations were made based on values obtained in triplicate for each sample according to methodology described by Bourne (1968). Hardness (force or height) of the first peak (first bite); cohesiveness, the ratio of the area of the second compression curve (A2) to that of the first compression curve [(A1) (expressed in arbitrary units)]; and elasticity the ratio of the base length of the second curve (D2) to the base length of the first curve (D1)

(reported as a percentage) were calculated. A dimensional analysis of the texture profile parameters is shown (Figure 3).

Figure 3. A dimensional analysis of the Instron texture profile parameters.

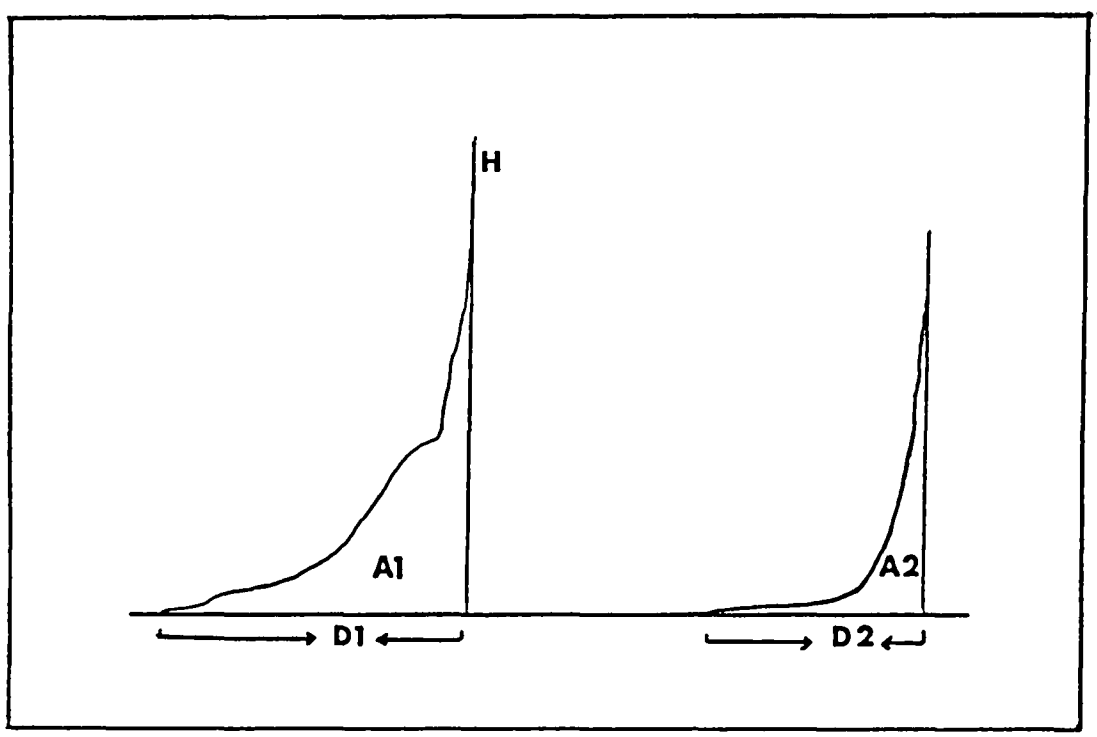


Figure 3. Instrumental Texture Profile Analysis (ITPA) from a Pacific whiting cooked gel. Double bite test. Hardness (H) in pounds; cohesiveness (A2/A1); elasticity (D2/D1) x (100).

Analysis of Cooked Abalone Texture

Cooked abalone was removed from refrigeration and allowed to temper at room temperature (22°C), for 1 hour. Cylinders, 1.4 cm diameter, were cut from the cooked abalone with a brass cork bore. Double bite compression measurements were performed as previously described.

Sensory Evaluation

Panel Training

A panel of eight staff members and graduate students at the Oregon State University Seafoods Laboratory, Astoria, OR were chosen on the basis of interest and availability. The objective of this training was to learn terms, techniques, the scaling procedure and practice until all panelists were performing in a similar manner.

Standards. Standards used for panel training were chosen from the list of food items constituting the standard rating scales for evaluation of cohesiveness, elasticity, chewiness and hardness for fish gels (Cardello et al., 1982). Some substitutions to these lists were made to compensate for current and local availability of items. The complete list of test items is shown for each standard scale (Table 2).

Table 2. Reference Standard Samples

Cohesiveness

Product	Brand, Type Preparation	Manufacturer	Sample size	Temperature
Cream cheese	Philadelphia	Kraft, Inc.	1 cm cube	ambient
Frankfurters	large, uncooked	Hygrade Foods	1 cm cube	ambient

Elasticity

Cream cheese	Philadelphia	Kraft, Inc.	1 cm cube	ambient
Frankfurters	large, uncooked	Hygrade Foods	1 cm cube	ambient
Marshmallow	small	Kraft, Inc.	1 cm cube	ambient

Chewiness

Rye bread	Fresh, Center	Croweat	1 cm cube	ambient
Frankfurters	large, unheated	Hygrade Foods	1 cm cube	ambient
Caramel candy	1 piece	Kraft, Inc.	1 cm cube	ambient

Hardness

Cream cheese	Philadelphia	Kraft, Inc.	1 cm cube	ambient
Frankfurters	large, uncooked	Hygrade Foods	1 cm cube	ambient
Gummy worms	1 piece	Kraft, Inc.	1.5x0.5x0.5cm	ambient

Procedure. Four sessions were conducted, each on separate days. Each session was devoted to the testing of a single textural attribute which included cohesiveness, elasticity, chewiness and hardness. At the beginning of each session all panelists were given written instructions (Appendix A). In addition to containing a description of the task, the instructions contained an operational definition of the attribute to be judged during that session. After reading the instructions and accompanying definition, the panelists were given a demonstration of the exact physical technique for judging the attribute and also became aquainted with scaling techniques and ballot to be used. During the training sessions, the panelists compared the textural attributes of various food items (Table 3) with cooked abalone samples for the purpose of selecting the most appropriate food item to serve as a reference standard for each attribute.

