AN ABSTRACT OF THE THESIS OF

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Title: Factors Affecting the Texture of Gels Prepared from Minced American Shad (Alosa sapidissima) Flesh.

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Machine separated flesh from American shad (Alosa sapidissima) was evaluated for preparing heat set gel products. Round fish frozen for up to 10 months at -18^0 C served as raw material for processing investigations. The effectiveness of various additives and processing procedures for improving gel strength and sensory characteristics were determined.

Addition of 0.5% polyphosphate to sols enhanced the hardness ($P \leq .005$), cohesiveness ($P \leq .01$) and springiness ($P \leq .001$) of heat set gels. Small amounts (0.5 and 1.0%) of dried egg white also improved hardness, cohesiveness and springiness ($P \leq .001$). Employing a two stage heat setting regime (40^0 C for 30 min followed by 90^0 C for 20 min) strengthened (hardness, cohesiveness and springiness) ($P \leq .001$) gels over a one stage (90^0 C for 30 min) heat set. Two stage heating improved gel

strength when sol formulations contained additives that improved, lowered or exerted no effect on gel strength.

Concentrations of dried egg white (1.0, 2.0, 3.0 and 4.0%) and potato starch (1.0, 2.0 and 5.0%) did not improve gel strength. Dried egg white (>1%) did not alter ($P>.05$) any physical parameters of gel texture. Potato starch (>1%) reduced gel hardness ($P\leq.001$). More basic pH conditions produced by the addition of 0.1 and 0.2% sodium carbonate to sols did not alter gel hardness or springiness ($P<.05$) and only caused a slight improvement in cohesiveness ($P\leq.001$).

The cryoprotectants sorbitol, (0.0, 2.0, 4.0, 6.0 and 8.0%) and sucrose (0.0, 2.0, 4.0 and 6.0%), reduced gel strength in a concentration dependent manner. Gel hardness was reduced in a linear manner as fish protein was replaced with sorbitol ($r = .976$) or sucrose ($r = .965$) in sols formulated to contain $74 \pm 1.5\%$ moisture. Cohesiveness was reduced in a similar manner ($r = .942$) by sorbitol, but not by sucrose. Gel springiness was not altered by additions of sorbitol or sucrose.

Incorporation of sucrose into formulations reduced sensory preference for the texture, flavor, appearance and overall desirability of heat set gels. Analysis of covariance of texture preference scores and physical measurements of texture reveal a strong linear correlation with hardness ($P = .0004$), but not with cohesiveness ($P = .6675$). Within the range of sucrose levels evaluated, harder gels were preferred.

Washing was evaluated for improving the strength and sensory preference for heat set gels containing 0.5%

polyphosphate and 0.5% dried egg white. Sols were set by heating for 30 min at 40^0 C followed by 90^0 C for 20 min and exposed to wood smoke. Gel hardness and springiness were reduced by washing ($P \leq .05$), but not cohesiveness ($P > .05$). This was surprising, since the gel strength enhancing effect of washing is well documented. Sensory preference for the flavor, color, texture or overall desirability of heat set gels was not affected ($P > .05$) by washing. Mean overall desirability scores for gels prepared from unwashed minced flesh of 5.25 and 5.27 for washed minced flesh were only slightly above a neutral preference (5.0 = neither like nor dislike).

Round shad yielded 65.06% planks, 41.20% minced flesh and 40.10% refined flesh. A single exchange wash followed by dewatering yielded 23.02% pressed flesh based upon round weight which was reduced to 20.68% by refining. Processing minced flesh into washed and refined flesh recovered 51.37% of total solids. The yield through refining was 97.33 and 89.83% respectively for unwashed and washed flesh. The protein and lipid content of flesh was not altered ($P > .05$) by washing, but ash content was reduced ($P \leq .001$).

Factors Affecting the Texture of Gels Prepared from Minced American Shad (Alosa sapidissima) Flesh.

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INTRODUCTION

American shad (Alosa sapidissima) is the largest member of the herring family. They are indigenous to the Atlantic Coast of North America with spawning populations that support commercial fisheries ranging from Florida to Labrador (Anon., 1987a). Shad were first transplanted to the Pacific Coast of North America in the early 1870s. They quickly spread and can now be found from Baja California to Alaska (Hart, 1973).

The only significant commercial fishery on the Pacific Coast is on the Columbia River during a two to three week period in May and June when the fish are migrating upriver. Of the 3 to 4 million fish that return to the Columbia River annually, only a fraction are harvested. Underutilization is principally due to poor market acceptability because of the excessive boniness of the fish (Anon., 1987b).

Equipment that separates fish flesh from bones has been developed and refined in the last forty years and offers a means for increased use of species with high bone content in their musculature. Unfortunately, the texture of the minced flesh separated by this equipment is unacceptable for many uses (Froning, 1981; Babbitt, 1986). A semblance of the original texture can be restored by creating protein gels.

A protein gel is an ordered network of salt solubilized

then heat set myofibrillar proteins. An analogous food system would be sausages such as hot dogs made from comminuted beef, pork, or poultry.

Interest in the United States in food products based on fish protein gels has increased recently as surimi technology has developed. Surimi is an intermediate product that consists of mechanically deboned fish flesh that has been washed with water and mixed with cryoprotectants. Washing removes fats, pigments, flavor components, and soluble proteins, thereby increasing the concentration of myofibrillar proteins which are essential for the formation of strong elastic gels. Cryoprotectants reduce the denaturation of myofibrillar proteins during frozen storage. The resulting product is white, with little or no flavor and a high degree of functional properties, most notably the ability to form chewy elastic gels (Lee, 1984; Suzuki, 1981). Surimi production remained centered in Japan, where it was used to produce a number of traditional products until the early 1970s when crab, shrimp, and scallop analogs prepared from surimi were developed. Since then, imports of surimi and surimi based analogs into the United States have increased steadily. It is predicted that by 1990 435,000 tons of analog products may be required yearly in the United States (Anon., 1987c).

The surimi industry today relies on Alaska pollock (Theragra charcogramma) as a raw material source. This fish is abundant, inexpensive, has a low fat content, a high proportion of white flesh, and good gel forming capability. A good deal of effort has been expended finding other fish that can be economically made into surimi. Two of the species examined sardine (Sardinops melanosticta) and Atlantic menhaden (Brevoortia tyrannus) belong to the same family as American shad (clupeidae) and have flesh with the same characteristics. Unfortunately, these characteristics include a high fat content and a high proportion of dark muscle which makes the production of a white, surimi with neutral flavor more difficult (Lanier, 1985; Sonu, 1986).

The objective of this investigation was to evaluate additives and processing conditions that affect the texture of gels made from American shad. Because of the marginal success other workers have achieved in trying to produce surimi from sardine and menhaden, no attempt was made to produce a highly refined product. The goal was to produce gels with minimum processing that had an acceptable flavor and texture. Because of the short time shad are available to the fishery, frozen round fish served as raw material for process investigations.

LITERATURE REVIEW

American Shad (Alosa sapidissima)

Description

American shad are a member of the family clupeidae which includes several economically important species such as herrings (Clupea sp.), sardines (Sardinops sp.), and menhaden (Brevoortia sp.).

The weight of males ranges from 0.7 to 2.7 kg; females weigh from 1.6 to 3.6 kg (Weiss-Glanz et al., 1986). Shad flesh generally has a high lipid content. Gooch et al. (1987) reported the proximate composition of raw shad fillets taken from the Southeastern United States to be 17.6 to 21.0% protein, 59.8 to 68.7% moisture, 10.6 to 20.3% lipid, and 1.2 to 1.5% ash. The lipid component contained 9.6 to 12.7% omega 3 fatty acids (20:5n3, 22:5n3, and 22:6n3).

Shad flesh is excessively bony. Each shad fillet has four rows of fine bones running from head to tail. These bones are next to the skin and are not attached to any other part of the skeleton which makes them very difficult to remove during processing and while eating. Shad contains a high proportion of dark flesh that lies close to the skin. The dark flesh has a higher content of fat and myoglobin.

Distribution

On the Atlantic Coast of North America, shad are found from Newfoundland to Florida and are most abundant from Connecticut to North Carolina (Weiss-Glanz, 1986). Shad were first introduced to the Pacific Coast of North America in 1871 with a small release into the Sacramento River of California. The first shad from this release began to appear in the Columbia River in 1876 as incidental catch in the salmon fishery. In 1886, 1 million shad fry from the Potomac and Susquehanna Rivers were distributed into the Columbia and its two major tributaries, the Willamette and the Snake. Shad are now established from Southern California to Cook Inlet, Alaska and westward to the Kamchatka Peninsula in Asia (Browning, 1980).

Life History

Shad are anadromous fish that spend several years in the ocean then return to freshwater to spawn. Spawning migrations are regulated by water temperature with spawning taking place as early as mid-November in Florida and as late as July in some Canadian rivers when water temperature reaches 12^0 C. Spawning takes place at night in shallow water with moderate current in the main stem of rivers.

Shad first spawn at 4 to 5 years old and have the ability to spawn more than once. Females may carry from 100,000 to

600,000 eggs. The fertilized eggs are semibouyant and drift with the current until hatching in 8 to 12 days. Newly hatched larvae are 7 mm long and are planktonic. They spend their first summer in freshwater and move into brackish water before entering the ocean in the fall when water temperatures begin to decline. Shad return to their natal rivers to spawn, but the history of their spread on the Pacific Coast from a few plantings obviously indicates a high degree of straying (Weiss-Glanz et al., 1986; Scott and Crossman, 1973; Hart, 1973).

Commercial Fishery

Shad are taken by a variety of methods that include gill and pound nets, beach seines, and otter trawls. Except for minor incidental catches, all of the commercial fisheries occur in bays and rivers after the fish have started spawning migrations (Anon., 1985).

On the Atlantic Coast, commercial fisheries for shad exist throughout their range of distribution, but populations have been declining due to blockage of runs by dams, pollution, and over fishing. In Maine, 95% of the rivers once used for spawning are now blocked by impassable dams (Weiss-Glanz, et al., 1986). A once abundant commercial fishery on the Delaware River was discontinued in 1957, when it became no longer economically feasible to operate because of decimation of stocks by pollution (Anon., 1985). The Atlantic Coast catch in 1896

was 50 million lb (22.7 million kg). By 1930, it had declined to 10 million lb, and by 1976, it was only 2 million lb. Efforts at rebuilding stocks have been successful in some areas and the Atlantic Coast catch had increased to over 3 million lb by 1983. However, populations in many areas are still in decline (Weiss-Glanz, et al., 1986).

The only commercial fishery on the Pacific Coast is on the Columbia River. The Columbia River season occurs in May and June at about the same time Atlantic markets are glutted (Anon., 1987a). The first commercial catch, 50,000 lb (22,676 kg) on the Columbia River, was landed in 1889. The largest catch was 1,535,000 lb, taken in 1963 (Browning, 1980). Catches have declined to a low of approximately 60,000 lb in 1984 (King, 1987). However, the decline in the commercial catch is not due to a decline in stock sizes, but is caused by a lack of market and season restrictions. Construction of dams on the Columbia has actually caused a proliferation of shad populations by opening of additional spawning and rearing habitat. Unfortunately, shad migrations coincide with runs of depressed stocks of sockeye and summer chinook salmon. The shad fishery must be operated with severe time, area, and gear restrictions to minimize the incidental catch of salmonids (King, 1987).

The Columbia River shad fishery is also plagued by lack of market and subsequent low prices. Fish are taken with gill nets mostly in the lower river below Bonneville Dam. The catch is not iced or refrigerated until it reaches the processor. In

general, because of its low price, shad is not handled with a great deal of care.

Size of Columbia River Stocks

The minimum run of shad in the Columbia River is calculated by adding the sport and commercial catch to the greatest dam count. The minimum run has ranged from 929,400 to 2,082,600 between 1977 and 1986 (Table 1). This is probably much lower than the actual run size. The count over The Dalles is consistently higher than the count over Bonneville Dam. Since The Dalles is upstream from Bonneville, this would indicate that a significant portion of the run is crossing the dams by some way other than the fishways (most likely through shipping locks). Since this happens at Bonneville, it probably also occurs at The Dalles. Also, there are a large number of fish that spawn below the dams and do not show up in the fishery. Bowers (1984) estimates the total annual run size to be 3.5 to 4 million fish.

Table 1. Minimum number (in thousands) of shad entering the Columbia River, 1977-86.[1]

Year	Catch		Dam Counts		Minimum Run
	Commercial	Sport	Bonneville	Dalles	
1977	61.9	11.0	495.7	856.5	929.4
1978	113.6	21.5	861.2	1,234.7	1,369.8
1979	120.3	27.5	1,039.9	1,398.2	1,546.0
1980	23.2	39.8	939.4	1,160.8	1,223.8
1981	21.8	49.1	881.2	1,089.0	1,223.8
1982	75.0	55.6	780.2	1,002.8	1,133.4
1983	85.0	65.6	1,420.0	1,932.0	2,082.6
1984	18.1	42.2	1,275.8	1,190.0	1,336.1
1985	35.4	30.1	975.0	1,389.5	1,455.0
1986	88.2	24.8	858.0	1,359.7	1,472.7

[1] King (1987)

Market

The wholesale price for shad with roe starts high in late winter and early spring and plummets by early May when the market becomes glutted with fish from New York and Connecticut. Whole shad with roe, 5 to 8 lb, start at $1.50/lb and drop to as low as $.40/lb. The market for just the roe is stronger, and the price remains steady at $2.00/lb for medium skeins (6 to 8 oz) and $2.50/lb for large skeins (8 to 10 oz) (Anon., 1987a).

