AN ABSTRACT OF THE THESIS OF

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Title: EFFECT OF CONDENSED PHOSPHATES AND STEAM PRECOOKING TIME ON THE YIELD AND QUALITY OF CANNED SHRIMP (PANDALUS JORDANI) MEAT

Abstract approved: David L. Crawford

Factors influencing the drained meat yield of canned Pacific shrimp through processing were investigated. The post-catch age, precooking time and application of polyphosphate to round shrimp were evaluated.

The moisture content and yield (% wet and dry wt.) of both precooked and drained canned meat was reduced as the steam (101°C) cooking time of round shrimp was extended according to well defined power functions ($P \leq .001$). The yield of drained meat for an example lot of shrimp was reduced by 0.87 wet weight and 0.21 dry weight percentage points as cooking time was extended from 40 to 160 sec; equivalent to 24.6 307X113 cans (4.5 oz drained wt.) per 1000 lb round shrimp. Extended precooking of shrimp to physically allow the introduction of the fill weight necessary to meet the drained meat standard of identity (4.5 oz) reduced yield potential. The linear relationship of drained meat weight (170 gm fill wt.) to precooking time showed that precooking time could be reduced from 127.8 to 17.2 sec. if the drained weight standard of identity were reduced from 4.5 to 4.0 oz. The power function relating precooking time to can (307X113; 4.5 oz drained weight) yield per 1000 lb of shrimp predicted an increased yield of 77.6 per 1000 lb of round shrimp for this reduced precooking time.

The application of polyphosphate (a commercial mixture of sodium tripoly- and hexametaphosphate) prior to processing interacted with muscle proteins during pretreatment or during early stages of steam precooking stabilizing heat labile proteins toward solubilization. An interaction with the collagen-like protein complement of connective tissue, swelling and stabilizing surface proteins was proposed. This sealed surface retarded the loss of soluble interior proteins through steam precooking.

The regression of drained meat yield (wet and dry wt.) on pretreatment polyphosphate concentration followed a power function ($P \leq .001$) for each lot of shrimp. Added meat polyphosphate was related in a linear manner to the increment of yield increase over controls. Polyphosphate added to steam cooked meat did not affect the yield of drained meat through thermal processing. Time and temperature dependent proteolytic degradation increased the effectiveness of pretreatments with regard to the increment of yield increase over controls and the quantity of added polyphosphate required to stabilize an increment of added yield. A decreased efficiency of polyphosphate for larger shrimp dependent on a decrease in the ratio of unformed and formed collagen with advancing shrimp age was proposed.

Polyphosphate pretreatment increased the water-holding capacity of shrimp meat through steam precooking and subsequent thermal processing. Elevated drained meat moisture contents were not quantitatively related to polyphosphate added to meat, but to the increment of yield increase through steam precooking afforded by a pretreatment. The degraded nature of protein retained and/or the physico-chemical effectiveness of polyphosphate with this stabilized protein increment was proposed as the cause of increased moisture-holding capacity.

Pretreatment with 6% polyphosphate produced increments of drained meat yield (wet wt.) increase over controls ranging from 2.8 to 4.7 percentage points; equivalent to 99.6 to 166.7 cans (307X113; 4.5 oz. drained meat wt.) per 1000 lb of round shrimp. Yield increases of 1.68 to 2.71 percentage points were accomplished with a 1.5% pretreatment. These increments of yield increase were accomplished with 224.6 to 256.3 and 108.1 to 109.1 mg added polyphosphate (as P_2O_5) per 100 gm of drained meat, respectively. The drained meat yield advantage over controls for a polyphosphate pretreatment was further improved by a potential reduction in precooking time required to meet the drained meat weight standard of identity.

The sensory characteristics of the drained meat were not significantly ($P \leq .05$) affected by polyphosphate pretreatments of up to 6% for 10 min. While not significant ($P \geq .05$), the texture and juiceness of canned meat from polyphosphate treated shrimp were preferred.

EFFECT OF CONDENSED PHOSPHATE AND STEAM PRECOOKING TIME ON THE YIELD AND QUALITY OF CANNED SHRIMP (*PANDALUS JORDANI*) MEAT

by

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TABLE OF CONTENTS

Table of Contents, continued:

LIST OF FIGURES

LIST OF TABLES

List of Tables, continued:

EFFECT OF CONDENSED PHOSPHATE AND STEAM PRECOOKING TIME ON THE YIELD AND QUALITY OF CANNED SHRIMP (*PANDALUS JORDANI*) MEAT

INTRODUCTION

Shrimp is one of the most important seafoods landed by fishermen in the United States. Since 1952, it has been the most valuable marine resource in the U.S. replacing salmon and tuna, one of which has occupied this position for many years. In recent years, the shrimp fishery has expanded considerably in the Pacific Northwest under the impetus of increased markets and with the innovation of an efficient shrimp peeling machine which allows the small variety of shrimp (*Pandalus jordani*) of this area to be processed without excessive labor costs.

Shrimp in the Pacific Northwest are mostly sold canned or in the cooked frozen state. The usual processing of shrimp products involves conditions that bring about substantial reduction in yield and quality. Raw round shrimp for instance are commonly held in ice for at least two days post-catch to facilitate machine-peeling. Shrimp are sometimes caught at far distances from the processing plants that necessitate storage during transportation in ice or refrigerated sea water (RSW) for up to four days. During subsequent precooking prior to peeling, coupled with thermal processing of the precooked meat in the case of canned shrimp, losses in juice and soluble constituents are encountered which eventually result in reduced yield and quality of the processed shrimp. Collins (1961) showed a considerable loss in yield as a function of holding time in either ice or RSW especially for canned shrimp.

Loss of fluid (drip) from muscle is of importance from several aspects. It constitutes a significant economic loss to the processor in terms of reduced yield. Severe fluid losses result in a drier and tougher cooked product and the nutritive value of the meat is decreased since proteins and minerals are lost with the drip. Flavor characteristics are also lost. From economic and quality standpoints, such losses should be minimized. The loss of fluid from meat and seafood products during processing is a widespread problem in the food industry, and the use of additives to counteract it is now a common practice in many countries. The most common additives used are the sodium salts of polyphosphates, used as mixtures of the various polyphosphates, single salts, or single salts plus sodium chloride (Sutton, 1969).

Much information has been compiled on the application of condensed phosphates to seafoods to improve moisture retention and texture of the processed meat. But such information on shrimp are limited and none has been provided for canned shrimp. The shrimp processing industry also lacks useful information regarding the precooking time and fill weight combination necessary to ensure the industrially established drained weight of 4.5 oz (127.6 gm).

This investigation was designed to evaluate the effect of round shrimp steam precooking time and polyphosphate pretreatment on the yield and quality of canned shrimp. Specifically, the interrelationship of precooking time with can fill weight; the interaction of polyphosphate pretreatment and precooking time; phosphate pretreatment concentration and the relationship of round shrimp age (ice storage) on the quality and yield of thermal processed drained meat were investigated.

LITERATURE REVIEW

General Morphology of Shrimp

The shrimp body is enclosed in a fairly thick shell whose main constituent is chitin (polyacetyl-glucosamine). The shell, also called the cuticle or integument, not only protects the body against various mechanical injuries but is also a supporting exoskeleton. The exoskeleton of both the body as a whole and of its appendages consists of separate segments.

The shrimp body is divided into two distinct sections; the anterior cephalothorax consists of the head and thorax which are covered by a common shield, the carapace. The sides of the carapace are called the pleura. The carapace protects and supports the most important viscera. In many shrimp, the dorsal side of the carapace bears a carina which either extends along the whole length of the carapace or is delimitated by the anterior part, merging with the rostrum.

There are two pairs of antennae which are biramous. The epistoma and the mouth appendages are situated below the antennae ,in the anteroventral section of the cephalothorax. All these appendages are modified legs (this also applies to the antennae). Shrimp have the following mouth appendages: one pair of mandibles, two pairs of maxillae and three pairs of maxillipeds. Five pairs of walking legs

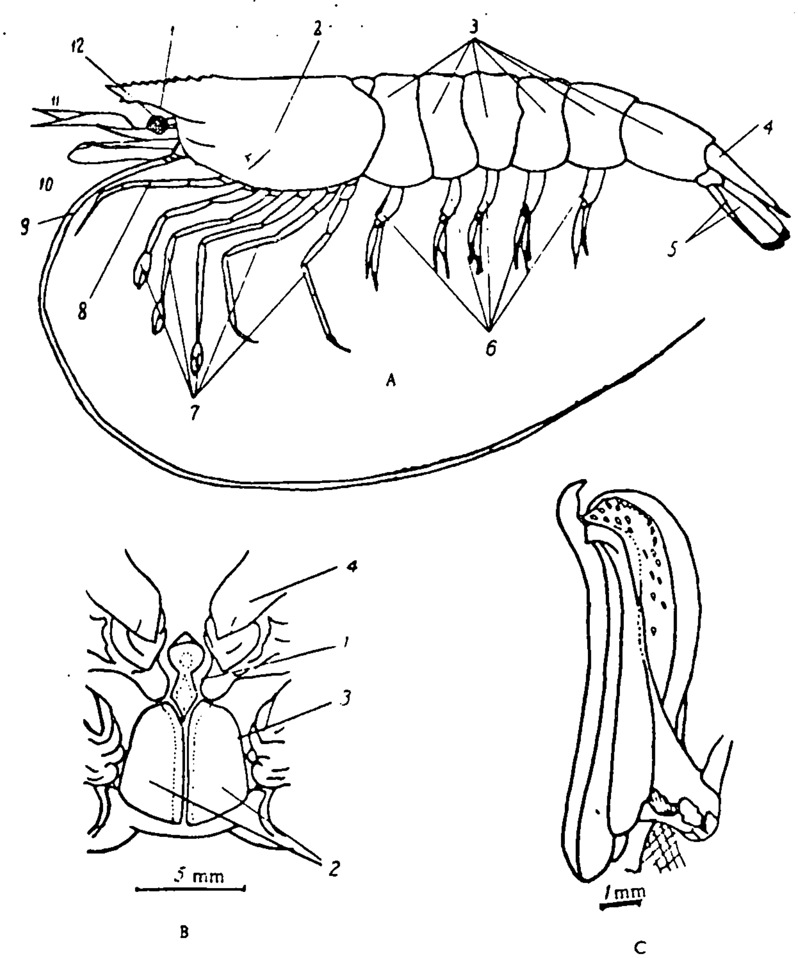

Figure 1. Morphological characteristics of the shrimp body.

A. Diagram of the external structure: 1 – rostrum; 2 – carapace; 3 – abdomen; 4 – telson; 5 – uropods; 6 – pleopods; 7 – walking legs; 8 – third maxilliped; 9 – flagellum of antennae; 10 – scaphocerite; 11 – flagella of antennules; 12 – eye.

B. Telicum of female: 1 – middle process; 2 – lateral plates; 3 – base of 5th pair of legs; 4 – base of 4th pair of legs.

C. Petasma of male.

are situated after maxillipeds 3 on the ventral side of the cephalothorax. The walking legs usually consist of seven segments. The females of the family Penacidae have between the last pair of walking legs a peculiar copulatory structure called the telicum.

The ventral side of the body (the abdomen) is divided into seven segments. The first five bear lateral overhanging appendages, the pleura, and on each segment, one pair of biramous extremities, the pleopods. Their structure is identical. The inner branches of the first two pairs of pleopods are in all shrimp modified into copulatory appendages. In males of the family penaeidae the copulatory appendages of the first pair of pleopods are fused into an unpaired copulatory organ, the petasma. The sixth abdominal segment is for the most part longer than the rest, more strongly compressed laterally, without pleura, but with a pair of large biramous legs (uropods) that form a fan-shaped tail fin when stretched. The seventh abdominal segment (telson) is an elongate triangle, often ending in a spine. Along the sides it may bear several pairs of spines or spinules. It does not have legs. The anus opens on the ventral surface of the telson. The hindgut passes through the whole abdomen to the telso. In addition to the hindgut, the abdomen contains the posterior horns of the ovaries or testes. All remaining area of the abdomen is filled with a powerful musculature comprising 40-45% of the total weight (Burukovskii and Bulanenkov, 1969).

Post-Catch Quality Changes in Shrimp

Deterioration of shrimp quality is generally considered to result from the combined action of enzymes from either the tissues or contaminating microorganisms, chemical reactions and physical handling (Fieger and Frilous, 1954; Fieger, Bailey, and Novax, 1958; Flick and Lovell, 1972).

Organoleptic studies made by Fieger and Friloux (1954) with ice-stored fresh headless shrimp showed that characteristic sweet flavor was gradually lost during the first 7 days of ice storage. This was followed by a period of 7 days during which they were tasteless and beyond 14 days storage, spoilage occurred with the development of off-flavor. They postulated that loss of quality during the early period of storage was caused by autolysis and with longer storage, spoilage occurred mainly through bacterial action. However, certain palatability attributes such as texture and juiciness have been observed to improve during the first three days of ice storage probably due to the autolytic changes (Flores and Crawford, 1973).