Sample Testing Procedure

After the training sessions, sample evaluation sessions began. Each panelist kept and referred to the written instructions and definitions of the attributes prior to each test session.

There were three different gel treatments (ratio of chunk to carrier: 70:30, 50:50, and 30:70) to be

evaluated. The testing procedure involved presenting the panel a tray with four pieces (1.5 cm x 1.5 cm x 0.5 cm) of a reference standard (selected previously) in one cup and four pieces of each treatment in a separate cup. Cups were coded with three-digit numbers and presented randomly. The four attributes were evaluated one at a time in one session and the sessions were repeated three times on three separate days on gels prepared from three separate lots of surimi. The cooked abalone (1.5 cm x 1.5 cm x 0.5 cm) also was evaluated at the end of each session. The testing procedures were basically the same as that of the gel treatments, except there were no numerical codes since there were no experimental treatments among abalone samples.

Treatments were evaluated by the panelists using magnitude estimation (Moskowitz, 1983). Panelists compared the magnitude of each sensory attribute of the cooked abalone and gels with those of the appropriate reference standard samples. The magnitude of each sensory attribute was estimated by assigning a number proportional to the standard magnitude rating of the attribute in the reference standard sample. For example, the standard rating of the reference sample for cohesiveness was 50. The panelists compared the cohesiveness of the cooked abalone and gels with that of the reference and assigned the abalone and treatment gel a magnitude estimation score

for cohesiveness; of 50 if it were equally cohesive, 100 if it were twice as cohesive, or any other proportional number.

Chemical Analyses

Proximate Composition

Proximate analyses were performed, in duplicate, according to AOAC methodology (1984). The proximate composition (moisture, protein, lipids and ash) of the three lots of Alaska pollock and samples of gelled product containing egg white, gluten and bovine serum albumin and samples of abalone was determined.

Determination of pH

The pH of each batter and raw abalone was measured. A 1:10 (sol or meat to distilled water) suspension was prepared by homogenization at 13,000-14,000 rpm with a Kinematica CH-6010 Polytron (Kriens-Lu, Lucern, Switzerland) for 30 seconds. The pH of the suspension was determined with a standardized Corning Model 240 pH meter.

Statistical Design and Analyses

Analysis of variance for preliminary work was conducted with the Stats Plus program (Human Systems Dynamics, Northridge, CA) with an Apple IIe computer. When analysis of variance revealed a significant effect ($P \leq 0.05$), the least significant difference (LSD) test was employed to determine differences between level and treatment means.

The variability of the magnitude estimation scores from the trained panel was reduced by dividing each score in a set by the geometric mean of the set. A set consisted of the estimation scores from a single panelist for the magnitude of a specific attribute in all three different ratio samples.

For analysis of the trained sensory panel results, there were three analyses of the data. The first was for the overall design, the second was for individual adjuncts and the third was for difference analysis. The experimental design treated panelists as a blocking factor since the same panelists were used for all evaluations. The ratio of chunk to carrier was considered as a nested factorial treatment set where the ratios were nested within each protein adjunct. The source of variation of panelist and adjunct was tested by panelist by adjunct interaction. The source of variation of panelist by

adjunct was tested by an error source of variation from the process replication over adjunct. For each adjunct, the ratio source of variation was tested by process replication by ratio within each individual adjunct. The panel by ratio in adjunct was tested by process replication across each ratio within adjunct effect.

For the analysis of the Instron test (TPA) results, the source of variation of adjunct was tested by replication within adjunct. In each adjunct, the source of variation of ratio was tested by error from each individual adjunct.

Data were evaluated by analysis of variance using the SAS (Statistical Analysis System, SAS Institute, Raleigh, NC). When analysis of variance resulted in a significant effect ($P \leq 0.05$), the least significant difference test (LSD) was employed to determine which treatment means were significantly different from each other (Petersen, 1985).

RESULTS AND DISCUSSION

Effect of Sodium Carbonate on Sol pH and Gel Texture

Preliminary work involved the incremental addition of sodium carbonate in sols and its effect on pH and texture. Five different levels of sodium carbonate were employed. Increasing the level of sodium carbonate from 0% to 0.2% increased the pH of the final sol from pH 6.65 to 7.73, respectively (Table 3). Final moisture content was 74.58% (±0.39%).

Table 3. Effect of Sodium Carbonate on Mean Gel Hardness as Measured by Instron Texture Profile Analysis and Sol pH.

Sodium Carbonate (Level)	Sol pH	Hardness[1] (N/g)
0%	6.65	94.84[a] (±2.78)
0.05%	6.95	104.95[b] (±1.16)
0.1%	7.35	109.25[bc] (±0.92)
0.15%	7.65	111.20[c] (±1.36)
0.2%	7.73	106.76[b] (±5.34)
LSD		5.0479

[1] $P < 0.001$

[a,b,c] Treatment means in a column with same letter were not significantly different ($P \leq 0.05$).

( ) Standard deviation.

There was a significant difference in gel hardness ($P<0.001$) among different levels of sodium carbonate added. Both gel elasticity ($P=0.2185$) and cohesiveness ($P>0.05$) were not found significantly different at any level.

