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 COOKED SHRIMP (PANDALUS JORDANI) MEAT

Abstract approved: ______________________

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Means of improving the cooked meat yield from Pacific shrimp through processing was investigated utilizing a laboratory scale mechanical peeler. The use of a polyphosphate (commercial mixture of sodium tripoly and sodium hexametaphosphate) pretreatment of round shrimp prior to steam precooking and subsequent mechanical peeling was evaluated. The effect of steam precooking time and its interrelationship with a polyphosphate pretreatment on meat yield was determined.

Meat yield (wet and dry weight) and moisture content decreased with respect to steam (101^{o}C) precooking time (sec) according to well defined power regression functions. Precooking induced solubilization of proteins and reduced the water-holding capacity of meat. The loss of soluble meat solids through precooking and the subsequent washing and mechanical action of peeling was dependent on the post-catch age of shrimp. Enzymatic degradation during post-catch ice storage increased the lability of shrimp proteins toward heat induced

solubility through precooking and the water-holding capacity of cooked meat. The meat yield (wet weight) loss for the range of commercially used steam precooking times (80 to 160 sec) for ready-to-eat meat was shown to be 3.6 percentage points; 36 lb of cooked meat/1000 lb of round shrimp.

Polyphosphate complexing of collagen-like and other soluble surface proteins in round shrimp during the initial stages of precooking elevated the intercept of the power regression of meat yield (wet and dry weight) on precooking time. This increment of complexed surface proteins possessed increased moisture-holding capacity and reduced the rate by which non-complexed interior proteins were lost through precooking. The rate of moisture loss through precooking was not affected by a polyphosphate pretreatment over the time range (40 to 240 sec) investigated.

The increment of meat yield increase over non-treated samples produced by polyphosphates was directly related to the concentration of the pretreatment solution or the increment of polyphosphate addition to the cooked meat by a power regression functions. Enzymatic degradation during post-catch ice storage facilitated the access of polyphosphate to body proteins improving their effectiveness. The increment of meat yield increase produced by a polyphosphate pretreatments of equal concentration over nontreated samples was related to post-catch age in a positive linear manner. Very fresh shrimp required higher polyphosphate pretreatment concentrations to optimize meat yield.

Polyphosphate pretreatment concentrations of between 1.5 to 3.0% for approximately 10 min provided optimum meat yield for samples reflecting commercial quality. Extended pretreatment (60 min) did not improve the effectiveness of polyphosphate interaction. Samples of commercial quality yielding 23.32 ± 0.49% cooked meat (4.45 ± 0.14% dry weight) (90 sec precook in steam, 101°C) produced a yield of 27.54 ± 0.83% (5.13 ± 0.14% dry weight) after a 10 min pretreatment in 1.5% polyphosphate; a 4.22 (0.68 dry weight) percentage point meat yield increase equivalent to 42.2 lb cooked meat/1000 lb of round shrimp.

Cooked shrimp meat contained phosphorus levels ranging from 607 to 727 mg P_2O_5/100 gm wet weight. Pretreatment for 10 min in 1.5, 3.0, and 6.0% polyphosphate produced an average increase of 73, 84, and 138 mg P_2O_5/100 gm wet weight over respective control samples; 0.126, 0.145, and 0.238% added polyphosphate (58% P_2O_5).

Treatment of round shrimp in polyphosphate solutions of widely varying concentration did not adversely affect the quality of frozen cooked meat. Flavor panel scores were not significantly reduced by polyphosphate concentrations up to 6.0%. Polyphosphate pretreatment did appear to somewhat accentuate the quality degradation mediated by post-catch ice storage.

The use of polyphosphates (1.5 to 3.0%) for pretreating shrimp just prior to steam precooking produced a marked increase in cooked meat yield. Its interaction with soluble proteins provides a means of reducing the loss of valuable protein through processing without reducing product quality or adding excessive amounts of condensed phosphates to cooked meat.

Effect of Condensed Phosphates and Steam Precooking Time on the Yield and Quality of Cooked Shrimp (<u>Pandalus jordani</u>) Meat

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INTRODUCTION

The Pacific shrimp (Pandalus jordani) is probably one of Oregon's newest seafood fisheries. The per capita consumption of shrimp in the U. S. in 1971 was 1.52 pounds (U. S. Dept. Commerce-NOAA-NMFS, 1973). This fishery began in 1957 and landings in 1977 were 48 million pounds, nearly double the 1976 record of 25.3 million pounds. Thus far the market for shrimp has expanded with increased production.

Shrimp in this fishery are caught with a towed trawl net, separated from trash fish and wash with sea water. The whole shrimp are then packed in alternate layers of ice in boxes or bins in the hold of the trawler according to catch date. The age of landed shrimp varies from one to four days post-catch. Upon landing at processing plants, shrimp are de-iced with potable water and then processed. For small Pacific shrimp, the hand picking cost alone exceeds the sale price of the product (Engesser, 1970; Langmo and Rudkin, 1970). Since the labor costs for picking small shrimp is high, large scale production in Oregon is carried out with the aid of mechanical peeler. After machine peeling, most shrimp meat is frozen vacuum-sealed in metal cans or in film pouches.

Shrimp are commonly held in ice or refrigerated sea water for at least two days so they can be efficiently peeled by machine. A large portion of the total shrimp catch is processed at three or more days post-catch because of the volume of shrimp landed in relation to processing capacity during periods of productive fishing. Holding shrimp increases cost and results in lower yield and quality because of physical damage and leaching of soluble components and development of off flavors and odors (Collins et al., 1960; Collins, 1960a; Collins, 1960b; Seagran et al., 1960; Collins, 1961). The application of polyphosphates to seafood has been shown to be useful in improving moisture retention, organoleptic quality, and preventing drip loss of the processed meat. Means of improving yield is of economic importance for such a high market value product as shrimp.

This investigation was designed to evaluate the effect of condensed phosphates and steam precooking time on the yield and quality of cooked shrimp meat. The relationship of post-catch age and polyphosphate pretreatment concentration and soaking time were investigated.

LITERATURE REVIEW

Life Span and Harvesting of Shrimp

Pink shrimp live in the Pacific Ocean from Alaska to San Diego, California. Fishing occurs between April and October when shrimp are most abundant, particularly on hard bottoms in waters 120-240 feet deep. In late autumn they move into deep waters, 240-1500 feet, where the female carries eggs from about November to April. After the eggs hatch, shrimp move inshore again. The pink shrimp reaches commercial size, about 50 mm, when 2-3 years old and reaches a maximum of about 75 mm at the end of its life span of 3-4 years. Pandalus jordani changes sex; both males and females are hatched, but the males change sex after a period and then behaves as females. Shrimp are caught by towing a trawl net from the stern of the trawler. As the net scrapes over the mud of the bottom, shrimp and other marine life are disturbed and are funneled into the bag or tail of the net. After one to three hours of trawling, the net is hauled aboard and emptied. The shrimp are separated from trash fish, washed with sea water, and stored in the hold of the vessel with alternating layers of ice. The stored whole shrimp may remain there up to four days. The shrimp are transported to the processing plant where they are unloaded and either stored or processed.

Post-catch Deteriorative Changes in Shrimp

Shrimp, like most seafoods, are highly perishable and factors responsible for their spoilage are of special interest to the seafood technologist. Round shrimp begin to undergo a degradative change in muscle proteins immediately post-catch. Deterioration of shrimp quality is generally considered to result from the combined action of enzymes from either tissues or contaminating microorganisms, chemical reactions, and physical handling (Fieger and Friloux, 1954; Flick and Lovell, 1972). Loss of quality during the early periods of storage is mainly caused by autolysis, while longer storage results in deterioration mainly through bacterial action (Fieger and Friloux, 1954). The primary result of autolysis is softening of texture. Although autolysis does not contribute directly to off odors, it may provide products that speed up microbial spoilage. Autolytic products are also capable of serving as substrate for an enzymatic browning reaction found in shrimp (Bailey and Fieger, 1954; Faulkner _et_ _al._, 1954; Bailey _et_ _al._, 1956). Phenol-amine derivatives are converted to melanins which give the shrimp an undesirable black color. Shrimp tissues are more delicate than tissues of other animals because of the reduced hydroxyproline content in shrimp collagen and this may be the reason for ease with which shrimp tissues are degraded by enyzmes (Thompson and Farragut, 1971).

Numerous studies have been made on the microbiological and biochemical changes that occur in shrimp after death. The relative importance of the various spoilage factors towards the quality of shrimp depends upon how the shrimp are handled. Bacteria and digestive enzymes may have a role in the spoilage of small Pacific shrimp which are not cleaned prior to storage in ice. There is an increase in pH upon storage (Bailey et al., 1956; Iyengar et al., 1960; Bethea and Ambrose, 1962; Flores and Crawford, 1973) and the numbers of bacteria increase (Green, 1949; Campbell and Williams, 1952; Fieger and Friloux, 1954; Fieger et al., 1958; Flores and Crawford, 1973). Trimethylamine oxide decreases in a linear manner in whole shrimp, and in the raw and cooked meat during iced storage (Flores and Crawford, 1973; Argaiz, 1976). Storage on ice results in increases in trimethylamine (Collins et al., 1960; Iyengar et al., 1960; Bethea and Ambrose, 1962; Flores and Crawford, 1973). Post-mortem increases in formaldehyde and dimethylamine also occur (Flores and Crawford, 1973; Argaiz, 1976). The carotenoid content of shrimp decreases upon storage and has been proposed as an index of quality (Faulkner and Watts, 1955; Collins and Kelley, 1969; Kelley and Harmon, 1972). Control of these factors is important for maintaining quality and maximizing the shelf life of shrimp.

Processing of Shrimp

Early processing of shrimp involved boiling in water followed by manual removal of the crust or shell. Since this operation required considerable time, labor, and expense, mechanical shelling devices are now being used. Mechanical peelers utilize counter-rotating rollers to pull and separate the inedible portion from the meat (Lapeyre and Coret, 1972; Shrmetta, 1976; Lapeyre, 1977). Two model of Laitram machine peelers are popular in the Pacific region; one which peels shrimp in the raw state and another which conditions the carcasses with a short steam precook prior to peeling. Shrimp peeled with the aid of steam (Model PCA Laitram machines) are usually frozen while shrimp peeled in a raw state (Model A Laitram machines) are usually canned or frozen. The use of these mechanical peelers for small Pacific shrimp in the Northwest reduces the cost of processing by eliminating hand labor in the heading and peeling process (Idyll, 1976).

Collins (1960a) found that freshly caught shrimp, although easy to peel by hand, are difficult to machine peel. He held fresh shrimp in iced or refrigerated sea water for at least two days to facilitate the machine peeling operation. Holding shrimp increases cost and results in lower yield because of physical damage and leaching; the longer that shrimp are held in refrigerated sea water or ice, the more leaching occurs throughout the processing operation (Collins, _et al._, 1960; Seagran, _et al._, 1960; Collins, 1960b; Collins, 1961).

Attempts have been made to increase shrimp quality and improve the peelability of fresh shrimp with various pretreatments prior to machine peeling. Lapeyre (1966) found that cooking whole shrimp prior to peeling produced a better yield and also preserved the naturally pigmented material on the surface of the shrimp meat. Collins and Kelley (1969) noted that peeling properties of fresh pink shrimp were improved by dipping the shrimp in a water bath at 43°C or 54°C for 2 minutes. Lapeyre (1968) reported that a heat pretreatment of shrimp enhanced shell removal efficiency. He observed and theorized that heating induced the formation and accumulation of a fluid and moisture zone between the muscle and shell of the shrimp body. The magnitude of heat induced protein solubility produced by brief citrate buffer pretreatments indicated that the integrity of the entire protein matrix may be stabilized by ionic bonding (Chao, 1979). At the molecular level, ionic bonding may not only link connective tissue proteins to the chitin-mineral matrix of the shell, but provide stability to the entire collagen/pro-collagen matrix of connective tissue between muscle and shell and between muscle segments (Chao, 1979). It is well established that heat and aging facilitate shell removal. The mechanism proposed by Lapeyre (1968) must be modified to account for the reductions in meat yield through the loss of protein during heating and aging associated with improved shell removal.

Application of Condensed Phosphates in Seafood Products

A solution of sodium tripolyphosphate has been shown to be useful in preventing drip loss and improving organoleptic quality of many seafood products. Sutton (1968) reported that polyphosphates had a two fold action; first by reducing the loss of fluid during thawing of frozen fillets and second, by increasing the water-retention of the fillets and thus improving textural properties of the cooked fish. The effect of the polyphosphates on reducing drip loss and preventing the dehydration of the fish muscle which leads to toughening was attributed to the solubilization of certain protein in the fish surface tissues. These proteins, drawn to the surface of the fish flesh, gelatinize and swell to eliminate extracellular spaces through which the fluids could exude from the interior of the fillets. Thus, the surface of the fillets were effectively sealed to prevent drip loss (Love and Abel, 1966).

Much information has been compiled concerning the application of polyphosphate to seafood to improve moisture retention, to prevent drip-loss upon thawing, and to reduce loss of yield upon cooking frozen fish fillets (Mahon, 1962; Mahon and Schneider, 1964; Son and Niven, 1977; Boyd and Southcott, 1965; Love and Abel, 1966). The color (Meyer, 1956) flavor (Mahon, 1962) and tenderness (MacCallum et al., 1964; Spinelli et al., 1968) of raw and cooked fresh fish has also been reported to be improved by treatment with polyphosphates. The effect of the polyphosphates on improving flavor may be due to a dipping effect, masking some of the symptoms of deterioration of poor quality seafood products and may only produce an impression that the quality is better.

The water retention of seafoods other than fish is also increased. Mahon and Schneider (1964) reported that the thawing-drip of frozen scallops was significantly reduced by a dip in a solution of sodium tripolyphosphate. Mathen (1970) found neutral solution of sodium tripolyphosphates improved the thawed and cooked yields of peeled and deveined prawns. The treatment also afforded a protective effect on proteins during frozen storage improving quality and reduced drip loss upon thawing of the frozen product. Garnatz et al. (1949) increased the tenderness of cooked and frozen shrimp to a significant degree by treating them with sodium and potassium phosphates. Bynagte (1972) patented the use of dips in various phosphate solutions to improve the extraction of meat from round shrimp. He claimed that the treatment of shrimp with a combination of 2 to 30% of sodium acid pyrophosphate and 2 to 15% of sodium tripolyphosphate or sodium metaphosphate or sodium hexametaphosphate or sodium trimetaphosphate made the peeling easier, retained the natural color, and improved the yield.