Bethea and Ambrose (1962) found that shrimp with pH from 7.24 to 7.8 were of good quality and shrimp with pH levels of 8.0 to 8.2 possessed fair to borderline quality with spoilage indicated by a pH above 8.2. Flores and Crawford (1973) observed a progressive increase in pH from 7.6 to 8.8 for intact Pacific shrimp during 8 days ice storage and suggested that seasonal variations and catch procedures might greatly affect the pH of shrimp immediately after removal from water.

Flick and Lovell (1972) suggested that flavor deterioration in ice-stored shrimp could be related to the production of inosine and hypoxanthine, plus the concurrent loss of inosine monophosphate. Unpublished results of work done with Pacific shrimp at the Seafood Laboratory of Oregon State University in Astoria, have shown that the loss of inosine monophosphate correlates very well with the quality of shrimp (Babbitt, 1975). Argaiz (1976) observed that the decomposition of trimethylamine oxide and the formation of trimethylamine, dimethylamine and formaldehyde in iced whole shrimp and in raw and cooked meat paralleled a corresponding steady decrease in organoleptic quality. Madero (1978) found that degradation of frozen cooked meat quality to be related to round shrimp age. Levels of trimethylamine oxide, trimethylamine, inosine monophosphate and hypoxanthine in cooked meat reflected the age of round shrimp. Differences in levels was related to chemical decomposition, drip loss and/or bacterial outgrowth (Madero, 1978).

The continuous washing action of melting ice causes a leaching of the native non-protein nitrogen formed through enzymatic hydrolysis of protein upon extended ice-storage of whole shrimp (Collins, Seagran, and Iverson, 1960).

Interaction of Phosphates With Proteins

The effect of the addition of condensed phosphates on meat and meat products has been reported by many investigators. Several theories have been advanced to explain the mechanisms by which meat is affected by phosphates alone or in combination with common salt (NaCl). Water retention, water binding, water holding capacity (WHC), cured meat volume, pH and meat swelling have been studied to demonstrate the effects of this additive. It is not the intention here to catalogue all these studies; only those relating to WHC/reduction of drip loss (both very important in seafood processing) have been selected for review.

(a) Mechanisms

Meat proteins are responsible for the binding of water in meat. Lean meat contains about 75% water. As little as 4-5% of the total water is bound as true hydration water which is tightly associated with the muscle proteins. The rest constitutes "free" water. The amount of hydration water is influenced little by the structure and electrical charges of the muscle proteins and by added salts. The strong changes in WHC occurring as a result of addition of salts such as NaCl or polyphosphates are determined by the extent to which the physically and chemically "free" water is immobilized within the microstructure of the tissue. The structural proteins are responsible for both the binding of hydration water and for immobilization of "free" water in meat. The spartial molecular arrangement of the muscle filaments also exerts a strong influence. Tightening the network of proteins as occurs at the isoelectric point of muscle (pH 5) decreases the amount of immobilized water while loosening of the protein structure that results on adding NaCl or condensed phosphates has the opposite effect (Hamm, 1971).

Hamm and Grau (1958) claimed that the effect of polyphosphates on WHC of meat is accounted for by their ability to remove the metal ions from salt bridges in muscle structural protein molecules. Muscle contains by nature the bivalent cations calcium, magnesium and zinc, a portion of which are bound by the myofibrillar proteins. It has been shown by numerous investigators that bivalent cations participate in the cross-linking between actin and myosin in the living muscle and it is probable that the same is the case for actomyosin in the state of vigor (Hamm, 1971). The elimination of metal ions by polyphosphates was proposed to be responsible for the increase in WHC of meat. This effect, the investigators claim, occur only at pH values greater than the isoelectric point.

The above theory proposed by Hamm and co-worker is supported by the observation of Bozler (1955) that a part of protein-bound muscle magnesium is extracted by polyphosphate containing solution and protein-bound calcium was not extracted. Baldwin and deMan (1968) found that added polyphosphates remove calcium, but not magnesium from their bound state with the insoluble beef muscle protein and Inklaar (1967) could not demonstrate an extraction of bound calcium or magnesium from meat with polyphosphate solutions. This finding prompted Hamm (1970) to suggest that reaction of phosphate anions with protein-bound calcium or magnesium in muscle may not necessarily result in an increase of extractability of these ions as a result of cleavage of the protein-cation bonds; it could be that only a single bond between the bivalent cation and protein is broken by binding of the phosphate anion, the other valence of the cation remaining connected with protein, as shown below:

$$\text{Protein-Mg}^{2+}\text{——Protein} + \text{PP} \longrightarrow \text{Protein—Mg——PP} + \text{Protein.}$$

In this manner, he claimed the crosslinking effect of the cation could be eliminated; the final result being an increase of WHC. The theory is further supported by other findings, e.g. Morita and Tonomura (1960) who suggested the formation of a chelate complex formed by myosin B (natural actomyosin) and pyrophosphate (PP) by means of bivalent cation.

Hamm's theory was however unacceptable to other workers on the ground that strong chelators such as EDTA and oxalate which show higher values for stability constants than those of polyphosphate do not exhibit a favorable effect on the water holding property of meat (Helendoorn, 1962; Sherman, 1961). Another major departure from Hamm's theory is the finding by Yasui, Sakanishi and Hashimoto (1964a, b) that PP and tripolyphosphate (TP) exert only a non-specific ionic strength effect on salt-free myofibrils and that only polymetaphosphate should specifically react with protein-bound bivalent cations or positively charged groups on the protein molecules, with the consequence that repulsion between the negative sites increase WHC.

It is possible that in addition to the bonding via protein-bound bivalent cations, phosphate anions may be directly bound to the positively charged groups of myofibrillar proteins, as is the case with other proteins (Lyons and Siebenthal, 1966). As a matter of principle, it is possible that the increase in WHC of meat caused by polyphosphates added to rigor or post-rigor muscle is due to the dissociation of actomyosin to actin and myosin (Weber and Portzehl, 1952). Polyphosphates anions are probably bound at the same site on the myosin molecule which is involved in the binding of actin (Kieley and Martonosi, 1968).

Regarding the question of whether added polyphosphates solubilize myofibrillar proteins, Hamm (1970) stated that the hydrating effect of PP or TP is not necessarily due to a partial solubilization of actomyosin. He claimed that at higher ionic strengths, such a dissolution may occur and improve WHC particularly of cooked meats by formation of a fine network of coagulated proteins.

In the presence of NaCl, the increase of WHC caused by PP or TP is remarkably stronger. This observation is shared by many workers but the hypothesis presented to explain the mechanism involved is as contradictory as described earlier in the absence of NaCl. Some authors were of the opinion that the decisive factor is the relatively high ionic strength brought about by the addition of polyphosphates (Bendall, 1954; Swift and Ellis, 1956; Poshyachinda and Deatherage, 1957). Hellendoorn (1962), however, showed that polyphosphates do exert specific effects on salted meat. Hamm (1960) suggested that the effect of polyphosphates on WHC of salt meat is through the elimination or breaking of cation-protein interactions. The evidence against this hypothesis is that both oxalate and EDTA form strong complexes with Ca^{2+} or Mg^{2+} but a comparison of the effect of mixtures of oxalate or EDTA with NaCl did not reveal any specific hydrating effect of these ions (Hellendoorn, 1962).

What seems to be a plausible explanation was offered by Yasui et al. (1964b) who claimed that the formation of univalent metal myosinate caused by the presence of NaCl increases the affinity of myosin B (natural actomyosin) for PP and TP. The reactivity of PP and TP with myosin through the formation of bivalent cation - phosphate complexes is remarkably increased. Highly polymerized polyphosphates such as hexametaphosphate are inhibited by the presence of high salt concentration and divalent cations. According to Yasui and coworkers, actomyosin can be dissociated only by PP and that TP has to be dephosphorylated to PP by the tripolyphosphatese activity of myosin B before it can dissociate actomyosin. The role of hexametaphosphate (HP) was confined to merely increasing the ionic strength like a normal salt unless TP or PP are produced from its spontaneous reversion or other type of decomposition. They concluded that addition of TP cannot immediately increase the WHC of meat until after a certain period when TP would have been broken down enzymatically. It can be observed in practice, however, that after addition of TP, the WHC of meat is instantly increased before any breakdown of TP could have occurred indicating that the explanation offered by Yasui and associates may not be absolutely acceptable.

From the foregoing, it can be seen that polyphosphate addition to meat will result in increase of WHC with or without NaCl, but much work is still necessary to elucidate the mechanism involved.

(b) Effects of Phosphates on Seafoods

Much information has been compiled concerning the application of phosphate to seafood to improve moisture retention and texture of the processed meat. Love and Abel (1966) reported on the effect of the polyphosphate in reducing drip loss and preventing dehydration of the fish muscle. Preslaughter injection of hexametaphosphate into lingcod was found by Buttkus and Tarr (1962) to be effective in reducing drip. Mahon (1962); Tanikawa, Akiba and Shitamori (1963) came to similar conclusions with dipped fresh haddock and frozen cod. MacCallum, Shieh and Chalker (1964) found that TPP was effective in reducing thaw-drip only when the fish were treated between freezings and not before freezing as done by Dyer, Brokerhoff, Hoyle, and Frazer (1964). Yields were also improved. Further work (Chalker, MacCallum and Idler, 1965) compared different methods of measuring thaw-drip, showing large variations between samples especially the TPP-treated ones. The latter gave about 23% less drip on the average in fish frozen 1-2 weeks. Boyd and Southcott (1965) discovered that TPP is effective in reducing thaw-drip in some species of fish such as Dover sole, Pacific cod, halibut and red snapper but not effective in some others, e.g. chinook salmon.

Spinelli and Weig (1968) designed and successfully tested a spray machine for applying polyphosphate solutions to minimize drip loss. It was found to work effectively on fresh fillets and show promise of equal effectiveness on frozen fillets. Spinelli, Petroy and Miyauchi (1968) showed that the formation of drip in irradicated Pacific ocean perch, petrale and English sole is effectively retarded when they are pretreated with more than 5% sodium tripolyphosphate in the dipping solution. The original appearance of fish was largely retained; the texture less altered and the flavor and odor unaffected. Sutton (1969) reported that polyphosphate treatments of cod muscle under suitable conditions can improve the water retention and quality of cod fillets. Addition of NaCl did not produce any improvement over phosphate alone. Using paired fillets, little difference in thaw-drip of TPP treated fillets as compared to undipped controls was found by Dyer et al. (1964). The yield of the frozen and thawed product over the control, however, was increased.

Love and Abel (1966) and Spinelli and Weig (1968) agreed that when fish fillets are treated with phosphates the surface layer of protein is modified so that its ability to hold water is greatly increased. The surface layer of modified proteins prevents the escape of fluid from the interior of the fillet with the result that drip formation is prevented.

Mathen (1968) showed that a neutral solution of sodium tripolyphosphate (STP) prevented drip loss and improved organoleptic quality of fresh frozen prawns without adversely affecting the biochemical characteristics. Tripolyphosphate was found by Hamm and Grau (1958) to be the most effective phosphate in reducing drip from meat. Neutral solutions of tripolyphosphate improved thawed and cooked meat yields, enhanced the retention of meat yield during frozen storage for peeled and deveined prawns and protected proteins from storage mediated denaturation (Mathen, 1970). Mahon, Schlamb and Brotsky

(1970) stated that the organoleptic quality of shrimp especially tenderness and juiciness is vastly improved by treatment with polyphosphate with and without salt (NaCl) after peeling prior to freezing and cooking.

EXPERIMENTAL

Materials

The raw round shrimp used in this investigation was obtained during the period August 22 to September 26, 1978, from commercial shrimp processing plants in Astoria, Oregon. Lots of shrimp differing in initial quality, age and size were obtained depending on experimental requirements. The shrimp were reiced at the laboratory (when not used immediately) and stored at 2°C.

The polyphosphate used was a commercial food grade mixture containing sodium tripolyphosphate and sodium hexametaphosphate (Brifisol D510; American Hoechst Corporation, Somerville, New Jersey). This commercial mixture is referred to as polyphosphate in subsequent discussion.

Processing Procedure

Deiced round shrimp were pretreated for 10 min in 1.5 x their weight of polyphosphate solution or water at ambient tap water temperature with occasional agitation. The shrimp were drained and steam precooked (101°C surface temperature) for designated time periods just prior to peeling with a laboratory scale mechanical peeler at a rate of 500 gm/min. Shell remaining on precooked shrimp was removed by hand. The weight of precooked meat was recorded.

Designated amounts of cleaned precooked meat were filled into 307 x 113 cans and 40 ml of 6.6% NaCl solution containing 0.75% citric acid was added. The cans were vacuum sealed (using appropriately coded lids) and thermally processed for 25 min at 242°F (116.5°C). The cans were rapidly cooled in water, dried and held at ambient room temperature prior to evaluation.