The 0.1% level of sodium carbonate was selected for further experiments. Though 0.15% sodium carbonate resulted in greater gel hardness, there was not a significant difference between 0.1% sodium carbonate and higher levels ($P>0.05$). In addition, the least quantity for optimal effectiveness is best to minimize total sodium in the final product. As a result, pH 7.3 to 7.7 in the final product resulted in the most desirable textural attributes even though Iwata et al. (1974), indicated that a pH above 7.0 resulted in a weaker gel. Both solubility of the proteins and the textural quality of kamaboko are at a minimum at the isoelectric zone of pH 5 to 6. Hamm and Deatherage (1960) demonstrated that the water holding capacity of the meat increased as the pH was raised above the isoelectric point (I.P. = 5.0 for meat). It was asserted that the electrostatic attraction between the protein molecules was eliminated as the alkalinity of the meat increased. The protein net charge was increased, which resulted in an increased repulsion of the peptide chains and consequently, an enlargement of the space between the protein molecules allowing greater penetration

of water into the matrix. According to Cheng et al. (1979), water holding capacity was closely related to the gel texture. As water holding capacity was enhanced, gels from sand trout had a firmer, more springy texture. This finding was supported by Lee and Toledo (1976). As the pH value becomes higher, the textural strengh of the kamaboko increases. The greater the increase in pH above 8, however, results in kamaboko with lower gel strength and less cohesiveness (Okada, 1985) and relates directly to swelling by the myosin heavy chain (Nishimoto et al., 1987).

Effect of Moisture

In addition to pH, the overall textural characteristics of surimi gels are affected by another factor, moisture. Firmness can be altered not only by ingredients but also by the moisture level in a given formula (Lee, 1986). The moisture content of commercial formulas ranges from 72% to 78%.

Preliminary work using Instron Texture Profile Analysis has shown that there were significant differences in both hardness ($P<0.001$) and cohesiveness ($P<0.001$) among different levels of moisture (Table 4). A five percent increase in moisture resulted in a 59% reduction in texture hardness and a 23% reduction in cohesiveness.

These results were in agreement with those of Lee and Toledo (1979) who reported that the strength of cooked gels made from comminuted Spanish mackerel decreased gradually as the moisture level was increased to 79%. Also, these researchers' results have shown that cohesiveness was significantly affected by moisture ($P<0.001$). In addition, Nishimoto et al. (1987) also demonstrated that higher water content decreased the strength of Alaska pollock gels. Similar occurrences have been reported with beef gels (Kenney et al., 1985; Acton et al., 1982; Hamm, 1960).

Table 4. Effect of Moisture on Mean Gel Hardness, Elasticity and Cohesiveness Measurements by Instron Texture Profile Analysis.

Moisture	Hardness[1] (N/g)	Elasticity[2] (%)	Cohesiveness[3]
73.24%	126.93[d]	72.07	33.26[b]
	(±2.85)	(±3.81)	(±2.18)
74.31%	121.26[d]	69.47	33.18[b]
	(±3.81)	(±2.60)	(±1.40)
75.39%	106.34[c]	70.76	38.49[c]
	(±6.82)	(±3.00)	(±1.31)
76.96%	84.87[b]	72.63	31.69[b]
	(±2.94)	(±1.81)	(±2.80)
77.66%	51.49[a]	65.30	25.59[a]
	(±2.79)	(±5.42)	(±2.13)
LSD	7.8659	---	3.0697

[1] $P<0.001$, [2] $P=0.0645$, [3] $P<0.001$.
[a,b,c,d] Treatment means in a column with same letter were not significantly different ($P\leq0.05$).
( ) Standard deviation.

Effect of Sol Mixing Time

As previously indicated, surimi is highly concentrated with myofibrillar protein, primarily actomyosin, which is solubilized by sodium chloride during mixing. According to Okada (1964), elasticity and resilience of surimi gels increases with elevated concentrations of actomyosin. Elasticity is dependent upon solubilization of actomyosin which cross-links into a gel network during heat setting.

Solubilization of actomyosin increases with extended comminution of surimi and reaches a maximum within 15-20 minutes of mixing (Lee, 1984). Beyond this mixing period, the temperature of the meat rises, resulting in protein-protein interaction which causes a decrease in gel-forming ability (Lee and Toledo, 1976). With temperature control, Acton et al. (1982) have demonstrated that a maximum mixing time of only 12 mins is necessary to solubilize myofibrillar proteins. On the basis of study of Spanish mackerel, Lee and Toledo (1974) recommended that mixing be continued until a sufficient solubilization is achieved, while keeping the temperature of the batter below 16°C. Alternately, the current Japanese mixing practice calls for 10°C as a maximum allowable temperature for Alaska pollock (Lee, 1984).

Here it was demonstrated that 30 minutes of mixing resulted in the highest elasticity (P=0.002), hardness (P<0.001) and cohesiveness [(P<0.001), (Table 5)]. During mixing, the temperature was held below 14°C. Final moisture content was 76.91% (±0.106).

Table 5. Effect of Sol Mixing Time on Mean Gel Hardness, Elasticity and Cohesiveness Measurements by Instron Texture Profile Analysis

Mixing Time	Hardness[1] (N/g)	Elasticity[2] (%)	Cohesiveness[3]
10 min	48.33[a] (±1.45)	55.97[a] (±1.93)	26.41[a] (±1.66)
20 min	68.21[b] (±2.27)	64.65[b] (±3.14)	34.25[b] (±1.10)
30 min	74.75[c] (±4.09)	64.98[b] (±0.76)	38.94[c] (±1.17)
40 min	62.18[b] (±4.16)	64.30[b] (±2.07)	32.71[b] (±2.35)
LSD	6.0457	4.0426	3.1053

[1] P<0.001, [2] P=0.002, [3] P<0.001.
[a,b,c]Treatment means in a column with same letter were not significantly different (P≤0.05).
( ) Standard deviation.

Effect of Protein Adjuncts

Serial levels, ranging up to 4%, of spray dried egg white, bovine serum albumin and gluten were added to each formulation to determine the optimum concentration for

texture development. Final moisture content for each formulation was 75.18% (±0.49), egg white; 74.82% (±0.33), gluten; and 74.67% (±0.30), bovine serum albumin.