EXPERIMENTAL

Precooking Time and Cooked Meat Yield

A lot (88 kg) of two day old round shrimp was obtained from a commercial source. The shrimp were briefly rinsed in cold fresh water and allowed to drain for a few minutes. The drained shrimp were divided into eight portions, cooked in steam at 101°C for 40, 60, 80, 100, 120, 160, 200, and 240 sec and peeled with a laboratory model mechanical peeler at a rate of 500 gm per min. Remaining shell was then removed by hand. Clean meat yield was reported as percent based upon round shrimp weight prior to steam precooking. The shrimp meat was packed in styrofoam cups with plastic lids (approximately 200 gm per unit) and frozen at -34°C. After freezing, the styrofoam cups were vacuum sealed in moisture proof plastic pouches and stored at -18°C.

Application of Condensed Phosphates

A compound mixture of food grade sodium tripolyphosphate and sodium hexametaphosphate (Brifisol D 510; American Hoechst Corporation, Somerville, N. J.) was used. For purpose of simplicity, the compound mixture of sodium tripolyphosphate and sodium hexametaphosphate is referred to as polyphosphate in the subsequent discussion.

Many of the polyphosphates used by the fish trade are proprietary mixtures marketed under brand names with no information as to proportions of the condensed phosphates present. Therefore, the concentration of this compound mixture is expressed in terms of percent by weight. Investigations were undertaken to evaluate the relationship of precooking time and polyphosphate pretreatment, the effect of polyphosphate concentration, the interrelationship of pretreatment polyphosphate concentration and soaking time, the interaction of polyphosphate pretreatment and iced shrimp age on cooked meat yield and quality.

Precooking Time and Polyphosphate Pretreatment

A lot (78 kg) of three day old round shrimp was obtained from a commercial source. The shrimp were briefly rinsed in cold fresh water and allowed to drain for a few minutes. The drained shrimp were divided into two sub-lots of four portions each. Each portion of the first sub-lot was subjected to 0.6% polyphosphate solution with occasional agitation for a period of 10 min in a solution/round shrimp (wt./wt.) relationship of 1.5. Each portion of the second sub-lot served as a control and was pretreated in water in a similar manner. After draining, the portions from both sub-lots were immediately cooked in steam at 101°C for 40, 80, 140, and 240 sec and peeled with a laboratory model mechanical peeler at a rate of

500 gm per min. Remaining shell was then removed by hand. After determining the cooked meat weight, the shrimp meat was treated in the manner previously described.

Concentration of Polyphosphates

Commercial samples of round shrimp were obtained with a known catch date yielding a wide range of storage times in ice and round shrimp qualities. Six to sixteen kg lots of each sample was subjected to polyphosphate concentrations of 0.0, 0.3, 0.6, 1.5, 3.0, and 6.0% for a period of 10 min in a polyphosphate solution/round shrimp (wt./wt.) relationship of 1.5. The round shrimp was agitated occasionally during the soaking process. After draining, each sample was cooked in steam at 101°C for 90 sec and peeled with a laboratory model mechanical peeler at a rate of 500 gm per min. After removing the remaining shell, the cooked shrimp meat was weighed and the yield computed (wt. cooked meat/wt. round shrimp). Cleaned cooked shrimp meat was then placed in styrofoam cups (approximately 200 gm per unit) and treated in the manner previously described.

Polyphosphate Pretreatment Concentration and Soaking Time

Commercial samples of round shrimp were obtained with a known catch date yielding a wide range of storage time in ice and round shrimp qualities. Six kg lots of each sample was subjected to polyphosphate solutions for time periods of 10, 30, and 60 min in a polyphosphate solution/ round shrimp (wt. / wt.) relationship of 1.5. A sample pretreated for 60 min in water at the same solution/ round shrimp weight relationship served as a control. Polyphosphate solution of 0.3, 0.6, and 1.5% was evaluated for the above listed time periods using triplicate lots for each polyphosphate concentration. The treated samples were drained and cooked in a steam at 101°C for 90 sec and peeled with a laboratory model mechanical peeler at a rate of 500 gm per min. Remaining shell was then removed by hand. Cooked shrimp meat was weighed and the yield was determined. The clean cooked meat was then placed in styrofoam cups (approximately 200 gm per unit) and treated in the manner previously described.

Polyphosphate Pretreatment and Iced Shrimp Age

A 96 kg lot of less than one day old shrimp was obtained from a commercial source. The shrimp were divided into six portions of 16 kg each, transferred to aluminum pans with drainers and held in ice at 2°C. Portions of 16 kg were subjected to polyphosphate concentration of 0 and 1% for 10 min in a polyphosphate solution/ round shrimp (wt. / wt.) relationship of 1.5. The round shrimp was agitated occasionally during the soaking process. After draining, each sample was cooked in steam at 101°C for 90 sec and peeled with a laboratory model mechanical peeler at a rate of 500 gm per min.

Remaining shell was then removed by hand. Cooked shrimp meat was weighed and the yield was determined. The clean cooked meat was then placed in styrofoam cups (approximately 200 gm per unit) and treated in the manner previously described. Portions of 16 kg were similarly processed after 3 and 6 days storage in ice.

Chemical Analysis

Sample Preparation

Samples of frozen precooked shrimp were thawed at refrigerator temperature and the entire contents of a styrofoam cups including the resulting drip were placed in a blender and homogenized into a paste. The homogenized paste was used for the determination of moisture content and phosphorus content.

Determination of Moisture Content

Moisture content was determined according to the method described by AOAC (1970). Homogenized samples (10 gm) were weighed into aluminum pans in triplicate, dried in an oven at 105°C for 16-24 hours and cool in dessicator. Weight loss were reported as percent moisture content.

Determination of Phosphorus Content

Homogenized sample (5 gm) were weighed into 30 ml crucibles in triplicate, dried approximately 16-24 hours at 105°C, and then cooled in dessicator. After determining weight loss, dried samples were charred slowly with a flame. Samples were ashed at 550°C overnight (8 hr). The crucibles were cooled and the ash was transferred to 25 ml flasks in the following manner: 3 x 1.0 ml washes with 6 N HCl followed by 3 x 1.0 ml distilled water washings. Samples were diluted to volume just prior to analysis and phosphorus contents were determined from this diluted phosphorus containing solution using the method described by Bartlett (1959). The phosphorus containing solution was made to 4.0 ml with distilled water and 0.8 ml of 1.25% ammonium molybdate in 6.12 N H_2SO_4 and 0.2 ml of Fiske-SubbaRow reagent were added in succession with mixing. The solution was heated for 7 min at 100°C and the absorbance determined at 830 nm. A standard curve was prepared using KH_2PO_4 solution (1 µg/ml). Phosphorus content was reported as P_2O_5 in mg/100 gm cooked meat wet and dry weight.

Sensory Evaluation

Flavor panel evaluations were carried out after two months post-processing using 20 staff members and students of the Department of Food Science. Frozen samples were thawed overnight at refrigerator temperature and serves in coded cups to judges isolated in individual booths. Panelists were asked to judge the shrimp for odor, texture, flavor, juiciness, and overall-desirability on a nine point desirability scale ranging from "9", highest affirmative value to "1", lowest affirmative value. Evaluation of the effect of polyphosphate concentration was carried out using frozen cooked meat derived from four shrimp samples each treated with 0.0, 1.5, 3.0, and 6.0% polyphosphate pretreatment. Evaluation of the sensory relationship of polyphosphate pretreatment and iced shrimp age was carried out using frozen cooked meat derived from samples after 1, 3, and 6 days ice storage each of which was treated in 0 and 1% polyphosphate solution. Duplicate flavor judgements were carried out with 10 identical judges using a paired/non-paired evaluation design.

Statistical Analysis

Regression analysis (Neter and Wasserman, 1974) was used to determine the relationship of yield wet and dry weight to precooking time, cooked meat moisture content to precooking time, cooked meat moisture content to wet and dry weight yield, wet and dry weight yield and phosphorus content to polyphosphate concentration, wet weight yield and moisture content to phosphorus content, and wet weight yield and moisture content to shrimp age.

Analysis of variance (Snedecor and Cochran, 1967) was used to determine the interrelationship of pretreatment polyphosphate concentration and soaking time on cooked meat yield wet and dry weight, cooked meat moisture content, and phosphorus content; the interaction of polyphosphate pretreatment and shrimp age (ice storage) on cooked meat yield wet and dry weight, cooked meat moisture content, and flavor panel scores; and the effect of polyphosphate concentration on flavor panel scores. Least significant differences (LSD) at the $p \leq 0.05$ level, and correlation coefficients were utilized in assessing the significance of the results.

RESULTS AND DISCUSSION

Effect of Precooking Time on Precooked Meat Yield

Commercial samples of two day old shrimp were used to evaluate the effect of precooking time on meat yield. Moisture content and cooked meat yield were determined and related to precooking time. Precooking time in steam ($101^{o}C$) for 40-240 sec prior to peeling greatly affected the yield and moisture content of the precooked meat derived from round shrimp. The change in cooked meat yield (% wet and dry weight) and meat moisture content with respect to precooking time (40, 60, 80, 100, 120, 160, 200, and 240 sec) is illustrated in Figures 1, 2, 3, and listed in Table 1. The percent wet and dry weight yield and percent moisture content of cooked meat derived from round shrimp decreased in an intrinsically linear manner with respect to precooking time yielding the power regression functions of $Y = 67.907\ X^{-0.170}$ ($r=-0.989$; $p \leq 0.01$), $Y = 10.259\ X^{-0.107}$ ($r = -0.971$; $p \leq 0.001$), and $Y = 85.858\ X^{-0.016}$ ($r = -0.951$; $p \leq 0.001$), respectively.

The recovery of meat from round shrimp was directly related to precooking time. Yield of raw meat from round shrimp was approximately 45 percent wet weight. Steam precooking of round shrimp for 40 an 240 sec greatly reduced the cooked meat yield to 36 and 26 percent, respectively (Table 1). Although steam precooking for

40 sec provided a 10 percentage points of yield advantage over that for 240 sec, the meat was not completely cooked. Shrimp are cooked to provide a product that is ready to eat, and to loosen the meat in the shell prior to peeling. The precooking time should be long enough to develop fully the flavor and texture of the shrimp meat and to loosen the meat from the shell; overcooking can destroy the flavor and reduce meat yield.

Commercial cooking times range from 80 to an excess of 160 sec. A 30 sec variation in cooking time (90-120 sec) would result in a dry weight yield differential of 0.192 percentage points. Conversion of this dry matter yield loss to a moisture equivalent of a 90 sec cook (79.89% moisture) would equal a wet weight yield loss of 0.955 percentage points which is equivalent to 9.55 lb of shrimp meat / 1000 lb of round shrimp. Ten PCA peelers could process 70,000 lb of shrimp per shift. A 30 sec over-cook (90 to 120 sec) would be equivalent to a loss of 668.78 lb of cooked shrimp meat which worth $2675.12 wholesale ($4.00/lb wholesale). With regard to the yield and quality attributes of the cooked meat, the optimum precooking time would be in the range of from 80 to 100 sec (steam; 101°C) depending on the size of shrimp being processed.

Figures 4 and 5 illustrate the relationship of percent moisture content to cooked meat yield (% wet and dry weight). A strong relationship ($r = 0.954$, $p \leq 0.001$ and $r = 0.900$, $p \leq 0.001$, respectively) was found between moisture content and wet and dry weight yield. Yield loss with respect to precooking time was due to a loss of both water and soluble meat solids through steaming and the washing and mechanical action of subsequent peeling (Fig. 4 and 5). These results correspond with the known effects of higher temperatures and longer cooking times in reducing water binding capacity and increasing water evaporation (Hamm and Deatherage, 1960; Bouton, *et al.*, 1976).

Table 1. Yield and moisture content of meat derived from round shrimp[1] after steam[2] precooking for various periods of time.

Precooking time (sec)	Round shrimp wt. (kg)	Meat yield Gm	Meat yield Wet wt. (%)	Meat yield Dry wt.(%)	Moisture content (%)[3]
40	12	4326.5	36.05	6.89	80.88 ± 0.09
60	5	1731.8	34.64	6.66	80.78 ± 0.18
80	14	4414.5	31.53	6.35	79.86 ± 0.20
100	5	1555.5	31.11	6.40	79.44 ± 0.12
120	15	4416.0	29.44	5.97	79.72 ± 0.09
160	15	4348.7	28.99	6.08	79.04 ± 0.07
200	6	1649.6	27.49	5.80	78.90 ± 0.11
240	16	4278.1	26.74	5.68	78.76 ± 0.10

[1] In ice two days post-catch

[2] 101°C

[3] n=6

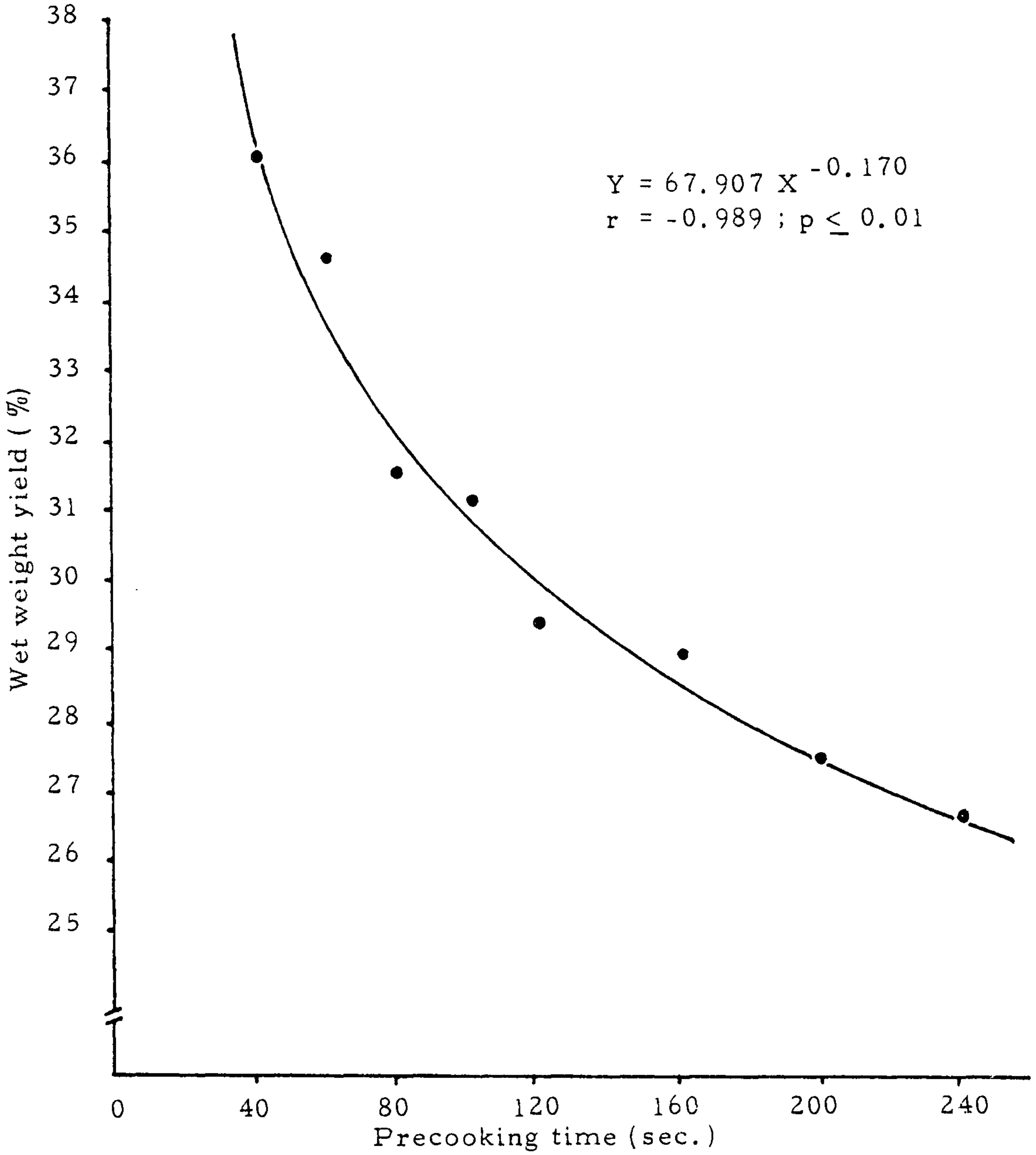

Figure 1. Regression of cooked meat yield (% wet wt.) on round shrimp precooking time.