Hand deboned fillets are also marketed on the Atlantic Coast. The deboning process consists of making a series of "V" cuts deep enough to remove the rows of bones without penetrating the skin. Deboning is a delicate process and requires the skill of a surgeon. Deboners receive $1.50 per fish (Anon., 1985).

Prices for deboned fillets also fluctuate. They start at $4.00/lb in February and drop to $2.00/lb by May. Roed carcasses and smaller males are sold for crab bait, usually for as little as $.05 per lb (Anon., 1987a).

Protein Gels

Gelation Mechanism

Muscle consists of sarcoplasmic, myofibrillar and connective tissue proteins. The proportion of each varies with species, but in general, fish muscle contains a higher percentage of myofibrillar and a lower percentage of connective tissue proteins than mammalian muscle (Suzuki, 1981).

Myofibrillar proteins play the predominant role in the majority of functional properties of meat (water binding, fat emulsification, gelation) (Acton and Dick, 1984). It is composed of myosin (50 to 60%), actin (15 to 30%) and other contractile proteins such as tropomyosin, troponin, actinin and connectin (Hultin, 1985). Myosin and the actomyosin complex seem to be the proteins that contribute the most to the formation of three dimensional gel networks and the role of myosin seems to be the best understood (Acton et al., 1983).

The first step in gel formation is extraction of the protein molecules. Grinding muscle tissue disrupts the sarcolemma and other membranes, breaks down the integrity of the

muscle fibers and frees myofibrils (Smith, 1988). When 2.0 to 3.0% sodium chloride (ionic strength of 0.6 or above) is added, myofibrils swell and myosin molecules are depolymerized. Hydrated chloride ions are attracted to the positively charged groups on the proteins breaking inter and intra molecular ionic bonds. The proteins net charge becomes more negative and the molecules become more dispersed (Acton et al., 1983).

When heat is applied to a myofibrillar protein sol, a two step transition takes place. The native protein is denatured, then reaggregated to form a protein gel. The process must be orderly to form a continuous, highly crosslinked, three dimensional protein matrix. The rate of the first reaction relative to the second is important. According to Ziegler and Acton (1984), the slower the second step relative to the first the better the denatured chains orient themselves to form a finer gel network.

Ziegler and Acton (1984) have summarized the conformational changes that take place when actomyosin is heated. At temperatures below 50^0 C, aggregation is minimal. The changes that occur involve such things as the dissociation of tropomyosin from the f actin backbone, dissociation of the f actin superhelix into single chains, conformational changes in the head and hinge regions of the myosin molecules and dissociation of the actin-myosin complex. When temperatures are above 55^0 C, the tail region of the myosin molecule begins unfolding and rapid aggregation commences.

The role of proteins other than myosin/actomyosin is not well known. Samejima et al. (1982) concluded that tropomyosin and troponin play little or no part in gelation. However, French (1986a, and 1986b) found good correlations between the tropomyosin content of 47 lots of pollock surimi and the water holding capacity of gels made from the surimi. He found that a surimi sample with all of the tropomyosin washed out had a water holding capacity of 16 g per g of surimi while surimi with high tropomyosin content had water holding capacities as high as 60 g per g of surimi. He also found that with samples that had the same tropomyosin content, higher gel strengths occurred if the troponin concentration was higher.

Relation between Fish Protein and Gel Strength

The strength of gels made from salt solubilized fish muscle is dependent on both the concentration and the quality of the proteins. According to Lanier (1986), gel rigidity is affected not only by protein concentration, but also by the total concentration of water imbibing solids. Water and fat are physically entrapped by the gel matrix. Many non-protein additives, such as starch, absorb water further impeding its movement through the gel matrix. Protein concentration determines the extent to which liquid components, such as fat and water, are tightly bound. However, as the concentration of

functional proteins is decreased with the addition of non-gelling solids, gel elasticity declines even though the gel is more rigid.

The functional quality of proteins also has a marked effect on gel strength. Elastic gels are dependent on the orderly denaturation and reaggregation of myofibrillar proteins. Any denaturation that occurs before the gel is in its final form will reduce the amount of well ordered crosslinks in the protein network and will be detrimental to gel strength. Denaturation may be caused by high temperature, extremes in ionic strength or pH, dehydration, or mechanical stress. Many of these conditions will occur during frozen storage of intact muscle and in a more pronounced manner in frozen minced fish muscle.

Freeze Denaturation

Shenouda (1980) reviewed the causes of denaturation during frozen storage and divided them into moisture related factors, factors related to fish lipids and denaturation mediated by the reductive decomposition of trimethylamine oxide. Formation of inter and intracellular ice crystals will rupture tissue and cell membranes exposing proteins to other deteriorative forces. A slower freezing rate promotes the formation of larger extracellular ice crystals which cause more tissue damage and, subsequently, more protein denaturation. During frozen storage, ice crystals have a tendency to melt and aggregate resulting in

a gradual growth of crystal size. This accretion of ice crystals is accelerated if there are temperature fluctuations, even if freezing temperatures are quite low. Since water increases in volume as it freezes, a continuous pressure on muscle microstructure results. This has been found to cause a significant decrease in the distance between contractile units leading to the formation of cross bridges between the units (Shenouda, 1980).

Migration of water molecules to form ice crystals will result in localized dehydration which may disrupt hydrogen bonding that stabilizes protein tertiary structure. Dehydration may also expose hydrophobic and hydrophilic side chains on the surface of proteins through disruption of the water barriers surrounding them. This could lead to deconformation and/or aggregation of protein molecules (Shenouda, 1980; Sikorski et al., 1976).

A portion of the water in the tissue remains liquid when fish are frozen. The proportion of liquid water declines as temperature is reduced, but some of the tissue water remains liquid even at -70^{0} C. Solutes are concentrated in the liquid phase as the temperature of the muscle is lowered. About 0.5% sodium and potassium chlorides are present in fresh fish muscle. The concentration in unfrozen water may reach 7.0% at -30^{0} C (Sikorski et al., 1976). High solute concentration will affect the stability of ionic bonds within and between peptide chains and cause a variety of conformational, dissociational and

aggregational changes. Myosin, for instance, if exposed to a concentrated solution for an extended period will dissociate into subunits which will undergo irreversible aggregation (Shenouda, 1980).

Reports disagree on the role that intact (nonhydrolyzed, unoxidized) lipids play in denaturation. Shenouda (1980) relates several studies that demonstrate a protective effect and speculates that neutral lipids stabilize proteins by diluting and neutralizing the hydrophobic effect of any free fatty acids present. However, Shenouda and Pigott (1974) demonstrated the possibility of negative interaction between intact triglycerides and proteins. They incubated lipids and protein extracted from the fish together at refrigerated temperatures and found evidence of the formation of insoluble lipoprotein complexes.

Fish tissue contains lipases and phospholipases that have significant activity at frozen storage temperatures. The accumulation of free fatty acid has been correlated with the loss of protein extractability (Shenouda, 1980). Sikorski et al. (1976) postulated that free fatty acids attach hydrophobically or hydrophilically to proteins. This creates sites for intermolecular cross-links and reduces solubility by replacing polar side chains with hydrophobic regions.

Fish lipids contain a high proportion of unsaturated fats which are very susceptible to oxidation. Some of the conditions that occur during frozen storage such as membrane disruption, dehydration, and formation of free fatty acids enhance

oxidation. Interactions between oxidized lipids and proteins result in formation of insoluble lipid-protein complexes, browning, and loss of the amino acids lysine, cysteine, histidine, and methionine.

Trimethylamine oxide is a compound that can be found in the blood and tissue of a variety of fish and shellfish. Tissue concentrations vary with species and with location and season. Trimethylamine oxide seems to participate in osmoregulation and may also be excreted to maintain nitrogen balance (Hebard et al., 1982). Trimethylamine oxide may be broken down enzymatically into dimethylamine and formaldehyde. Formaldehyde is highly reactive and aggregates proteins by formation of methylene bridges between protein molecules. The enzyme TMAOase, which is very active at frozen storage temperatures, is not as widely distributed among species as trimethylamine oxide. Species with a high TMAOase activity, such as gadoids (cod, hake, pollock) exhibit deleterious textural changes during frozen storage as a result of formaldehyde formation (Shenouda, 1980).

The deteriorative changes related to dehydration, lipids, and the reductive decomposition of trimethylamine oxide occur at a much faster rate in minced flesh than in intact muscle. Mincing disrupts tissue which accelerates water loss and allows mixing of components that are usually separate .

In the 1960s, Japanese workers discovered the effectiveness of cryoprotectants in stabilizing minced fish. The first

commercial application used 10% sucrose and 0.2-0.5% polyphosphate. A number of other compounds; such as, monosaccharides, oligosaccharides, small polysaccharides, dialcohols, polyalcohols, carboxylic acids, amino acids and phosphates have been shown to be effective (Matsumoto, 1980).

Suzuki (1981) listed the following criteria for an effective cryoprotectant: (1) the molecule should have one essential functional group, either -OH, -COOH, or $-OPO_3H_2$, and more than one supplementary group, -OH, -COOH, $-NH_2$, -SH, $-SO_3H$, or $-OPO_3H_2$; (2) the functional groups must have suitable space between them and be properly oriented with each other; (3) and the molecule should be relatively small.

According to Matsumoto (1980) cryoprotectants function by retarding the deleterious effects of dehydration. Cryoprotectant molecules bind to protein molecules by ionic and or hydrogen bonding. The cryoprotectants reduce the displacement of water molecules as ice crystals are formed and prevent protein molecules from coming close enough to undergo irreversible aggregation. This same association between protein molecules and cryoprotectant molecules also serves to retard unfolding of the protein molecules as water is displaced.

Additives that Improve Gel Strength

Phosphates

Phosphates play an important role in enhancing the solubility of proteins and their potential for forming strong gels. Hamm (1970) reviewed the interaction between phosphates and meat proteins and determined that the increase in water binding capacity (which is related to gel strength) was due to the favorable influence of elevated pH and ionic strength on protein solubility. He also suggested that the ability of phosphate to break down salt bridges between proteins by chelating divalent cations favors enhanced protein solubility by increasing intermolecular repulsive forces which loosens protein microstructure. A number of other authors (Bendall, 1954; Yasui et al., 1964; and Weiner et al., 1969) have indicated that increased protein solubility results through the dissociation of actomyosin into actin and myosin by phosphate.

Okada (1985a) also found that the addition of 0.2 to 0.3% polyphosphate to kamaboko (fish protein gel) produced stronger gels and improved moisture retention. He attributed this to its ability to enhance the extractability of myofibrillar proteins. He concluded that improved solubility was related to a higher pH and ionic strength and to specific interactions between proteins and phosphates.

The type of phosphate used has a strong effect on gel

strength or binding ability. Okimura et al. (1959) tested varying levels of sodium pyrophosphate and sodium tripolyphosphate in kamaboko and found that pyrophosphate performed better than tripolyphosphate and that a mixture of the two (0.3% addition of a mixture of 6 parts tripolyphosphate to 4 parts pyrophosphate) resulted in the strongest gels.

Trout and Schmidt (1984) measured the effect of different phosphates on the cooked yield and tensile strength of restructured beef rolls and found varying levels of effectiveness among the phosphates tested. They demonstrated that phosphates increased binding ability in the following order: pyrophosphate > tripolyphosphate > tetrapolyphosphate > hexametaphosphate = orthophosphate. It was concluded that 90 to 96% of the variation in binding could be explained in terms of changes in ionic strength and pH.

In a later investigation, Trout and Schmidt (1986) evaluated the same five phosphates in combination with NaCl. They tested the effect of phosphate type at varying pH levels and ionic strengths and found: (1) binding ability improved in a linear manner to maximum values when both ionic strength and pH were elevated; (2) most (80%) of the variation in binding ability was due to changes in pH and ionic strength; (3) all the phosphates (except orthophosphate) had a synergistic effect with sodium chloride if ionic strength was greater than 0.15; (4) the extent of the synergistic effect was improved as ionic strength was raised; (5) the effect of the phosphates was decreased as

the polymer length was increased. They concluded that influence of phosphate on myofibrillar extraction was less important than changes in hydrophobic interactions of proteins, and subsequently, in protein conformation during heating when the gel matrix is formed. They also suggested that any increase in actomyosin dissociation by phosphate was not significant.

Phosphate not only will enhance the binding of ground meat and fish products, but will also inhibit lipid oxidation. Because of tissue disruption and incorporation of large amounts of air, the lipid component of comminuted meats and fish are much more susceptible to oxidation. Phosphates inhibit oxidation by sequestering iron and copper which catalyze lipid autoxidation reaction (Ellinger, 1972; Shimp, 1985; King and Earl, 1988).