Egg White

Egg white is a common ingredient of many surimi-based foods (Burgarella et al., 1985a,b) even though the gel-strengthening ability of egg white, as related to its composite reinforcing and water-binding properties is not clearly understood (Lee, 1986). It has been proposed that egg white proteins act as a "filler" by filling the intersitital spaces between myofibrillar proteins (Burgarella et al., 1985a,b). Lee (1986), however, indicated that egg white causes the surimi-based product to be significantly less elastic, firm, and cohesive than starch, which makes a partially heat-set extradate more elastic and stretchable. The surimi-based product with egg white is also more brittle and elastic after the final cooking.

The ability of egg albumin to form gels upon heating is a major factor in its use (Woodward and Cotterice, 1986). According to Siegle et al. (1979), egg white does not interfere with interactions between myosin molecules, and the types of molecular interactions stabilizing the egg white gel are likely of the same nature as those stabilizing the myosin gel.

During preliminary work, egg white was added for testing of gel hardness, elasticity and cohesiveness at four different concentrations (Table 6). There were significant differences in gel hardness ($P<0.001$) and cohesiveness ($P<0.001$).

Table 6. Effect of Egg White on Mean Gel Hardness, Elasticity and Cohesiveness Measurements by Instron Texture Profile Analysis.

Egg White (Level)	Hardness[1] (N/g)	Elasticity[2] (%)	Cohesiveness[3]
0%	96.67[b]	71.57	35.58[b]
	(±2.43)	(±1.18)	(±0.77)
1%	111.25[c]	75.44	44.58[c]
	(±6.35)	(±5.68)	(±0.93)
2%	116.60[c]	73.34	41.75[c]
	(±6.99)	(±2.86)	(±4.59)
3%	99.33[b]	72.09	27.77[a]
	(±5.95)	(±1.69)	(±1.46)
4%	80.34[a]	68.40	24.93[a]
	(±0.15)	(±5.02)	(±1.78)
LSD	9.294	---	4.294

[1] $P<0.001$, [2] $P=0.2940$, [3] $P<0.001$.
[a,b,c] Treatment means in a column with the same letter were not significantly different ($P\leq0.05$).
( ) Standard deviation.

Two per cent added egg white produced the hardest gel. Cohesiveness was the greatest at the one per cent level of added egg white. There was not a significant difference in elasticity (P=.2940) at any level. In addition, as levels were increased, a notable odor of egg white developed.

Gluten

The addition of ingredients that bind water or fat and impede their free movement through the fish gel matrix without interfering with the gel network formed by the muscle proteins is the key to ingredient induced enhancement of gel strength (Lanier, 1986). The structure of fish gels may be reinforced to varying degrees by adding wheat gluten. The composition and the large molecular size of gliadins and of glutenins explain much of the behavior of gluten. Rich in glutamine (over 33% by weight) and in hydroxy amino acids, they are prone to hydrogen bonding. This accounts largely for the water absorption capacity and for the cohesion-adhesion properties of gluten (Fennema, 1985). In addition, Siegel et al., (1979) demonstrated that in the presence of salt and phosphate, wheat gluten was the only protein having a significantly higher binding ability than nonmeat proteins such as egg white, isolated soy protein and blood plasma.

Four different levels of gluten were added to surimi batter and gels were evaluated for texture. There were significant differences in gel hardness ($P<0.001$) and cohesiveness [($P=0.0135$) (Table 7)]. Two percent added gluten resulted in greatest gel hardness. There was, however, a small but insignificant reduction in elasticity at the two per cent level of added gluten.

Table 7. Effect of Gluten on Mean Gel Hardness, Elasticity and Cohesiveness Measurements by Instron Texture Profile Analysis.

Gluten (Level)	Hardness[1] (N/g)	Elasticity (%)	Cohesiveness[2]
0%	83.00[b]	73.36	35.65[a b]
	(±10.22)	(±2.40)	(±3.20)
1%	92.59[c]	72.25	38.34[b]
	(±6.69)	(±2.02)	(±5.04)
2%	101.86[c]	68.98	41.36[b]
	(±1.80)	(±5.85)	(±5.09)
3%	86.20[b]	72.35	42.32[b]
	(±6.60)	(±1.74)	(±1.32)
4%	63.37[a]	73.15	30.34[a]
	(±6.43)	(±4.46)	(±0.70)
LSD	12.5535	---	6.4983

[1] $P<0.001$, [2] $P=0.0135$.
[a, b] Treatment means in a column with same letter were not significantly different ($P\leq0.05$).
( ) Standard deviation.

Bovine Serum Albumin

One of the important functional qualities of bovine serum albumin (BSA) is its high water-binding capacity and the heat-stable water/plasma gel formed. This water-binding property also provides increased skin elasticity of frankfurters or sausages (Duxbury, 1988). In addition to processed meat applications, such as, delicatessen hams and sausages, the varied functionalities of powdered beef plasma can enhance binding strength in ham loaves and boneless fish products.

Hermannson (1982) investigated the effect of 4-6% added BSA in plasma gels at pH 7.0-9.0 heated at 82°C. It was determined that compression force increased with protein concentration both at pH 9.0 and at pH 7.0. The maximum force at the breaking point increased with the protein concentration at pH 7.0.

Based on these results, bovine serum albumin was added to surimi for improving gel texture. There were significant differences in hardness (P=0.003) and elasticity [(P=0.0149), (Table 8)]. There was not a significant difference in cohesiveness (P=0.4440). Elasticity was greatest at the three percent level of added BSA. However, there was not a significant difference between the two and three percent levels of added bovine serum albumin. Gel hardness was greatest

between the one and three percent levels of bovine serum albumin (P=0.03).