Processing Investigations

Relationship of Precooking Time and Fill Weight to Drained Meat Yield

A lot of 2 day post-catch shrimp was divided into 8 portions and precooked for 40 (12 kg), 60 (5 kg), 80 (14 kg), 100 (5 kg), 120 (15 kg), 160 (15 kg), 200 (6 kg) and 240 (16 kg) sec.

Fill weights of 150, 160 and 170 gm of clean meat per can were employed for each of the samples precooked for 40 - 80 - 120 - 160 and 240 sec., and 170 gm only for samples precooked for 60 - 100 and 200 sec.

Interaction of Precooking Time and Polyphosphate Pretreatment on Drained Meat Yield

A lot of 3 day post-catch shrimp was divided into 8 portions. Four portions were pretreated in water and four in a 0.6% polyphosphate solution. Samples of control (water treated) and polyphosphate pretreated shrimp were precooked for 40 (8 kg), 80 (9 kg), 140 (10 kg), and 240 (12 kg) sec. Cans were filled with 160 gm of cleaned meat.

Relationship of Shrimp Age and Polyphosphate Pretreatment to Drained Meat Yield

Shrimp stored in ice (2°C) for 1, 3 and 6 days were pretreated in water and in 1% polyphosphate solution and precooked for 90 sec. One and three day post-catch treatment samples were 16 and 12 kg lots, respectively, while 12 and 14 kg samples of 6 day post-catch shrimp were used for polyphosphate and control treatments, respectively. Cans were filled with 170 gm of clean precooked meat.

Effect of Polyphosphate Pretreatment Concentration on Drained Meat Yield

Two different lots of round shrimp aged 2 and 3 days post-catch in ice were each divided into 5-16 kg portions. Portions from each lot were pretreated with 0, 0.5, 1.5, 3 and 6% polyphosphate solution and precooked 90 sec prior to peeling. Cans were filled with 170 gm of cleaned precooked meat from each treatment.

Analysis and Evaluation Procedures

Drained Meat Weight

An 8-mesh sieve was placed on a clean 8.75-inch funnel set up in such a manner that liquor was accumulated in a 200 ml graduated cylinder. Five replicate cans were opened and the contents in each spread evenly over the meshes of the sieve and allowed to drain for 2 min. The drained meat was carefully transferred into a tared beaker and the weight recorded.

Precooked and Drained Meat Yields

The yield (% wet and dry wt.) of the precooked meat was determined based on round shrimp weight [weight of cleaned meat (wet and dry wt.)/round shrimp weight]. Drained meat yield (% wet and dry wt.) was determined based on the appropriate round shrimp or precooked meat weights.

Sample Preparation for Analysis

Treatment samples of precooked and canned drained meat were homogenized into a smooth paste utilizing a laboratory blender. Precooked meat samples that were frozen prior to analysis were thawed over-night at refrigerator temperature and the entire contents of the container including drip was utilized for sample preparation. The homogenized paste was used for the determination of moisture and total phosphorus content.

Moisture Determination

Moisture content of both cooked and drained meat was determined according to the method described by AOAC (AOAC, 1970). Homogenized samples (10 gm) were weighed into aluminum pans, dried in an oven at 105°C for 16-24 hrs and cooled in a dessicator. Weight loss was reported as percent moisture content. Moisture was determined in triplicate for the precooked meat and in triplicate for each of the replicate cans of the drained meat.

Phosphorus Analysis

Total phosphorus content in drained meat was determined by utilizing canned shrimp obtained from the investigation of the effect of polyphosphate pretreatment concentration on drained meat yield. Two replicate cans were randomly selected per treatment and the drained meat separated as previously described. About 5 gm of the homogenized sample was weighed into a 30 ml crucible and dried 16-24 hrs in an oven at 105°C. The dried samples were charred slowly with a flame and ashed at 550°C overnight (8 hrs.). The ash was transferred into a 25 ml volumetric flask by washing thrice; first with $\geq$ 1 ml 6 N HCl and then with $\geq$ ml of distilled water. The flask was diluted to volume just prior to analysis. Total phosphorus was determined according to procedures described by Bartlett (1959)

(1959). Phosphorus content was reported as P_2O_5 in mg/100 g of drained shrimp meat (wet and dry wt.).

Flavor Panel Evaluation

Drained meat samples were assessed by a panel comprised of staff members of the Department of Food Science and Technology, in Corvallis, Oregon. Samples were evaluated for odor, texture, juiciness, flavor and overall desirability using a 9-point hedonic scale ranging from 9, "extremely desirable," to 1, "extremely undesirable." Some evaluations consisted of duplicate 10 judgment evaluations of the same sample using identical judges, but at different times. Others were evaluated once by 10 or 25 judges. The significance of differences among mean scores was determined using analysis of variance procedures (Snedecor and Cochran, 1967).

RESULTS AND DISCUSSION

Relationship of Precooking Time and Fill Weight to Yield and Quality of Canned Shrimp

Moisture and soluble solids were lost from raw round Pacific shrimp during steam precooking (101°C) (Table 1). The moisture and yields (% wet and dry weight) of precooked meat were reduced in a manner following a power regression function (Table 2; Figures 2 and 3). The moisture content reduction of 1.8 percentage points upon increasing precooking time from 40 sec. to 160 sec. was accompanied by a 7.1 wet weight and 0.9 dry weight percentage point reduction in yield of precooked meat.

The yields of drained meat after thermal processing were directly related to yield losses in precooked meat associated with steam precooking (Table 3). The reduction of drained meat yield (% wet and dry weight) with increasing precooking time similarly followed a power regression function (Table 4; Figure 4). Increasing the precooking time from 40 sec to 160 sec resulted in a loss of about 25 cans per 1000 lb of round shrimp processed with a 170 gm fill weight (Table 3). This reduction can be attributed mainly to the losses that occurred during steam precooking of the round shrimp. Drained meat moisture content was not affected by the higher moisture content of precooked meat with shorter precooking times (Table 5).

TABLE 1. Yield and Moisture Content of Meat Derived from Round Shrimp[1] Precooked[2] for Varying Time Periods.

Precooking time (sec)	Weight		Precooked meat moisture (%)	Yield (%)[3]	
	Round shrimp (kg)	Precooked shrimp (kg)		Wet wt.	Dry wt.
40	12.0	4326.5	80.88	36.05	6.89
60	5.0	1731.8	80.78	34.64	6.66
80	14.0	4414.5	79.86	31.53	6.35
100	5.0	1555.5	79.44	31.11	6.40
120	15.0	4416.0	79.72	29.44	5.97
160	15.0	4348.7	79.04	28.99	6.02
200	6.0	1649.6	78.90	27.49	5.80
240	16.0	4278.1	78.76	26.74	5.71

[1] In ice two days post-catch

[2] Steam; 101°C.

[3] Based upon round shrimp weight

TABLE 2. Regression of Precooked Meat Yield[1] and Moisture Content on Steam (101°C) Precooking Time.

Regression	Equation	Correlation Coefficient
Yield (% wet wt.)on time (sec):	$y = 67.907X^{-.170}$	-.9893[2]
Yield (% dry wt.)on time (sec):	$y = 10.237X^{-.107}$	-.9749[2]
Moisture (%) on time (sec):	$y = 85.865X^{-.016}$	-.9627[2]

[1] Based upon round shrimp weight.

[2] Sig. $P \leq .001$; n = 8.

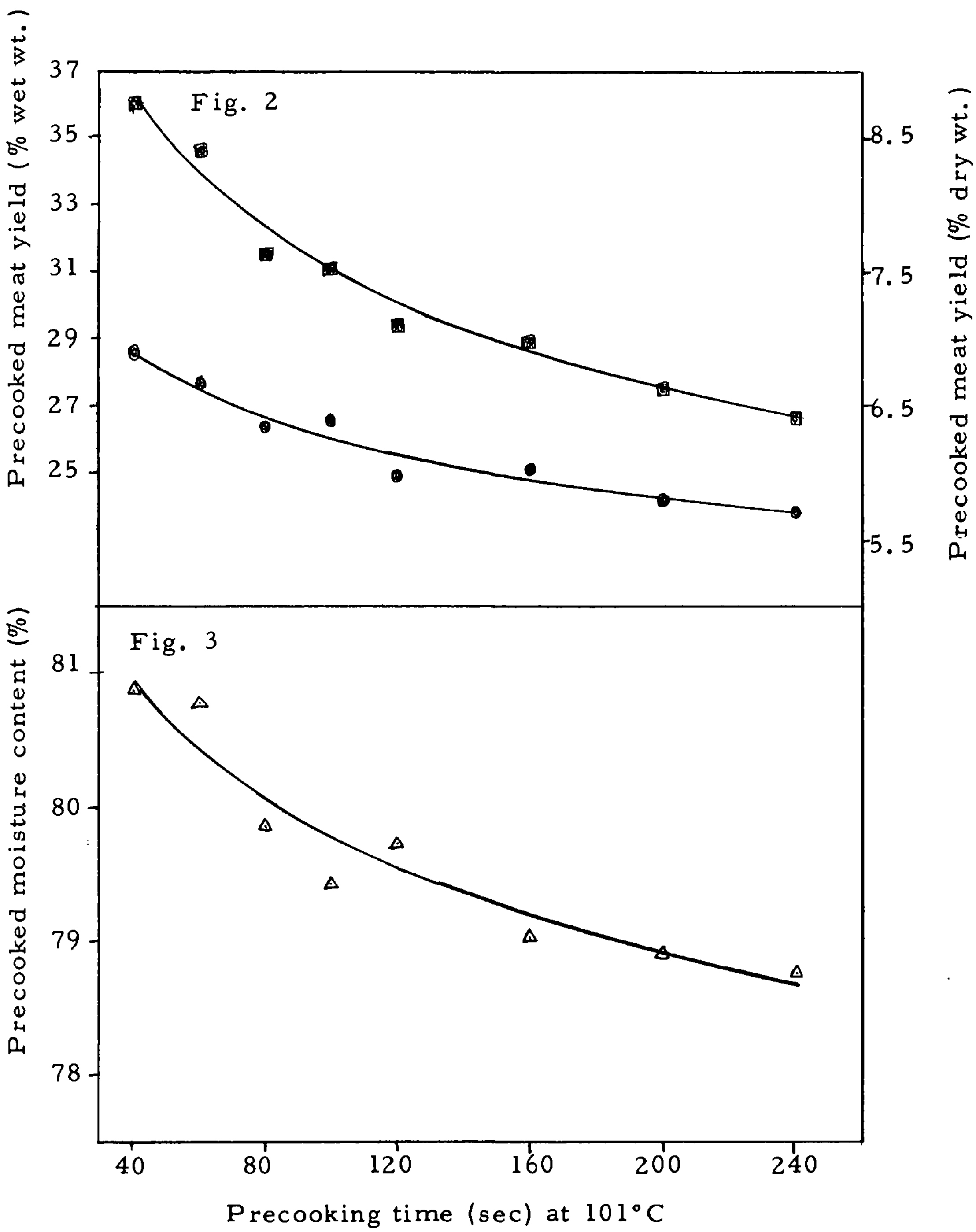

Figure 2. Regression of precooked meat yields (■ % wet weight; ● % dry weight) on round shrimp precooking time.

Figure 3. Regression of precooked meat moisture content (%) on round shrimp precooking time (▲).

TABLE 3. Yield and Moisture Content of Drained Meat Derived from Round Shrimp Precooked[1] for Varying Time Periods.

Precooking time (sec)	Precooked meat fill wt. (gm)	Drained meat Wt./can (gm) Wet	Drained meat Wt./can (gm) Dry	Drained meat Moisture (%)	Meat yield[2] Wet wt. (%)	Meat yield[2] Dry wt. (%)	Meat yield[2] Cans[3]/ 1000 lb.
40	150	99.17	24.54	75.25	28.83	5.90	847.3
	160	107.90	26.51	75.43	24.31	5.98	864.4
	170	111.32	27.04	75.66	23.60	5.76	839.2
60	170	116.77	28.69	75.42	23.78	5.85	845.8
80	150	107.90	26.81	75.14	22.67	5.64	806.3
	160	115.35	28.50	75.28	22.73	5.62	808.2
	170	122.97	30.29	75.36	22.80	5.62	810.8
100	170	128.25	31.51	75.42	23.46	5.77	834.3
120	150	112.70	27.81	75.32	22.13	5.46	786.9
	160	121.92	30.02	75.38	22.42	5.52	797.4
	170	129.25	31.57	75.57	22.37	5.47	795.6
160	150	116.35	29.02	75.06	22.48	5.61	799.4
	160	125.97	30.99	75.40	22.82	5.62	811.4
	170	134.37	33.04	75.41	22.91	5.64	814.6
200	170	136.90	33.69	75.39	22.13	5.45	787.0
240	150	120.65	29.74	75.34	21.50	5.30	764.4
	160	129.45	31.64	75.55	21.63	5.29	769.1
	170	137.85	33.71	75.54	21.67	5.30	770.8

[1] Steam, 101°C

[2] Based upon the average drained wt. of 4 replicate cans.

[3] 307 x 113 cans; 4.5 oz. drained meat wt.