Starch

Starch is added to most commercial kamaboko and shellfish analogs to improve texture and reduce cost by allowing the addition of water without reducing gel strength (Okada, 1985a). The kamaboko industry in Japan uses potato, wheat, corn or sweet potato starch at levels of 5 to 20% (Suzuki, 1981). The starch participates in the gel network as a dispersed phase and strengthens the gel by composite reinforcing and water binding (Lee, 1984). Gelatinization of the starch must take place within the gel network to achieve its full gel strengthening

potential. The temperature for the onset of gelatinization is from 63 to 76^0 C, depending on the type of starch used (Okada, 1985a). Pregelatinized starch produces a weak and brittle gel (Wu et al., 1985; Kim and Lee, 1987).

Different types of starch produce varying effects on the characteristics of protein gels. Kim and Lee (1987) measured the effect of eight different starches on the texture of surimi gels. They found good correlations between the rheological behavior of the starches and gel texture. Starches with higher viscosity and higher water holding capacity produced firmer, more cohesive gels. Starches containing a higher proportion of amylose produced gels that became more rubbery and had a higher percentage expressible moisture after seven days of refrigerated storage (4^0 C). These changes were attributed to accelerated retrogradation. Overall, they found that potato starch strengthened gels to the greatest extent and theorized that the reinforcing effect of starch occurred when starch granules embedded in the protein matrix swell during gelatinization. This exerted pressure and absorbed water from the gel matrix resulting in a firmer and more compact gel. These observations are supported by differential scanning calorimetry measurements reported by Wu et al. (1985) of sol to gel transformations during heating. They found that gel strengthening was dependent on gelatinization temperature, degree of swelling and water uptake by the starch granules.

Egg White

Commercial kamaboko producers in Japan add up to 20% egg white, either raw or frozen, to enhance the glossiness of the final product and to improve gel strength (Akahane, 1983; Okada, 1985). Although egg white is widely used commercially, the results of research into its effect on gel strength are ambiguous.

Okada (1985a) obtained significantly higher breaking strengths with the addition of 5, 10, and 20% frozen egg white, but only when the gels were heated at 40^0 C for one hour before 90^0 C cooking. Gels that were heated only at 90^0 C showed little or no improvement in gel strength.

Arocha and Toledo (1982) found that sausages made from minced fish that contained egg white were judged to be significantly better by a sensory panel. However, the fat and moisture content between treatments, with and without egg white, did not seem to be well controlled and may have influenced the results.

Iso et al. (1985) demonstrated an increase in gel strength with the addition of 5, 10, 15 and 20% dried egg white. However, when treatment moisture was adjusted to the same content, a linear decrease in gel strength resulted. The authors concluded that egg white does not contribute to the gel network and only acts as a filler. Lee and Kim (1985) also found a linear reduction in gel strength with addition of from 3

to 12% egg albumen. They suggested that egg albumen may interfere with the crosslinking of myofibrillar proteins.

Burgarella et al. (1985a, 1985b) measured changes in gel rigidity and structural failure properties during thermal processing of fish, egg white, and mixed fish and egg white protein gels. They concluded that the two proteins gel independently with no cooperation in gel formation. They also found that mixtures of the two proteins had less rigidity than either pure fish gels or pure egg white gels, indicating a dilution of one protein by the other.

Processing and Gel Strength

Washing

The Japanese kamaboko industry began washing minced fish flesh to remove fats and oil, reduce fishy odors, and increase whiteness. It soon became evident that gels prepared from washed flesh were also stronger and more elastic (Sonu, 1986).

Okada (1964) found that gels prepared from washed flesh had a higher gel strength and more water holding capacity than from unwashed flesh. He also observed that the addition of fats to washed flesh did not affect gel strength and that addition of soluble fish protein extracts lowered gel strength. When soluble extracts with the protein component removed were added to washed flesh, gel strength was not changed. He concluded

that the observed strengthening of gels that occurred after washing was attributed to a higher myosin content. Sarcoplasmic proteins (soluble proteins) reduce gel elasticity by interfering with myofibrillar crosslinking.

Kudo et al. (1973) also compared the gel forming capability of washed and unwashed flesh from several species of fish and found that washing generally improved gel strength. Washing was required to produce gels from some species, but for other species, strong, elastic gels could be prepared from either washed or unwashed minced flesh. Hennigar et al. (1988) also produced gels with acceptable textures (as measured by the fold test) from unwashed minced flesh.

Lee (1985, 1986) found that extraction of soluble proteins was a function of agitation time, but excessive contact between water and minced flesh resulted in hydration of the myofibrillar proteins making dewatering difficult. Higher water to meat ratios extracted a larger quantity of material, but not enough to warrant the additional water treatment costs. With an agitation time of ten min, the amount of additional material extracted (soluble protein and trimethylamine oxide) was no longer significant after three exchanges. He recommended 3:1 or 4:1 water to minced flesh ratio and observed that wash water with a pH of 6.5 to 7.0 at or below 10^0 C yielded minced flesh with maximum water holding capacity. The addition of 0.1 to 0.2% salt to water used in the last wash improved the efficiency of dewatering and yielded flesh with a lower moisture content.

Lee (1985, 1986) recommended using soft water since calcium and magnesium cause texture deterioration during frozen storage and iron and manganese reduce whiteness.

Solubilization pH

Miyake and Tanaka (1969) prepared gels from flesh of a number of different species of fish. The pH of the raw sol was adjusted before heat gelation with sodium hydroxide and sodium carbonate. They found that pH had a strong effect on gel strength and that adjustment with the weak base yielded higher gel strengths. The pH at which the strongest gel was produced was different for each of the species tested. The optimum pH for the gelation of muscle from dark fleshed species (bluefin, tuna, mackerel, yellowtail) was 6.2-6.7, while white fleshed species (flatfish, Alaska pollock, isaki, Japanese seabass) produced maximum gel strength at pH 7.0-7.5.

Improved gel strength, as a function of pH, is related to changes that occur in protein solubility. Changes in pH alter the net charge of the protein molecules and influences their interaction with water. At the isoelectric point of proteins, their net charge is at the minimum, protein-protein interactions are at the maximum and protein hydration is at the minimum. As the pH is adjusted away from the isoelectric point, the net charge increases creating more sites for interactions with the surrounding water (Cheftel et al., 1985).

In addition to its effect on protein solubility, the pH of sols effect the bonding associated with reaggregation during heating. According to Acton et al. (1983), the aggregate network is dependent on pH. He observed that the optimum pH for development of gel rigidity for actomyosin gels occurred at pH 6.0.

Processing Temperature

The formation of semitransparent gels at temperatures below 50^0 C is a phenomenon that seems to be unique to fish protein sols. This is referred to as suwari or setting (Suzuki, 1981). Shimizu (1985) noted a vast difference in the degree of setting among fish species. He also found that sols that were set prior to cooking at 80^0 C were stronger and more elastic than those not allowed to set. A strong correlation between the setting tendency of a fish species and the strength and elasticity of the cooked gels was observed. Tropical species were observed to have a lower tendency for setting than cold water species. Shimizu (1985) speculated that setting tendency was related to the thermostability of the myofibrillar proteins. Micrographs of cooked gels revealed a denser and more homogeneous structure when set at 40^0 C for 60 min prior to cooking at 80^0 C than those that were only heated at 80^0 C for 30 min (Niwa, 1985).

Lanier et al. (1982) concluded that setting allows a slow denaturation and unfolding of the protein molecules which

produces stronger, more elastic gels than direct cooking at 90^0 C where aggregation occurs rapidly and unfolding is limited. The authors demonstrated that setting will occur at temperatures as low as 0^0 C and stressed the importance of forming products as soon after solubilization as possible to avoid disrupting prematurely set gels.

Measurement of Gel Strength

Bourne (1978) divided instrumental texture measurements into three categories: (1) empirical tests, those that are found from practical experience to be well correlated with textural quality; (2) imitative tests, those that attempt to imitate the conditions to which food is subjected in the mouth; (3) fundamental tests, those that measure basic properties such as stress and strain at failure, Poisson's ratio, and Young's modulus.

Four tests have been used extensively to evaluate the texture of gels prepared from minced flesh or surimi. The punch and folding tests were developed by Japanese researchers to evaluate kamaboko texture. The punch test is carried out on a cylindrical sample (3 cm diameter by 3 cm length) using a 5 mm diameter probe. The force required to penetrate the sample with the probe and the amount of sample deformation at failure are measured. Force divided by

deformation is expressed as stiffness (Lanier et al., 1985).

The folding test uses a 5 mm thick sample slice. The sample is folded in half, then folded in half again. The gel is rated on a 1 to 5 scale based on the point at which fracture occurs (Suzuki, 1981).

Texture profile analysis is conducted on a small cylindrical sample (1 to 2 cm diameter by 1 to 2 cm length). The sample is compressed either radially or axially to a predetermined percentage of its original diameter or length (usually 75%). The first compression is followed immediately by a second compression. The instrumentation yields a plot of force to deformation. The maximum force from the first compression divided by sample weight is recorded as hardness. Cohesiveness is determined by dividing the area of the second peak by the area of the first peak. Springiness is the amount of recovery of the sample after the first compression and is calculated as a percentage by dividing the base length of the second curve by the base length of the first curve (Lanier et al., 1985; Hamann, 1988).

A sample cylinder (1.9 cm diameter and 2.54 cm length) that has been reduced to a dumbbell shape by grinding the center portion of the cylinder to a 1.0 cm diameter in a special grinding assembly is used for the torsion test. The sample is mounted on a modified viscometer and twisted until gel failure occurs. Shear stress is calculated from the force at failure. Shear strain is calculated from the time to failure; rigidity is

computed by dividing stress by strain (Lanier et al., 1985).

Lanier et al. (1985) and Montejano et al. (1985) evaluated the above procedures to determine their accuracy by measuring their correlation to sensory texture ratings. They found the correlations between torsion measurements and sensory parameters were the highest. No significant changes in sample shape and size occurred during testing so that the torque required to fracture the sample was dependent only on sample rigidity. The torsion test directly measures two independent failure property descriptors, stress and strain. Strain is a good measure of protein quality or functionality, while stress measures protein concentration. Texture profile analysis correlated strongly with sensory ratings only if gel fracture could be consistently induced. The punch test introduced error because gel samples decrease in height and bulge at the sides before the probe penetrates the surface of the gel. These changes in specimen shape were more pronounced in hard, low moisture gels and in highly deformable gels. The punch test yielded accurate results only for a narrow range of gel strengths. The fold test only distinguished among samples of low deformability and could not be used to rank samples of high deformability.

Hamann (1988) reviewed instrumental measurement of protein gels and concluded that imitative or empirical tests which yield only cutting or punch force values are equivalent to measuring only stress with a fundamental test. If cohesiveness values are proportional to stress values, Hamann (1988) indicated that

correlations with sensory data would be good. However, if variations in cohesiveness are not proportional to variations in stress, a test that yields strain values or values proportional to strain is necessary to fully specify gels. Texture profile analysis produces parameters (hardness and cohesiveness) that correlate well with stress and strain making texture profile analysis the best of the imitative or empirical tests.

The Surimi Industry

Surimi is an intermediate product consisting of deboned, minced, and washed fish flesh. Kamaboko is a generic term for salt solubilized, heat set gels made from surimi. The technique of making kamaboko was developed in Japan in 1100 AD when fishermen discovered that fish would keep longer if minced, washed, ground with salt, and heated. Commercial kamaboko production was dependent on and limited by fluctuating inshore fisheries until 1959, when cryoprotectants were developed. This enabled manufacturers to stockpile raw material (surimi) and allowed exploitation of vast stocks of Alaska pollock (Lee, 1984). During the period between 1960 and 1973, the availability of a stable supply of raw material allowed the total production of kamaboko and fish sausage to increase from 509,000 tons to 1,187,000 tons (Okada, 1985b).

The next important development in the production of surimi

based products occurred in the mid-1970s when imitation crab legs prepared from surimi were developed. Prior to this, surimi based products were consumed almost entirely in Japan. After the development of crab and other shellfish analogs, Japanese exports of surimi based products increased exponentially from 2,600 metric tons in 1981 to 32,462 metric tons in 1984, 80% of which went to the United States (Sonu, 1986). The value of 1985 surimi imports to the United States is estimated to be 150 million dollars, making it one of the major U.S. fishery imports (Anon., 1987c).

The fact that U.S. waters are the principal source of surimi raw material (Alaska pollock), and the ever increasing popularity of surimi based products with American consumers, has stimulated development of a surimi industry in this country (Sonu, 1986). Three U.S. companies with Japanese participation are currently producing surimi in shore-based plants in Alaska, and two other U.S. companies are outfitting ships for high seas production (Anon., 1987c).

Surimi Production from Species Similar to Shad

Sardine (Sardinops melanosticta)

Dwindling stocks of Alaska pollock and uncertain access to foreign pollock fisheries led the Japanese to search for alternative species to provide raw material for their surimi industry. In 1977, an $8 million project involving government laboratories, private industry and universities was launched to develop procedures for producing surimi from sardines that are found in great abundance in Japanese waters (Sonu, 1986). Surimi production from sardine poses a number of problems: (1) high fat content; (2) high percentage of sarcoplasmic proteins; (3) high percentage of dark muscle; (4) small fish size; (5) brief landing season; (6) rapid drop in muscle pH postmortem; and (7) rapid loss of protein functionality (Sonu, 1986).