Table 8. Effect of Bovine Serum Albumin on Mean Gel Hardness, Elasticity and Cohesiveness Measurements by Instron Texture Profile Analysis

BSA[a] (Level)	Hardness[1] (N/g)	Elasticity[2] (%)	Cohesiveness
0%	101.52[a]	74.18[a]	40.56
	(±1.34)	(±0.29)	(±1.87)
1%	130.39[b]	73.62[a]	43.54
	(±3.38)	(±1.24)	(±1.73)
2%	131.88[b]	77.03[b c]	43.71
	(±1.88)	(±1.39)	(±1.86)
3%	124.11[b]	78.25[c]	42.14
	(±8.05)	(±0.40)	(±1.81)
4%	99.84[a]	75.84[a b]	42.68
	(±4.96)	(±0.19)	(±1.10)
LSD	9.6701	1.8180	---

[1] P<0.003, [2] P<0.0149.
[a,b,c] Treatment means in a column with same letter were not significantly different (P≤0.05).
( ) Standard deviation.

Proximate Composition of Raw Abalone and Analog Batters

The moisture content of each gel (different ratio) with protein adjuncts was considered acceptable [(75.26% to 76.32%) (Table 9)]. There were no significant differences between each gel in ash, lipid, and protein content. However, carbohydrate in analogs was quite different when abalone was compared with gels and would relate directly to the presence of cryoprotectants (sucrose and sorbitol) in the surimi. The lower protein and lipid content of the analog and thus, nutrtitional inferiority, in comparison with abalone, would mandate labelling as an imitation product from a regulatory aspect.

Table 9. Mean Proximate Composition[1] of Raw Abalone and Analog Batters

	Analog Batters				
Ratio	Control	EW[3]	Gluten	BSA[4]	Abalone
(30:70)[2]					
(50:50)					
(70:30)					
Moisture	75.894	75.610	76.184	75.636	77.595
	(±0.024)	(±0.356)	(±0.088)	(±0.200)	(±0.507)
	75.277	75.323	75.786	75.820	
	(±0.290)	(±0.805)	(±0.432)	(±1.116)	
	76.013	75.264	75.785	75.543	
	(±0.281)	(±0.258)	(±0.338)	(±0.233)	
Protein	15.50	15.770	16.636	16.004	18.02
	(±0.412)	(±0.173)	(±0.473)	(±0.519)	(±0.800)
	15.584	16.959	16.495	15.851	
	(±0.584)	(±0.820)	(±0.430)	(±0.206)	
	15.422	16.955	16.527	16.415	
	(±0.321)	(±0.473)	(±0.104)	(±0.352)	
Lipid	0.430	0.380	0.408	0.322	1.31
	(±0.006)	(±0.009)	(±0.020)	(±0.000)	(±0.090)
	0.460	0.432	0.385	0.414	
	(±0.001)	(±0.008)	(±0.006)	(±0.027)	
	0.461	0.460	0.383	0.389	
	(±0.020)	(±0.050)	(±0.062)	(±0.043)	
Ash	2.622	2.649	2.548	2.750	1.31
	(±0.043)	(±0.061)	(±0.034)	(±0.076)	(±0.370)
	2.690	2.617	2.605	2.753	
	(±0.039)	(±0.059)	(±0.016)	(±0.033)	
	2.654	2.720	2.674	2.798	
	(±0.032)	(±0.032)	(±0.025)	(±0.039)	
CHO[5]	5.544	5.591	4.224	5.283	0.475
	5.989	4.669	4.729	5.163	
	5.540	4.601	4.631	4.855	

[1] n=6
[2] Chunk to carrier (CH: CA)
[3] Egg white
[4] Bovine serum albumin
[5] Carbohydrate, determined by difference
( ) Standard deviation

ITPA of Abalone and Analog Gels

Sensory

Humans are the best instrument for evaluating food texture, since they can simultaneously perceive, analyze, integrate, and interpret a large number of textural sensations (Larmond, 1976). According to Szczesniak et al. (1963), however, elasticty is difficult to perceive sensorially because of the sharp edge and relative insensitivity of the teeth.

The panelist effect was significant for each attribute, meaning that some panelists were using larger numbers than others. Each adjunct (ADJ) and ratio [RAT(ADJ)] in each adjunct were significantly different in both hardness ($P<0.0001$) and cohesiveness [($P<0.0001$), (Table 10). Also, the ratio in each adjunct [RAT(ADJ)] was significantly different in elasticity ($P<0.0038$). Interaction between panel by ratio in each adjunct [PxRAT(ADJ)] was significantly different in elasticity ($P<0.0018$) and chewiness ($P<0.0001$). For elasticity the interaction was caused by one panelist rating the 70/30 ratio much lower than the 50/50 ratio, which was in disagreement with other panelists' ratings. For chewiness, one panelist rated the 30/70 ratio much lower than the 50/50 ratio, in disagreement with the other panelists' ratings, thus causing the interaction. Since

in each case only one panelist appeared to be responsible for the interaction, the significance of the main ratio effect remains valid.

Table 10. Analysis of Variance of Overall Design of Magnitude Estimation Scores from Trained Panel Testing.

Source	Hardness P[i]	Elasticity P	Cohesiveness P	Chewiness P
PAN[a]	0.0001***	0.0016**	0.0001***	0.0001*
ADJ[b]	0.0001***	0.1105	0.0004***	0.1252
PxADJ[c]	0.0750	0.2000	0.2039	0.0562
RAT(ADJ)[d]	0.0001***	0.0038**	0.0200*	0.0829
R(cont)[e]	0.0003***	0.0053**	0.0422*	0.0853
R(EW)[f]	0.0698	0.0994	0.5820	0.0214*
R(Glu)[g]	0.7426	0.7765	0.7939	0.9003
R(BSA)[h]	0.0016**	0.1775	0.0159*	0.3362
PxRAT(ADJ)[i]	0.3657	0.0018**	0.4037	0.0001***

a; Panel, b; Adjunct, c; Panel by Adjunct, d; Ratio in Adjunct e; Ratio in control, f; Ratio in egg white, g; Ratio in gluten h; Ratio in bovine serum albumin, i; Panel by Ratio in adjunct *,**,***refer to significance at the $P \leq 0.05$, 0.01, 0.001.
[i]probability levels associated with the F test.