TABLE 4. Regression of Drained Meat Yield[1] on Steam (101°C) Precooking Time.

Regression	Equation	Correlation coefficient
Yield (% wet wt.) on time (sec):	$y = 28.300\ x^{-.046}$	-.8108[3]
Yield (% dry wt.) on time (sec):	$y = 6.899\ x^{-.044}$	-.7397[3]
Yield (no. 307 x 113 cans[2]/ 1000 lb) on time (sec):	$y = 1006.2\ x^{-.046}$	-.8108[3]

[1] Based upon round shrimp weight; drained meat yield from 170 g fill wt.

[2] Computed upon the basis of 4.5 oz (127.573 gm) drained meat/ 307 x 113 can.

[3] Sig. $P \leq 0.001$; n = 32.

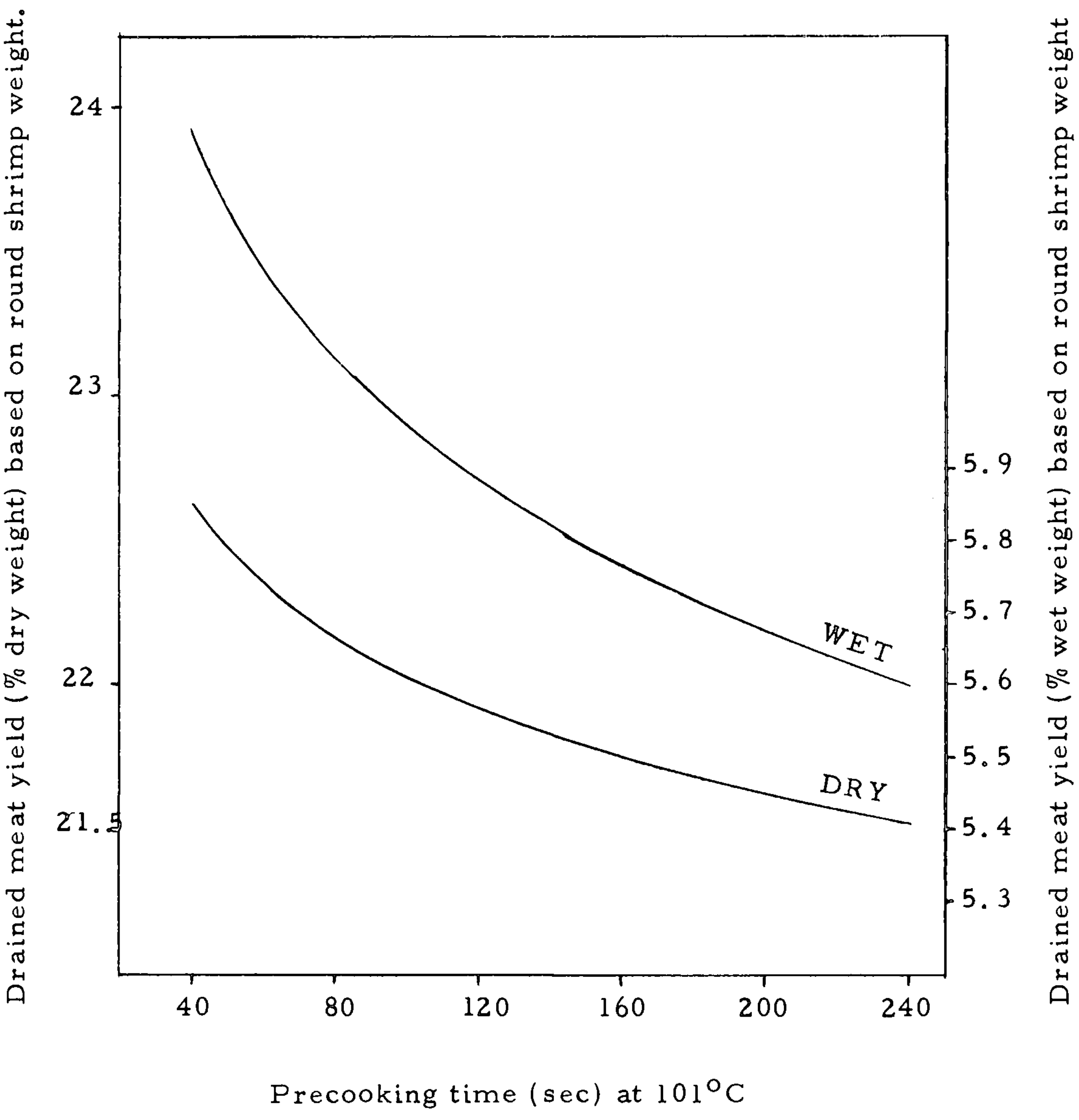

Figure 4. Regression of drained meat yields (% wet weight and % dry weight) on round shrimp precooking time.

TABLE 5. Effect of Steam (101°C) Precooking Time and Fill Weight on Drained Meat Moisture Content and Yield.

Factor	Precooked meat fill wt.	Precooking time	Fill wt. x precooking time
Moisture content (%)	8.54[4]	2.32[1]	0.42[1]
Yield (% wet wt.)	6.48[3]	162.42[4]	2.57[2]
Yield (% dry wt.)	1.52[1]	76.50[4]	1.50[1]

	Factor mean ranking	
Factor	Fill wt. (gm)	Precooking time (sec)
Moisture content (%)	170>160>150	240>40>120>160>80
Yield (% wet wt.)	160>170>150	40>80>160>120>240
Yield (% dry wt.)	160>150>170	40>80>160>120>240

[1]NS $P \geq 0.05$ [2]Sig. $P \leq 0.05$ [3]Sig. $P \leq 0.005$

[4]Sig. $P \leq 0.001$

Factor level means with same underline did not vary significantly ($P > .05$).

The fill weight of the cans influenced the drained meat moisture and yield wet weight (Table 5). Drained meat yield dry weight was not affected. More moisture was associated with the drained meat from cans with a higher fill weight of precooked meat. The ratio of solids to can liquor content and<or the concentration of NaCl and citric acid appeared to affect the moisture content of drained meat.

The weight of drained meat per can (gm wet and dry) for a specific fill weight increased in a linear manner as the precooking time was lengthened (Table 6). This increase can be attributed to the increasing amount of solids present in each can per unit fill weight of precooked meat as the precooking time was extended. The rate functions for the regression equations increased as fill weight was increased (wet and dry wt.) (Table 6). This was a reflection of the higher moisture contents associated with greater fill weights noted earlier and an apparent decrease in the quantity of solids solubilized through thermal processing as the ratio of solids in the can to liquor volume increased.

The constraints of the standard of identity for canned shrimp have a marked effect on potential drained meat yield. The established drained weight for a 307 x 113 can of shrimp of 4.5 oz (127.573 gm) must be yielded from a maximum possible fill weight of about 170 gm (5.996 oz). Shrimp must be precooked to a moisture content that will physically allow a precooked meat fill weight that will yield the

TABLE 6. Relationship of Can Fill Weight, Drained Meat Weight and Steam (101°C) Precooking Time to Drained Meat Yield.

Regression	Weight basis	Equation	Correlation coefficient
Meat wt. /307 x 113 can (150 gm precooked meat fill wt.) on time (sec):	Wet	y=.1025x+98.2317	.9482[1,2]
	Dry	y=.0248x+24.3691	.9313[1,2]
Meat wt. /307 x 113 can (160 gm precooked meat fill wt.) on time (sec):	Wet	y=.1065x+106.4865	.9485[1,2]
	Dry	y=.0251x+26.3180	.9232[1,2]
Meat wt. /307 x 113 can (170 gm precooked meat fill wt.) on time (sec):	Wet	y=.1282x+111.1891	.9273[1,3]
	Dry	y=.0317x+27.2397	.9273[1,3]

Drained wt. (307 x 113 can (oz)	Precooking time required to achieve drained wt. with 170 gm precooked meat fill wt. (sec)	Yield of canned shrimp meat (307 x 113 cans; 4.50 oz. drained weight equivalent/ 1000 lb round shrimp[4]
4.50	127.8	805.4
4.25	72.5	826.0
4.00	17.2	883.0

[1] Sig. P $\geq$ .001   [2] n = 20   [3] n = 32

[4] Based upon the regression of drained meat yield (No. 307 x 113 cans 4.5 oz drained wt. /1000 lb round shrimp) on precooking time (sec) (Table 4).

desired drained weight. The loss of solids during extended precooking (Tables 1 and 2; Figures 1 and 2) to attain a moisture content that will produce the required drained meat weight from a physically attainable fill weight reduces the potential yield of drained meat.

The possible marked improvement in drained meat yield is illustrated by computed yields attainable by reduced precooking times which would be possible if the required drained meat weight for a 307 x 113 can were reduced (Table 6). For example, with a 170 gm fill weight a reduction in precooking time from 127.8 sec to 17.2 sec would be possible if the standardized drained meat weight was reduced from 4.5 to 4.0 oz. The accompanying increase in total drained meat yield would be equivalent to 77.6 307 x 113 cans with 4.5 oz of drained meat per 1000 lb of round shrimp. This would equal an increased value of $105.08/1000 lb of round shrimp ($32.50/case of 24 cans; wholesale price, August 1979).

Flavor panel scores did not vary significantly with regards to fill weight, precooking time or factor interaction ($P > .05$) for all sensory characteristics (Table 7). This result could have been related to the large variation in individual panel scores which reflected a wide difference in the preference of judges for canned shrimp. A trend towards preference for the texture, juiciness and flavor of drained meat derived from shrimp precooked for shorter periods of time was observed. Mean panel scores for juiciness ($x=-.6766$; $P \leq .01$),

TABLE 7. Effect of Steam (101°C) Precooking Time and Fill Weight on Drained Meat Flavor Characteristics.

Precooking time (sec)	Precooked meat fill wt. (gm)	Mean[1] flavor panel scores[2]				
		Odor	Texture	Juiciness	Flavor	Over-all desirability
40	150	6.0±1.41	6.2±1.32	6.3±1.77	6.5±1.43	6.4±1.26
	160	6.3±1.42	6.1±1.52	6.3±1.57	6.3±1.49	6.2±1.40
	170	6.1±1.52	5.6±2.12	6.1±1.85	6.5±1.43	6.2±1.55
80	150	5.8±1.99	6.3±1.49	6.1±1.37	5.9±1.29	6.1±1.37
	160	5.9±1.52	5.9±1.37	6.2±1.62	6.2±1.14	5.8±1.23
	170	6.9±1.29	6.0±1.76	5.5±1.35	6.6±0.70	6.3±0.95
120	150	6.8±1.48	6.4±1.71	6.1±1.66	6.5±1.65	6.2±1.55
	160	6.2±1.32	6.2±1.23	5.9±1.52	6.3±1.25	6.5±1.18
	170	6.3±2.11	5.7±1.77	6.0±1.63	6.3±1.57	6.3±1.64
160	150	5.5±1.58	5.8±1.55	5.7±1.57	6.4±0.97	6.4±0.70
	160	6.4±1.26	6.1±1.91	5.8±1.75	6.3±1.57	6.2±1.40
	170	6.6±1.78	6.0±1.94	6.0±1.49	5.9±1.45	6.3±1.49
240	150	6.0±1.33	5.5±1.27	5.8±1.40	6.3±1.25	6.2±1.23
	160	6.3±1.70	5.8±1.03	5.7±1.34	6.0±1.25	6.1±0.99
	170	5.7±2.00	5.6±1.90	5.6±1.58	6.0±1.49	5.7±1.57

Factor	F-value: 3 x 5 factorial analysis of variance		
	Fill wt.[3]	Precooking time[3]	Fill wt. x precooking time[3]
Odor	0.45	0.29	0.79
Texture	0.40	0.39	0.21
Juiciness	0.15	0.48	0.16
Flavor	0.07	0.29	0.33
Over-all desirability	0.09	0.38	0.23

[1] n = 10

[2] Scale: 9, highest affirmative value, to 1, lowest affirmative value.

[3] NS $P \geq 0.05$

texture ($r = .4260$; $P \leq .10$) and flavor ($r = .4619$; $P \leq .10$) decreased in a somewhat linear manner as precooking time was extended. Loss of soluble flavor and protein components through steam precooking could account for this trend.

The proper choice of precooking time and fill weight is vital in maximizing drained meat yield. Generally, the yield of drained meat could be optimized by (a) reducing precooking time to only that required; (b) optimizing relationship between liquor and precooked meat, and (c) changing the standard of drained meat identity for canned shrimp which would allow for shorter precooking times and optimum meat yields. The above general recommendations should be viewed as guidelines only since drained meat yield is also influenced by the storage age, quality and size of raw round shrimp.

Interaction of Precooking Time and Polyphosphate Pretreatment on Drained Meat Yield and Quality

The loss of meat moisture and solids through processing was retarded by a polyphosphate pretreatment of round shrimp prior to steam precooking and subsequent mechanical peeling (Table 8). Loss of moisture and solids from precooked meat from both water and polyphosphate treated round shrimp followed well-defined power regression functions (Table 9). Polyphosphate treatment substantially increase meat solids stabilization especially during the early

TABLE 8. Yield and Moisture Content of Cooked Meat Derived from Polyphosphate and Water Treated[1] Round Shrimp[2] Precooked[3] for Various Time Periods.