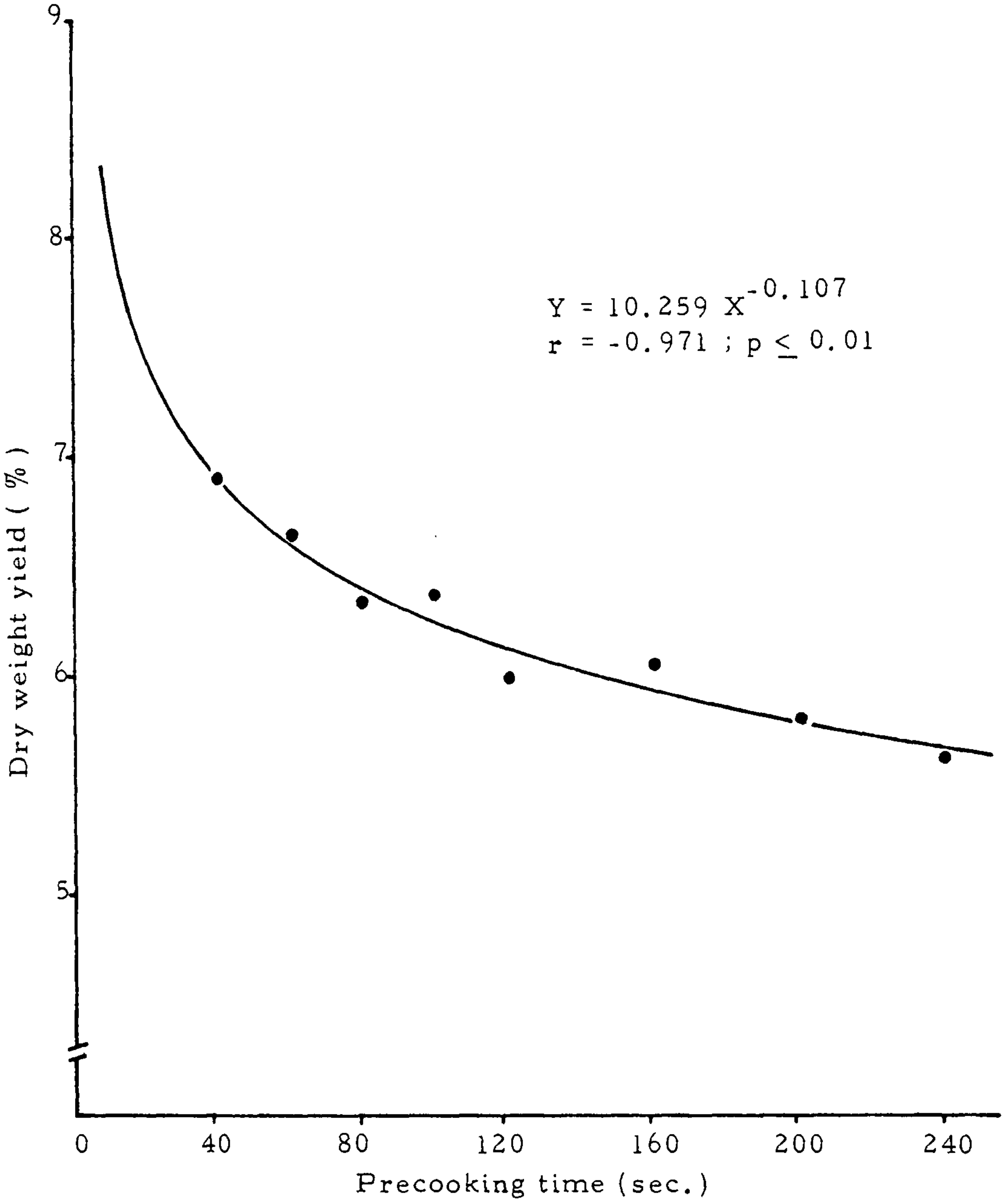

Figure 2. Regression of cooked meat yield (% dry wt.) on round shrimp precooking time.

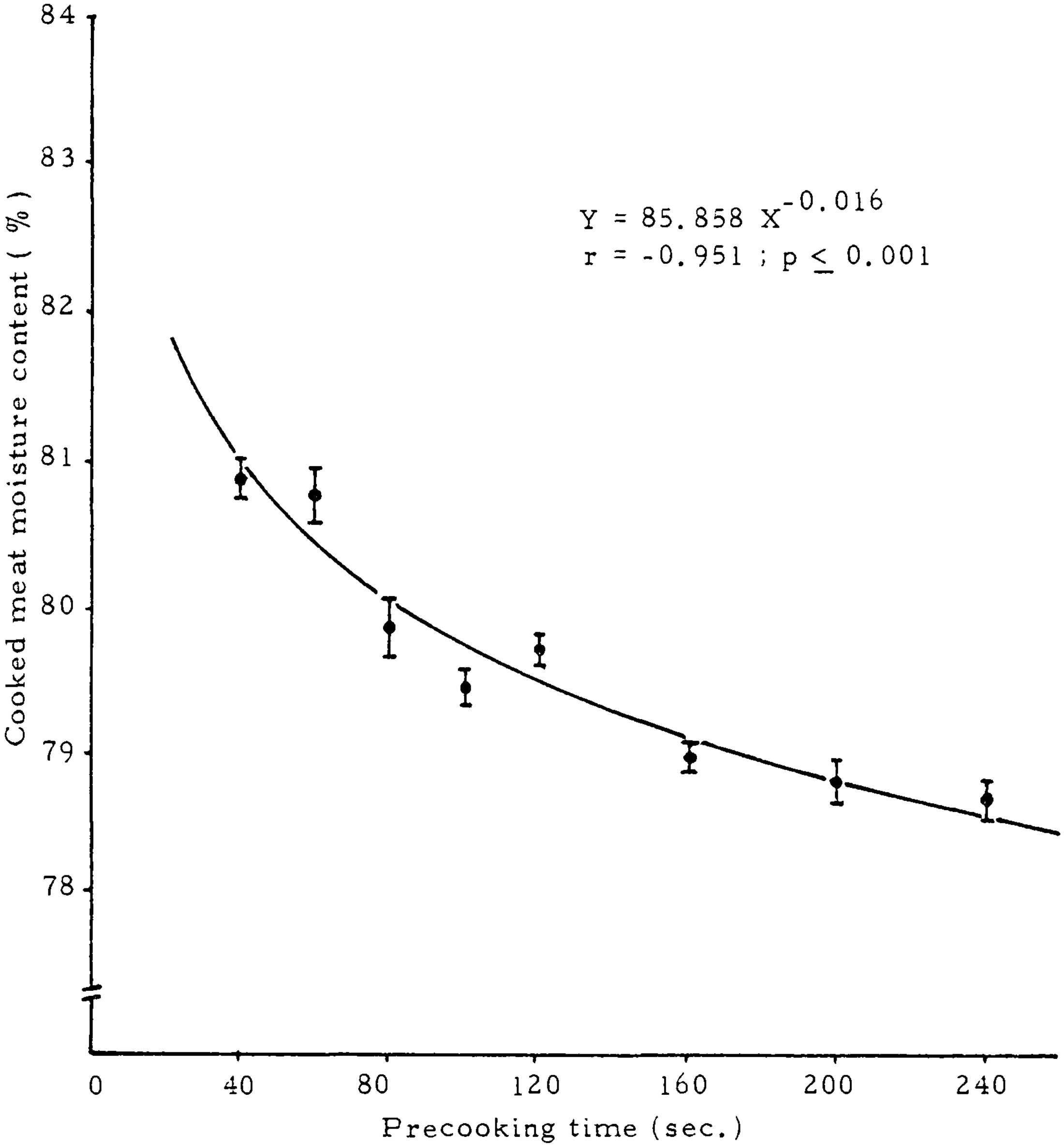

Figure 3. Regression of cooked meat moisture content (%) on round shrimp precooking time.

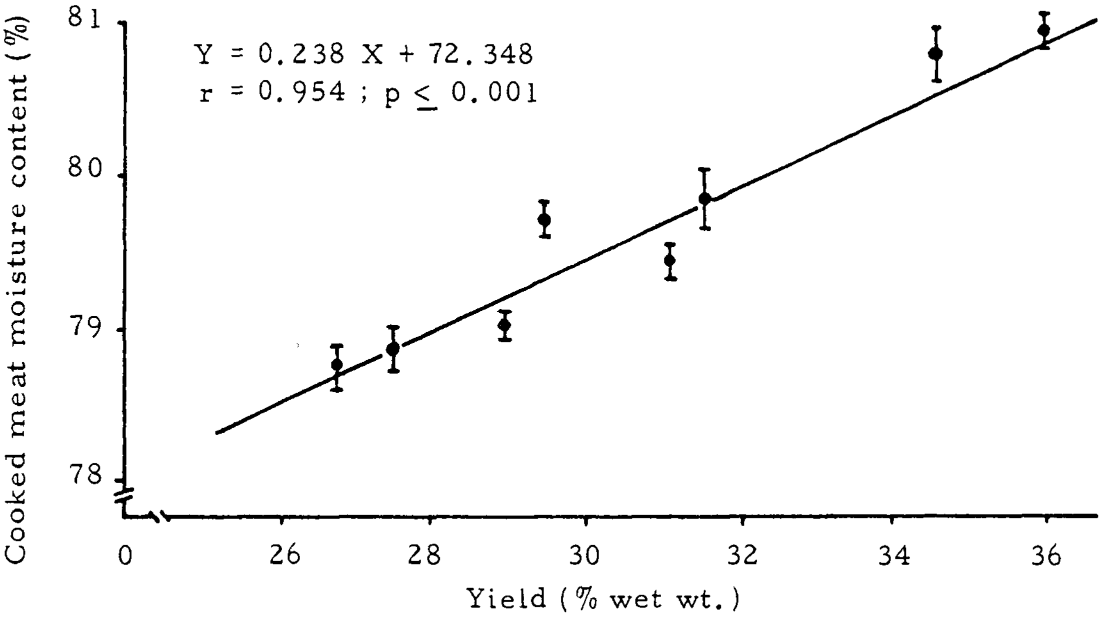

Figure 4. Regression of cooked meat moisture content (%) on yield (% wet wt.).

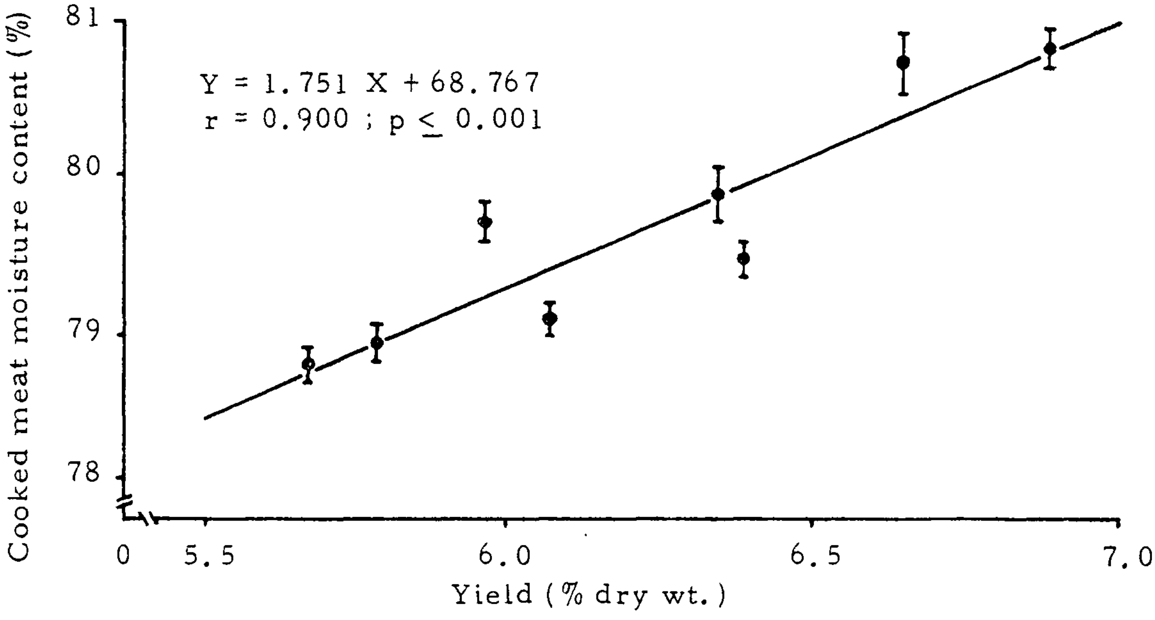

Figure 5. Regression of cooked meat moisture content (%) on yield (% dry wt.).

Effect of Precooking Time and Polyphosphate Pretreatment on Precooked Meat Yield

Commercial samples of three day old shrimp were used to evaluate the relationship of precooking time and polyphosphate pretreatment on cooked meat yield and moisture content. The change in cooked meat yield (% wet and dry weight) and moisture content with respect to precooking time for treated and non-treated samples is illustrated in Figures 6, 7, 8 and listed in Table 2.

Samples peeled without polyphosphate pretreatment showed a yield loss related to precooking time following a power regression pattern similar to that found previously. However, the rate of loss of moisture and soluble proteins as reflected in wet and dry weight yield was more for three day old shrimp than that for two day old shrimp (Fig. 1, 2 and 3) ($m = -.252 > m=-.170$ for wet weight yield, $m = -.176 > m=-.107$ for dry weight yield, and $m = -.019 > m = -.016$ for moisture content). Time and temperature storage relationship prior to processing induce degradative changes in the body protein of round shrimp. It appears this degradation rendered proteins more susceptible to heat induced solubilization. More extensive degradation of the three day old sample of shrimp may have resulted in a loss of protein by the washing action of melting ice during storage reducing its potential yield over that of the two day old sample. The intercept for the power regression of dry weight meat yield on precooking time was 9.336 for three day old shrimp while the intercept for the two day old shrimp was 10.259.