The results of the LSD test of the means for each adjunct are shown in Table 11. Adjuncts were significantly different in hardness ($P<0.0001$) and cohesiveness ($P<0.0004$). The panel judged that bovine serum albumin was the highest in all attributes but to significance with only hardness and cohesiveness ($P\leq0.05$). The addition of egg white resulted in values for gel hardness and cohesiveness significantly higher than the control, but not as high as the bovine serum albumin ($P\leq0.05$). There was not a significant difference between control and gluten in hardness and elasticity ($P>0.05$).

Table 11. Means of Trained Panel Attribute Ratings for Each Adjunct.

Adjunct	Hardness	Elasticity	Cohesiveness	Chewiness
Control	0.066[c]	0.071	0.081[c]	13.31
Egg White	0.088[b]	0.081	0.098[b]	13.72
Gluten	0.066[c]	0.070	0.092[b c]	12.97
BSA[1]	0.104[a]	0.084	0.116[a]	14.50
LSD:	0.0154	--	0.0139	--

[1]bovine serum albumin

[a,b,c]Treatment means in a column with same letter were not significantly different ($P\leq0.05$).

Magnitude estimation and chewiness mean scores for the analogs and for natural abalone for each ratio treatment are shown in Table 12. The low ratio (30:70) for the control and the egg white adjunct had the greatest level of gel hardness, cohesiveness, elasticity and chewiness. However, the high ratio (70:30) in the bovine serum albumin treatment had the greatest level of gel hardness, cohesiveness, elasticity and chewiness. None of the ratios in the gluten adjunct were significantly different ($P<0.05$). The loss of hardness in high ratio (70:30) of egg white and gluten is indicative of adjuncts that would act as interstitial fillers to the actomyosin gel network. Therefore as chunks were added they interupted the gel network of the carrier. This phenomenon is indicated also by measurements of cohesiveness. The control, egg white and gluten treatments were less cohesive as the ratio of texturized chunks increased. With the bovine serum albumin adjunct, however, the gel hardness, elasticity, cohesiveness and chewiness increased with the ratio of added, texturized chunks. This indicated reactivity between the texturized chunk and the carrier possibly by linkage via sulfhydryl and disulfide interchange.

Table 12. Mean Magnitude Estimation Scores for Sensory Attributes of Analogs for Each Ratio and for Natural Abalone.

		Mean Magnitude Estimates			
Adjunct	Ratio	Hardness	Elasticity	Cohesiveness	Chewiness
Control	30:70	0.1527[a]	0.1557[a]	0.1334[a]	14.21
	50:50	0.0537[b]	0.0134[b]	0.0544[b]	13.04
	70:30	0.0077[b]	0.0425[b]	0.0546[b]	12.66
	LSD	0.0619	0.0817	0.0691	--
Egg White	30:70	0.1320	0.1243	0.1200	14.67[a]
	50:50	0.0572	0.0557	0.0854	13.46[b]
	70:30	0.0740	0.0619	0.0880	13.04[b]
	LSD	--	--	--	1.13
Gluten	30:70	0.0751	0.0629	0.0970	13.08
	50:50	0.0693	0.0827	0.1009	13.04
	70:30	0.0522	0.0617	0.0782	12.79
BSA	30:70	0.0337[b]	0.0333	0.0467[b]	13.75
	50:50	0.1109[a]	0.1081	0.1478[a]	14.67
	70:30	0.1665[a]	0.1115	0.1529[a]	15.08
	LSD	0.0622	0.2037	0.0764	--
Abalone		0.3599	0.2037	0.3227	25.50

[a,b,c]Treatment means in a column in each adjunct with same letter were not significantly different ($P \leq 0.05$).

Analysis of variance of the difference between mean ratings of abalone and the analogs are shown in Table 13. The mean differences were calculated by substracting the value for the analog from that of abalone. Therefore the statistical analysis was exactly the same as for overall design (Table 10).

Table 13. Analysis of Variance of Difference between Analogs and Natural Abalone by Trained Panel Testing.

Source	Hardness P[i]	Elasticity P	Cohesiveness P	Chewiness P
PAN[a]	0.0001***	0.0001***	0.0001***	0.0001***
ADJ[b]	0.0001***	0.1105	0.0004***	0.1252
PxADJ[c]	0.9972	1.0000	0.9999	0.9996
RAT(ADJ)[d]	0.0001***	0.0038**	0.0200*	0.0829
R(cont)[e]	0.0003***	0.0053**	0.0422*	0.0853
R(EW)[f]	0.0698	0.0994	0.5820	0.0214*
R(Glu)[g]	0.7426	0.7765	0.7939	0.9003
R(BSA)[h]	0.0016**	0.1775	0.0159*	0.3362
PxRAT(ADJ)[i]	0.3657	0.0018**	0.4037	0.0001***

a; Panel, b; Adjunct, c; Panel by Adjunct, d; Ratio in Adjunct e; Ratio in control, f; Ratio in egg white, g; Ratio in gluten h; Ratio in bovine serum albumin, i; Panel by Ratio in adjunct *,**,***refer to significance at the $P \leq 0.05$, 0.01, 0.001.
[i]probability levels associated with the F test.

Gel hardness, cohesiveness and chewiness at the 70:30 ratio containing bovine serum albumin were the closest to those of abalone (Table 14). With gel elasticity,

however, the low ratio (30:70) in the control was the closest to that of abalone. As a result, the panel indicated that the high ratio (70:30) containing bovine serum albumin was, overall, the most similar in textural character to abalone.

Table 14. Magnitude Estimation Scores of the Difference Between the Analogs and Natural Abalone.