Precooking time (sec)	Polyphosphate conc. (%)	Round shrimp (kg)	Precooked meat moisture (%)	Yield		
				Gm	Wet wt (%)	Dry wt (%)
40	0.0	8.0	81.28	2055.5	25.69	4.81
	0.6	8.0	82.18	2616.9	32.71	5.83
80	0.0	9.0	80.79	2024.8	22.50	4.32
	0.6	9.0	81.28	2528.1	28.09	5.26
140	0.0	10.0	79.52	2016.1	20.16	4.13
	0.6	10.0	80.58	2481.4	24.18	4.82
240	0.0	12.0	78.65	1932.3	16.10	3.44
	0.6	12.0	79.38	2534.0	21.12	4.35

[1] 10 min   [2] In ice three days post-catch   [3] Steam; 101°C

TABLE 9. Regression of Precooked Meat Yield[1] and Moisture Content on Steam (101°C) Precooking Time.

Regression	Polyphosphate conc. (%)	Equation	Correlation coefficient
Yield (% wet wt) on time (sec):	0.0	$y=66.785X^{-.252}$	-.9788[3]
	0.6	$y=80.329X^{-.241}$	-.9971[4]
Yield (% dry wt) on time (sec):	0.0	$y=9.325X^{-.175}$	-.9630[2]
	0.6	$y=10.661X^{-.162}$	-.9983[4]
Moisture (%) on time (sec):	0.0	$y=87.432X^{-.019}$	-.9776[3]
	0.6	$y=88.211X^{-.019}$	-.9889[3]

[1] Based upon round shrimp weight

[2] Sig. $P \leq .05$

[3] Sig. $P \leq .025$

[4] Sig. $P \leq .005$

precooking stage. A precooking time of 40 sec provided an increase in yield of 7.02 wet weight and 1.02 dry weight percentage points over the control (water pretreatment) against a similar increase of only 4.02 wet weight and 0.69 dry weight percentage points at a precooking time of 140 sec (Table 8). The rate of yield loss (wet and dry weight) through steam precooking was also retarded by a polyphosphate pretreatment. The rate function for the regression of meat yield on precooking time for control samples was 104.6% wet weight and 108.0% dry weight of polyphosphate treated samples (Table 9).

Although pretreatment with polyphosphate increased precooked meat moisture content over the control (Table 8), the rate of moisture loss during steam precooking for both was nearly identical (Table 9). Based upon the regressions of meat moisture on precooking time, the difference in moisture content ranged from 0.793 percentage points at 40 sec to 0.797 percentage points at 240 sec.

The improvement in precooked meat yield resulting from polyphosphate pretreatment of round shrimp was directly reflected in drained meat yields after thermal processing (Table 10). The loss in drained meat yield (wet and dry weight) was related to precooking time by well-defined power regression functions (Table 11; Figures 5 and 6) for both water and polyphosphate pretreated round shrimp. The rate of yield loss in drained meat (wet weight) as precooking time was extended was greater for phosphate treated samples (Table 11).

TABLE 10. Yield and Moisture Content of Drained Meat Derived from Polyphosphate and Water Treated Round Shrimp Precooked for Various Time Periods.

Precooking time (sec)	Polyphosphate conc. (%)	Drained meat: Wt./can[2] (gm)		Drained meat: Moisture (%)	Yield based on round shrimp wt.: Percent		Yield based on round shrimp wt.: Cans[3]/1000 lb	Yield based upon precooked meat wt. (%)	
		Wet	Dry		Wet wt.	Dry wt.		Wet wt.	Dry wt.
40	0.0	95.00	24.54	74.17	14.36	3.71	510.4	59.38	81.93
	0.6	101.48	24.27	76.08	19.53	4.67	694.3	63.43	85.13
80	0.0	110.56	27.62	75.01	14.63	3.66	520.2	69.10	89.88
	0.6	111.36	26.68	76.00	18.40	4.41	654.2	69.48	89.08
140	0.0	118.58	29.96	74.74	14.06	3.55	500.1	74.11	91.41
	0.6	120.92	29.16	75.88	17.65	4.26	627.5	75.58	93.85
240	0.0	125.50	31.18	75.16	11.89	2.95	422.7	78.44	91.26
	0.6	127.20	30.80	75.78	15.80	3.83	561.8	79.50	93.36

[1] Steam; 101°C

[2] Based upon the average drained wt. of 4 replicate cans; 160 gm precooked meat fill wt.

[3] 307 x 113 cans; 4.5 oz drained meat wt.

TABLE 11. Regression of Drained Meat Yield[1] on Steam (101°C) Precooking Time.

Regression	Polyphosphate conc. (%)	Equation	Correlation coefficient
Yield (% wet wt) on time (sec):	0.0	$y=22.871X^{-.098}$	-.7835[3]
	0.6	$y=31.850X^{-.113}$	-.9643[3]
Yield (% dry wt) on time (sec):	0.0	$y=6.292X^{-.117}$	-.8397[3]
	0.6	$y=7.406X^{-.105}$	-.9581[3]
Yield (No. 307X113 cans[2]/1000 lb) on time (sec):	0.0	$y=764.690X^{-.098}$	-.7825[3]
	0.6	$y=1065.704X^{-.113}$	-.9646[3]

[1] Based upon round shrimp weight; drained meat yield from 160 gm fill wt.

[2] Computed upon the basis of 4.5 oz (127.573 gm) drained meat/ 307X113 can.

[3] Sig. $P \leq .001$; n = 20.

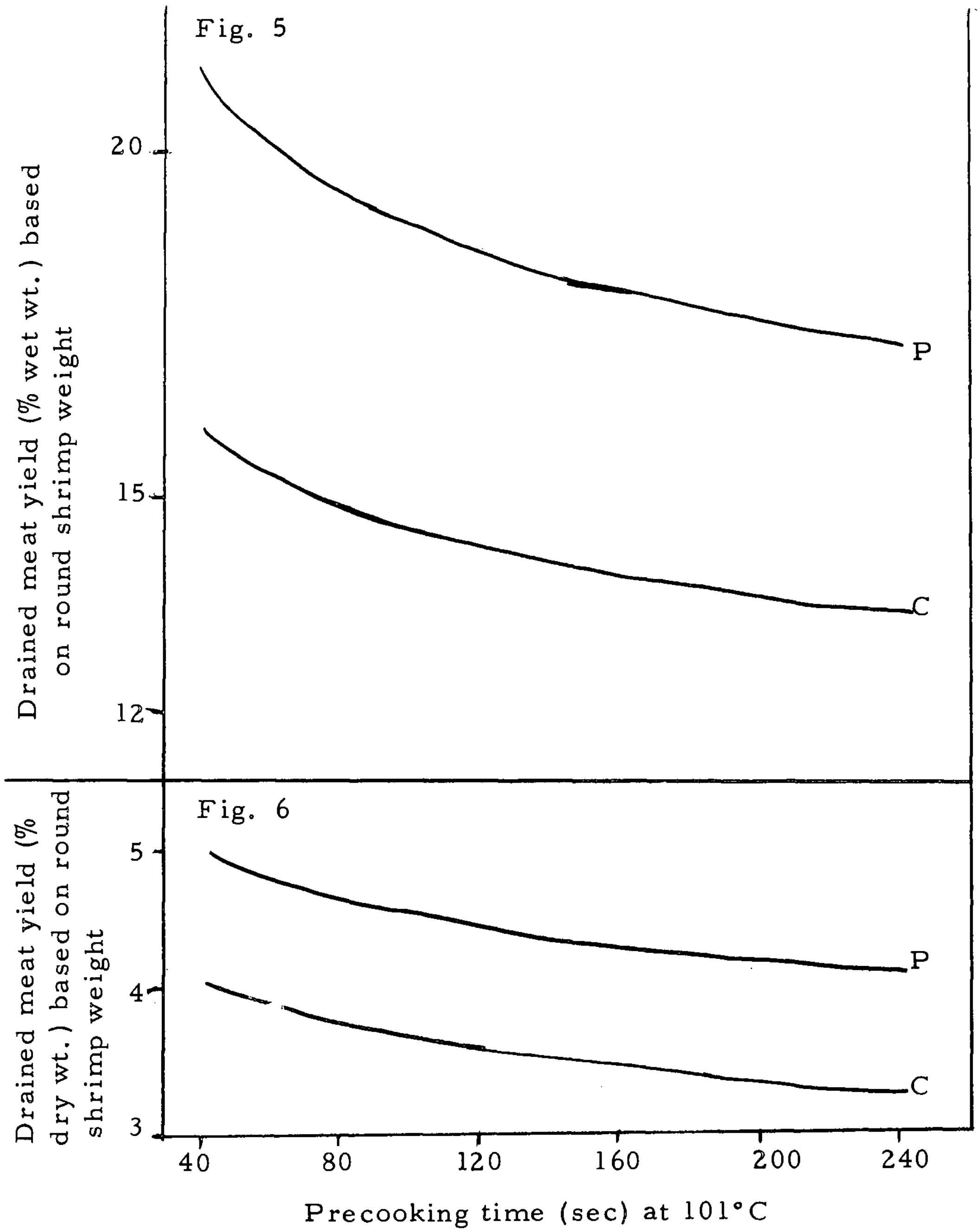

Figure 5. Regression of drained meat yield (% wet weight) on round shrimp precooking time.

Figure 6. Regression of drained meat yield (% dry weight) on round shrimp precooking time.

P = 0.6% Polyphosphate pretreatment solution

C = Control (water pretreatment)

This differed from that observed earlier for precooked meat. The anomaly could be attributed to the higher precooked meat moisture content and the decrease in its degree of retention by meat through thermal processing. On the contrary, polyphosphate treatment reduced the rate of yield (dry weight) loss in drained meat as precooking time was extended (Table 11).

Polyphosphate treatment and precooking time significantly affected drained meat moisture content (Table 12). The higher moisture contents of precooked meat associated with polyphosphate treatment were reflected in drained meat moisture contents. At a precooking time of 40 sec., the drained meat moisture content was increased by 2.5% over the control, while the increase was 1.5% at 140 sec. The moisture content of drained meat from control and polyphosphate treated shrimp varied differently with regard to precooking time. Control samples gained in moisture as precooking time was extended. This might be due to more solids per 160 gm fill weight yielded by longer precooking times which resulted in an increase in the ratio of solids to liquor and/or citric acid concentration. In contrast, polyphosphate treated samples possessed moisture contents that were reduced as precooking time was extended.

The marked yield (wet and dry wt.) improvement by polyphosphate on precooked and subsequent drained meat affords an additional yield advantage by reducing the precooking time required to achieve

TABLE 12. Relationship of Precooking Time and Polyphosphate Pretreatment to the Moisture Content and Yield of Drained Meat from Precooked Meat.

Factor	F-Value: Pretreatment	F-Value: Precooking time (sec)	F-Value: Pretreatment x time
Moisture content (%)	469.003[3]	10.534[3]	25.279[3]
Yield (% wet wt.)[4]	91.432[3]	1749.889[3]	2.233[1]
Yield (% dry wt.)[5]	47.008[3]	277.843[3]	11.928[3]

	Pretreatment	Precooking time (sec)
Moisture content (%)	0.6>0.0	80>240>140>40
Yield (% wet wt.)[4]	0.6>0.0	240>140>80>40
Yield (% dry wt.)[5]	0.6>0.0	140>240>80>40

Regression	Polyphosphate conc. (%)	Equation	Correlation coefficient
Moisture content (%) on precooking time:	0.0	$y=72.631X^{.006}$	.7540[3]
	0.6	$y=76.718X^{-.002}$	-.6164[2]
Yield (% wet wt.) on precooking time:	0.0	$y=34.237X^{.154}$	.9809[3]
	0.6	$y=39.564X^{.128}$	.9930[3]
Yield (% dry wt.) on precooking time:	0.0	$y=67.253X^{.059}$	.8614[3]
	0.6	$y=69.649X^{.056}$	.9204

[1] NS $P \geq .05$ [2] Sig. $P \leq .005$ [3] Sig. $P \leq .001$

[4] Wt. drained meat (wet)/wt. precooked meat (wet).

[5] Wt. drained meat (dry)/wt. precooked meat (dry).
Level means with same underline did not vary significantly ($P > .05$).

the standard of drained weight identity for canned shrimp. The maximum fill weight for a 307X113 can of 170 gm of precooked meat would require a 75.04% yield of drained meat to achieve the 4.5 oz standard. A precooking time for round shrimp of 162 sec for water and 145 sec for polyphosphate treated shrimp would be required to achieve this drained meat yield based upon the regression of drained meat yield (wet wt.) (based on precooked meat) on precooking time listed in Table 12. The combined increase in drained meat yield of the polyphosphate pretreatment and reduced precooking time would be equivalent to 4.27 percentage wet weight and 0.904 dry weight based upon the regressions of yield (round shrimp basis) on precooking time listed in Table 11. This would be equivalent to 142.7 307X113 cans (4.5 oz drained weight/1000 lb of round shrimp worth $193.23 wholesale (wholesale price Sept. 1979; $32.50/case of 24 307X113 cans).