Polyphosphate pretreatment had a positive effect on precooked meat yield and its moisture content. The wet and dry weight yield of cooked meat and moisture content were greatly increased over the controls after various period of cooking (Figures 6, 7, and 8). During the initial stages of cooking, polyphosphate interacted with heat solubilized proteins to decrease the rate at which proteins were heat solubilized and water was eliminated from the product. This stabilization of proteins toward heat solubilization appears to be a function of two possible mechanisms: (a) complexing of surface proteins markedly reduced their susceptibility toward heat solubilization and (b) the complex surface proteins also retarded the loss of non-complex soluble proteins and retained more water through cooking by a physicochemical protection. The greater incremental yield increase of polyphosphate treated over control samples during the initial stages of precooking was probably a reflection of polyphosphate complex surface proteins and a larger portion of non-complex soluble proteins retained through the physical protection afforded by the complex surface proteins.

The wet (Fig. 6) and dry (Fig. 7) weight yield differences between control and polyphosphate pretreatment decreased rapidly during initial stages of precooking (from percentage points of 7.02% wet and

1.02% dry weight at 40 sec cook to percentage points of 5.59% wet and 0.94% dry weight at 80 sec cook), but were relatively stable after 80 sec cook (Figures 6 and 7). Conversely, the rate of moisture loss through cooking for the control ($m = -.019$) and polyphosphate treated ($m = -.019$) samples were equal (Fig. 8). These findings suggest that polyphosphate pretreatment of round shrimp does not greatly retard the rate of moisture loss through precooking, but does retain a rather uniform amount of moisture over control samples. The reduction of the incremental yield increase over controls during subsequent period of cooking reflected partial solubilization of the complex surface proteins. These results emphasized the importance of maintaining an optimum precooking time (ca. 90 sec) even with a polyphosphate pretreatment to obtain optimum yield and water-holding capacity.

Moisture content of the cooked meat from polyphosphate treated samples was directly related to the wet and dry weight yield in a linear manner ($r = 0.986$, $n = 12$; $p \leq .001$ for wet and $r = 0.987$, $n = 12$; $p \leq .001$ for dry weight yield, respectively) (Figures 9 and 10). The same moisture and yield relationship was also observed for the control samples. However, their rate functions were greater than that for the polyphosphate treated samples ($m = 0.290 > m = 0.238$ for wet and $m = 2.006 > m = 1.863$ for dry weight yield). This means that as the yield is decreasing during cooking, more water is lost in control samples. In another word, the treated samples retains more water, thus supporting the physico-chemical protection afforded by the complex surface proteins.

Polyphosphate pretreatment of round shrimp prior to steam (101°C) precooks of 90 and 160 sec increased the dry weight yield over a nontreated sample precooked for 90 sec by 0.89 and 0.45 percentage points, respectively. This dry matter converted to shrimp meat with a moisture equivalent of the control sample precooked for 90 sec (80.23% moisture) would be equal to a wet weight yield increase of 4.501 and 2.276 percentage points, respectively, which would be equivalent to 45.01 and 22.76 lb of shrimp meat/1000 lb of round shrimp. Ten PCA peelers processing 70,000 lb of shrimp per shift could achieve a wet weight yield increase of 3150 and 1593 lb of cooked meat worth $12,600 and $6372 (90 and 160 sec precook, respectively) ($4.00/ lb wholesale) with a 0.6% polyphosphate pretreatment over untreated shrimp precooked for 90 sec. A 70 sec over-cook (90 to 160 sec) for 70,000 lb of polyphosphate treated round shrimp would be equivalent to a loss of 1557 lb of cooked shrimp meat worth $6228. Pretreatment of round shrimp prior to processing coupled with control of precooking times can result in a marked increase in the economic return from processing.

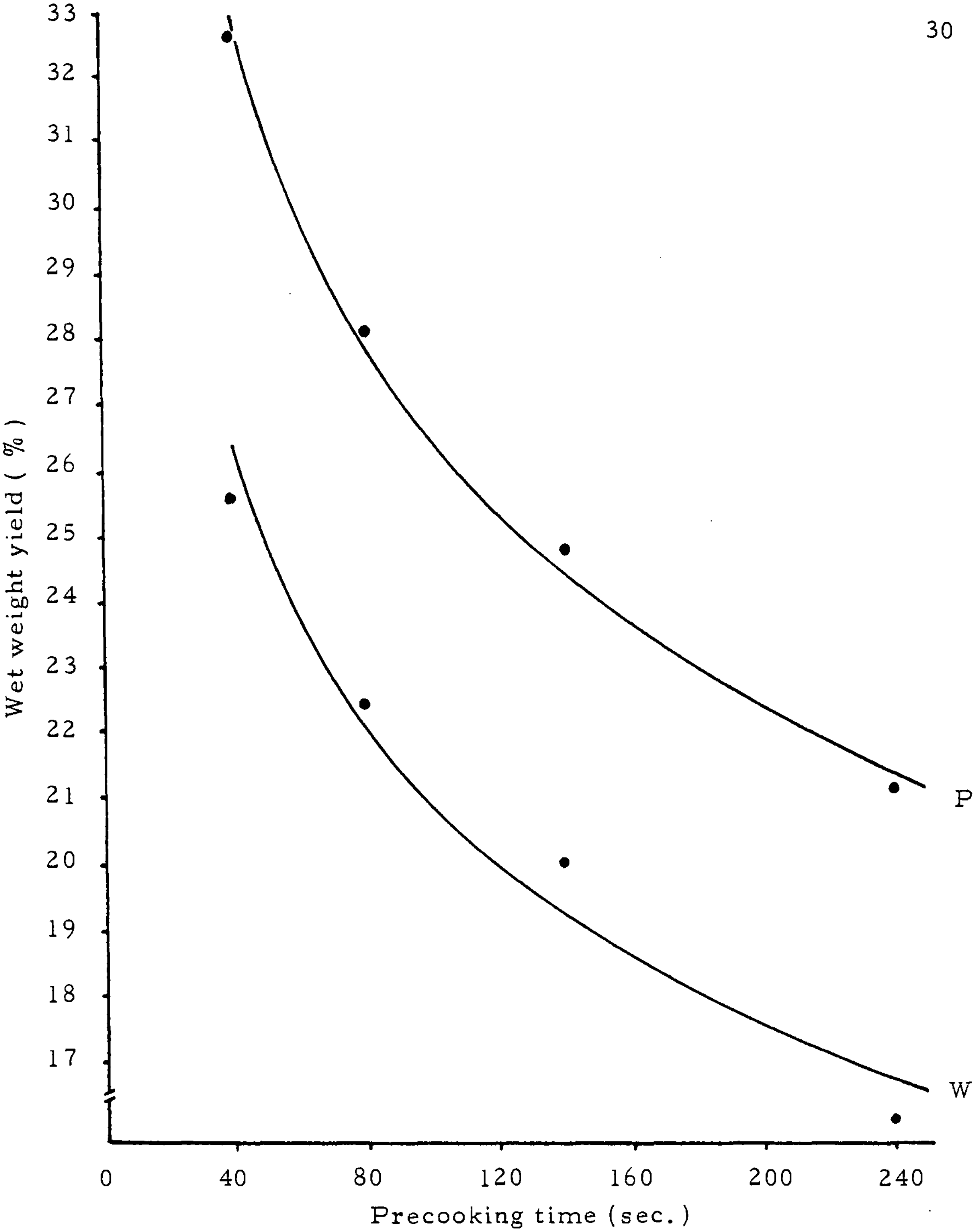

Figure 6. Regression of cooked meat yield (% wet wt.) on the precooking time for polyphosphate and water treated round shrimp. (P = 0.6% polyphosphate solution, 10 min : $Y = 80.350\ X^{-0.240}$, $r = -0.997$; $p \leq 0.01$) (W = water, 10 min : $Y = 66.786\ X^{-0.252}$, $r = -0.979$; $p \leq 0.05$).

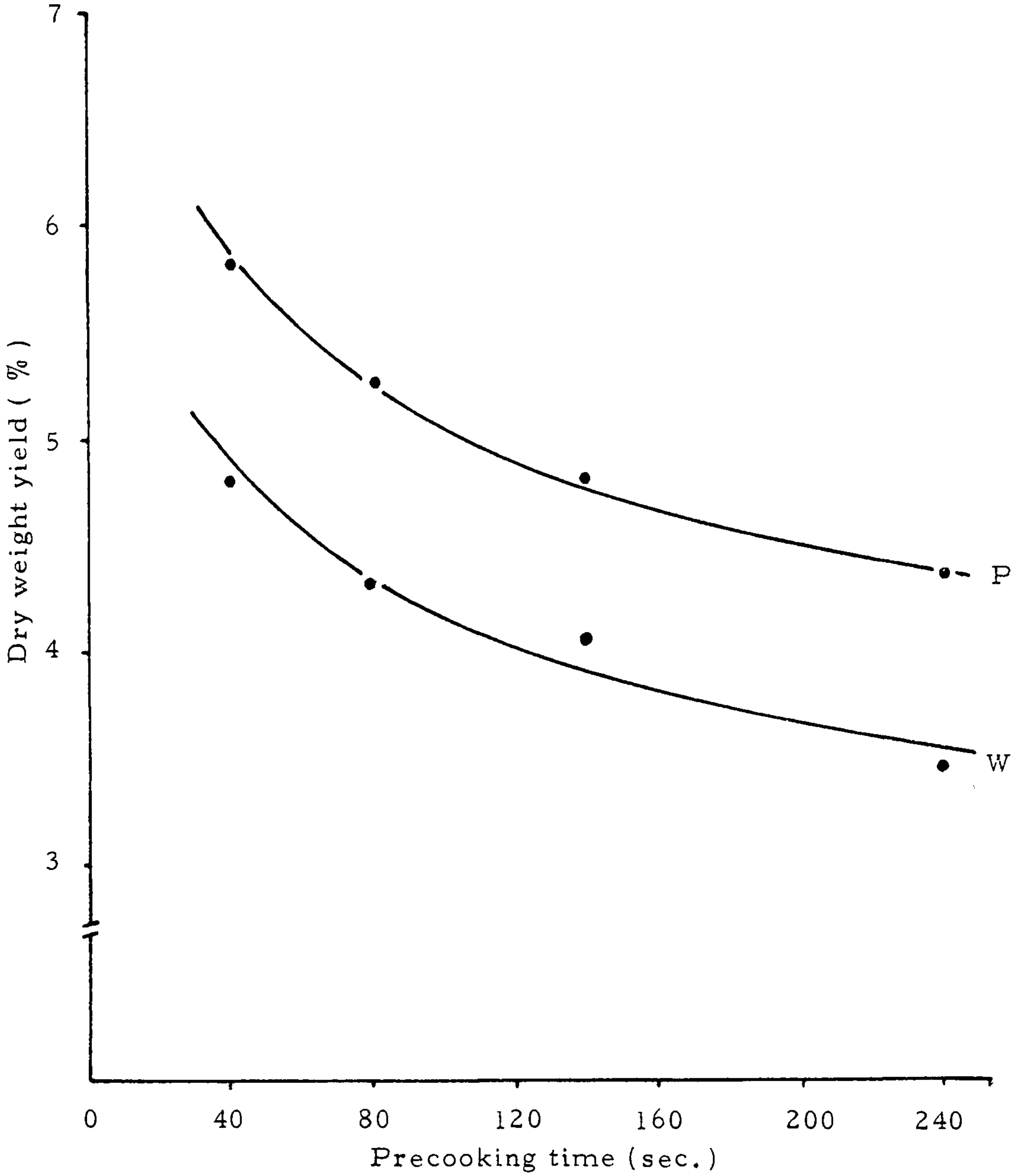

Figure 7. Regression of cooked meat yield (% dry wt.) on the precooking time for polyphosphate and water treated round shrimp. (P = 0.6% polyphosphate solution, 10 min : $Y = 10.635\ X^{-0.162}$, $r = -0.998$; $p \leq 0.01$) (W = Water, 10 min : $Y = 9.336\ X^{-0.176}$, $r = -0.963$; $p \leq 0.05$).

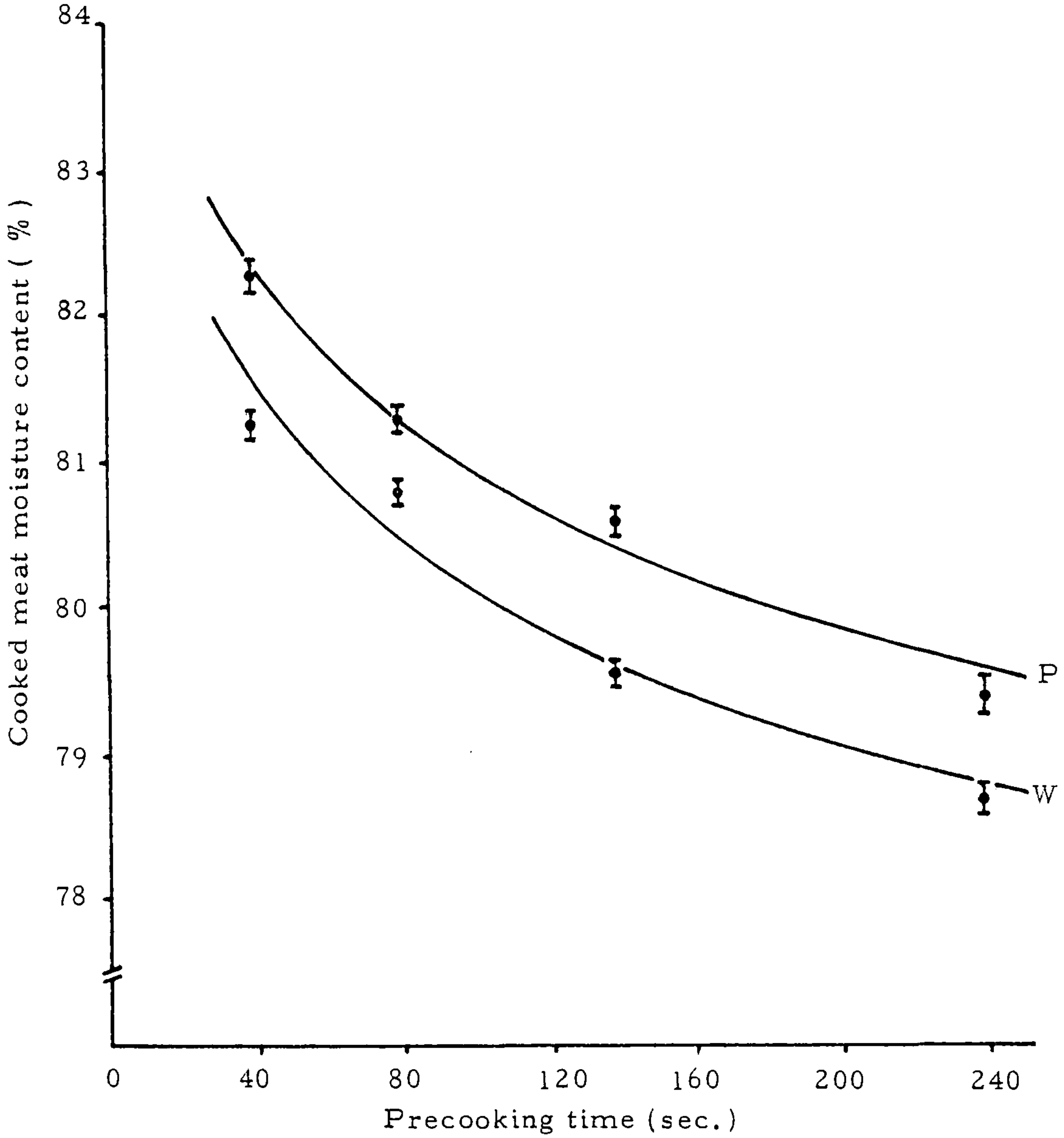

Figure 8. Regression of cooked meat moisture content on the precooking time for polyphosphate and water treated round shrimp. (P = 0.6% polyphosphate solution, 10 min : $Y = 88.212\ X^{-0.019}$, $r = -0.984$; $p \leq 0.001$) (W = Water, 10 min : $Y = 87.42\ X^{-0.019}$, $\bar{r} = -0.977$; $p \leq 0.001$).