The dark muscle content of sardine is 10 to 20% of the total muscle as opposed to 1 to 2% in pollock. Dark muscle contains a higher percentage of heme pigments, fat and trimethylene oxide. Separation of the two meat fractions was essential for producing a white, odorless surimi with a neutral flavor like that produced from pollock. Removal of the dark muscle severely reduced yield (Suzuki, 1981). The overall higher fat and sarcoplasma content required large amounts of water for processing and increased waste treatment requirements (Sonu, 1986).

Sardine tissue has a high glycogen content. Post mortem glycolysis that converts glycogen to lactic acid reduced muscle pH to as low as 5.6. Since myofibrillar protein is more susceptible to denaturation if the pH drops below 6.0, sardines have to be processed rapidly after catching and the pH of the muscle restored to neutral as soon as possible. Japanese researchers found that gel strength dropped below critical levels if sardines are kept longer than one day on ice (Sonu, 1986).

Two methods of surimi production have been applied to sardines on a commercial basis. The first involved use of existing pollock processing equipment. Fish were mechanically filleted and deboned with a drum type deboner. No effort was made to separate out dark muscle. Washing was accomplished in three stages. The first stage used 4 parts of a 0.5% solution of sodium bicarbonate solution to 1 part meat. After gentle agitation, the meat was allowed to settle and the fat was skimmed off the surface with directed jets of water. The second washing was with water at 4:1 ratio with minced flesh. The third wash used a 0.3% solution of sodium chloride to facilitate dewatering. This system used existing facilities and produced relatively high yields of surimi, but product quality was low. The resulting surimi was highly pigmented, produced weak gels, and possessed a fishy odor (Sonu, 1986).

The second method was similar to the first. The most notable difference was that the dark muscle was separated out.

Fillets were passed flesh side up under a high pressure jet of water (10 to 20 kg/cm^2). White muscle is more friable and was fragmented and washed off the fillet leaving behind the dark muscle attached to the skin. The white muscle was collected in a rotary sieve. Processing after this step was similar to the first method. The resulting surimi was white, had high gel strength and no fishy odor. Yields were low (15 to 17%), and water requirements were very high ($68m^3$/day to produce 1.3 metric tons) (Sonu, 1986).

Menhaden (Brevoortia sp.)

Atlantic menhaden (B. tyrannus) and gulf menhaden (B. patronus) constitute an enormous resource. In 1983 menhaden formed 53% of the U.S. finfish landings (1.3 million metric tons or 2.9 billion pounds). Menhaden are used exclusively to produce fish meal and non-edible oil, both of relatively low value. Menhaden landings represented only 5% of the landed value of U.S. finfish (Lanier, 1985).

Researchers have turned to surimi technology to convert menhaden into products for human consumption. Unfortunately, menhaden presents the same problems as sardine; a high fat and dark muscle content, and small size. In addition, menhaden possess a high level of proteolytic activity that seems to be endogenous to the muscle and not due to contamination from viscera or parasite infestation (Lanier, 1985).

Lanier (1985) was able to successfully separate white muscle from dark muscle if the fish were processed within 8 to 12 hours after capture. Dark muscle, in fresh fish, is much tougher than white muscle and more resistant to separation by the deboning equipment. By reducing the belt pressure on the drum, much of the dark muscle can be left attached to the skin of the fillets. Dark muscle remaining in the flesh was removed with residual bones, skin, scales, and connective tissue by passing the minced flesh through a strainer equipped with 1 mm holes. The author determined that the presence of dark meat in the minced flesh did not affect gel strength but had a strong negative effect on flavor, odor, and color.

Washing was accomplished in three stages, each with 3 to 5 parts water to 1 part meat. Wash tanks were equipped with automatic controls to maintain pH at 6.8 to 7.0. After each washing, the meat was allowed to settle, then water was decanted off or the meat was passed through a rotary screen. The meat was dewatered in a screw press between each washing.

The volume of wash water needed was significantly reduced by employing a counter current washing system. Effluent from the third washing stage was used to wash the second stage and effluent from the second stage was used for the initial wash. This reduced wash water volume by one third without affecting soluble protein removal. Solute was concentrated in the effluent and would allow for a more efficient recovery of fats and soluble proteins.

The process developed by Lanier (1985) produced low surimi yields (15%). He suggested that surimi production might be feasible if operations were carried out in conjunction with an existing reduction plant that could process waste into meal and oil.

Lanier (1985) evaluated the effect of different heating regimes on the protease activity in menhaden muscle. He incubated samples at varying temperatures between 40 and 80^0 C for times ranging between 0 and 20 min. Each incubation treatment was followed by a 90^0 C cook for 10 min. He found that proteases were active at 50^0 C as indicated by a decline in gel strength as incubation time was extended. Maximum protease activity occurred between 55 and 75^0 C. The strongest gels were produced by heating at 40^0 C for 15 to 20 min, followed by 90^0 C for 10 min.

The surimi produced from menhaden contained 1 to 3% fat. Lanier (1985) evaluated the stability of the residual fat content and methods to control fat rancidity. He measured rancidity chemically and with a trained sensory panel after 1, 3, 5, and 10 months of frozen storage at -30^0 C. Treatments included: (1) a control that was packaged in oxygen permeable polyethylene bags; (2) a sample treated with a food grade enzyme system designed to consume oxygen and vacuum packaged; (3) a sample treated with a lemon juice/phosphate preparation and vacuum packaged; and (4) a sample treated with sodium ascorbate/sodium citrate and vacuum packaged. He found that,

lemon juice phosphate and the enzyme system in conjunction with vacuum packaging reduced formation of rancidity while the ascorbate treatment enhanced rancidity development. Except for the ascorbate treatment, all the samples, including the control, remained stable with no sensory scores over 5 (slightly detectable) after 10 months of frozen storage.

MATERIALS AND METHODS

Materials

Raw material for processing investigations was derived from six lots of gill net caught shad from the Columbia River. Fish and separated planks were glazed and frozen at -29^0 C then stored at -18^0 C on the dates listed below:

Lot Number	Condition	Date Received and Frozen
1	roe removed	6-10
2	planked	6-10
3	round	6-10
4	round	6-22
5	round	6-23
6	round	6-26

Brifisol S-1, a mixture of 50% sodium tripolyphosphate and 50% tetra-sodium pyrophosphate (BK-Ladenburg Corp., Cresskill, NJ), dried egg white (Milton G. Waldbaum Co., Wakefield NB), and potato starch (Western Polymer Corp., Tulelake, CA) were used to formulate gels. Sol pH was adjusted with reagent grade Na_2CO_3.

Fish Processing

Fish were hand planked and washed. Flesh was separated from the bone and skin of planks with a model 805 Ikeuchi flesh separator (Ikeuchi Tekkosho Ltd., Japan). Machine separation

was accomplished by pressing the planks between a rotating rubber belt and a perforated metal drum (4 cm. diameter perforations). Belt tension was adjusted to the lightest setting to limit the amount of dark flesh (which is adjacent to the skin) that was included in the separated minced flesh.

Minced flesh was washed in a mixture of ice and water (approximately 10% ice) at a ratio of 1 part flesh to 5 parts water by weight. The mixture was gently stirred by hand for 5 min then poured into a model SD-8 screwpress dehydrator (Ikeuchi Tekkosho Ltd., Japan). The screwpress was operated at the slowest speed to obtain maximum water removal.

Both washed and unwashed flesh were refined with a model S1 Ikeuchi flesh strainer (Ikeuchi Tekkosho Ltd., Japan) to remove residual scales, bone, connective tissue and pieces of skin. The refiner was operated with a minimum back pressure which allowed for a partial removal of dark flesh.

Flesh was collected and weighed after each processing step. Yields were calculated as a percent of the starting weight and did not include flesh holdup in machines (screw press, 1-2 kg; refiner, 800 g). Samples were also collected after each processing step for compositional analysis.

Gel Preparation

Fish were processed into minced flesh and held at (4^0 C) overnight. The moisture level of the sols was adjusted to 74% with distilled water based upon determined minced flesh moisture contents. Required amounts of NaCl, phosphate and Na_2CO_3 were dissolved in added water then mixed (Kitchen Aid Mixer, model K5SS, Hobart Co., Troy, OH) with minced flesh and other dry components at slowest speed for 30 min (total sol wt. 500 g). When potato starch was incorporated into formulations, it was added after 20 min mixing time and then mixed an additional 10 min. Mixing was carried out at 4^0 C to maintain sol temperatures below 8^0 C. Samples of the minced flesh and each sol were retained and held (4^0 C) for pH determination. Sols were packed into plastic trays (10.5 X 8.5 X 2.5 cm thick), 2 trays of approximately 200 g each per treatment. Trays were placed in moisture-vapor proof plastic bags and vacuum sealed (Cryovac model 6250-B, Duncan, SC). One tray from each treatment was heat set in water at 90^0 C for 30 min; the other, at 40^0 C for 30 min followed immediately by 90^0 C for 20 min. Heat set samples were immediately chilled in ice water for 30 to 40 min then held (4^0 C) overnight prior to Texture Profile Analysis (TPA).

Gels used for sensory evaluation were prepared in the same manner as those for TPA with the following exceptions. Treatments were mixed in batches of 800 g each. Sols were

packed directly into a moisture-vapor proof plastic bags (18 X 23 cm, 350 g per unit). The bags were vacuum sealed and the raw sol was forced to one end of the bag to form a rectangular loaf (9.5 X 170 X 2.5 cm thick) with rounded edges. Samples were heat set in water at 40^0 C for 30 min followed immediately by 90^0 C for 20 min. Gels were chilled in ice water for 30 to 40 min, then removed from the film package and sampled for moisture determination.

The remaining gels were coated with a mixture of 4 parts brown sugar to 1 part water (by weight) to enhance exterior color development during smoking. After refrigeration for 1 hr, the gels were placed in a smoke house (Grand-Prize Electric Smoke House Model KD 1400, Koch Supplies Inc., Kansas City, MO) equipped with an external smoke generator using alder chips for fuel. The gels were smoked at ambient temperature (21 to 23^0 C) for 2 hr then removed from the smoke house. Smoke house temperature was then increased to 190^0 C and the gels were exposed to an additional hr of smoke and heating. The gels were cooled at 4^0 C for 1 hr, then vacuum sealed and frozen at -20^0 C. Samples were held at -20^0 C for sensory evaluation and TPA.

Experiment Segments

The addition of various additives to sol formulations, the use of one and two stage heat setting regimes and washing of flesh were evaluated. Investigations were directed toward optimizing gel strength and sensory preference. Sols were all prepared using 2.0% salt and were formulated to contain 74% moisture. Each evaluation was replicated using 3 separate lots of fish with the exception of the evaluation of varying levels of egg white in combination with different concentrations of sodium carbonate (Experiment 3) where two replications were performed.

Investigations involved discrete segments with the following defined objectives and additional variables. Experiment 1: The strength of gels prepared from sols containing 0.0 and 0.5% polyphosphate was determined. Sols were heat set by both one and two stage heating regimes. Experiment 2: The effect of the addition of 0.0, 1.0, 2.0, 3.0 and 4.0% dried egg white to sols on gel strength was evaluated. Sols contained 0.5% poly phosphate and were heat set using both one and two stage heating. Sols used in Experiment 1 and 2 were prepared from the same lots of fish. The 0.5% polyphosphate treatment in Experiment 1 was used for the 0.0% egg white treatment in Experiment 2. Experiment 3: The interrelationship of egg white level and varying pH was determined from gels prepared from sols containing 3 levels of egg white (0.0, 0.5

and 1.0%) and sodium carbonate (0.0, 0.1 and 0.2%). All sols contained 0.5% polyphosphate and were set using both one and two stage heating regimes. Experiment 4: The influence of potato starch addition on gel strength was established from gels prepared from sols containing 0.0, 2.0 and 5.0%. Sols were set using both one and two stage heating regimes. Experiment 5: Sols containing 0.0, 2.0, 4.0, 6.0 and 8.0% of the cryoprotectant sorbitol were used to evaluate changes produced in gel strength. All formulations contained 0.5% polyphosphate and dried egg white and were heat set using both one and two stage heating regimes. The use of the same lots of fish for preparing sols in Experiment 4 and 5 allowed the use of the 0.0% potato starch treatment from Experiment 4 to be used for the 0.0% sorbitol treatment in Experiment 5. Experiment 6: Alterations in the gel strength and sensory preference produced by varying levels of the cryoprotectant sucrose was determined for gels prepared from sols containing 0.0, 2.0, 4.0 and 6.0% sucrose. All sol formulations contained 0.5% polyphosphate and dried egg white and were heat set only by the two stage heating regime. Experiment 7: The changes in gel strength and sensory preference afforded by washing were determined from gels prepared from sols containing unwashed and washed minced flesh, 0.5% polyphosphate and dried egg white. Sols were set using the two stage heating regime.

Chemical Analysis

Composition

Moisture, protein, fat and ash were determined, in duplicate, using standard AOAC (1984) methods. The moisture content of minced fish used in each treatment and replicate was determined immediately after processing. Samples from heat set gels were frozen after TPA and determined later. The moisture content of gels subjected to smoking was determined immediately before and after smoking at the same time TPA took place. The composition of deboned flesh, washed flesh, and refined flesh, both washed and unwashed, used for each replicate was determined.

pH

The pH of the minced flesh used for each treatment and each sol was determined from a 10 g sample homogenized with 90 g distilled water for 30 sec. (Kinematica CH-6010 Kriens-LU Homogenizer, Switzerland). A Corning pH meter, Model 240 (Corning Ciba Diagnostics Co., Corning, NY.) was used to measure pH.