The yield of drained meat from precooked meat through thermal processing was somewhat affected by precooking time and polyphosphate pretreatment of round shrimp. The drained meat yield (wet and dry wt.) based upon precooked meat weight (Table 10) was significantly improved (Table 12) by polyphosphate pretreatment. This can be attributed largely to the better retention of moisture and solids by polyphosphate treated samples over the control samples through steam precooking. The rate of increase in drained meat yield (wet and dry wt.) as precooking time was lengthened was lower in the polyphosphate samples than the control samples. This indicates that soluble components and moisture retained in greater amounts through precooking by polyphosphate pretreatment were more labile to loss to can liquor through thermal processing. A large portion of these more labile soluble components were lost by control samples through precooking. While polyphosphate pretreatment significantly and favorably affected drained meat yield based upon precooked meat, the drained meat yield (dry weight) of polyphosphate treated shrimp only approximated 101.8% of control shrimp.

Polyphosphate pretreatment and precooking time did not alter the flavor characteristics of canned shrimp meat. Panel scores for the odor, texture, juiciness, flavor and overall-desirability did not vary significantly ($P \geq 0.05$) with regard to either factor (Table 13). A trend towards a preference for all sensory factors except the odor of drained meat from polyphosphate treated round shrimp was evident. Mean panel scores for all sensory factors decreased as precooking time was extended to 240 sec reflecting the loss of factors important to flavor characteristics through steam precooking.

Relationship of Shrimp Age and Polyphosphate Pretreatment to Drained Meat Yield

Polyphosphate treatment and storage time in ice markedly affected cooked meat yield (Table 14). Polyphosphate treatment

TABLE 13. Effect of Steam Precooking Time and Polyphosphate Pretreatment on Drained Meat Flavor Characteristics.

Precooking time (sec)	Polyphosphate conc. (%)	Mean[1] flavor panel score[2]				
		Odor	Texture	Juiciness	Flavor	Desirability
40	0.0	6.30	5.50	5.55	5.80	5.65
	0.6	5.90	6.15	6.15	6.05	6.05
80	0.0	6.40	5.90	5.95	5.85	6.05
	0.6	5.85	5.65	6.15	6.20	6.05
140	0.0	6.25	5.15	5.80	5.95	5.80
	0.6	6.25	5.60	6.10	6.00	5.80
240	0.0	5.95	5.25	5.30	5.55	5.30
	0.6	5.85	5.85	6.05	5.85	6.00

	F-Value: 2 x 4 factorial analysis of variance		
	Polyphosphate conc. (%)[3]	Precooking time (sec)[3]	Polyphosphate x time[3]
Odor	0.995	0.303	0.237
Texture	1.532	0.507	0.507
Juiciness	2.760	0.330	0.212
Flavor	0.639	0.233	0.049
Over-all desirability	0.871	0.314	0.333

[1] n = 20

[2] Scale: 9, highest affirmative value, to 1, lowest affirmative value.

[3] NS $P > .05$

TABLE 14. Yield and Moisture Content of Cooked[1] Meat Derived from Polyphosphate and Water Treated[2] Round Shrimp Stored for Various Time Periods in Ice[3].

Round shrimp age (days)	Polyphosphate conc. (%)	Round shrimp (kg)	Precooked meat moisture (%)	Yield		
				Gm	Wet wt (%)	Dry wt (%)
1	1.0	16	79.92	4065.8	25.41	5.10
	0.0	16	79.85	3629.5	22.68	4.57
3	1.0	12	82.18	3134.5	26.12	4.65
	0.0	12	80.83	1969.5	16.41	3.15
6	1.0	12	83.54	3324.7	27.71	4.56
	0.0	14	82.38	2724.6	19.46	3.43

[1] 90 sec.; steam (101°C)

[2] 10 min.

[3] 2°C

increased cooked meat yield wet weight over control samples by 2.73, 9.71 and 8.25 percentage points after 1, 3 and 6 days ice storage, respectively. Cooked meat yield dry weight showed commensurate increases for the polyphosphate samples over controls. The cooked meat yield wet weight for polyphosphate treated shrimp increased with respect to ice storage. The yield increased by 0.71 and 2.30 percentage points at 3 and 6 days ice storage, respectively, over that after 1 day of ice storage. Conversely, meat yield dry weight for polyphosphate treated shrimp decreased with respect to storage time. This indicated that the increase in cooked meat yield observed for the phosphate treated shrimp with respect to ice storage time was due to an increase in cooked meat moisture content. The cooked meat moisture content for polyphosphate treated shrimp increased by 2.26 and 3.62 percentage points at 3 and 6 days ice storage, respectively, over that for 1 day ice storage.

The control samples showed a tendency toward wet weight yield reduction despite an increase in cooked meat moisture content of 0.98 and 2.53 percentage points at 3 and 6 days of ice storage, respectively. This reflected the ice storage induced enzymatic degradation of muscle proteins producing an increase in water holding capacity through cooking and heat induced protein solubility. This is further reflected in the cooked meat yield dry weight which was markedly reduced at 3 and 6 days ice storage over the 1 day old sample.

Polyphosphate pretreatment retarded this loss in cooked meat yield during storage. This was evident in the reduction in yield dry weight which was much greater for control than polyphosphate treated samples. Cooked meat yield dry weight in the control samples was reduced by 1.42 and 1.14 percentage points at 3 and 6 days ice storage, respectively, over the 1 day old sample while a corresponding 0.45 and 0.54 percentage point reduction for polyphosphate treated samples was observed. The increase in moisture content with respect to ice storage was greater in the phosphate treated than the water treated (control) samples.

The drained meat yields reflected the differences observed for cooked meat yield resulting from polyphosphate treatment, but those observed for ice storage were somewhat modified (Tables 15 and 16). Polyphosphate pretreatment significantly increase drained meat yields wet weight over controls by 1.94, 6.67 and 4.61 percentage points at 1, 3 and 6 days ice storage, respectively. Drained meat yields dry weight were 0.50, 1.38 and 0.95 percentage points greater than the controls, respectively. The drained meat yield wet weight for both polyphosphate and water treated samples tended to decrease with respect to ice storage time. The wet weight yield for polyphosphate treated shrimp was reduced by 1.29 and 0.36 percentage points at 3 and 6 days of storage, respectively, over 1 day old shrimp. Wet weight yield for water treated shrimp showed a markedly greater

TABLE 15. Yield and Moisture Content of Drained Meat Derived from Polyphosphate and Water Treated Round Shrimp[1] Stored for Various Time Periods in Ice.

Round shrimp age (days)	Polyphosphate conc. (%)	Drained meat: Wt./can (gm)[2] Wet	Drained meat: Wt./can (gm)[2] Dry	Drained meat: Moisture (%)	Yield[3]: Percent Wet wt.	Yield[3]: Percent Dry wt.	Yield[3]: Cans[4]/ 1000 lb.
1	1.0	125.33	31.00	75.27	18.73	4.63	666.0
	0.0	125.83	30.97	75.39	16.79	4.13	596.9
3	1.0	113.53	27.07	76.16	17.44	4.16	620.1
	0.0	111.53	28.80	74.18	10.77	2.78	382.8
6	1.0	112.73	25.51	77.37	18.37	4.16	653.2
	0.0	120.18	28.07	76.64	13.76	3.21	489.2

[1] Precooked 90 sec.; steam 101°C.

[2] Based upon the average drained wt. of 4 replicate cans; 170 gm precooked meat fill wt.

[3] Based upon round shrimp wt.

[4] 307X113 cans; 4.5 oz drained meat wt.

TABLE 16. Effect of Round Shrimp Age and Polyphosphate Treatment on Drained Meat Yield and Moisture Content.

Factor	F-Value		
	Polyphosphate conc.[1]	Age[1]	Polyphosphate conc. x age[1]
Yield (% wet wt)	14282.1	3279.3	1376.2
Yield (% dry wt)	10134.1	3482.0	737.6
Yield (cans/1000 lb)	14277.7	3278.1	1375.6
Moisture (%)	628.1	1167.8	312.7

Factor	Level mean ranking	
	Polyphosphate conc.	Age
Yield (% wet wt)	1>0	1>6>3
Yield (% dry wt)	1>0	1>6>3
Yield (cans/1000 lb)	1>0	1>6>3
Moisture (%)	1>0	6>1>3

[1] Sig. $P \leq .001$

Level means with same underline did not vary significantly ($P > .05$)

reduction; 6.02 and 3.03 percentage points at 3 and 6 days ice storage, respectively. The drained meat yield dry weight generally reflected the reductions in wet weight yield with respect to ice storage.

Drained meat yiélds wet weight for polyphosphate treated shrimp with respect to ice storage time was partially maintained by increased drained meat moisture contents. The increase observed in cooked meat moisture content for polyphosphate samples with respect to ice storage was reflected to a lesser degree in drained meat moisture content. The control samples showed only a tendency toward higher moisture contents as ice storage was extended. The elevated moisture contents in cooked meat, whether a result of polyphosphate pretreatment or ice storage were reflected in the drained meat moisture contents. The increases in drained meat moisture content resulting from a phosphate treatment were not as great as increases resulting from ice storage based upon the magnitude of the F-values listed in Table 16.

The marked effect of both polyphosphate treatment and ice storage is illustrated by the can (307X113; 4.5 oz drained weight) yield per 1000 lb of round shrimp (Table 15). Polyphosphate pretreatment yielded 69.1, 237.3 and 164.0 more cans of shrimp meat from round shrimp stored for 1, 3 and 6 days in ice, respectively, than the control samples. This increased yield would be worth $93.57, $321.34 and $222.08, respectively (wholesale price Sept.

1979; \$32.50/case of 24 307X113 cans). The reduction in yield for polyphosphate treated shrimp after 3 and 6 days of ice storage was relatively small; 45.9 and 12.8 cans per 1000 lb of round shrimp, respectively. Conversely, the reduction for the control sample amounted to 214.1 and 107.7 cans at 3 and 6 days, respectively; a reduction in yield worth \$289.93 and \$145.84, respectively.

Treatment of round shrimp with polyphosphate did not affect the flavor characteristic of the drained canned meat (Table 17). Panel scores for all flavor factors did not vary significantly ($P \geq .05$). Although not significant, the texture and juiciness of polyphosphate treated samples were preferred. Control samples were preferred for their odor, flavor and overall desirability.

Storage of round shrimp in ice generally reduced flavor panel scores (Table 17). The reduction in quality was not significant with regard to scores for odor, texture, juiciness and overall desirability. Scores for the flavor of drained meat from one day old shrimp were significantly ($P < .005$) superior to those for drained meat from shrimp held in ice for 3 and 6 days. The effects of pretreatment and ice storage interacted in a significant ($P < .025$) manner with regard to flavor scores.

The results showed that pretreatment of raw round shrimp with polyphosphate improved the yield and moisture retention of drained canned meat and that the effect was more pronounced in older shrimp.

TABLE 17. Effect of Round Shrimp Age and Polyphosphate Treatment on Drained Meat Flavor Characteristics.

Round shrimp age (days)	Polyphosphate conc. (%)	Mean[1] flavor panel score[2]				
		Odor	Texture	Juiciness	Flavor	Desirability
1	1.0	6.10	6.15	6.30	6.75	6.25
	0.0	6.45	6.15	6.25	7.05	6.50
3	1.0	6.00	6.50	6.70	6.25	6.00
	0.0	5.80	5.50	5.75	5.35	5.15
6	1.0	5.50	6.10	5.85	5.25	5.15
	0.0	6.10	6.25	6.10	6.40	6.05

Factor	F-value		
	Polyphosphate conc.	Age	Polyphosphate conc. x age
Odor	1.12[3]	1.50[3]	1.00[3]
Texture	0.64[3]	0.09[3]	1.04[3]
Juiciness	0.67[3]	0.37[3]	1.39[3]
Flavor	0.40[3]	6.30[5]	4.24[4]
Desirability	0.10[3]	2.87[3]	2.71[3]

Factor	Polyphosphate conc.	Age
Odor	0> 1	1> 3> 6
Texture	1> 0	6> 1> 3
Juiciness	1> 0	1> 3> 6
Flavor	0> 1	1> 6> 3
Desirability	0> 1	1> 6> 3

1 n = 20

2 Scale: 9, highest affirmative value, to 1, lowest affirmative value.

3 NS P $\geq .05$

4 Sig. P $\leq .025$

5 Sig. P $\leq .005$

Level means with same underline did not vary significantly (P > 0.05)

The reduction in cooked meat yield, drained meat yield and flavor panel scores, generally observed for the 3 day old control sample over those observed for the 6 day old control sample might be a reflection of improper peeler settings and/or steam precooking time.