Table 2. Yield and moisture content of meat derived from polyphosphate[1] and water treated[2] round shrimp[3] precooked[4] for various periods of time.

Precooking time (sec)	Polyphophate conc. (%)	Round shrimp wt. (kg)	Meat yield			Moisture content[5] (%)
			Gm	Wet wt. (%)	Dry wt. (%)	
40	0.0	8	2055.5	25.69	4.81	81.28 ± 0.07
40	0.6	8	2616.9	32.71	5.83	82.18 ± 0.19
80	0.0	9	2024.8	22.50	4.32	80.79 ± 0.04
80	0.6	9	2528.1	28.09	5.26	81.28 ± 0.03
140	0.0	10	2016.1	20.16	4.13	79.52 ± 0.09
140	0.6	10	2481.4	24.81	4.82	80.58 ± 0.10
240	0.0	12	1932.3	16.10	3.44	78.65 ± 0.06
240	0.6	12	2534.0	21.12	4.35	79.38 ± 0.11

[1] 0.6%   [2] 10 min   [3] In ice three days post-catch   [4] 101°C   [5] n = 3

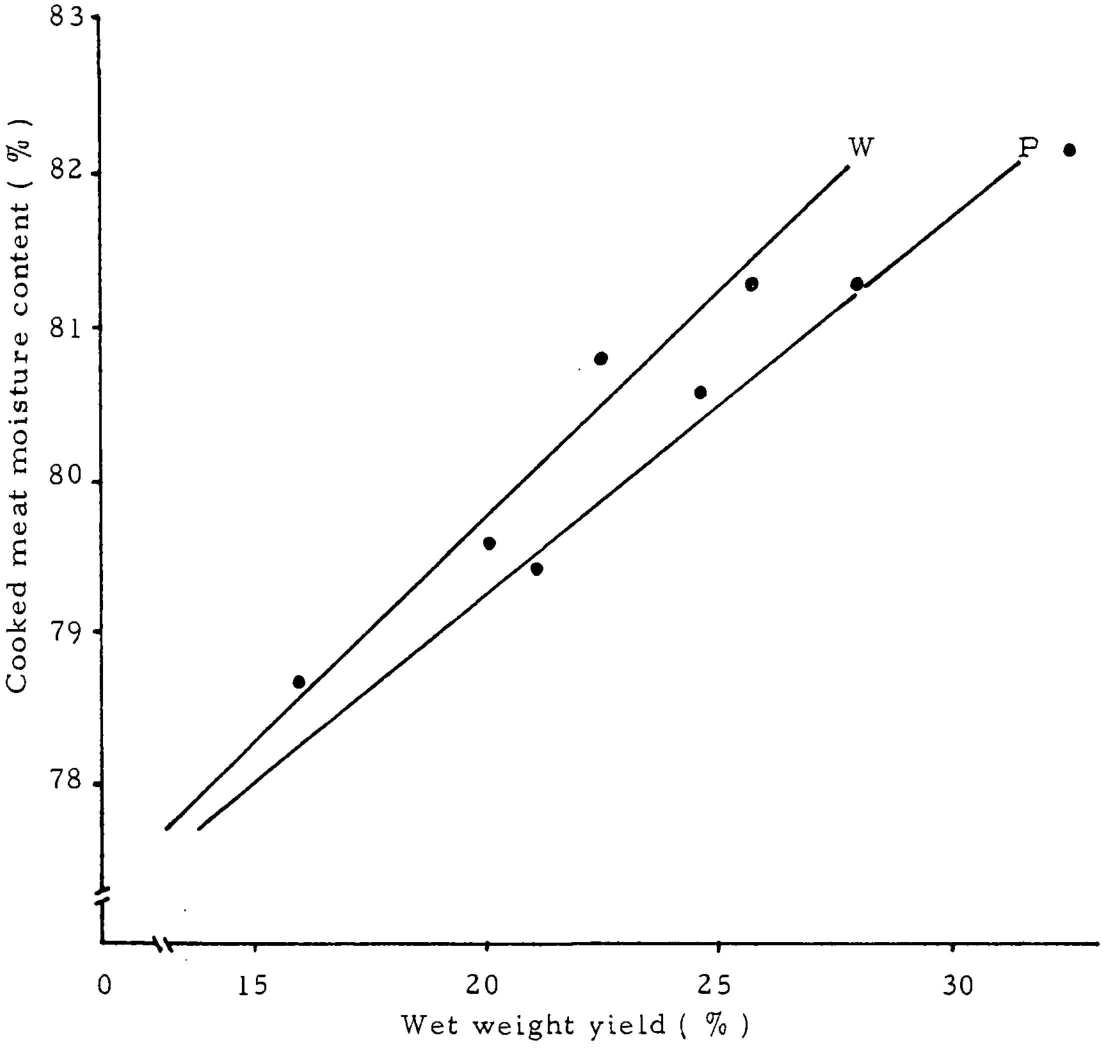

Figure 9. Regression of cooked meat moisture content (%) on yield (% wet wt.) of cooked meat derived from polyphosphate and water treated round shrimp. (W = Water, 10 min : $Y = 0.290 X + 73.996$, $r = 0.977$; $p \leq 0.001$) (P = 0.6% polyphosphate solution, 10 min : $Y = 0.238 X + 74.506$, $r = 0.986$; $p \leq 0.001$).

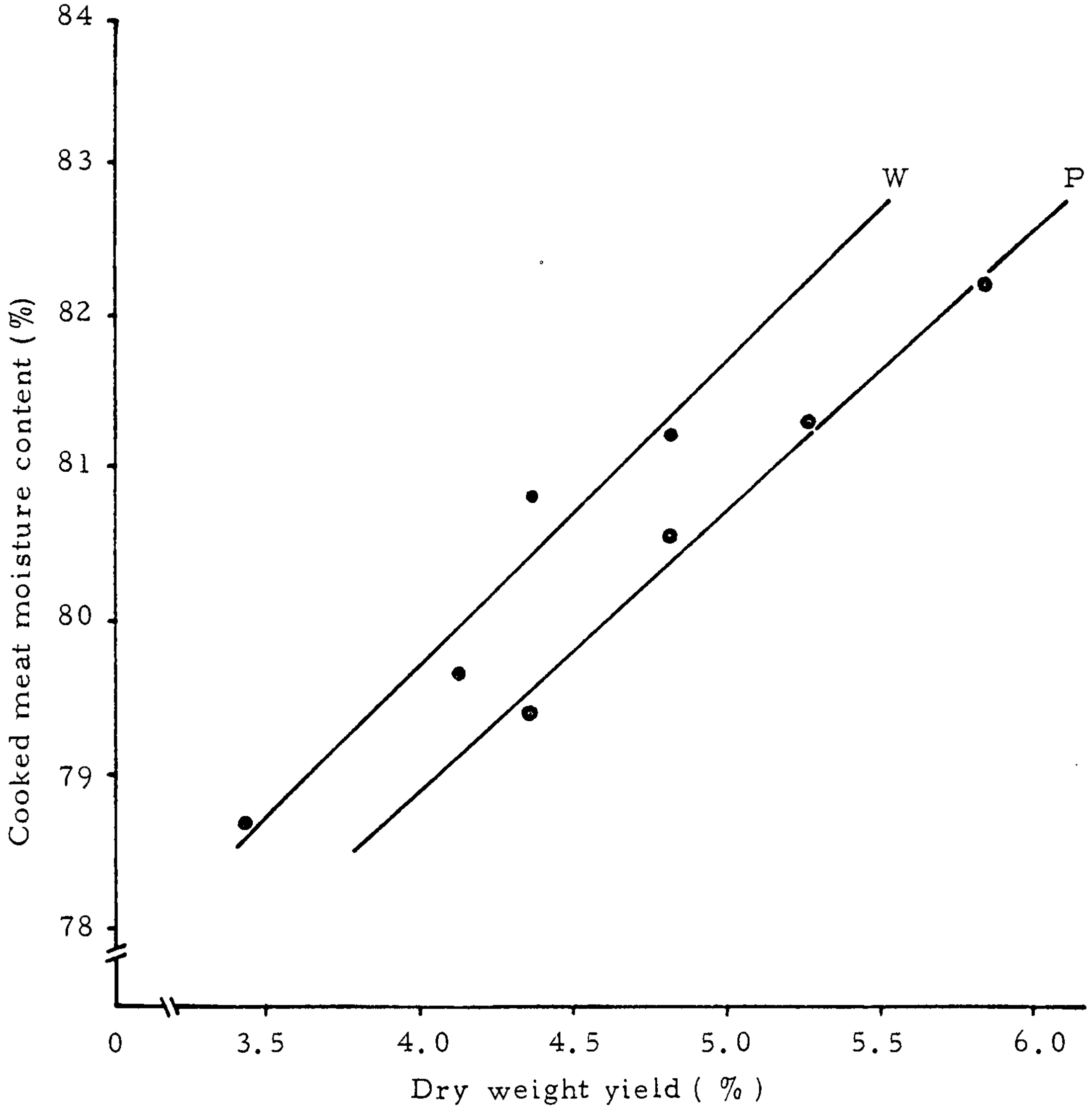

Figure 10. Regression of cooked meat moisture content (%) on yield (% dry wt.) of cooked meat derived from polyphosphate and water treated round shrimp. (W = Water, 10 min : $Y = 2.006 X + 71.686$, $r = 0.952$; $p \leq 0.001$) (P = 0.6% polyphosphate solution, 10 min : $Y = 1.863 X + 71.417$, $r = 0.987$; $p \leq 0.001$).

Effect of Polyphosphate Concentration on Cooked Meat Yield

The enhancement of cooked meat yield by pretreatment of round shrimp in polyphosphate solution (10 min) prior to steam precooking (101°C; 90 sec) and subsequent mechanical peeling was investigated. Shrimp samples represented a wide range of sizes (chronological age) and quality variations induced by time and temperature relationships representative of commercial post-catch handling and pre-processing storage conditions. The effect of a wide (0.0, 1.5, 3.0, 6.0%) and narrow (0.0, 0.3, 0.6, 1.5%) range of pretreatment polyphosphate concentration were evaluated using two groups of samples, each composed of four replicate lots.

The degree of yield improvement produced over-all by a pretreatment was dependent upon polyphosphate concentration. Treatment in polyphosphate solution (0.0 - 6.0%) (Tables 3 and5) produced yield increases directly related to the power regression functions of $Y = 24.310\ X^{0.132}$ ($r = 0.839$, $n = 32$; $p \leq .005$) wet weight and $Y = 4.647\ X^{0.108}$ ($r = 0.750$, $n = 32$; $p \leq .005$) dry weight. Based upon these over-all power regression functions, 43.9 and 44.5% of the wet and dry weight meat yields, respectively, of the total yield incremental increase produced by a 6.0% polyphosphate treatment was achieved with a 1.5% polyphosphate solution. A 3.0% polyphosphate treatment produced 68.6 and 69.7%, respectively, of this yield potential. Cooked meat yield for all control lots range from 22.75 to 26.55% (24.31 ± 1.44; n = 8) wet weight and from 4.27 to 5.41% (4.69 ± 0.40%; n = 8) dry weight (Tables 3 and 5). Treatment in 1.5% polyphosphate solution produced yields ranging from 26.67 to 31.80% (28.18 ± 1.64; n = 8) wet weight and from 5.00 to 5.69% (5.26 ± 0.27; n = 8) dry weight resulting in a mean percentage point increase of 3.87% wet and 0.57% dry weight, respectively, over control samples.

The quality status and/or size composition of individual shrimp samples was directly related to the polyphosphate concentration dependency of cooked meat yield improvement. The increment of meat yield increase (percentage points) by a 1.5% polyphosphate pretreatment over respective control samples was positively related to post-catch age in a linear manner ($r = 0.762$, $n = 8$; $p \leq .05$) (Tables 3 and 5). Three of the four samples composing the first group of samples (Table 3) were far superior to shrimp normally processed; meat yields ranged from 23.26 to 26.55% (25.30 ± 1.42%) wet and from 4.41 to 5.41% (4.93 ± 0.44%) dry weight. Commercial cooked meat yields average 22% wet weight. Treatment of these samples with 1.5% polyphosphate produced incremental yield (percentage point) increases ranging from 1.08 to 5.97 (3.53 ± 2.00, n = 4) which represented 23.9 to 88.3% of the potential yield produced by a 6.0% polyphosphate pretreatment. Pretreatment in 3.0% polyphosphate did not greatly improve yield or the uniformity of response by the different samples; percentage point wet weight yield increases over respective controls ranged from 1.31 to 5.91 (3.86 ± 1.90, n = 4). Only after a 6.0% treatment was the incremental yield increase more uniformly optimized over that observed after a 1.5% treatment; the percentage point yield increase over respective controls ranged from 4.53 to 6.76 (5.58 ± 1.23, n = 4).

Control samples of shrimp composing the second group of samples treated with a narrow range of polyphosphate concentrations (0 - 1.5%) (Table 5) produced yields closely resembling that common to commercial production; yields ranged from 22.75 to 23.85% (23.32 ± 0.49%; n = 4) wet and from 4.27 to 4.61 (4.45 ± 0.14%; n = 4) dry weight. Treatment of these samples in only a 1.5% polyphosphate solution produced more uniformly optimized yields to a range of from 26.67 to 28.55% (27.54 ± 0.83%; n = 4) wet and from 5.00 to 5.29% (5.13 ± 0.14%; n = 4) dry weight; a mean percentage point increase in yield over control samples of 4.22 wet and 0.68 dry weight.