Texture Profile Analysis (TPA)

TPA was carried out as described by Lanier et al. (1985). Gels were held at room temperature (20 to 23^0 C) for 2 hr before testing. Five samples (1.5 cm diameter by 1.0 cm long) were cut from each treatment and weighed. Samples with obvious air holes were discarded.

Samples were subjected to double bite compression using an Instron Universal Testing Machine, Model TM-M (Instron Corp., Canton, MA). A cross head speed of 10 cm/min and chart speed of 100 cm/min was used. Each sample was compressed axially 2 times to 80% of its original length.

Hardness was calculated as the peak force at the first compression divided by the sample weight and expressed as Newtons (N)/g. Cohesiveness was computed as the ratio of the area of the second peak divided by the area of the first peak and expressed as a percentage. Springiness was a measure of how much the sample recovered in length after the first compression. It was calculated by dividing the base length of the second peak by the base length of the first peak and expressed as a percentage.

Sensory Evaluation

Sensory evaluations were conducted at the Sensory Evaluation Laboratory of the Department of Food Science and

Technology at Oregon State University under the supervision of Dr. Mina McDaniel. A consumer panel of 35 people, with no specific training, used a 9 point hedonic scale (Larmond, 1977) to evaluate samples (scale range: 9 = like extremely, to 5 = neither like nor dislike, to 1 = dislike extremely).

Panelists were asked to rate their preference for the flavor, texture, appearance and overall desirability of gels containing varying levels of sucrose (Experiment 6). Samples were held at -20^0 C for 5 to 6 days prior to sensory evaluation and subjected to TPA 2 days before evaluations. Gels prepared from washed and unwashed flesh (Experiment 7) were judged for flavor, texture, color and overall desirability. Samples were held for 12 days at -20^0 C prior to sensory evaluations and subjected to TPA 4 days before evaluation. Both sensory evaluations included 3 replicates of each treatment.

Samples were thawed overnight at 4^0 C, then cut into cross section slices 3 to 5 mm thick. Slices were covered with plastic wrap and held at 4^0 C prior to evaluation. Each panelist was presented one slice from each treatment and replicate. All of the treatments and replicates were presented to the panelists at the same time (4 sucrose levels x 3 fish lot replicates = 12 samples, Experiment 6; washed and unwashed flesh x 3 fish lots = 6 samples, Experiment 7).

Statistical Analysis

TPA values from Experiments 1 (phosphate addition and heating regime), 2 (egg white concentration and heating regime), 4 (potato starch concentration and heating regime), and 5 (sorbitol concentration and heating regime) were analyzed using a two factor analysis of variance as described by Petersen (1985). Values from Experiment 3 (egg white concentration, sodium carbonate concentration and heating regime) were analyzed with a three factor analysis of variance (Petersen, 1985).

TPA values from Experiments 6 (sucrose concentration) and 7 (washing) were analyzed using a one factor analysis of variance. Sensory scores from Experiments 6 and 7 were analyzed using a Statistical Analysis System (SAS) program (SAS Copyright (c) 1985, SAS Institute, Inc., Cary, NC). A one factor analysis of variance was employed. The mean square of the panelist x treatment term was used instead of MS (error) to calculate the treatment F ratio as suggested by Lundahl and McDaniel (1988). When analysis of variance revealed a significant difference among treatments, the least squares difference test was used to separate treatment means.

The correlation between Instron measurements and sensory texture preference scores from Experiment 6 (sucrose concentration) was determined by analysis of covariance and multiple regression using Statgraphics (Statistical Graphics System, Statistical Graphics Corporation, Copyright (c) 1986, STSC INC.).

RESULTS AND DISCUSSION

Polyphosphate

Addition of 0.5% polyphosphate to minced flesh gels (Experiment 1) significantly increased the hardness ($P \leq .005$), cohesiveness ($P \leq .01$) and springiness ($P \leq .001$) of heat set gels (Table 2). A combination of phosphate addition and two stage heating produced gels with the highest values for all three texture parameters. Hardness and cohesiveness were significantly improved by two stage heating only when phosphate was present. Hardness was significantly ($P \leq .005$) improved by phosphate addition under both heating regimes, but cohesiveness was only improved ($P \leq .01$) under the two stage heating regime. Phosphate addition and heat setting regime interacted in a significant manner ($P \leq .05$) to affect the springiness of gels. Springiness was improved ($P \leq .001$) by phosphate addition to gels set with both heating regimes, but the increase in springiness with two stage heating only occurred when phosphate was not present.

Trout and Schmidt (1984) concluded that 96% of variations in the texture of restructured beef rolls that were treated with polyphosphates could be explained by changes they caused in pH and ionic strength. In this investigation, phosphate addition did not significantly ($P > .05$) alter the mean pH of the raw sols

(Table 3), but had a marked affect on gel texture. The changes observed demonstrated the dissociating action of phosphates on actomyosin described by Bendall (1954), Yasui et al. (1964) and Weiner (1969). Improved protein solubilization in the presence of phosphates produced harder, more cohesive and springier heat set gels. While phosphate significantly improved the hardness and cohesiveness of gels subjected to a two stage heating regime, springiness was not effected. The unfolding of

Table 2. Effect of polyphosphate addition and heating regime on gel strength.

	Heating Regime					
	Hardness (N/g)		Cohesiveness (%)		Springiness (%)	
Polyphosphate (%)	90[1]	40/90[2]	90[1]	40/90[2]	90[1]	40/90[2]
0.0	26.84	31.22	21.94	25.76	49.37	60.05
0.5	36.12	55.45	27.00	35.91	66.53	68.14
LSD (.05)	12.94		7.12		6.10	

Factorial analysis of variance

		F-value		
Source	D.F.	Hardness	Cohesiveness	Springiness
Block	2	7.50[5]	9.16[5]	23.83[7]
Temperature (T)	1	10.19[5]	9.56[5]	12.15[6]
Phosphate (P)	1	19.88[7]	13.64[6]	51.26[8]
T x P	1	3.91[3]	1.53[3]	6.62[4]

[1] 90^0 C for 30 min
[2] 40^0 C for 30 min then 90^0 C for 20 min
[3] NS $P > .05$; [4] $P \leq .05$; [5] $P \leq .025$; [6] $P \leq .01$; [7] $P \leq .005$; [8] $P \leq .001$

proteins in the absence of phosphate that occurred during 40^{0} C heat setting was equal to changes produced by phosphate addition in developing springiness in gels heated under the one stage regime. These observations tend to support solubilization or unfolding of proteins to be the most important factor for developing the springiness characteristic of the gels. The time allowed for ordering of the gel matrix afforded by the two stage heating regime did not greatly improve gel springiness. Conversely, while solubilization or unfolding of proteins was important, the time afforded by the two stage heating regime for ordering of the gel matrix improved gel hardness and cohesiveness to a much greater extent.

Table 3. Protein and moisture content and pH of gels containing polyphosphate.[1]

Polyphosphate (%)	pH[2]	Moisture (%)[3]	Protein (%)[4]
0.0	6.36[a]	72.44	14.68
0.5	6.63[a]	73.55	14.38

1 n=3
2 Values in the same column with the same superscript did not vary (P>.05)
3 Cooked gels
4 Protein content of gels computed from minced flesh protein content

Egg White and Sodium Carbonate

Addition of egg white to sols (0.0 to 4.0%) (Experiment 2) did not affect ($P>.05$) the hardness, cohesiveness or springiness of the heat set gels (Table 4). Two stage heating significantly improved ($P\leq.001$) hardness, cohesiveness, and springiness of gels over those set with the one stage heating regime. Inspection of individual treatment means (Table 4) revealed that gels subjected to two stage heat setting were consistently harder, springier and more cohesive than gels heat set at 90^0 C containing the same quantity of egg white. Gels containing 1% egg white and set with two stage heating had the highest values for hardness, cohesiveness and springiness. Although values were higher for gels containing 1.0% egg white, egg white addition did not cause a significant ($P>.05$) change in hardness, cohesiveness, or springiness. Among the gels set using one stage heating, those containing 1% egg white had the highest values for hardness and cohesiveness and the second highest values for springiness. However, values for hardness and cohesiveness did not vary significantly ($P=.05$) from all the other levels of egg white, but springiness was significantly ($P=.05$) higher than gels containing 2.0, 3.0, and 4.0% egg white.

The small improvement in gel texture resulting from the addition of 1% egg white, while not significant unless compared to higher levels of egg white, suggested that lower levels of

egg white could enhance gel strength in a significant manner. This hypothesis was further supported by the fact that values for hardness, cohesiveness and springiness were reduced by levels of egg white greater than 1% in a progressive manner which was commensurate with significant ($P<.05$) reductions in the fish protein content of the gels (Table 5).

Table 4. Effect of egg white content and heating regime on gel strength.

Egg White (%)	Heating Regime					
	Hardness (N/g)		Cohesiveness (%)		Springiness (%)	
	90[1]	40/90[2]	90[1]	40/90[2]	90[1]	40/90[2]
0.0	36.12	55.45	27.00	35.91	66.53	68.14
1.0	43.82	68.12	28.72	38.91	64.54	70.63
2.0	38.36	60.34	27.27	35.17	57.67	67.34
3.0	40.70	57.32	28.23	31.79	57.62	67.68
4.0	39.85	53.43	28.63	31.70	55.61	65.86
LSD (.05)	12.72		5.96		7.38	

Factorial analysis of variance

Source	D.F.	F-value		
		Hardness	Cohesiveness	Springiness
Block	2	11.89[4]	18.68[4]	35.02[4]
Temperature (T)	1	50.06[4]	28.16[4]	23.01[4]
Egg White (EW)	4	1.74[3]	1.15[3]	3.12[3]
T x EW	4	0.49[3]	1.29[3]	1.12[3]

Ranking of Level Means[5]

	Egg White	Temperature
Hardness	0.0 < 4.0 < 3.0 < 2.0 < 1.0	90 < 40/90
Cohesiveness	3.0 < 4.0 < 2.0 < 0.0 < 1.0	90 < 40/90
Springiness	4.0 < 2.0 < 3.0 < 0.0 < 1.0	90 < 40/90

1 90^0 C for 30 min
2 40^0 C for 30 min then 90^0 C for 20 min
3 NS P>
4 P≤ .001
5 Means with the same underline are not significantly different P = .05

Table 5. Protein and moisture content and pH of gels containing varying levels of egg white.[1]

Egg White (%)	pH	Moisture (%)[2]	Protein (%)[3,4]
0.0	6.63	73.55	14.38[a]
1.0	6.64	73.69	13.76[a,b]
2.0	6.62	73.36	13.47[abc]
3.0	6.61	73.79	12.54[bc]
4.0	6.63	74.13	11.93[c]

[1] n=3
[2] Cooked gels
[3] Protein content of gels computed from minced flesh protein content
[4] Values in the same column with the same superscript did not vary ($P<.05$, $LSD_{.05} = 1.424$)

Several authors have demonstrated that minced fish and surimi gels are strengthened by disulfide crosslinks (Itoh et al., 1979; Niwa, 1985; Jiang et al., 1986). Egg white proteins possess a high concentration of sulfhydryl groups (Regenstein and Regenstein, 1984). Shimata and Matsushita (1980) found that coagulation of egg albumin is dependent on intermolecular disulfide crosslinks that are formed during heating. Albumin coagulums were observed to harden as the solution pH was elevated from 6.0 to 8.0. Beneficial effects from egg white addition would be related to sulfhydryl-disulfide interchange between fish and egg white proteins and may require the adjustment of sol pH to a more basic level to take full advantage of their interaction with fish proteins.

Lower levels of egg white (0.5, and 1.0%) under varying pH conditions (adjustment with 0.0, 0.1 and 0.2% Na_2CO_3) yielded

improved gel strengths (Experiment 3). Varying levels of egg white and heat setting regime significantly altered ($P \leq .001$) the hardness, cohesiveness and springiness of gels (Table 6). More basic sol pH levels (Table 7) produced by addition of varying levels of sodium carbonate significantly affected ($P \leq .001$) only cohesiveness.

Ranking of level means revealed that two stage heating produced the hardest gels ($P=.05$). Gels containing 0.5% egg white were harder than those with 1%, which were harder than gels containing 0% egg white ($P=.05$). Inspection of individual treatment means also revealed that in all cases, the hardness of gels heat set using the two stage regime were superior to those heat set at 90^0 C. An egg white concentration of 0.5% produced the hardest ($P=.05$) gels that were heat set at 90^0 C. The hardness of gels set with two stage heating and containing 0.5 and 1.0% egg white were equal and both superior to gels with 0.0% egg white. These relationships were true at all levels of sodium carbonate. Inspection of treatment means supported the findings observed from ranking level means that harder gels were produced by the two stage heating regime and by an egg white concentration of 0.5%. However, treatment means indicated that harder ($P=.05$) gels were produced when no sodium carbonate was added to sols containing an optimum level of egg white (0.5%) and heat set under optimum conditions (two stage heating).