Effect of Polyphosphate Pretreatment Concentration on Drained Meat Yield

The concentration of polyphosphate pretreatment solution markedly affected the retention of solids and moisture through steam cooking and subsequent mechanical peeling (Table 18). The regression of cooked meat yield (wet weight) on pretreatment polyphosphate concentration followed a power function (replicate I: $r=.9535$, $P\leq.025$; replicate II: $r=.922974$, $P\leq.05$). A similar power function was generally observed for cooked meat yield (dry weight) (replication I: $r=.9212$, $P\leq.05$; replication II: $r=.8659$, $P\leq.10$).

The yield response of replicate I and II to varying concentrations of polyphosphate differed. A 4.52 wet weight and a 0.63 dry weight percentage point increase in yield was produced by 6.0% pretreatment concentration over the control for replicate I while replicate II showed a 6.54 wet weight and a 0.93 dry weight percentage point increase for similar pretreatment concentrations. Lower concentrations of polyphosphate were much more effective in increasing yield of replicate II (composed of older round shrimp) than replication I. A .5%

TABLE 18. Yield and Moisture Content of Precooked[1] Meat Derived from Round Shrimp Treated[2] with Varying Concentrations of Polyphosphate.

Replication	Polyphosphate conc. (%)	Round shrimp (kg)	Precooked meat moisture (%)	Yield Gm	Yield Wet wt. (%)	Yield Dry wt. (%)
	0.0	16.0	81.45	4086.2	25.54	4.74
	0.5	16.0	81.49	4216.3	26.35	4.88
I[3]	1.5	16.0	81.67	4621.5	28.88	5.29
	3.0	16.0	82.06	4740.8	29.63	5.32
	6.0	16.0	82.13	4809.6	30.06	5.37
	0.0	16.0	81.05	3721.5	23.26	4.41
	0.5	16.0	81.27	4247.3	26.55	4.97
II[4]	1.5	16.0	81.49	4323.2	27.02	5.00
	3.0	16.0	81.87	4384.4	27.40	4.98
	6.0	16.0	82.08	4767.5	29.80	5.34

[1] 90 sec in steam; 101°C.

[2] 10 min.

[3] In ice two days post-catch.

[4] In ice three days post-catch.

pretreatment of replicate I only produced a yield (wet wt.) equivalent to 103.2% of the control while a similar pretreatment of replication II produced a yield (wet wt.) that was 114.1% of the control. The yield response by varying polyphosphate concentrations was influenced by the age and quality of round shrimp. Fresh shrimp may require stronger polyphosphate concentration to produce a maximum yield response.

The retention of cooked meat moisture through steam cooking and subsequent mechanical peeling was related to pretreatment concentration by a power function (replication I: $r=.9626$, $P\leq.01$; replication II: $r=.9941$, $P\leq.001$). The more effective yield response by polyphosphate for replicate II over I produced a more efficient retention of meat moisture. The rate of meat moisture increase for replication II was 1.38 x that of replication I. A 6% pretreatment produced 0.68 percentage point increase in moisture content over control for replication I while a similar pretreatment produced 1.03 percentage point for replication II. Generally, increased retention of meat moisture accompanied an increase in meat yield.

The drained meat yield and moisture content through thermal processing reflected the marked interaction of pretreatment polyphosphate concentration with the factors observed for cooked meat (Tables 19 and 20). The significant (Table 20) regression of drained meat yield (% wet and dry weight; computed from the drained weight

TABLE 19. Yield and Moisture Content of Drained Meat Derived from Round Shrimp[1] Treated with Varying Concentrations of Polyphosphate.

Replication	Polyphosphate conc. (%)	Drained meat: Wt./can (gm)[2] Wet	Drained meat: Wt./can (gm)[2] Dry	Drained meat: Moisture (%)	Yield based upon round shrimp wt. Percent: Wet wt.	Yield based upon round shrimp wt. Percent: Dry wt.	Cans[3]/ 1000 lb.	Yield based upon precooked meat wt. (%): Wet wt.	Yield based upon precooked meat wt. (%): Dry wt.
I[4]	0.0	120.76	29.39	75.68	18.14	4.42	645.6	71.09	93.21
	0.5	116.74	28.69	75.43	18.10	4.45	643.4	68.67	91.14
	1.5	116.64	28.18	75.84	19.82	4.79	704.6	68.61	90.43
	3.0	116.28	27.58	76.28	20.27	4.81	720.6	68.47	90.43
	6.0	118.48	27.44	76.84	20.95	4.85	744.9	69.69	90.31
II[5]	0.0	112.32	30.06	75.42	16.74	4.11	595.0	71.95	93.32
	0.5	122.48	29.58	75.85	19.12	4.62	680.0	72.05	92.90
	1.5	119.20	28.80	75.84	18.95	4.58	673.6	70.12	91.51
	3.0	120.10	28.51	76.27	19.36	4.59	688.3	70.65	92.49
	6.0	122.22	28.16	76.96	21.42	4.93	761.7	71.89	92.43

[1] Precooked 90 sec; steam 101°C.

[2] Based upon the average drained wt. of 5 replicate cans; 170 gm precooked meat fill wt.

[3] 307x113 can; 4.5 oz. drained meat wt.

[4] In ice two days post-catch.

[5] In ice three days post-catch.

TABLE 20. Effect of Polyphosphate Concentration on Drained Meat Yield and Moisture Content.

Factor	F-value: Polyphosphate conc	Replicate	Polyphosphate conc x replicate
Yield (% wet wt.)[1]	1374.8[4]	102.6[4]	191.3[4]
Yield (% dry wt.)[1]	656.7[4]	131.6[4]	130.7[4]
Yield (cans/1000 lb)[1-2]	1372.2[4]	102.5[4]	191.1[4]
Moisture (%)	213.9[4]	2.3[6]	10.3[4]
Yield (% wet wt.)[3]	44.6[4]	287.5[4]	12.2[4]
Yield (% dry wt.)[3]	24.5[4]	78.2[4]	5.4[5]

	Level mean ranking: Polyphosphate conc.	Replicate
Yield (% wet wt.)	0<.5<1.5<3.0<6.0	I>II
Yield (% dry wt.)	0<.5<1.5<3.0<6.0	I>II
Yield (cans/1000 lb)	0<.5<1.5<3.0<6.0	I>II
Moisture (%)	0<.5<1.5<3.0<6.0	II>I
Yield (% wet wt.)	1.5<3.0<.5<6.0<0	II>I
Yield (% dry wt.)	1.5<6.0<3.0<.5<0	II>I

[1] Based upon round shrimp weight.

[2] 307x113 cans; 4.5 oz. drained meat weight.

[3] Based upon precooked meat weight.

[4] Sig. $P \leq .001$ [5] Sig. $P \leq .005$ [6] NS $P \geq .05$

Level means with same underline did not vary significantly ($P \geq .05$).

of five replicate cans) on pretreatment polyphosphate concentration followed well defined power functions (replicate I: r=.9577 wet wt., r=.9038 dry wt., $P \leq 0.001$; replicate II: r=.9019 wet wt., r=.8531 dry wt.; $P \leq 0.001$).

Pretreatment polyphosphate concentration was more effective on older shrimp (replication II over I). A 6% pretreatment of replication II produced an increase of 4.68 percentage points (wet wt.) and 0.82 (dry wt.) over the control while similar pretreatments produced an increase of 2.81 percentage points (wet wt.) and 0.43 (dry wt.) for replication I. The rate of drained meat yield increase for replication II was 1.24 x (wet wt.) and 1.34 x (dry wt.) that of replicate I. Lower concentrations of polyphosphate were effective on older shrimp. For example, the increments of drained meat yield increase by a 1.5% polyphosphate pretreatment over the respective controls were 2.21 percentage points (wet wt.) and 0.47 percentage point (dry wt.) for replication II (older shrimp); 1.68 percentage points (wet wt.); 0.37 percentage point (dry wt.) for replication I. The drained meat yield (wet and dry wt.) for replication I was significantly better than replication II (Table 20). This reflected the difference in initial quality and age between the two replicate samples of round shrimp.

Drained meat moisture content (Table 19) increased according to a well defined and significant (Table 20) power function as the pretreatment polyphosphate concentration increased (replicate I: r=.9033,

$P \leq .001$; replicate II: $r = .9349$, $P \leq .001$). The more efficient moisture retention in cooked meat (Table 18) from replication II over replication I as polyphosphate concentration was increased was reflected in drained meat moisture contents. The rate of increase in the drained meat moisture content of replication II was 1.08 times that of replication I as pretreatment polyphosphate concentration was increased. Although the moisture content of drained meat from replication II did not vary significantly from that of replication I (Table 20), the significant interaction between polyphosphate concentration and replication supports the above observations. Based upon the moisture content of the cooked meat fill weight and the average moisture content of the drained meat weight an average of $35.95 \pm 1.10\%$ of moisture was lost from replication I and $33.465 \pm .95\%$ from replication II through thermal processing. This indicates that the year class composition or initial quality of round shrimp strongly influenced the amount of moisture retained in drained meat through thermal processing, regardless of polyphosphate concentration.

Pretreatment of round shrimp with polyphosphate did not improve the yield of drained meat from precooked meat through thermal processing (Table 19). While the concentration of polyphosphate pretreatment significantly affected yield (Table 20), samples without a polyphosphate treatment produced superior drained meat yields. The small, but significant increase in yield observed for the round shrimp listed in Table 10 was not observed with the two replicates detailed in Table 19. The storage induced quality or year class composition of a particular lot of round shrimp may be a more important factor in determining the yield of drained meat from precooked meat through thermal processing. The greater significance of the effect of replication over that of polyphosphate concentration (Table 20) tends to support this view. The variation with the previous results (Table 10) could be due to similar differences in year class composition and quality. The higher quality sample (replication I) produced a superior yield, but the solids present in the cooked meat were more labile and lost through thermal processing than the solids contained in the older sample (replication II). This is the same relationship observed for moisture lost from cooked meat through thermal processing.

The increment of polyphosphate uptake over control samples of drained meat (wet and dry wt.) was directly related to the polyphosphate concentrations of the pretreatment solution by power functions (replicate I: $r=.9986$ wet wt., $r=.9985$ dry wt., $P\leq.005$; replicate II: $r=.9186$ wet wt., $P\leq.10$; $r=.9452$ dry wt., $P\leq.05$) (Table 21). The relationship between the increment of drained meat yield increase to the corresponding increment of polyphosphate uptake followed a linear relationship with a moderate degree of correlation (replicate I: $r=.9320$ wet wt., $P\leq.10$; $r=.7967$ dry wt., $P\leq.20$) (replicate II:

TABLE 21. Phosphate Content of Drained Meat Derived from Round Shrimp Treated with Varying Concentrations of Polyphosphate.

Replicate	Polyphosphate conc. (%)	Mg/100 gm (P_2O_5)	
		Wet wt.	Dry wt.
I	0.0	632.6	2593.6
	0.5	679.8	2777.4
	1.5	740.7	3061.8
	3.0	794.6	3340.9
	6.0	888.9	3824.4
II	0.0	600.5	2659.4
	0.5	683.2	2829.3
	1.5	710.3	2950.1
	3.0	719.0	3012.9
	6.0	825.1	3544.6

$r = .9709$ wet wt., $P \leq .05$; $r = .9452$ dry wt., $P \leq .10$). Although the above linear relationship was observed within a round lot replicate, the quantitative relationship between phosphate uptake and yield uptake varied considerably between round shrimp replicates. For example, 1.5% polyphosphate dip of replication II produced a phosphate uptake over the control of 109.8 mg P_2O_5/100 gm (wet wt.) with a drained meat yield increase of 2.21 percentage points wet weight and 0.47 percentage points dry weight; this nearly equaled the increment of yield increase observed for replication I after a 6% polyphosphate dip with 256.3 mg/100 gm (wet wt.) increase in P_2O_5 over the control. This variation was due to differences in storage age, quality and possibly year class composition of the raw shrimp comprising the two replicates.

The phosphate uptake in drained meat did not affect the moisture content of drained meat. Replicate I possessed relatively higher levels of added phosphate than replication II, but drained meat moisture contents did not vary significantly (Table 20). Precooked meat from replication I lost more moisture than replication II through thermal processing despite higher phosphorus contents in replication I. This showed that polyphosphate uptake by precooked meat did not influence the moisture content of drained meat. The higher moisture content of drained meat from polyphosphate treated round shrimp was probably due more to the year class composition or quality of shrimp which made available proteins that tends to hold more moisture and optimize the interaction with polyphosphate. The larger size of replicate I samples might be responsible for the higher levels of retained phosphate.