The yield response of polyphosphate treated samples over controls appears to be directly related to the degree of deterioration induced by post-catch storage. Deterioration of the physical structure of shrimp during storage would allow access of solution to the muscle and/or body structure increasing the degree of interaction or the amount of polyphosphate occluded to the shrimp upon entry into the steam precooker. More concentrated polyphosphate solutions would disrupt membranes of physically intact shrimp allowing more efficient exposure of polyphosphates to the shrimp muscle. Although optimum cooked meat yield was achieved with a 6.0% solution, the meat yield of shrimp with a quality status common to commercial operations would be most economically improved by concentration greater than 1.5, but less than 3.0%.

The phosphorus content (P_2O_5, mg %) of cooked meat from polyphosphate treated shrimp samples was directly related to the polyphosphate concentration (0.0, 1.5, 3.0, 6.0% solution) yielding the power regression functions of $Y = 671.710\ X^{0.093}$ ($r = 0.818$, $n = 16$; $p \leq 0.005$) mg % wet and $Y = 3510.643\ X^{0.114}$ ($r = 0.816$, $n = 16$; $p \leq 0.005$) mg % dry weight (Table 3). The cooked meat phosphorus content for the control samples ranged from 607 to 727 (670 ± 51, n = 4) mg % wet and from 3177 to 3626 (3490 ± 212, n = 4) mg % dry weight. Polyphosphate pretreatment of shrimp samples with 1.5, 3.0, and 6.0% solution yielded a cooked meat with an average phosphorus content of 743 ± 5 (739-751), 754 ± 27 (714 - 774), 808 ± 48 (762 - 871) mg % wet and of 3985 ± 232 (3642 - 4158), 4070 ± 251 (3791-4298), 4388 ± 332 (4066-4852) mg % dry weight, representing an average increase of 73, 84, 138 mg % wet and 495, 580, 898 mg % dry weight, respectively, over controls (Table 4).

These increases converted to polyphosphate (Brifisol D 510, 58% P_2O_5) would be equal to an average increase in polyphosphate of 0.126, 0.145, and 0.238%, respectively, over controls. Scheurer (1968) also found the concentration of sodium tripolyphosphate in the haddock fillets to be directly proportional to the concentration of the salt in the dip solution.

The incremental increase of cooked meat phosphorus content (wet weight) by polyphosphate pretreatment over respective control samples positively contributed to the increment of wet weight yield increase by a well defined power regression function of $Y = 0.374 X^{0.539}$ ($r = 0.788$, $n = 12$; $p \leq 0.005$). The resulting average increase of 73 ± 51, 84 ± 62, 138 ± 84 ($n = 4$) mg % phosphorus wet weight in cooked meat achieved by 1.5, 3.0, 6.0% polyphosphate pretreatments respectively, corresponded to average wet weight yield increases of 3.53 ± 2.00, 3.86 ± 1.90, 5.58 ± 1.23 ($n = 4$) percentage points over control samples. The quality and/or size composition for individual shrimp samples reflected its incremental increases in phosphorus (wet and dry weight). Cooked meat from five day old shrimp contained 607 mg % P_2O_5 wet wt., the lowest content found in the four control samples. The treatment of this sample with polyphosphate solutions considerably increased the phosphorus contents over the control; 184.9, 182.1, and 191.3% of the average increase (mg % wet wt., n = 4) achieved with 1.5, 3.0, and 6.0 % polyphosphate pretreatment, respectively.

The yield improvement by a polyphosphate pretreatment was associated with the increase in cooked meat moisture content. The moisture content for all control lots (Tables 3 and 5) range from 79.61 to 81.45 % (80.73 ± 0.61, n = 8). A 1.5% polyphosphate treatment produced cooked meat with moisture ranging from 79.78 to 82.11% (81.32 ± 0.68, n = 8) resulting in a mean percentage point increase of 0.59% over control samples. A variation in moisture response among individual samples appeared to be related to the quality of shrimp. The incremental increase (percentage points) of cooked meat moisture content over respective control samples by a 1.5% polyphosphate pretreatment was directly related to post-catch age in a linear manner ($r = 0.843$, $n = 8$; $p \leq 0.01$). Treatment with 3.0 and 6.0% polyphosphate solution (Table 3) further increased the cooked meat moisture content yielding the range from 79.82 to 82.30% (81.51 ± 1.14, n = 4) and from 79.91 to 82.61% (81.68 ± 1.21, n = 4) which represent a mean percentage point increase of 0.97 and 1.14, respectively, over control samples. The associated increase (percentage points over respective control samples) in cooked meat moisture content produced by polyphosphate pretreatment was positively related to the incremental increase of cooked meat

Table 3. Yield and moisture and phosphorus content of meat derived from round shrimp pretreated with a wide range of polyphosphate concentrations prior to precooking[1]

Shrimp age (days)	Polyphosphate conc. (%)	Round shrimp wt. (kg)	Meat yield (gm)	Moisture content (%)[2]	Cooked meat yield (%)		Phosphorus level (mg P_2O_5/100 gm)	
					wet wt.	dry wt.	wet wt.	dry wt.
2	0.0	6	1594	79.61	26.55	5.41	727	3537
	1.5	6	1658	79.78	27.63	5.59	739	3642
	3.0	6	1672	79.82	27.86	5.62	766	3791
	6.0	6	1865	79.91	31.08	6.24	818	4066
5	0.0	6	1550	80.04	25.83	5.16	607	3177
	1.5	6	1908	82.11	31.80	5.69	742	4158
	3.0	6	1905	82.30	31.74	5.62	760	4266
	6.0	6	1956	82.61	32.59	5.67	871	4852
2	0.0	16	4086	81.45	25.54	4.74	656	3626
	1.5	16	4622	81.67	28.88	5.29	741	4060
	3.0	16	4741	82.06	29.63	5.32	774	4298
	6.0	16	4810	82.13	30.06	5.37	762	4280
3	0.0	16	3722	81.05	23.26	4.41	691	3619
	1.5	16	4323	81.49	27.02	5.00	751	4079
	3.0	16	4384	81.87	27.40	4.97	714	3924
	6.0	16	4768	82.08	29.80	5.34	780	4356

[1] 90 sec at 101°C

[2] n=3

Table 4. Mean[1] yield and moisture and phosphorus content of meat derived from round shrimp pretreated with a wide range of polyphosphate concentrations prior to precooking[2]

	Polyphosphate solution (%)			
	0.0	1.5	3.0	6.0
wet wt. yield (%)	25.30 (±1.42)[3]	28.83 (±2.12)	29.16 (±1.97)	30.88 (±1.27)
dry wt. yield (%)	4.93 (±0.44)	5.39 (±0.31)	5.38 (±0.31)	5.66 (±0.42)
moisture content (%)	80.54 (±0.86)	81.26 (±1.02)	81.51 (±1.14)	81.68 (±1.21)
P_2O_5 (mg % wet wt.)	670.25 (±51.17)	743.25 (± 5.32)	753.50 (±26.95)	807.75 (±48.20)
P_2O_5 (mg % dry wt.)	3489.75 (±212)	3984.75 (±232)	4069.75 (±251)	4388.50 (±332)

[1] n = 4 [2] 90 sec at 101°C [3] ( ) = S. D.

Table 5. Yield and moisture content of meat derived from round shrimp pretreated with a narrow range of polyphosphate concentrations prior to precooking[1]

Shrimp age (days)	Polyphosphate conc. (%)	Round shrimp wt. (kg)	Meat yield (gm)	Moisture content (%)[2]	Cooked meat yield (%)	
					wet wt.	dry wt.
2	0.0	5.0	1155	80.89	23.11	4.42
	0.3	6.0	1380	80.95	23.00	4.38
	0.6	6.0	1540	81.30	25.67	4.80
	1.5	5.5	1491	81.50	27.10	5.01
3	0.0	6.0	1415	80.93	23.58	4.50
	0.3	6.0	1365	80.90	22.75	4.34
	0.6	6.0	1644	81.55	27.41	5.06
	1.5	6.0	1713	81.47	28.55	5.29
3	0.0	6.0	1365	81.23	22.75	4.27
	0.3	6.0	1502	81.36	25.04	4.67
	0.6	6.0	1475	80.97	24.57	4.68
	1.5	6.0	1600	81.26	26.67	5.00
3	0.0	6.0	1431	80.66	23.85	4.61
	0.3	6.0	1560	81.16	26.00	4.90
	0.6	6.0	1635	81.35	27.26	5.08
	1.5	6.0	1669	81.27	27.82	5.21

[1] 90 sec at 101°C

[2] n = 3

Table 6. Mean[1] yield and moisture content of meat derived from round shrimp pretreated with a narrow range of polyphosphate concentrations prior to precooking[2]

	Polyphosphate solution (%)			
	0.0	0.3	0.6	1.5
wet wt. yield (%)	23.32 (±0.49)	24.20 (±1.58)	26.23 (±1.36)	27.54 (±0.83)
dry wt. yield (%)	4.45 (±0.14)	4.57 (±0.26)	4.90 (±0.20)	5.13 (±0.14)
moisture content (%)	80.93 (±0.23)	81.09 (±0.21)	81.29 (±0.24)	81.38 (±0.13)

[1] n = 4 [2] 90 sec at 101°C [3] ( ) = S. D.

phosphorus content (mg % wet over respective control samples) in a linear manner ($r = 0.817$, $n = 12$; $p \leq 0.005$).

Since pretreatment of round shrimp with polyphosphate provided a finite amount of phosphorus occluded to the cooked meat, the yield response of polyphosphate treated samples over controls was probably a result of the interaction between polyphosphate and shrimp muscle. During the pretreatment (10 min), polyphosphate penetrated through the pores of the shrimp cuticle and interacted or complexed with the protein matrix of the subcuticle and other proteins, leading to an increase in the solubility of the protein. These solubilized proteins then swelled the surface tissues and sealed it to prevent the loss of fluid and soluble solid components. The complexed surface proteins markedly reduced their susceptibility toward heat solubilization during steam precooking. Therefore, more surface proteins and its associated water-holding capacity were conserved through cooking.

Effect of Polyphosphate Pretreatment Concentration and Soaking Time on Cooked Meat Yield

The interrelationship of polyphosphate solution concentration and soaking time prior to steam precooking (101°C; 90 sec) and subsequent mechanical peeling was investigated. The effects of a narrow (0.3, 0.6, and 1.5%) range of pretreatment polyphosphate concentration in relationship to various soaking times (10, 30, and 60 min) were evaluated using commercial samples. Samples pretreated in water for 60 min served as control.

Pretreatment of shrimp in polyphosphate solution (0.3, 0.6, and 1.5%) significantly ($p \leq 0.01$) improved the cooked meat yield. The mean of wet weight yield (Table 7) for all control lots of 22.26 ± 0.64% (n = 9) was improved to 26.26 ± 1.48, 26.74 ± 1.34, and 28.61 ± 0.95% (all based on level mean, n = 9) for lots treated with 0.3, 0.6, and 1.5% polyphosphate solution, respectively. Meat yield dry weight reflected the improvement observed on a wet weight basis (Table 8).

Varying the soaking time (10, 30, and 60 min) in polyphosphate solution did not significantly ($p \geq 0.05$) improve yield. Mean yield, however, did show a small degree of irregular soaking time dependency. Mean yields wet and dry weight from samples soaked for 60 min were all inferior to either a 10 or 30 min soak. The level mean of meat yield after 10, 30, and 60 min pretreatment were 27.16 ± 1.47, 27.40 ± 1.68, and 27.05 ± 1.81 (n = 9) %, respectively. Polyphosphate concentration did not significantly ($p \geq 0.05$) interact with soaking time.

The highest concentration of polyphosphate evaluated (1.5%) was clearly the most effective with respect to the relationship of soaking time to yield. A 1.5% polyphosphate pretreatment (10 min) increased the wet weight yield over controls by 6.56 percentage points. The dry weight yield (Table 8) of meat generally reflected the changes observed for the wet weight yield.

Neither polyphosphate pretreatment concentration nor soaking time significantly ($p \geq 0.05$) affected cooked meat moisture content (Table 9). Based upon level mean ranking, moisture content did increase slightly with respect to polyphosphate concentration and soaking time. Level mean of moisture content for a 10 min pretreatment was 80.86 $\pm$ 1.10 ($n = 9$)%. Pretreatment after 30 and 60 min increased the level mean of moisture content to 81.10 $\pm$ 1.22 ($n = 9$) and 81.40 $\pm$ 1.23 ($n = 9$)%, respectively. Mean moisture for all control lots was 80.93 $\pm$ 1.15 ($n = 9$)%. Based upon the mean for controls, 0.17 and 0.47 percentage points of moisture increase over controls was achieved with 30 and 60 min pretreatment, respectively.

The phosphorus content (P_2O_5, mg % wet and dry weight) of cooked meat varied significantly ($p \leq 0.01$) with regard to polyphosphate concentration (Tables 10 and 11). The mean of phosphorus content for all control lots of 581 $\pm$ 32 ($n = 9$) mg % wet weight was increased to 592 $\pm$ 33, 632 $\pm$ 26, and 673 $\pm$ 31 (based on level mean, $n = 9$) resulting in an incremental level mean increase of 11, 51, and 92 mg percentage points wet weight (Table 10). Varying the soaking time did not significantly ($p \geq 0.05$) increase the phosphorus content of cooked meat. Polyphosphate concentration did not significantly

($p \geq 0.05$) interact with soaking time. The dry weight phosphorus content of cooked meat generally reflected the changes observed for the wet weight content. The highest mean of phosphorus content (wet and dry weight) was achieved after a 1.5% polyphosphate pretreatment and the content increased slightly as the soaking time was extended. The incremental increase of mean phosphorus content over controls after a 1.5% polyphosphate pretreatment (10 min) were 65 mg % wet and 498 mg % dry weight, respectively.

Time and temperature relationship during the soaking process may enhance the deterioration of shrimp body proteins. A longer soak would allow more deterioration of the physical structure of shrimp to occur increasing the interaction between polyphosphate and shrimp body proteins. The higher incremental increase in wet and dry weight yield observed by the polyphosphate pretreatment over respective controls, comparing to previous results, was probably due to the loss of yield from controls through cooking. This greater loss was induced by the higher degree of deterioration which occurred during the extended 60 min soaking in water.

Table 7. Yield (% wet wt.) of precooked[1] meat from round shrimp pretreated in varying concentrations of polyphosphate for varying time periods.