The overall effect of sodium carbonate on hardness was not significant ($P>.05$), but egg white and sodium carbonate

interacted in a significant manner ($P \leq .001$). Sols containing 0.1 and 0.2% sodium carbonate produced harder ($P = .05$) gels than sols with 0.0% sodium carbonate when no egg white was present, but the level of sodium carbonate in the sols did not alter ($P = .05$) the hardness of gels when 0.5% egg white was added to the formulations. The hardness of gels containing 1.0% egg white and heat set at 90^0 C were not affected ($P = .05$) by sodium carbonate concentration. However, when gels were set by the two stage heating regime, sols containing 0.0% sodium carbonate were harder ($P = .05$) than those containing 0.1 and 0.2% sodium carbonate.

Heat setting with the two stage heating regime and concentrations of 0.5% egg white and 0.2% sodium carbonate produced the most ($P = .05$) cohesive gels based on level mean ranking. Inspection of individual treatment means showed the overall findings regarding heat setting regime to be true in all cases except for gels containing 0.0% egg white in combination with 0.1% sodium carbonate. Gels set at 90^0 C were equally ($P = .05$) as cohesive as counterpart gels set under the two stage heating regime.

Sodium carbonate and egg white concentration interacted to affect cohesiveness ($P \leq .05$). The addition of sodium carbonate to sols containing 0.0% egg white improved ($P = .05$) gel cohesiveness, although no difference ($P = .05$) was observed between 0.1 and 0.2%. This was true for gels containing 0.5% egg white and heat set at 90^0 C, but gels set with two stage

heating were not altered (P=.05) by the addition of sodium carbonate. Sols containing 1.0% egg white and heat set at 90^0 C were not affected (P=.05) by additions of sodium carbonate and those set under the two stage regime were only improved (P=.05) by 0.2% sodium carbonate.

Inspection of individual treatment means for cohesiveness supported optimum conditions regarding heat setting regime (two stage) and egg white concentration (0.5%) observed by ranking level means. However, the level of sodium carbonate (0.2%) that produced the most cohesive gels, as demonstrated by ranking of level means, did not have a significant (P=.05) effect on gels produced with optimum levels of egg white (0.5%) and set under optimum conditions (two stage).

Ranking of level means indicated that maximum (P=.05) springiness was produced by the two stage heating regime and by 0.5 or 1.0% egg white. Sodium carbonate addition did not significantly (P=.05) improve springiness. Inspection of individual treatment means for springiness indicated that sols heat set using a two stage regime were superior (P=.05) to all counterparts heat set at 90^0 C except for gels containing 0.0% egg white in combination with 0.0 or 0.2% sodium carbonate and 0.5% egg white in combination with 0.1% sodium carbonate. Sodium carbonate level did not (P=.05) affect the springiness of gels heat set at 90^0 C. This was true (P=.05) for gels heat set using the two stage regime and containing 0.5 and 1.0% egg white in combination with 0.0 or 1.0% sodium carbonate, but gels

containing 0.0% egg white and 0.0% sodium carbonate were less ($P=.05$) springy than counterparts containing 0.1 and 0.2% sodium carbonate. This detailed interrelationship of individual treatment means was the source of the observed significant ($P\leq.05$) interaction between heat setting regime and egg white and sodium carbonate concentrations.

In summary, low concentrations of egg white (0.5 and 1.0%) and heat setting regime had significant ($P\leq.001$) effects on gel strength with 0.5% egg white and two stage heating producing the highest values for hardness, cohesiveness and springiness. Sodium carbonate caused a significant increase in the mean pH of the raw sols ($P\leq.01$, Table 8), was only reflected by a significant ($P\leq.001$) overall effect on gel cohesiveness. Sodium carbonate addition produced significantly harder ($P=.05$) gels if no egg white was present, but when egg white was added and two stage heating was used, gel strength decreased. The relationship between sodium carbonate, egg white and heat setting regime was similar with respect to cohesiveness. If no egg white was present or if egg white was added, but gels were heated at only 90^0 C, then cohesiveness increased as sodium carbonate was added. However, when egg white was present and gels were set with two stage heating, addition of sodium carbonate had no effect.

A more basic pH would improve protein solubility and reduce protein aggregation that occurs more readily nearer to the isoelectric point (Cheftel et al., 1985). Higher pH would also

promote the formation of disulfide cross-links by sulfhydryl-disulfide interchange. The fact that sodium carbonate addition only benefited gel strength when egg white was not present suggests that its effect on protein solubility may have been more important than its promotion of sulfhydryl-disulfide interchange. Sonu (1986) suggested raising the pH of minced sardine flesh during washing by using a 0.5% solution of sodium bicarbonate. Earlier pH adjustment of minced shad flesh may have been more effective at improving gel strength.

Table 6. Effect of egg white content, sodium carbonate content and heating regime on gel strength.

Egg White (%)	Na Carb. (%)	Heating Regime: Hardness (N/g) 90[1]	Hardness (N/g) 40/90[2]	Cohesiveness (%) 90[1]	Cohesiveness (%) 40/90[2]	Springiness (%) 90[1]	Springiness (%) 40/90[2]
0.0	0.0	42.79	55.53	26.43	30.18	59.99	55.65
	0.1	51.15	68.61	31.75	40.31	57.85	63.70
	0.2	53.30	69.07	36.47	40.98	60.00	64.86
0.5	0.0	71.26	87.35	36.25	44.78	61.86	70.65
	0.1	70.31	79.99	41.28	44.00	64.55	68.46
	0.2	68.95	79.59	41.15	46.74	61.92	69.41
1.0	0.0	58.82	86.30	33.09	40.27	59.43	67.43
	0.1	62.00	77.75	35.42	42.27	61.57	67.96
	0.2	60.76	74.32	37.52	45.43	62.78	67.74
LSD .05		7.99		4.58		4.94	

Factorial analysis of variance

Source	D.F.	F-value: Hardness	Cohesiveness	Springiness
Block	1	61.26[5]	1.39[3]	2.56[3]
Temperature (T)	1	150.02[5]	72.74[5]	42.80[5]
Egg White (EW)	2	82.96[5]	41.16[5]	19.56[5]
Na Carb. (SC)	2	0.35[3]	25.23[5]	2.30[3]
T x EW	2	2.42[3]	0.62[3]	3.65[4]
T x SC	2	1.77[3]	0.05[3]	0.39[3]
EW x SC	4	7.78[5]	3.49[4]	1.24[3]
T x EW x SC	4	1.68[3]	1.61[3]	3.48[4]

1 90^0 C for 30 min
2 40^0 C for 30 min then 90^0 C for 20 min
3 NS $P > .05$
4 $P \leq .05$
5 $P \leq .001$

Table 7. Effect of egg white content, sodium carbon content and heating regime on gel strength: ranking of level means[1].

	Egg White	Na2CO	Temperature
Hardness	0.0 < 1.0 < 0.5	0.0 < 0.2 < 0.1	90 < 40/90
Cohesiveness	0.0 < 1.0 < 0.5	0.0 < 0.1 < 0.2	90 < 40/90
Springiness	0.0 < 1.0 < 0.5	0.0 < 0.2 < 0.1	90 < 40/90

[1] Means with the same underline did not vary (P=.05).

Table 8. Protein and moisture content of gels containing varying levels of egg white and sodium carbonate. [1]

Sod. Carb. (%)	Egg White (%)	pH	Average pH[4]	Moisture (%)[2]	Protein (%)[3]
0.0	0.0	6.52	6.53[a]	73.22	14.66
	0.5	6.54		73.34	14.61
	1.0	6.53		73.77	14.54
0.1	0.0	6.83	6.83[b]	73.46	14.36
	0.5	6.84		73.85	14.29
	1.0	6.84		73.82	14.23
0.2	0.0	7.15	7.16[c]	73.45	14.04
	0.5	7.19		74.04	13.98
	1.0	7.16		74.15	13.76

[1] n=2
[2] Cooked gels.
[3] Protein content of gel computed from minced flesh protein content.
[4] Values in the same column with the same superscript did not vary (P<.01, $_{L}SD_{.05}$ = 0.132).

Potato Starch

Varying levels of potato starch (0.0, 1.0, 2.0 and 5.0%) incorporated into sols (Experiment 4) had a minimal influence on gel characteristics. Hardness was altered ($P \leq .001$), but cohesiveness and springiness were not ($P > .05$) affected (Table 9). The two stage heat setting regime improved ($P \leq .001$) all three of the parameters describing gel characteristics over single stage heat setting. Potato starch content and heat setting regime did not interact ($P > .05$) to alter the hardness, cohesiveness or springiness of heat set gels.

Ranking of level means for hardness revealed that addition of potato starch tended to reduce gel hardness. Gels containing 0.0 and 1.0% starch produced gels of equal ($P = .05$) hardness which were superior to those containing 2.0 and 5.0%. Inspection of treatment means indicated that a significant reduction in hardness over that observed for gels containing 0.0% starch only occurred with the addition of 5.0% starch for both heat setting regimes. The overall improved hardness afforded gels heat set by the two stage over the one stage regime was reflected ($P = .05$) by all counterparts containing equal levels of potato starch.

The two stage regime favorably ($P = .05$) improved the cohesiveness of gels at all concentrations of starch over the one stage heat set. This was also true ($P = .05$) for the springiness of gels containing 0.0 and 1.0% starch. However,

the springiness of gels that contained 2.0 and 5.0% starch were equal (P=.05). Although not significant, potato starch produced a small concentration dependent increase in the springiness of gels which was more evident for gels heat set by the one stage regime.

These data are in disagreement with the observations of Kim and Lee (1987) who found significant increases in gel strength with the addition of 5% potato starch. They maintained a constant water content among treatments which presumably altered protein concentrations in a manner similar to those reported for this investigation (Table 10). Wu et al. (1985) also found that addition of 5% potato starch increased the strength of surimi gels. Gel reinforcement by potato starch is dependent of starch gelatinization. Swelling during gelatinization strengthens the gel by exerting pressure on and absorbing water from the protein matrix (Kim and Lee, 1987).

The above successful trials with potato starch were conducted using surimi made from red hake (Urophycus chuss) or Alaska pollock (Theragra chalcogramma). Both species have a low fat content and gels made from washed minced flesh probably had fat concentrations of less than 1%. The gels prepared from shad in this investigation were prepared from unwashed minced flesh and contained from 5.90 to 7.60% fat (estimated from the measured fat content of the minced flesh. This higher fat content may have affected starch gelatinization. According to Whistler and Daniel (1985) lipids may complex with amylose and

retard swelling. In a low fat system such as white bread, 96% of the starch can be fully gelatinized, while in high fat systems such as cookies or pie crust, a large proportion of the starch does not gelatinize. Lack of starch gelatinization would eliminate the gel reinforcing effect of potato starch and gel strength would decrease because of lowered protein concentration (Table 10).

Table 9. Effect of potato starch content and heating regime on gel strength.

Potato Starch (%)	Heating Regime: Hardness (N/g) 90[1]	Hardness (N/g) 40/90[2]	Cohesiveness (%) 90[1]	Cohesiveness (%) 40/90[2]	Springiness (%) 90[1]	Springiness (%) 40/90[2]
0.0	70.56	98.50	31.62	39.54	61.52	68.96
1.0	64.19	94.53	29.64	40.58	62.87	69.73
2.0	61.40	79.34	29.28	35.51	63.05	67.58
5.0	55.23	73.10	29.32	38.57	66.90	70.54
LSD .05	9.60		4.84		5.40	

Factorial analysis of variance

Source	D.F.	F-value: Hardness	Cohesiveness	Springiness
Block	2	48.62[4]	16.91[4]	7.23[3]
Temperature (T)	1	110.52[4]	57.83[4]	19.94[4]
Potato St. (PS)	3	16.51[4]	1.58[3]	1.67[3]
T x PS	3	2.15[3]	0.78[3]	0.53[3]

Ranking of Level Means[5]

	Potato Starch	Temperature
Hardness	5.0 < 2.0 < 1.0 < 0.0	90 < 40/90
Cohesiveness	2.0 < 5.0 < 1.0 < 0.0	90 < 40/90
Springiness	2.0 < 0.0 < 1.0 < 5.0	90 < 40/90

[1] 90^0 C for 30 min
[2] 40^0 C for 30 min then 90^0 C for 20 min
[3] NS P> .05
[4] P≤ .001
[5] Means with the same underline did not vary (P=.05)

Table 10. Protein and moisture content of gels containing varying levels of potato starch.[1]

Potato Starch (%)	pH	Moisture (%)[2]	Protein (%)[3,4]
0.0	6.59	72.59	15.23[a]
1.0	6.66	72.57	14.56[ab]
2.0	6.69	72.54	13.90[b]
5.0	6.74	73.56	11.92[c]

[1] All values are the means of 3 replicates
[2] Moisture measured on cooked gels
[3] Protein concentration of gel calculated using measured protein concentration of mince
[4] Values with the same superscript in the same column did not vary ($P<.01$, $LSD_{.05} = 1.197$)

Cryoprotectants

Incorporation of varying levels (0.0, 2.0, 4.0, 6.0 and 8.0%) of sorbitol into sols that were heat set using two stage and one stage heat setting regimes (Experiment 5) altered ($P \leq .001$) gel hardness and cohesiveness (Table 11). Sorbitol concentration did not ($P > .05$) affect the springiness of gels. The two stage heating regime produced harder ($P \leq .001$) and more cohesive ($P \leq .001$) and springy gels than the one stage regime. Sorbitol concentration in the sol interacted with heat setting regime to affect gel cohesiveness ($P \leq .025$), but not ($P > .05$) hardness or springiness.