The use of a polyphosphate for pretreatment of round shrimp would have a marked economic value. Pretreatment in a 6% polyphosphate solution produced an increase of 99.3 and 166.7 307x113 cans per 1000 lb of round shrimp for replicates I and II, respectively (Table 19). This would be equivalent to a dollar value increase of $132.40 and $222.27, respectively, per 1000 lb of round shrimp ($32/case of 24 307x113 cans; wholesale price Sept. 1979). If a 1:1.5 (wt:wt) shrimp:polyphosphate solution ratio was used for pretreatment and the solution was used only once, it would require 90 lb of polyphosphate costing $36 (wholesale price estimate Sept. 1979: $0.40/lb) to treat 1000 lb of shrimp. This would yield a cost:benefit ratio of 1:3.68 and 1:6.17 for replications I and II, respectively. These cost:benefit relationships should be considered as a minimum since the reuse of polyphosphate solution would markedly improve the cost relationship. Experience has shown that approximately 260 lb of solution is occluded to 1000 lb of round shrimp. This would allow the processing of 5769 lb of shrimp per 1500 lb of polyphosphate solution increasing the cost:benefit ratios to an estimated optimum of 1:21.2 and 1:35.6 for replications I and II, respectively.

Pretreatment of round shrimp in polyphosphate solutions up to 6% before steam precooking and subsequent mechanical peeling did not alter the flavor characteristics of drained meat (Table 22). Mean flavor panel scores for the odor, texture, juiciness, flavor and desirability did not vary significantly ($P > .05$) with regard to phosphate concentration. The apparent considerable difference observed between the quality of replication I and II reflected in cooked meat yield was not reflected in flavor panel scores.

Mechanism for the Action of Polyphosphate in Improving Meat Yield of Shrimp

Pacific shrimp begin to undergo a time and temperature dependent degradation of muscle proteins immediately post-catch through the action of *in situ* proteases and on extended storage by microbial action. This degradation results in the reduced yield (dry weight) and increased moisture holding capacity of meat through cooking, detailed in the results of the investigation. The reduction in cooked meat yield and subsequently drained meat yield after thermal processing upon extended ice storage appears to be related to two main functions: (1) Enzymatic degradation results in a loss of protein from round shrimp through the washing action of melting ice. (2) Degradation increases the lability of muscle proteins toward heat induced solubilization markedly increasing the quantity lost through steam

TABLE 22. Effect of Polyphosphate Concentration on Drained Meat Flavor Characteristics.

Replication	Polyphosphate conc. (%)	Mean flavor panel scores				
		Odor	Texture	Juiciness	Flavor	Desirability
	0	6.04	5.36	5.40	6.00	5.68
	.5	6.20	5.24	5.56	6.08	5.84
I	1.5	6.24	5.72	5.64	6.16	5.92
	3.0	6.16	5.76	5.80	6.00	5.92
	6.0	5.72	5.40	5.72	5.64	5.84
	0	6.12	5.64	5.84	6.04	5.96
	.5	5.96	5.60	5.72	6.04	5.76
II	1.5	5.92	5.44	5.92	5.96	5.88
	3.0	5.84	5.48	5.80	5.80	5.72
	6.0	5.80	5.68	5.96	6.12	5.80

Factor	F-value		
	Polyphosphate conc.[1]	Replication[1]	Polyphosphate conc. x replication[1]
Odor	0.31	0.41	0.17
Texture	0.09	0.10	0.39
Juiciness	0.16	1.01	0.10
Flavor	0.13	0.01	0.33
Desirability	0.03	0.01	0.15

[1] NS $P \geq .05$

precooking. The latter and most important function was shown in this investigation to have a high degree of dependance on steam precooking time.

This investigation revealed that the improved water holding capacity and yield (wet and dry wt) of precooked meat produced by a short polyphosphate pretreatment of round shrimp prior to processing was reflected in drained meat yields after thermal processing. Polyphosphate penetrated through the pores of the shrimp shell during the 10 min. pretreatment and interacted with shrimp muscle proteins during exposure or during the initial stages of precooking, reducing the loss of moisture and solid constituents, presumably protein. The dependency of cooked and drained meat yield on polyphosphate pretreatment concentration followed well defined power functions. Increments of yield increases over controls produced by varying the pretreatment concentration correlated with corresponding increments of phosphate added, in a linear manner.

The effectiveness of polyphosphate concentration reflected in meat yield increase and the quantity of added phosphate associated with an increment of meat yield, was dependent upon the quality of a particular lot of round shrimp. Degradation during ice storage improved the effectiveness of a particular polyphosphate concentration to increase meat yield over control samples and appeared to produce a greater movement of yield increase over controls with less phosphate addition to the meat. This improved efficiency could be related to two possible processes occurring during ice storage: (1) Breakdown of the physical structure of shrimp would allow more rapid and complete access of polyphosphate into the body of the shrimp during treatment allowing more extensive exposure. (2) Proteolytic breakdown of body proteins documented by the increase in water-holding capacity of meat through steam cooking improved the efficiency of the interaction of polyphosphate with surface muscle proteins.

The polyphosphate associated with cooked meat had little effect on the yield of drained meat from cooked meat. Polyphosphate that had interacted during pretreatment and/or during the initial stages of precooking and stabilized proteins labile to loss through steam precooking appeared to render stability through thermal processing. No substantial evidence was developed that would support a significant polyphosphate action beyond that observed during steam precooking. The direct comparison of the drained meat yield of control and treated samples based upon cooked meat weight are compromised by the much greater loss of heat labile proteins through steam precooking by control samples over polyphosphate treated samples. Apparently, heat labile proteins stabilized by polyphosphate through steam cooking were as stable through thermal processing as proteins retained by control samples.

An increased retention of moisture through steam precooking and subsequent thermal processing comprised a portion of the increment of added yield associated with polyphosphate pretreatment. Although the action of polyphosphates is generally associated with the addition of water to food products and a more efficient retention through cooking, the elevated moisture content observed in steam cooked and canned, drained meat was not directly related to added polyphosphate. Elevated moisture contents were related to an increased retention of proteins labile to loss during steam precooking. Since proteolytic degradation during ice storage increased the lability and the moisture-holding capacity of these proteins during steam precooking and thermal processing, it is reasonable to assume that proteins retained by polyphosphate interaction would possess an increased degree of moisture-holding capacity. It is clear that observed elevated moisture levels may be related more to the type of protein retained by polyphosphate interaction rather than a strictly physicochemical action of polyphosphate.

The yield enhancing action of polyphosphate would appear to involve a complexing with the connective tissue proteins of the subcuticle of the shrimp body. These proteins in white shrimp (<u>Penaeus setiferous</u>) have been characterized by Thompson and Thompson (1968, 1970a and 1970b) to be collagen-like in nature and to differ from vertebrate collagen by the replacement of hydroxyproline with tryptophan. Their molecular weight was smaller and the protein component was composed of a greater ratio of unformed collagen to collagen laid down as a tissue. Thompson and Farragut (1970) proposed these molecular differences to be responsible for the rapid rate and ease with which shrimp tissue are degraded by enzymes and heat. The instability of Pacific shrimp proteins toward solubilization in steam which was enhanced by protein degradation during ice storage appears to support a similar system. Variations observed in the yield from various samples of shrimp could also be explained by a possible difference in the unformed collagen to collagen laid down as tissue (formed) ratio. Shrimp of a younger age class produced a lower yield and appeared to degrade at a much more rapid rate during ice storage than larger and older shrimp. Young, smaller shrimp may possess a higher quantity of less stable, unformed collagen.

The basic action of polyphosphate with the surface connective tissues of shrimp probably involves an increase in the electrostatic repulsion (loosening of molecular structure) and solubility (water-holding capacity) of its protein component. Binding of polyphosphates with muscle proteins is known to increase the polar groups of proteins increasing their solubility (Linko and Nikkila, 1961; Hamm, 1971) and water-holding capacity (Yasui et al., 1964a and b). The protein polyphosphate complexes thus formed swelled and sealed surface tissues. Based upon the results of this investigation this proposed action of polyphosphate produced enhance yields through steam cooking and subsequent thermal processing through two means: (1) Surface proteins complexed with polyphosphate were rendered a high degree of stability toward heat induced solubilization. (2) Swelling of the proteins composing the surface tissues sealed the surface of the shrimp muscle reducing the loss of fluid and soluble proteins from the interior of the shrimp meat through steam cooking and subsequent thermal processing.

SUMMARY

The application of polyphosphate to round shrimp was investigated as a means of improving the yield and quality of canned shrimp meat through steam precooking, mechanical peeling and thermal processing. The influence of precooking time and ice storage of round shrimp on yield and their interaction with polyphosphate pretreatment were evaluated.

The investigation produced the following major results: (1) The loss of moisture and solids from shrimp through steam (101°C) precooking followed a well defined power regression function ($P \leq .001$). Drained meat yield after thermal processing was directly related with losses associated with steam precooking. The regression of drained meat yield (wet and dry weight based on round shrimp weight) on precooking time followed a related power function ($P \leq .001$).

(2) Precooked meat fill weights decreasing the ratio of solids to liquor volume produced increased drained meat yield (wet weight) and moisture content. Fill weight did not affect drained meat yield dry weight.

(3) Polyphosphate applied to round shrimp interacted with muscle proteins during pretreatment or during early stages of steam precooking stabilizing heat labile proteins toward solubilization and enhanced moisture retention. The interaction enhanced yield by

stabilizing a significant increment of meat proteins throughout steam precooking and appeared to retard the loss of heat labile proteins presumably from the interior of the shrimp meat. Enhanced yields of cooked meat produced by polyphosphate pretreatment were directly reflected in the yield of canned drained meat.

(4) The regression of the yield of steam cooked and thermal processed drained meat on polyphosphate pretreatment concentration followed a well defined power function ($P \leq .001$). Added phosphate (as P_2O_5) and the increment of yield increase over controls were directly dependent in a linear manner. These relationships were quantitatively only true within a single lot of shrimp.

(5) The effectiveness of a polyphosphate pretreatment concentration was dependent upon ice storage time post-catch and, although not well documented, the year class composition of a particular lot of shrimp. Degradation during ice storage could have improved effectiveness through (a) a breakdown of the physical structure of shrimp providing more extensive exposure during pretreatment and/or (b) proteolytic degradation of body proteins improving the interaction with polyphosphate. The lower efficiency of polyphosphate for lots composed of older year class shrimp could be directly related to a high ratio of formed (laid down in tissue) to unformed collagen. Lots composed of younger year class shrimp may have possessed a higher content of unformed collagen more susceptible to heat induced

solubilization which was very effectively stabilized by polyphosphate interaction.

(6) Polyphosphate pretreatment increased the water-holding capacity of shrimp meat through steam precooking and subsequent thermal processing. Elevated canned drained meat moisture contents were not quantitatively related to polyphosphate added to meat, but to the increment of yield increase through precooking afforded by a pretreatment. The degraded nature of stabilized protein retained and/or the physico-chemical effectiveness of polyphosphate with this stabilized protein increment was proposed as the cause of increased moisture-holding capacity.

(7) Yield improvement by a polyphosphate pretreatment was accomplished through the retention of solids and moisture through steam precooking. Polyphosphate added to meat through steam precooking did not greatly affect the yield of canned drained meat based on precooked meat weight. Pretreatment with 6% polyphosphate produced increments of drained meat yield (wet wt.) increases over controls ranging from 2.8-4.7 percentage points based upon round shrimp weight; equivalent to 99.6 to 166.7 cans (307x113, 4.5 oz. drained meat wt.) per 1000 lb of round shrimp. Yield increases of 1.68 to 2.71 percentage points were accomplished with a 1.5% pretreatment. These increments of yield increase were accomplished by 224.6 to 256.3 and 108.1 to 109.1 mg added polyphosphate (as

P_2O_5) per 100 gm of drained meat, respectively. The drained meat yield advantage over controls for a polyphosphate pretreatment was further improved by a potential reduction in precooking time required to meet the drained meat weight standard of identity.

(8) Polyphosphate pretreatment did not significantly affect the flavor characteristics of canned shrimp meat. A trend towards a preference for canned meat derived from polyphosphate treated round shrimp with regard to all flavor factors was observed. Neither fill weight or precooking time significantly affected flavor panel scores. Mean panel scores for juiciness, texture and flavor tended to decrease slightly as precooking time was extended. Storage of round shrimp in ice generally reduced flavor panel scores.

(9) The results of this investigation supported two basic actions of polyphosphate in improving yields through steam cooking and subsequent thermal processing: (1) Surface proteins complexed with polyphosphate were rendered a high degree of stability toward heat induced solubilization. (2) Swelling of the proteins composing the surface tissues sealed the surface of the shrimp muscle reducing the loss of moisture and soluble proteins from the interior of the shrimp muscle through steam precooking.

This investigation illustrated the marked loss of edible shrimp meat during the processing of Pacific shrimp which is accentuated by the industry imposed drained meat weight standard of identity. Three opportunities to enhance the canned shrimp meat yield were demonstrated: (1) The application of adequate quantities of polyphosphate to round shrimp prior to steam precooking. (2) Reducing steam precooking time within practical commercial control to only that required to achieve the drained meat standard of identity. (3) Lower the drained meat weight standard of identity which would reduce the solids requirement of a feasible fill weight and the corresponding steam precooking time. This opportunity would further enhance the yield improvement of applied polyphosphates.

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