Polyphosphate conc. (%)	Rep./shrimp age (days)	control	Soaking time (min)			Polyphosphate treatments
			10	30	60	
0.3	1/2	22.06	26.17	25.95	26.78	
	2/2	22.35	24.85	24.95	23.95	
	3/4	23.05	28.14	27.64	27.93	
	Mean	22.49	26.39^{a}	26.18^{a}	26.22^{a}	26.26
	S.D.	0.51	1.65	1.36	2.06	1.48
0.6	1/2	22.06	27.78	27.87	27.61	
	2/2	22.96	25.56	25.13	24.58	
	3/3	22.50	26.97	28.30	26.90	
	Mean	22.51	26.77^{a}	27.10^{ab}	26.36^{a}	26.74
	S.D.	0.45	1.12	1.72	1.58	1.34
1.5	1/3	22.18	29.44	29.53	29.83	
	2/2	22.32	28.50	29.26	28.08	
	3/2	20.85	27.08	27.97	27.78	
	Mean	21.78	28.34^{a}	28.92^{b}	28.56^{a}	28.61
	S.D.	0.81	1.19	0.83	1.11	0.95

	Factorial analyses	
	F-value	Ranking of level means
Polyphosphate conc.	6.594[2]	$\underline{1.5} > \underline{0.6 > 0.3}$
Soaking time	0.137[3]	$\underline{30 > 10 > 60}$
Conc. x time	0.099[3]	

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[1] 90 sec at 101°C [2] Sig. $p \leq 0.01$ [3] N.S. $p \geq 0.05$

Mean values in a column with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$)

Table 8. Yield (% dry wt.) of precooked[1] meat from round shrimp pretreated in varying concentrations of polyphosphate for varying time periods.

Polyphosphate conc. (%)	Rep./shrimp age (days)	control	Soaking time (min)			Polyphosphate treatments
			10	30	60	
0.3	1/2	4.24	5.16	5.02	5.06	
	2/2	4.60	5.10	5.09	4.78	
	3/4	4.00	5.07	4.80	4.64	
	Mean	4.28	5.11^{a}	4.97^{a}	4.83^{a}	4.97
	S.D.	0.30	0.05	0.15	0.21	0.18
0.6	1/2	4.24	5.00	5.24	4.96	
	2/2	4.60	5.10	4.94	4.86	
	3/3	4.18	5.16	5.30	4.86	
	Mean	4.34	5.09^{a}	5.16^{ab}	4.89^{a}	5.05
	S.D.	0.23	0.08	0.19	0.06	0.16
1.5	1/3	3.96	5.11	4.96	5.11	
	2/2	4.09	5.54	5.48	5.32	
	3/2	4.27	5.44	5.68	5.55	
	Mean	4.11	5.36^{a}	5.37^{b}	5.33^{b}	5.35
	S.D.	0.15	0.22	0.37	0.22	0.26

Factorial analyses

	F-value	Ranking of level means
Polyphosphate conc.	8.815[2]	1.5 > 0.6 > 0.3
Soaking time	1.866[3]	10 > 30 > 60
Conc. x time	0.468[3]	

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[1] 90 sec at 101°C [2] Sig. $p \leq 0.01$ [3] N.S. $p \geq 0.05$

Mean values in a column with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Table 9. Moisture content (%) of precooked[1] meat from round shrimp pretreated in varying concentrations of polyphosphate for varying time periods.

Polyphosphate conc. (%)	Rep./shrimp age (days)	control	Soaking time (min) 10	30	60	Polyphosphate treatments
0.3	1/2	80.77	80.27	80.65	81.12	
	2/2	79.41	79.49	79.61	80.03	
	3/4	82.66	81.99	82.64	83.37	
	Mean	80.95	80.58	80.97	81.51	81.02
	S.D.	1.63	1.28	1.53	1.70	1.37
0.6	1/2	80.77	82.02	81.19	82.05	
	2/2	79.97	80.05	80.35	80.21	
	3/3	81.44	80.85	81.26	81.93	
	Mean	80.73	80.97	80.93	81.40	81.10
	S.D.	0.73	0.99	0.51	1.03	0.79
1.5	1/3	82.16	82.65	83.22	82.85	
	2/2	81.68	80.55	81.27	81.05	
	3/2	79.53	79.90	79.71	80.02	
	Mean	81.12	81.03	81.40	81.31	81.25
	S.D.	1.40	1.44	1.75	1.43	1.35

	Factorial analyses F-value	Ranking of level means
Polyphosphate conc.	0.065[2]	1.5 > 0.6 > 0.3
Soaking time	0.361[2]	60 > 30 > 10
Conc. x time	0.080[2]	

[1] 90 sec at 101°C   [2] N.S. $p \geq 0.05$

Level means with the same underline did not vary significantly ($p = 0.05$).

Table 10. Phosphorus content (mg P_2O_5/100 gm wet wt.) of precooked[1] meat from round shrimp pretreated in varying concentrations of polyphosphate for varying time periods.

Polyphosphate conc. (%)	Rep./shrimp age (days)	control	Soaking time (min)			Polyphosphate treatments
			10	30	60	
0.3	1/2	537	600	546	548	
	2/2	599	624	634	621	
	3/4	545	587	606	564	
	Mean	560	604^a	595^a	578^a	592
	S.D.	33.7	18.8	44.9	38.4	33.0
0.6	1/2	537	575	645	634	
	2/2	593	603	646	646	
	3/3	616	645	643	654	
	Mean	582	608^a	645^{ab}	645^b	632
	S.D.	40.6	35.2	1.5	10.1	26.0
1.5	1/3	607	608	684	689	
	2/2	607	720	678	692	
	3/2	585	668	647	677	
	Mean	600	665^b	670^b	686^b	673
	S.D.	12.7	56.0	19.8	7.9	31.4

	Factorial analyses	
	F-value	Ranking of level means
Polyphosphate conc.	15.060^2	$\underline{1.5} > \underline{0.6} > \underline{0.3}$
Soaking time	0.350^3	$\underline{30 > 60 > 10}$
Conc. x time	0.970^3	

[1] 90 sec at 101°C [2] Sig. $p \leq 0.01$ [3] N.S. $p \geq 0.05$

Mean values in a column with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Table 11. Phosphorus content (mg P_2O_5/100 gm dry wt.) of precooked[1] meat from round shrimp pretreated in varying concentrations of polyphosphate for varying time periods.

Polyphosphate conc.	Rep./shrimp age (days)	control	Soaking time (min) 10	30	60	Polyphosphate treatments
0.3	1/2	2803	3060	2834	2895	
	2/2	2915	3044	3107	3261	
	3/4	3138	3280	3475	3390	
	Mean	2952	3128^{a}	3138^{a}	3182^{a}	3149
	S.D.	170.5	131.9	219.5	256.8	217.5
0.6	1/2	2803	3200	3414	3523	
	2/2	2963	3017	3287	3272	
	3/3	3313	3357	3414	3621	
	Mean	3026	3191^{a}	3372^{ab}	3472^{ab}	3345
	S.D.	260.8	170.2	73.3	180.0	178.5
1.5	1/3	3389	3528	4109	4003	
	2/2	3309	3681	3622	3648	
	3/2	2831	3312	3184	3370	
	Mean	3176	3507^{a}	3638^{b}	3674^{b}	3606
	S.D.	301.7	185.4	462.7	317.3	305.1

Factorial analyses

	F-value	Ranking of level means
Polyphosphate conc.	7.060^{2}	1.5 > 0.6 > 0.3
Soaking time	0.964^{3}	60 > 30 > 10
Conc. x time	0.162^{3}	

[1] 90 sec at 101°C [2] Sig. $p \leq 0.01$ [3] N.S. $p \geq 0.05$

Mean values in a column with the same exponent letter did not vary significantly (p = 0.05).

Level means with the same underline did not vary significantly (p = 0.05).

Effect of Polyphosphate Pretreatment and Iced Shrimp Age on Yield and Quality of Cooked Meat

The relationship between the post-catch age of shrimp and meat yield enhancement by a polyphosphate pretreatment was investigated. The effect of a water and 1% polyphosphate pretreatment prior to steam precooking (101°C; 90 sec) and subsequent mechanical peeling was evaluated for shrimp stored in ice (2°C) for 1, 3, and 6 days post-catch.

The degree of yield improvement by the polyphosphate pretreatment was directly related to ice storage. The increment of meat yield increase (percentage points) by the pretreatment over respective control samples after 1 and 3 days storage in ice was 2.73 and 9.71 wet and 0.53 and 1.50 dry weight, respectively (Table 12). The yield response by the pretreatment was not uniformly optimized after 6 day ice storage; the increment yield increase over respective controls was 8.25 wet and 1.13 percentage points dry weight which was slightly less than that observed after 3 day ice storage.

Extended storage of shrimp in ice resulted in a reduction of meat yield. Meat yield after 1 day ice storage for the controls was 22.68% wet and 4.57% dry weight. Storage of shrimp in ice for 3 and 6 days resulted in a yield loss of 6.27 and 3.22 percentage points wet and 1.42 and 1.14 dry weight, respectively. This yield loss reflected the degradative process induced by post-catch storage. Polyphosphate pretreatment retarded this loss in meat yield during storage.

The dry weight yield after one day ice storage was 5.10% for polyphosphate treated samples. After 3 and 6 day ice storage, treated samples produced yields of 4.65 and 4.56% dry weight reflecting a reduction of 0.45 and 0.54 percentage points, respectively. Although the dry weight yield was reduced during ice storage, the polyphosphate pretreatment of shrimp after 6 day ice storage still provided a meat yield approximating that for controls after 1 day of ice storage. With respect to wet weight yield, polyphosphate treated shrimp showed a small increase during ice storage. Based upon the yield after 1 day ice storage (25.41%), 0.71 and 2.30 percentage points of yield increase were achieved after 3 and 6 day ice storage, respectively.

The wet weight meat yield improvement by the polyphosphate pretreatment during ice storage was associated with an increase in cooked meat moisture content. The increment of increase in moisture content over respective controls after 1, 3, and 6 days was 0.07, 1.35, and 1.16 percentage points, respectively. However, both controls and pretreated samples showed an increase in moisture content during extended storage in ice. The increment of increase (percentage points) in moisture content after 3 and 6 day ice storage over that observed after 1 day ice storage was 0.98 and 2.53 for controls and 2.26 and 3.62 for polyphosphate treated samples, respectively.

Table 12. Yield and moisture content of meat derived from round shrimp stored for various time periods in ice[1] and pretreated[2] with polyphosphate solution prior to precooking.[3]

Ice storage (days)	Polyphosphate conc.(%)	Round shrimp wt. (kg)	Meat yield			Moisture content (%)
			Gm	Wet wt.(%)	Dry wt.(%)	
1	0	16	3629.5	22.68	4.57	79.85 ±0.20
1	1	16	4065.8	25.41	5.10	79.92 ±0.01
3	0	12	1969.2	16.41	3.15	80.83 ±0.03
3	1	12	3134.5	26.12	4.65	82.18 ±0.20
6	0	14	2724.6	19.46	3.43	82.38 ±0.22
6	1	12	3324.7	27.71	4.56	83.54 ±0.01

[1] 2°C [2] 10 min [3] 90 sec at 101°C

Meat yield reduction related to ice storage was complicated by an increase in moisture content. The degree of moisture increase was greater for the pretreated samples than that for controls. Based upon the incremental increase observed for the controls after 3 and 6 day ice storage, 1.28 and 1.09 percentage points increase in moisture content over controls was found for treated samples stored in ice for the same time period. Since pretreatment of shrimp with polyphosphate retained more water and retarded the loss of dry matter through cooking, the incremental increase in wet weight yield observed during extended ice storage for the polyphosphate treated samples was due to the partial replacement of dry matter with water. The results showed that pretreatment of shrimp with polyphosphate improved the yield and moisture retention of the cooked meat through cooking and that the effect was more pronounced for older shrimp.

Mechanism for the Improvement in Meat Yield of Shrimp by Condensed Phosphates and Steam Precooking

The addition of polyphosphate increases the water-holding capacity of muscle proteins only at pH values > IP and to an extent which increased with rising pH (Hamm and Grau, 1958). They also suggested that the influence of salts of phosphates is due to an elimination of the alkaline-earth ions in muscle by precipitation, sequestering, or ion exchange. The effect of polyphosphates on meat hydration appears to be a function of three factors: (a) the change of pH values, (b) the non-specific effect of ionic strength, and (c) the specific effects of the polyphosphate, which are due to certain interaction between the anion and the myofibrillar proteins (Hamm, 1971).

The results of this investigation showed that pretreatment of shrimp with polyphosphate increased wet and dry weight yield, moisture, and phosphorus contents of the cooked meat (Tables 3 and 5; Figures 6, 7, 8). Increases in yields and phosphorus content were concentration dependent (Table 4). The incremental mean increase of wet and dry weight yield and moisture content over respective controls was correlated well with the increased phosphorus content of cooked meat (Table 3).

Pretreatment of shrimp in a solution of polyphosphate would allow access of polyphosphate to the muscle and/or body structure of shrimp and consequently increase the pH and ionic strength of their environment. Weiner _et_ _al_. (1969) found that dissociation of actomyosin to actin and myosin could occur at ionic strength as low as 0.15. Binding of polyphosphates with muscle proteins results in an increase of polar groups on the protein increasing their solubility (Linko and Nikkila, 1961; Hamm, 1971). Concurrently, interaction of polyphosphate with the protein matrix of the sub-cuticle (collagen-like proteins) and other proteins would lead to an increase in the electrostatic repulsion and the solubility of the proteins. These protein-polyphosphate complexes (loosening of the molecular structure) then swelled and sealed the surface tissues preventing the loss of fluid and soluble solid components resulting in a yield improvement through steam precooking.

Thompson and Thompson (1968, 1970a, and 1970b) found the composition of the connective tissue of white shrimp (Penaeus setiferous) to be largely composed of "collagen-like" proteins which differed from collagen of vertebrates and other invertebrates by the replacement of hydroxyproline with tryptophan in its amino acid composition. This collagen-like proteins of the shrimp would be readily susceptible to heat solubilization. The reduction of rate at which proteins were heat solubilized together with the consistent maintaining of moisture retention through steam precooking indicated that complexed collagen-like proteins were less susceptible to heat solubilization. These complexed surface proteins retarded the loss of non-complexed soluble proteins from the interior of the shrimp body and retained more water in an immobilized state through cooking.

The degree of yield improvement by polyphosphate pretreatment was enhanced by deterioration process induced by post-catch storage. Storage of round shrimp in ice mediated a proteolytic degradation of shrimp body protein increasing the access of solution to the muscle proteins and their degree of interaction. The proteolytic degradation was documented by the storage time dependent increase in the water-holding capacity of meat through cooking (Table 12).