Ranking of level means (Table 12) indicated that hardness of gels was reduced ($P = .05$) with each incremental addition of sorbitol to sols. This was also true ($P = .05$) for cohesiveness except for gels containing 2.0 and 4.0% sorbitol where an equal degree of cohesiveness was observed. Although not significant, varying levels of sorbitol addition to sols produced values for springiness with a similar relationship.

Sols containing 0.0% sorbitol heat set using the two stage regime produced the hardest ($P = .05$) gels (Table 12). Addition of sorbitol to sols reduced hardness in a concentration dependant manner for both heat setting regimes. At lower levels of sorbitol (0.0 to 4.0%), sols heat set using the one stage regime were equal ($P = .05$) in hardness to sols containing a 2.0% additional increment of sorbitol content that were set using two

stage heating.

Inspection of individual treatment means for cohesiveness (Table 12) revealed that 0.0% sorbitol produced the most (P=.05) cohesive gel. Addition of sorbitol reduced gel cohesiveness for each heat setting regime in a manner dependent upon sorbitol concentration. The effect of sorbitol content on cohesiveness was less pronounced for the two stage heat setting regime. At 0.0 and 2.0% sorbitol, the cohesiveness of gels heat set using the two stage regime were superior (P=.05) to those for counterparts heat set using the one stage regime. At concentrations $\geq$ 4.0%, the cohesiveness of gels heat set using the two regimes were equal (P=.05). These relationships produced the significant interaction of sorbitol concentration and heat setting regime on cohesiveness.

The two stage heating regime produced more ($P \leq .001$) springy gels overall, but inspection of individual treatment means indicated that gels heat set using the one stage regime and containing 0.0, 2.0 and 4.0% sorbitol were equal (P=.05) to all gels heat set using the two stage regime regardless of sorbitol concentration. Only at the 8.0% level of sorbitol, was a significant (P=.05) difference observed between counterparts with the same sorbitol content.

Addition of sorbitol to sols reduced the fish protein content. The low temperature portion of the two stage heating regime produced a greater degree of heat induced unfolding of fish proteins and more time for gel matrix ordering than the one

stage treatment. Improved gel hardness, cohesiveness and springiness resulted from this process. The effectiveness of two stage heating, with regards to gel hardness and cohesiveness, was reduced as sorbitol replaced fish protein in the sols. Conversely, reduced protein concentration did not limit the effectiveness of the two stage heating regime for improving gel springiness within the range of sorbitol concentrations evaluated.

Table 11. Effect of sorbitol content and heating regime on gel strength.

Sorbitol (%)	Heating Regime					
	Hardness (N/g)		Cohesiveness (%)		Springiness (%)	
	90[1]	40/90[2]	90[1]	40/90[2]	90[1]	40/90[2]
0.0	70.56	98.50	31.62	39.54	61.52	68.96
2.0	53.25	73.40	29.59	36.27	60.16	68.20
4.0	37.22	51.39	29.85	32.60	60.56	69.46
6.0	25.96	33.19	26.16	27.14	59.31	67.11
8.0	14.63	18.56	23.03	25.15	49.83	63.53
LSD .05	9.31		3.03		9.74	

Factorial analysis of variance

Source	D.F.	F value		
		Hardness	Cohesiveness	Springiness
Block	2	48.00[5]	18.32[5]	15.02[5]
Temperature (T)	1	54.91[5]	40.28[5]	19.41[5]
Sorbitol (S)	4	148.05[5]	42.02[5]	2.39[3]
T x S	4	4.80[3]	4.42[4]	0.29[3]

[1] 90^0 C for 30 min
[2] 40^0 C for 30 min then 90^0 C for 20 min
[3] NS $P > .05$
[4] $P \leq .025$
[5] $P \leq .001$

Table 12. Effect of sorbitol content and heating regime on gel strength: ranking of treatment[1] and level[2] means.

Hardness[3]		Cohesiveness[3]		Springiness[3]	
% Sorbitol	Heating Regime	% Sorbitol	Heating Regime	% Sorbitol	Heating Regime
8.0	90^{a}	8.0	90^{a}	8.0	90^{c}
8.0	$40/90^{ab}$	8.0	$40/90^{ab}$	6.0	90^{bc}
6.0	90^{bc}	6.0	90^{b}	2.0	90^{ab}
6.0	$40/90^{cd}$	6.0	$40/90b^{c}$	4.0	90^{ab}
4.0	90^{d}	2.0	90^{cd}	0.0	90^{ab}
4.0	$40/90^{e}$	4.0	90^{cd}	8.0	$40/90^{ab}$
2.0	90^{e}	0.0	90^{d}	6.0	$40/90^{ab}$
0.0	90^{f}	4.0	$40/90^{d}$	2.0	$40/90^{ab}$
2.0	$40/90^{f}$	2.0	$40/90^{e}$	0.0	$40/90^{ab}$
0.0	$40/90^{g}$	0.0	$40/90^{f}$	4.0	$40/90^{a}$

	% Sorbitol	Temperature
Hard.	8.0 < 6.0 < 4.0 < 2.0 < 0.0	90 < 40/90
Cohes.	8.0 < 6.0 < 4.0 < 2.0 < 0.0	90 < 40/90
Spring.	8.0 < 6.0 < 2.0 < 4.0 < 0.0	90 < 40/90

[1] Treatments means with the same superscript did not vary (P=.05)
[2] Level means with the same underline did not vary (P=.05)
[3] Ranked from lowest to highest in a column

Table 13. Protein and moisture content of gels containing varying levels of sorbitol. [1]

Sorbitol (%)	pH	Moisture (%)[2]	Protein (%)[3,4]
0.0	6.59	72.59	15.23[a]
2.0	6.66	72.83	13.97[b]
4.0	6.71	72.98	12.58[c]
6.0	6.72	72.60	11.25[d]
8.0	6.80	73.34	9.93[e]

[1] All values are the means of 3 replicates
[2] Moisture measured on cooked gels before smoking
[3] Protein concentration of gels calculated using measured protein concentration of mince
[4] Values with the same superscript in the same column did not vary ($P<.01$, $LSD_{.05} = 1.041$)

The interrelationship of varying physically determined gel textural characteristics (Instron measurements) to sensory preference was evaluated by measuring gels containing 0.0, 2.0, 4.0 and 6.0% sucrose that were set using a two stage heat setting regime (Experiment 6). The varying levels of sucrose altered gel hardness ($P\leq.001$), cohesiveness ($P\leq.05$) but not springiness ($P>.05$) (Table 14). Ranking of treatment means for hardness revealed a sucrose concentration dependent reduction in hardness (Table 15). Sucrose levels of 0.0 and 2.0% were of equal hardness ($P=.05$); 4.0 and 6.0% gels were softer and not equal ($P=.05$). Reduced ($P=.05$) cohesiveness was only observed at the 6.0% level of sucrose (Table 15). Gels containing 0.0, 2.0 and 4.0% sucrose were equally cohesive ($P=.05$). Gel hardness reflected the reduction in sol protein content (Table 16) as sucrose replaced the fish protein content. Neither the

cohesiveness nor springiness of gels reflected this reduction in sol protein content.

Sensory evaluation determined a significant ($P \leq .001$) difference in sensory factors (texture, appearance, flavor and overall desirability) (Table 14). For all sensory factors, panelists preferred ($P=.05$) gels containing 0.0 and 2.0% sucrose (Table 15). Gels containing 4.0 and 6.0% sucrose were less ($P=.05$) preferred; those with 4.0% sucrose were more ($P=.05$) preferred than 6.0%. The ranking of sensory scores was identical to the ranking for hardness which was dependent upon sucrose concentration.

Analysis of the covariance of scores for texture preference with hardness, cohesiveness and springiness revealed a strong linear relationship between hardness and texture preference (covariance including all three physical measurements: $P=.0139$; covariance of hardness and texture preference only: $P=.0004$) (Table 17). No strong relationship was shown for the relationship between texture preference and cohesiveness ($P=.7594$) or springiness ($P=.6675$).

These results indicate that sucrose levels between 0.0 and 6.0% do not greatly alter gel cohesiveness and springiness, but these levels reduced hardness in a linear manner. Panelists preferred the hardest gels within the range of sucrose levels evaluated and did not prefer softer gels. The lowered preference, with regard to flavor and desirability, as sucrose levels were elevated also suggested that panelists did not prefer the sweet flavor of the added sucrose.

Table 14. Effect of sucrose content on gel strength and sensory preference.[1]

Test	Sucrose (%) 0.0%	2.0%	4.0%	6.0%
Instron Measurement				
Hardness	80.18	71.40	53.44	32.51
Cohesiveness	38.56	41.40	39.57	34.62
Springiness	71.55	70.11	67.47	67.96
Sensory				
Texture	5.47	5.49	4.85	4.05
Appearance	5.16	5.07	4.61	4.26
Flavor	5.86	5.50	4.86	4.35
Desirability	5.70	5.47	4.82	4.14

Analysis of variance

Instron Measurement

Source	D.F.	F-value Hardness	Cohesiveness	Springiness
Sucrose	3	31.19[6]	4.54[4]	0.90[3]

Sensory Preference

Source	D.F.	F-value[2] Texture	Appearance	Flavor	Overall Desire.
Panelist (P)	34	13.95[6]	22.99[6]	9.23[6]	18.80[6]
Sucrose (S)	3	20.33[6]	13.17[6]	21.59[6]	36.34[6]
P x S	102	1.67[6]	1.43[5]	1.33[4]	1.15[3]

[1] All treatments heated at 40^0 C for 30 min then 90^0 C for 20 min then smoked

[2] F-values for the panelist effect and sucrose effect were determined using the MS for P x S as the error term

[3] NS $P > .05$

[4] $P \leq .05$

[5] $P \leq .025$

[6] $P \leq .001$

Table 15. Effect of sucrose content on gel strength and sensory preference: ranking of Instron and sensory treatment means.[1]

Test		
Instron		
	Hardness	6.0 < 4.0 < 2.0 < 0.0
	Cohesiveness	6.0 < 0.0 < 4.0 < 2.0
	Springiness	4.0 < 6.0 < 2.0 < 0.0
Sensory		
	Texture	6.0 < 4.0 < 0.0 < 2.0
	Appearance	6.0 < 4.0 < 2.0 < 0.0
	Flavor	6.0 < 4.0 < 2.0 < 0.0
	Desirability	6.0 < 4.0 < 2.0 < 0.0

[1] Means with the same underline did not vary (P = .05)

Table 16. Protein and moisture content and pH of gels containing varying levels of sucrose.[1]

Sucrose (%)	pH	Moisture (%)[2]	Moisture (%)[3]	Protein (%)[4,5]
0.0	6.55	72.78	69.05	15.85[a]
2.0	6.55	71.91	68.22	14.47[b]
4.0	6.66	72.83	69.78	13.09[c]
6.0	6.69	73.76	69.23	11.71[d]

[1] n =3
[2] Cooked gels before smoking
[3] Cooked gels after smoking
[4] Protein content of gels computed from minced flesh protein content
[5] Values with the same superscript in the same column did not vary ($P<.01$, $LSD_{.05} = 1.177$)

Table 17. Analysis of covariance of sensory texture preference scores and Instron texture measurements.

Covariance with Instron hardness, cohesiveness, and springiness

	D.F.	F Value	Significance Level
Covariates			
hardness	1	26.870	.0139
cohesiveness	1	.116	.7594
springiness	1	.232	.6675
Main Effects			
sucrose	3	2.462	.2393
fish lot	2	.051	.9512

Covariance with Instron hardness only

	D.F.	F Value	Significance Level
Covariates			
hardness	1	71.643	.0004
Main Effects			
sucrose	3	2.588	.1657
fish lot	2	.328	.7350

Fish Protein Content and Gel Strength

The gels prepared for Experiments 3-6 were formulated to have the same moisture content (74% ± 1.5%). Many treatments involved the addition of varying quantities of dry ingredients which required additional water to maintain constant moisture levels. Added water replaced fish proteins and in some of the experiments this significantly varied the protein content among treatments (Tables 5, 10, 13, 16).

Sorbitol and sucrose have no reinforcing effect on gel strength and are added to washed flesh only for cryoprotection during frozen storage (Suzuki, 1981). In this investigation, addition of varying levels of sucrose or sorbitol (Experiments 5 and 6) demonstrated how the addition of these cryoprotectants weakens gel strength by diluting gel protein content. Gel hardness was significantly reduced as sorbitol and sucrose content increased (Tables 11 and 14). The regression of the hardness of these gels on their respective protein contents (wet wt.) decreased in a linear manner ($P \leq .001$) (Table 18).

Hamann and Lanier (1986) observed that the hardness and cohesiveness of minced fish and surimi gels are not independent and will generally vary in a consistent way. This was the case when sorbitol was incorporated into minced shad flesh sols. Sorbitol reduced ($P \leq .001$) cohesiveness in a concentration dependent manner and the correlation between protein content (wet wt.) and cohesiveness was highly significant ($P \leq .001$;

r=.942). However, sucrose did not produce similar results. The effect of sucrose content in gels on cohesiveness was less significant ($P \leq .05$) (Table 14). Separation of treatment means revealed that only the cohesiveness of gels containing 6% sucrose were significantly ($P=.05$) lower than the 2 and 4% gels. The regression of gel cohesiveness on respective gel protein contents (wet wt.) did not decrease in a linear manner ($P>.05$; r=.426).