		Difference of Magnitude Estimates			
Adjunct	Ratio	Hardness	Elasticity	Cohesiveness	Chewiness
Control	30:70	0.2071[a]	0.0481[a]	0.1893[a]	11.29
	50:50	0.3060[b]	0.1612[b]	0.2683[b]	12.45
	70:30	0.3685[b]	0.1903[b]	0.2681[b]	12.83
	LSD	0.0619	0.0817	0.0691	--
Egg White	30:70	0.2278	0.0795	0.2027	10.83[a]
	50:50	0.3026	0.1481	0.2373	12.04[b]
	70:30	0.2857	0.1419	0.2347	12.45[b]
	LSD	--	--	--	1.13
Gluten	30:70	0.2846	0.1409	0.2257	12.42
	50:50	0.2905	0.1210	0.2218	12.46
	70:30	0.3076	0.1420	0.2446	12.71
BSA	30:70	0.3261[b]	0.1704	0.2760[b]	11.75
	50:50	0.2489[a]	0.0956	0.1749[a]	10.83
	70:30	0.1933[a]	0.0923	0.1699[a]	10.42
	LSD	0.0622	--	0.0764	--

[a,b,c]Treatment means in a column in each adjunct with same letter were not significantly different ($P \leq 0.05$).

Instron Texture Profile Analyses

Analysis of variance of Instron Texture Profile Analysis data indicated that the adjuncts were significantly different in hardness ($P<0.0005$) and cohesiveness [($P<0.0310$), (Table 15)]. The ratio effect in each adjunct treatment was significantly different in hardness ($P<0.0075$). Within individual adjuncts, only the ratio in the control was significantly different in hardness ($P<0.0005$), and only the ratio in the bovine serum albumin was significantly different for cohesiveness ($P<0.0176$).

Table 15. Analysis of Variance of Overall Design of Instron Texture Profile Analysis Data.

Source	Hardness P[i]	Elasticity P	Cohesiveness P
ADJ[a]	0.0005***	0.2798	0.0310*
RAT(ADJ)[b]	0.0075**	0.0750	0.0715
R(cont)[c]	0.0005***	0.1037	0.8928
R(EW)[d]	0.6462	0.1700	0.1296
R(Glu)[e]	0.6701	0.5276	0.2887
R(BSA)[f]	0.1711	0.7397	0.0176*
REP(ADJ)[g]	0.2589	0.4967	0.0594

a; Adjunct, b; Ratio in Adjunct, c; Ratio in control, d; Ratio in egg white, e; Ratio in gluten, f; Ratio in bovine serum albumin, g; Replication in adjunct
*,**,***refer to significance at the $p\leq 0.05$, 0.01, 0.001.
[i]probability levels associated with the F test.

Mean scores for each adjunct are shown in Table 16. Bovine serum albumin had greatest level of gel hardness and cohesiveness. However, egg white had the most elastic gel. Addition of any of the three adjuncts caused significantly increased hardness as compared to the control ($P \leq 0.05$). For cohesiveness, addition of only bovine serum albumin caused a significant increase over the control ($P \leq 0.05$). Although elasticity measurements were higher than the control in the three adjuncts, none were significantly higher ($P > 0.05$).

Table 16. Means of Instron Texture Profile Parameters for Each Adjunct.

Adjunct	Hardness	Elasticity	Cohesiveness
Control	99.28[b]	66.74	36.39[b]
Egg White	110.94[a]	69.15	38.37[ab]
Gluten	109.31[a]	68.81	36.75[b]
BSA[1]	113.51[a]	67.28	42.33[a]
LSD:	4.57	--	3.98

[1]bovine serum albumin
[ab]Treatment means in a column with same letter were not significantly different ($P \leq 0.05$).

As previously indicated, the Instron data analyzed across ratios (Table 17) only hardness with the control sample ($P < 0.0005$) and cohesiveness within the bovine serum albumin adjuncts ($P < 0.0176$) were significant. For

hardness, the control 30:70 and 50:50 were significantly higher than the 70:30 sample ($P \leq 0.05$). For cohesiveness, the bovine serum albumin 70:30 was significantly higher than the 50:50 sample ($P \leq 0.05$). By inspection of Tables 12 and 17, it is possible to compare trained panel results with the Instron texture measurements. For gel hardness, the panel was able to detect differences ($P \leq 0.05$) among the bovine serum albumin samples, while no significant differences were found using the Instron ($P > 0.05$). With elasticity, there were no significant differences among the control ratios. For cohesiveness, the panel was able to detect differences ($P \leq 0.05$) in the control ratios while the Instron could not. This lack of significance for the Instron reading could have been due to variation between replications. For this type of sample, more than three readings may be necessary to achieve a valid measurement of sample differences. In addition, more sensitive methods of instrumental texture profiling may be necessary. Lanier has developed the torsion testing cell which can be fitted to an Instron Universal Testing Machine. This involves measuring the physical parameters of stress and strain required to produce failure in a torsion-type device (Lanier, 1986). In such a plot, gel rigidity (defined as stress/strain at failure) is used as the ordinate instead of the gel strength (stress at failure). The human mouth seems able to perceive the

relative ratio of rigidity, or stiffness, to the cohesiveness/elasticity of a product. A higher value of this ratio measured (instrumentally) in a product indicates that it produces a brittle sensation in the mouth, e.g., the food structure strongly resists deformation, but upon subjection to sufficient force will collapse before appreciable deformation of the food has occurred (Lanier, 1986). Ratio values obtained would then correlate with different sensory properties.

Table 17. Mean Scores from Instron Texture Profile Analyses for Gel Hardness, Elasticity and Cohesiveness of the Analog and Natural Abalone

		Mean of textural attributes		
Adjunct	Ratio	Hardness	Elasticity	Cohesiveness
Control	30:70	105.04[a]	70.77	36.96
	50:50	102.13[a]	63.86	36.36
	70:30	90.66[b]	65.60	35.85
	LSD	6.37	---	---
Egg White	30:70	112.70	71.45	39.82
	50:50	111.23	70.44	40.56
	70:30	108.89	65.57	34.72
Gluten	30:70	110.35	70.45	34.97
	50:50	107.68	68.07	38.01
	70:30	109.90	67.91	37.26
BSA	30:70	112.47	67.78	42.26[ab]
	50:50	112.02	66.38	40.38[b]
	70:30	116.04	67.68	44.35[a]
	LSD	---	---	2.16
Abalone		216.63	70.58	60.64

[a,b]Treatment means of three columns in each adjunct with same letter were not significantly different($P \leq 0.05$).