In summary, the mechanism by which meat yield and water-holding capacity was improved through the action of polyphosphate and steam precooking could have as a basis the following physico-chemical functions: (1) The pretreatment of round shrimp with polyphosphate formed protein-polyphosphate complexes. The degree of polyphosphate-complex formation was enhanced by the degradation process occurring during ice storage. The complexed proteins then swelled and sealed the surface tissues preventing the loss of fluid and soluble solid components through steam precooking. (2) Complexing of collagen-like proteins markedly reduced their susceptibility toward heat solubilization. The complexed surface proteins also retarded the loss of non-complex soluble proteins from the interior of the shrimp body and retained more water through cooking by a physical protection.

Sensory Evaluation of the Quality of Cooked Meat Derived from Round Shrimp Pretreated in Polyphosphate Solution

Flavor panels were carried out after two months frozen storage to evaluate the effect of polyphosphate concentration and the interrelationship of polyphosphate concentration and ice storage on frozen shrimp quality. Pretreatment of round shrimp prior to steam precooking and subsequent mechanical peeling with polyphosphate solutions of varying concentration (Tables 3 and 4) did not affect the quality of frozen cooked meat (Tables 13 and 14). Factorial analysis of variance showed that odor, texture, juiciness, flavor, and overall-desirability did not vary significantly with regard to polyphosphate concentration or sample replication. Polyphosphate concentration did not interact significantly with sample replicates with regard to all sensory factors. Inspection of individual treatment means for polyphosphate treated samples did show some reduction for scores over control samples, but differences were not significant ($p \geq 0.05$).

Mean scores for the odor, texture, juiciness, and overall-desirability of cooked meat derived from shrimp age for varying period in ice ($2^{O}C$) (1, 3, and 6 days) treated with water and polyphosphate solution (Table 12) are listed in Tables 15, 16, 17, 18, and 19, respectively. Cooked meat derived from control samples did not show a significant difference in mean scores for the odor, texture, and juiciness during ice storage, but mean scores for flavor and overall-desirability were significantly reduced after three and six day ice storage. Scores for the juiciness and odor of polyphosphate treated samples were not significantly reduced by ice storage of the round shrimp. Texture, flavor, and overall-desirability scores were significantly reduced after three and six days of storage. The interaction between shrimp age and treatment was not significant. Flores and Crawford (1973), Argaiz (1976), and Madero (1978) showed a similar quality deterioration in cooked meat during ice storage of round shrimp.

Pretreatment of round shrimp after one day storage in ice with polyphosphate showed a small but non-significant increase of mean scores for texture, juiciness, flavor, and overall-desirability based upon individual treatment mean ranking. Although factorial analysis showed no significant difference between cooked meat derived from non-treated and treated round shrimp, scores for treated samples were somewhat reduced from those observed for non-treated samples after three and six days of ice storage. This was particularly true for texture scores. The polyphosphate pretreatment appeared to accentuate the quality deterioration mediated by the ice storage of round shrimp.

The effect of polyphosphate in improving flavor of seafood products is disputed. Claims for improved flavor may be due to the dipping effects masking some of the symptoms of deterioration of poor quality seafood products and may only give the impression that the quality is better. Spinelli _et al._ (1968) detected no differences in flavor or odor when they directly compared fishfillets or steaks dipped in polyphosphate solutions with controls. The addition of sodium tripolyphosphate to dips for fishfillets has been reported to significantly improved the texture and tenderness of the treatedfillets over controls (MacCallum et al., 1964; Spinelli et al., 1968). Garnatz et al. (1949) also increased the tenderness of cooked and frozen shrimp to a significant degree with a treatment of sodium and potassium phosphates.

The results of these flavor panel evaluations support the positive effect of polyphosphate on the quality of fresh frozen cooked meat derived from shrimp stored in ice for short periods of time. The improvement in quality was not documented for meat derived from treated round shrimp of poor quality. Conversely, a polyphosphate pretreatment appeared to somewhat accentuate storage induced quality deterioration. The magnitude of this quality difference, although not significant, needs further investigation, particularly in relation to long term frozen storage of cooked shrimp meat.

Table 13. Mean[1] flavor panel scores for frozen meat derived from round shrimp treated[2] with varying concentrations of polyphosphate prior to steam precooking[3] and subsequent peeling.

Pretreatment conc. (%)	Sensory factor				
	odor	texture	juiciness	flavor	overall-desirability
0.0	6.98	6.60	6.98	6.51	6.49
1.5	6.84	6.62	6.80	6.36	6.32
3.0	7.02	6.61	6.80	6.38	6.36
6.0	6.85	6.45	6.86	6.40	6.38

[1] n = 80 judgements [2] 10 min [3] 90 sec at 101°C

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value

Table 14. Analysis of variance[1] of panel scores for frozen meat derived from round shrimp treated[2] with varying concentrations of polyphosphate prior to steam precooking[3] and subsequent peeling.

Sensory factor source of variation	F-Value			Factor means ranking[4]	
	Samples (S)	Conc. (C)	S X C	Samples	Concentration
Odor	0.796[5]	0.346[5]	0.185[5]	3 > 4 > 2 > 1	3.0 > 0.0 > 6.0 > 1.5
Texture	0.820[5]	0.181[5]	0.638[5]	2 > 1 > 3 > 4	1.5 > 3.0 > 0.0 > 6.0
Juiciness	1.313[5]	0.248[5]	0.517[5]	2 > 3 > 1 > 4	0.0 > 6.0 > 1.5 > 3.0
Flavor	0.091[5]	0.111[5]	0.204[5]	1 > 4 > 3 > 2	0.0 > 6.0 > 3.0 > 1.5
Overall-desirability	0.054[5]	0.135[5]	0.195[5]	2 > 3 > 1 > 4	0.0 > 6.0 > 3.0 > 1.5

[1] Factorial design: $a = 4$, $b = 4$, $n = 20$

[2] 10 min

[3] 90 sec at 101°C

[4] Factor level means with the same underline did not vary significantly ($p = 0.05$).

[5] N.S. $p \geq 0.05$

Table 15. Mean odor scores for frozen cooked[1] meat derived from polyphosphate treated[2] and non-treated round shrimp stored in ice for various time periods.

Shrimp age (days)	Mean[3]	Polyphosphate conc. (%) 0	Polyphosphate conc. (%) 1
1	age	6.35^a	6.10^a
3	age	6.35^a	6.30^a
6	age	6.40^a	6.15^a

	Factorial analyses F-value	Factorial analyses Ranking of level means
Age (A)	0.053[4]	$\underline{3 > 6 > 1}$
Polyphosphate (P)	0.536[4]	$\underline{0 > 1}$
A x P	0.071[4]	

[1] 90 sec at 101°C   [2] 10 min   [3] n = 20   [4] N.S. $p \geq 0.05$

Mean scores in a column (age) with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value

Table 16. Mean texture scores for frozen cooked[1] meat derived from polyphosphate treated[2] and non-treated round shrimp stored in ice for various time periods.

Shrimp age (days)	Mean[3]	Polyphosphate conc. (%) 0	Polyphosphate conc. (%) 1
1	age	6.40^a	6.65^a
3	age	5.50^a	4.95^b
6	age	5.55^a	4.70^b

	Factorial Analyses	
	F-value	Ranking of level means
Age (A)	7.087[4]	1 > 3 > 6
Polyphosphate (P)	1.280[5]	0 > 1
A x P	0.939[5]	

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[1] 90 sec at 101°C

[2] 10 min

[3] n = 20

[4] Sig. $p \leq 0.01$

[5] N.S. $p \geq 0.05$

Mean scores in a column (age) with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value

Table 17. Mean juiciness scores for frozen cooked[1] meat derived from polyphosphate treated[2] and non-treated round shrimp stored in ice for various time periods.

Shrimp age (days)	Mean[3]	Polyphosphate conc. (%)	
		0	1
1	age	6.50^a	6.60^a
3	age	5.80^a	6.15^a
6	age	6.00^a	5.85^a

	Factorial analyses	
	F-value	Ranking of level means
Age (A)	2.182[4]	1 > 3 > 6
Polyphosphate (P)	0.136[4]	1 > 0
A x P	0.283[4]	

[1] 90 sec at 101°C [2] 10 min [3] $n = 20$ [4] N.S. $p \geq 0.05$

Mean scores in a column (age) with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value

Table 18. Mean flavor scores for frozen cooked[1] meat derived from polyphosphate treated[2] and non-treated round shrimp stored in ice for various time periods.

Shrimp age (days)	Mean[3]	Polyphosphate conc. (%)	
		0	1
1	age	6.35^{a}	6.65^{a}
3	age	5.00^{b}	5.05^{b}
6	age	5.45^{ab}	5.15^{b}

	Factorial Analyses	
	F-value	Ranking of level means
Age (A)	5.826[4]	$\underline{1} > \underline{6 > 3}$
Polyphosphate (P)	0.002[5]	$\underline{1 > 0}$
A x P	0.215[5]	

[1] 90 sec at 101°C

[2] 10 min

[3] $n = 20$

[4] Sig. $p \leq 0.01$

[5] N.S. $p \geq 0.05$

Mean scores in a column (age) with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value.

Table 19. Mean overall-desirability scores for frozen cooked[1] meat derived from polyphosphate treated[2] and non-treated round shrimp stored in ice for various time periods.

Shrimp age (days)	Mean[3]	Polyphosphate conc. (%)	
		0	1
1	age	6.35^a	6.90^a
3	age	5.00^b	4.90^b
6	age	5.15^b	4.75^b

	Factorial analyses	
	F-value	Ranking of level means
Age (A)	11.209[4]	$\underline{1} > \underline{3 > 6}$
Polyphosphate (P)	0.002[5]	$\underline{1 > 0}$
A x P	0.707[5]	

[1] 90 sec at 101°C [2] 10 min [3] $n = 20$ [4] Sig. $p \leq 0.01$

[5] N.S. $p \geq 0.05$

Mean scores in a column (age) with the same exponent letter did not vary significantly ($p = 0.05$).

Level means with the same underline did not vary significantly ($p = 0.05$).

Nine point desirability scale ranging from 9, highest affirmative value, to 1, lowest affirmative value

SUMMARY AND CONCLUSIONS

The effects of condensed phosphates and steam precooking time on the yield and quality of cooked shrimp meat derived from round shrimp were investigated utilizing a laboratory scale mechanical peeler. The relevant factors of polyphosphate concentration, steam precooking time, soaking time, and shrimp age (ice storage) were also investigated to determine their relative importance in improving yield and quality of cooked shrimp meat processed by mechanical peelers.

Precooking of round shrimp in steam (101°C) for 40 to 240 sec prior to mechanical peeling greatly affected the yield and moisture content of the precooked meat. Heat induced solubilization of protein during steam precooking together with the subsequent washing and mechanical action of the peeling operation caused a loss of both water and soluble meat solids, thus reducing meat yield. The recovery of meat through steam precooking for round shrimp was directly related to precooking time in an intrinsically linear manner. Cooking time must be as short as possible. Slow steaming or longer precooking time results in a decrease in water-holding capacity and a loss of cooked meat yield. A short steam precooking of 80 to 100 sec would produce optimum yield and quality attributes of the cooked meat.

The addition of condensed phosphates (sodium tripoly and sodium hexametaphosphate) coupled with short steam precooking for shrimp prior to mechanical peeling produced superior cooked meat yield. The wet and dry weight yield of cooked meat, derived from round shrimp soaked in 0.6% polyphosphate solution, increased significantly over controls. The effectiveness of pretreatment with polyphosphate on meat yield decreased with longer periods of precooking. This emphasized the importance of maintaining optimum precooking time (ca. 90 sec) in using polyphosphate pretreatment to obtain optimum moisture retention and cooked meat yield.

Pretreatment of round shrimp with polyphosphate solution prior to mechanical peeling greatly improved the cooked meat yield. The pretreatment also increased the moisture and phosphorus contents of cooked meat. Wet and dry weight yield, moisture and phosphorus contents were directly related to polyphosphate concentration. Most of the economical improvement in yield over control samples was achieved by a 1.5% polyphosphate pretreatment concentration (10 min) which provided an incremental mean increase (percentage points) of 3.87% wet and 0.57% dry weight. The increment of increase in wet and dry weight yield as well as moisture content by polyphosphate pretreatment over controls correlated very well with added phosphorus (P_2O_5). The increase in cooked meat yield and associated water-holding capacity obtained by polyphosphate pretreatment may result from two mechanisms: (a) Interaction of polyphosphate with the protein matrix of the sub-cuticle (collagen-like proteins) and other proteins leaded to an increase in the electrostatic repulsion and the solubility of the proteins. These solubilized proteins then swell the surface tissues and seal it to prevent the loss of fluid and soluble solid components, resulting in yield improvement through steam precooking. (b) Complexing of collagen-like proteins markedly reduced their susceptibility toward heat solubilization.

The favorable action of polyphosphate on yield improvement was not enhanced by increasing the soaking time from 10 to 60 min. Mean yield functions, however, did show a small degree of soaking time dependency in an irregular manner which was less pronounced after a 60 min pretreatment. Varying the soaking time in polyphosphate pretreatment of round shrimp did not significantly increase the moisture and phosphorus content of cooked meat. No significant interaction was observed between polyphosphate concentration and soaking time. Polyphosphate pretreatment at 1.5% solution for 10 min was clearly most effective with respect to the relationship of soaking time to yield and quality of cooked meat.

Round shrimp begin to undergo a degradative change in muscle proteins immediately post-catch. This degradative process which occurred during ice storage was directly related to a reduction in cooked meat yield. The yield reductions were associated with an increased moisture retention of the meat through cooking. Moisture partially replaced dry matter in wet meat yield after extended storage in ice. Polyphosphate pretreatment at 1% solution prior to steam precooking and subsequent mechanical peeling reduced meat yield loss produced by the degradative process occurring during ice storage, thus improving the meat yield and moisture retention of the processed meat. The observed increases in wet weight yield during extended storage in ice for round shrimp pretreated with polyphosphate were associated with the partial replacement of dry matter with water. The degree of improvement in meat yield and moisture retention in the processed meat was greater for shrimp with longer period of storage in ice than for fresh shrimp.

The effect of polyphosphate on round shrimp under widely varying concentration did not significantly affect the quality of frozen cooked meat. Flavor panel scores for odor, texture, juiciness, flavor, and overall-desirability of fresh frozen cooked meat were not significantly altered in an adverse manner by the pretreatment. Flavor panel scores for frozen cooked meat derived from round shrimp decreased in a significant and progressive manner during extended storage in ice. Polyphosphate pretreatment improved the texture, flavor, juiciness, and overall-desirability of frozen cooked meat derived from fresh shrimp. The effect of the pretreatment was not documented for shrimp stored for longer period of time in ice (more than three day ice storage).

Pretreatment of round shrimp, either fresh or less than 3 day ice storage, in 1.5% polyphosphate solution for a period of 10 min prior to a short (80 to 100 sec) steam precooking and subsequent mechanical peeling could markedly improve the cooked meat yield under commercial conditions without significantly altering quality. The application of this process would eliminate the loss of yield resulting from the aging process which is used commercially by the fish industry to improve the shell removal function of machine peelability.

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