Foegeding (1987) also found that the hardness of gels was dependent upon the protein content of salt soluble proteins extracted from turkey breast and thigh. Lanier et al. (1985) observed a similar relationship between protein concentration and gel strength. They used torsional shear to measure the strength of gels made from pollock surimi and determined that rigidity measurements (stress/strain) was more sensitive to gel protein content, while strain at failure measurements were better indicators of protein functional quality.

In this investigation, the addition of varying levels of egg white (Table 5) and potato starch (Table 10) varied fish protein content in the sols. Correlations of gel texture descriptors with protein contents, in both cases, was not highly significant (Table 18). Both potato starch and egg white have demonstrated a gel reinforcing effect (Lee, 1984; Kim and Lee, 1987; Okada, 1985a; and Iso et al. 1985). Neither egg white nor potato starch were shown to reinforce the gel strength of sols prepared from shad flesh (Tables 4 and 9). The replacement of

fish protein in sols with egg white or potato starch obscured any positive reinforcing by these additives.

Table 18. Correlation of protein content with Instron measurements.

Additive	n	Correlation Coefficients		
		Hardness	Cohesiveness	Springiness
Sorbitol	15	0.976[3]	0.942[3]	0.295[1]
Sucrose	12	0.965[3]	0.426[1]	0.589[2]
Potato Starch	12	0.820[3]	0.278[1]	0.041[1]
Egg White	15	0.420[1]	0.566[2]	0.234[1]

[1] NS $P > .05$; [2] $P \leq .05$; [3] $P \leq .001$

Minced Flesh Washing

The sensory preference and strength of gels prepared from sols containing unwashed and washed flesh were determined (Experiment 7). Sols were prepared with 2% salt and were formulated to contain 74% moisture. Phosphate and egg white were added at the 5% level. These two components at the indicated content were previously shown to improve gel texture characteristics.

The preparation of unwashed and washed flesh for this investigation outlined the yield composition relationships expected from machine deboning, washing and dewatering and refining. Round shad yielded 65.06% planks, 41.20% minced flesh

and 40.10% refined flesh (Table 19). A single exchange wash followed by dewatering yielded 23.02% pressed minced flesh based upon round weight which was reduced to 20.68% by refining. The yield through refining was 97.33 and 89.83%, respectively, for unwashed and washed flesh.

Table 19. Yield from processing round fish into unwashed and washed refined minced flesh.

Process Component	Kg	Yield (%)[1]
Round	68.60	100.00
Planks	44.63	65.06
Total deboned minced flesh	28.26	41.20
Unwashed treatment		
Deboned minced flesh	7.50	41.20
refined flesh	7.30	40.10
Washed treatment		
Deboned minced flesh	20.76	41.20
Washed, dewatered flesh	11.60	23.02
Refined, washed flesh	10.42	20.68

[1] Based upon round fish weight

Ash content was reduced ($P \leq .001$) by washing. The protein and lipid content of minced flesh on a percent dry weight basis were not ($P > .05$) altered by washing (Table 20). Even though little change in the lipid and protein content of the flesh was observed, a large reduction in the total weight of both components occurred during washing. This loss was a function of dissolved and separated solids during washing, loss of particulate through the screwpress screen during dewatering and machine holdup. Washing reduced total solids in minced flesh by 42.97%; washing and refining by 48.63%. This loss in solids involved a reduction of protein of 41.77 and 46.97%, fat of 41.55 and 48.18% and ash of 75.00 and 79.24% through washing and refining respectively. Loss of solids by washing and dewatering were somewhat exaggerated, since the relatively small quantities of minced shad processed (mean of 20.76 kg) magnified the effect of quantities lost through machine holdup.

Table 20. Composition of mechanically deboned, washed and refined shad flesh.

Process Component	Percent (wet wt.)[1]			
	Protein	Lipid	Ash	Moisture
Deboned	18.82 (0.13)	10.84 (1.35)	1.18 (0.01)	70.18 (1.07)
Washed	19.78 (0.98)	11.38 (0.51)	0.53 (0.02)	69.53 (0.79)
Unwashed refined	18.89 (0.09)	10.63 (0.75)	1.15 (0.02)	70.25 (0.38)
Washed refined	19.58 (1.28)	10.95 (0.36)	0.48 (0.03)	69.48 (1.06)
	Percent (dry wt.)[1,2]			
Deboned	61.11 (2.65)	35.07 (2.80)	3.82 (0.15)	
Washed	62.40 (1.97)	35.94 (2.01)	1.66 (0.06)	
Unwashed refined	61.62 (1.56)	34.64 (1.70)	3.74 (0.15)	
Washed refined	63.09 (2.20)	35.36 (2.24)	1.54 (0.50)	

[1] Values are means of three lots of fish
[2] Differences in % dry wt.:
Protein: F-value =.500 (NS $P>.05$)
Lipid: F-value =.180 (NS $P>.05$)
Ash: F-value =378.6 ($P\leq.001$)

Table 21. Effect of washing on the proximate composition of minced shad flesh.

Process Component	Solids Weight (kg)	Kg		
		Protein	Lipid	Ash
Deboned Minced	6.19	3.783	2.171	0.236
Washed Dewatered	3.53	2.203	1.269	0.059
% Reduction	(42.97)	(41.77)	(41.55)	(75.00)
Washed Dewatered Refined	3.18	2.006	1.125	0.049
% Reduction	(48.63)	(46.97)	(48.18)	(79.24)

The losses observed in this investigation for minced shad flesh were similar to those reported by Babbitt et al. (1985) for the washing, dewatering and refining of minced flesh from Alaska pollock (Table 23). Although yields were similar and provide a reference, processing was not comparable. The minced flesh from Alaska pollock was derived from fresh fish and washed 3 times in a 2:1 water and minced flesh relationship followed by dewatering and refining using similar equipment. A yield of 19% of washed refined flesh was obtained from Alaska pollock based on round weight which represented a 51.05% recovery of solids contained in the unwashed, minced flesh. Minced shad flesh was derived from frozen fish and was washed only once in a 5:1 water to minced flesh relationship. Of the solids contained in unwashed minced flesh, 51.37% was recovered.

Table 22. Effect of washing on the proximate composition of minced Alaska pollock.[1]

Process Component	Solids Weight (kg)	Kg		
		Protein	Lipid	Ash
Deboned Minced	17.12	15.53	0.58	1.02
Washed Dewatered Refined	8.74	8.45	0.25	0.44
% Reduction	(48.95)	(45.61)	(56.35)	(95.67)

[1] From Babbitt et al. (1985).

Washing significantly ($P \leq .05$) reduced gel hardness and springiness (Table 23). Cohesiveness was reduced by washing, but not in a significant ($P > .05$) manner. Washing should have enhanced gel strength by removing soluble proteins that interfered with the formation of the gel matrix. The protein and moisture content of gels prepared from unwashed and washed flesh were nearly identical (Table 20) and would not explain the difference observed. Seki et al. (1980) found a marked decrease in the solubility of sarcoplasmic proteins from sardine after only 1 day of ice storage. Frozen storage of shad should have reduced the solubility even more, rendering washing less efficient. This would explain a lack of enhancement of gel strength with washing, but not a decrease. Denaturation of fish proteins through low pH or elevated temperature during washing, dewatering and refining could have reduced gel strength. However, the pH of the raw sols prepared from unwashed (pH 6.24)

and washed (6.28) minced flesh (Table 23) were nearly identical and the temperature of the minced flesh through processing was never allowed to exceed 10^0 C. The lower strength of gels prepared from washed over unwashed flesh may have developed from the short frozen storage period (8 days) that gels were subjected to before texture was evaluated. Washing may have increased the susceptibility of gel proteins to deterioration by freezing and thawing.

Sensory evaluation did not determine a significant ($P>.05$) difference between the flavor, color, texture or overall desirability of gels prepared from sols containing washed and unwashed minced flesh (Table 23). The overall level of acceptance of the gel product was not high. The significant ($P\geq.001$ and .005) difference in the manner in which panelists scored the product for the various acceptance factors indicated a wide variation of acceptance. Inspection of individual panelist's scores reveal a group that distinctly disliked the product and a group that considered it very acceptable.

Table 23. Effect of washing on gel strength and sensory preference.[1]

Test	Treatment: Unwashed[2]	Treatment: Washed[3]
Instron		
Hardness	67.31	53.63
Cohesiveness	36.30	30.98
Springiness	65.56	58.17
Sensory		
Texture	4.95	5.21
Color	5.02	5.31
Flavor	5.81	5.53
Desirability	5.25	5.27

Analysis of variance

Instron

Source	D.F.	F-value: Hardness	Cohesiveness	Springiness
Treatment	1	8.48[5]	4.52[4]	7.83[5]

Sensory

Source	D.F.	F-value[9]: Texture	Color	Flavor	Overall Desire.
Panelist (P)	35	6.32[8]	8.70[8]	2.70[7]	4.75[8]
Treatment (T)	1	1.59[4]	3.61[4]	1.91[4]	0.01[4]
P x T	35	2.01[7]	1.31[8]	1.54[5]	1.65[6]

[1] All treatments heated at 40^0 C for 30 min then 90^0 C for 20 min then smoked

[2] Gel protein 14.86%, moisture of cooked gel before smoking 73.22%, after smoking 68.83%, pH raw sol 6.24

[3] Gel protein 14.82%, moisture of cooked gel before smoking 73.13%, after smoking 68.53%, pH raw sol 6.28

[4] NS $P>.05$; [5] $P\leq.05$; [6] $P\leq.025$; [7] $P\leq.005$; [8] $P\leq.001$

[9] F-values for the panelist effect and the sucrose effect were determined using the MS for P x S as the error term

SUMMARY AND CONCLUSIONS

Minced flesh, either unwashed or washed, from round American shad frozen (-18^0 C) for up to 10 months was demonstrated to retain sufficient functional quality to form hard, elastic gels. The addition of 0.5% phosphate and 0.5% or 1.0% dried egg white enhanced gel strength. Phosphate elevated sol pH, fish protein solubility and produced a stronger gel matrix. Low concentrations of dried egg white reinforced gel strength through improved sulfhydryl-disulfide exchange during heat setting. Two stage heat setting (a 40^0 C heat treatment before heating at 90^0 C) improved gel strength over a one stage (90^0 C) treatment on a consistent basis both in the presence of additives that enhanced as well as reduced gel strength characteristics. The low temperature stage of the two stage heating regime enhanced protein unfolding and allowed time for a more ordered gel matrix to form.

Adjustment of sol pH to more basic conditions (0.1% Na_2CO_3, pH 6.53 to 6.83; 0.2% Na_2CO_3, pH 6.53 to 7.16) using sodium carbonate to enhance protein solubilization did not materially improve gel strength. Gel cohesiveness was only slightly improved and hardness and springiness were not altered. Addition of egg white and potato starch in quantities >1.0% reduced gel strength. The reinforcing effects observed for low levels of dried egg white were diminished through dilution of

fish protein in the sols when concentrations were greater than 1.%. The well documented reinforcing effect of potato starch was not observed in combination with shad flesh. The absence of reinforcing was likely a function of high lipid content (up to 7.60%) of flesh which retarded starch gelatinization during heat setting.

The cryoprotectants, sorbitol and sucrose, reduced gel strength in a concentration dependent manner. Diminished gel strength was a function of lower fish protein content in the sols. Gel hardness was reduced in a linear manner as fish protein was replaced with sorbitol ($r = .976$) or sucrose ($r = .965$) in sol formulations. Cohesiveness was correlated ($r = .942$) with reduced sol protein contents only when sorbitol was added to sol formulations. Gel springiness was not altered by additions of sorbitol and sucrose.

Incorporation of sucrose into formulations reduced the sensory preference for the texture, flavor, appearance and overall desirability of heat set gels. Analysis of covariance of sensory texture preference scores and physical measurements of gel texture revealed a strong correlation with hardness ($P = .0004$), but poor correlation with cohesiveness ($P = .7594$) and springiness ($P = .6675$). Within the range of sucrose levels evaluated, the harder gels were preferred.

Washing was evaluated for improvement of gel strength and sensory preference. Round shad yielded 65.06% planks, 41.20% minced flesh and 40.10% refined flesh. A single exchange wash

followed by dewatering yielded 23.02% flesh based upon round weight which was reduced to 20.68% by refining. The yield through refining was 97.33 and 89.83%, respectively, for unwashed and washed flesh. Processing minced flesh into washed and refined flesh recovered 51.37% of total solids. The protein and lipid content of the flesh was not altered by washing, but ash content was reduced. Washing significantly reduced gel hardness and springiness, but not cohesiveness. This was an unexpected result, since the improvement in gel strength by washing is well documented. Sensory preference for flavor, color, texture and overall desirability was not improved by washing. The heat set product was not highly preferred by panelists. Mean overall desirability scores for gels prepared from unwashed flesh of 5.25 and 5.27 for washed were only slightly above a neutral preference (5.0= neither like nor dislike). Inspection of individual scores revealed a group of panelists that distinctly did not prefer the product and a group that indicated a high preference for the product.

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