The trends associated with Instron measurements of gel hardness and cohesiveness were similar to those seen by the trained sensory panel. There was a trend in loss of hardness and cohesiveness as the ratio of added chunks increased from 30:70 to 70:30 (CH:CA). This indicated that there were similar results between the instrumental method (ITPA) and the trained sensory panels.

The analysis of variance of differences in mean values between the analogs and natural abalone is shown in Table 18. Textural attributes were not significantly affected by the type of protein adjunct ($P>0.05$). The ratio main effect was not significant when tested across all adjuncts ($P>0.05$). When adjuncts were tested separately, hardness was significant for the egg white ratios ($P<0.0153$) and cohesiveness was significant for the control ratios ($P<0.0423$).

Table 18. Analysis of Variance of Difference between Analogs and Natural Abalone by Instron Texture Profile Analysis.

Source	Hardness P[1]	Elasticity P	Cohesiveness P
ADJ[a]	0.8828	0.9998	0.9985
RAT(ADJ)[b]	0.7159	0.9663	0.1663
R(cont)[c]	0.8480	0.9274	0.0423*
R(EW)[d]	0.0153*	0.8359	0.2204
R(Glu)[e]	0.8075	0.4956	0.7154
R(BSA)[f]	0.4587	0.4724	0.6438
REP(ADJ)[g]	0.0001***	0.0001***	0.0001***

a; Adjunct, b; Ratio in Adjunct, c; Ratio in control, d; Ratio in egg white, e; Ratio in gluten, f; Ratio in bovine serum albumin, g; Replication in adjunct
*,**,***refer to significance at the $P\leq 0.05$, 0.01, 0.001.
[1]probability levels associated with the F test.

The main differences are presented in Table 19. The high ratio (70:30) of the bovine serum albumin treatment

had the smallest value for hardness and cohesiveness, therefore being closest to abalone texture. Of the analog, bovine serum albumin (70:30) was the closest to being an abalone analog-type product.

Table 19. Mean Scores of Difference between Analogs and Natural Abalone from Instron Texture Profile Analysis.

		Mean of difference in attributes		
Adjunct	Ratio	Hardness	Elasticity	Cohesiveness
Control	30:70	111.59	-0.190	23.08[b]
	50:50	114.50	6.720	23.68[b]
	70:30	125.97	4.983	27.19[a]
	LSD	---	---	2.980
Egg White	30:70	103.93[b]	-0.873	20.21
	50:50	105.39[b]	0.143	19.48
	70:30	107.73[a]	5.006	25.32
	LSD	3.169	---	---
Gluten	30:70	106.28	0.133	25.07
	50:50	108.95	2.513	22.03
	70:30	106.73	2.670	22.78
BSA	30:70	104.16	2.796	17.78
	50:50	104.61	4.197	19.66
	70:30	100.58	2.900	15.69

[a,b]Treatment means of three columns in each adjunct with same letter were not significantly different($P \leq 0.05$).

SUMMARY AND CONCLUSIONS

1. Use of sodium carbonate (0.1%) to raise the pH from 6.75 to 7.7 increased the hardness of kamaboko gels.

2. A decrease in moisture level in kamaboko caused a significant increase in hardness ($P<0.001$) and cohesiveness ($P<0.001$). When the moisture level was 73.24%, the gel hardness was greatest.

3. Sol mixing time significantly affected gel texture in the properties of hardness ($P<0.001$), elasticity ($P=.002$) and cohesiveness ($P<0.001$). To produce a strong, elastic and cohesive gel, 30 minutes of mixing was required. Shorter and longer periods of mixing caused weaker gels to be formed.

4. Egg white, gluten and bovine serum albumin, in serial concentrations, were evaluated for enhancement of textural parameters. Two per cent levels of each adjunct were determined to most favorably enhance gel texture and were used for analog development.

5. As the ratio of added chunk (chunk: carrier) increased from 30:70 to 70:30, hardness and

cohesiveness decreased in the control, egg white and gluten treatments. This indicated that the chunk disrupted the gel network.

6. In the presence of added bovine serum albumin and a greater ratio of the chunk (70:30), hardness, cohesiveness and elasticity were enhanced. This indicated that there was reactivity between the chunk and carrier.

7. Analysis of difference between the means of varying ratios and adjuncts from abalone means indicated that the control and gluten (30:70) treatments were closest to the elasticity of abalone from results of ITPA and the trained panel, respectively. Bovine serum albumin (70:30) was closest for properties of hardness and cohesiveness. Overall, The bovine serum albumin (70:30) treatment might be closest to an abalone.

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APPENDIX

Table A1. Descriptions and Operational Definitions of Tasks for Sensory Evaluation

Definition	Technique
Cohesiveness	
Degree to which a substance is compressed between the molars before it breaks.	Place sample between molar teeth, compress and evaluate the amount of deformation before rupture. Expectorate and rinse with spring water. Expectorate water.
Elasticity	
Degree to which a product returns to its original shape once it has been compressed between the molars.	Place sample between the molars and compress partially; remove force and evaluate the degree of recovery. Expectorate and rinse with spring water.
Chewiness	
Number of chews necessary to prepare for swallowing.	Place sample with thumb and index finger between the molars and masticate at one chew per second at a force equal to that required to penetrate a gum drop in 1/2 second, counting the number of chews required to reduce the sample to a state ready for swallowing. Rinse with spring water after expectorating the sample.
Hardness	
Force required to compress a substance between the molars.	Place sample between the molars and bite down evenly, evaluating the force required to compress the food.