Meat Yield and Shell Removal Functions of Shrimp Processing

Oregon State University
Extension Marine Advisory Program
A Land Grant / Sea Grant Cooperative
Special Report 597
July 1980

Meat Yield and Shell Removal Functions of Shrimp Processing

David L. Crawford
Department of Food Science and Technology
Seafoods Laboratory
Astoria, OR 97103

The biochemical changes that occur in Pacific Shrimp *(Pandalus jordani)* after catch relate directly to the efficiency of the shell removal and meat yield functions of mechanical peelability. Cooked meat yield can be markedly improved through the application of procedures and practices that retard deterioration and modify their effect during processing.

The abdomen of the shrimp is largely filled with muscle and connective tissue that account for a powerful musculature comprising 40 to 45% of the total shrimp weight. The connective tissue attaches individual muscle segments and the entire muscle system to the shell.

Shrimp connective tissue is composed largely of a collagen-like protein that differs from vertebrate collagen in molecular weight and amino acid composition. The shrimp muscle system also contains a higher amount of unformed collagen (that is, collagen not laid down as a defined functional tissue).

The molecular characteristics of shrimp collagen make it more susceptible to deterioration through the action of proteolytic enzymes than collagen of higher animals. Proteolytic action increases the lability of shrimp collagen toward heat induced solubilization.

Degradation of connective tissue attaching the musculature to the shell during post-catch storage is responsible for enhancing the shell removal function of mechanical peelability. The powerful systems of the shrimp itself and, upon extended storage, the proteases of spoilage micro-organisms are the source of this activity. Unfortunately, this action also unfavorably alters musculature proteins with regard to the yield function of mechanical peelability.

Muscle proteins become more soluble after extended storage. Connective tissue, because of its instability toward proteolytic attack, is predominantly involved. The rate and degree of deterioration depends on storage temperatures and on how long the shrimp are kept in storage. The washing action of melting ice and exposure to water during pumping and fluming reduces cooked meat yield; mechanical action accentuates losses during pumping and fluming.

Deterioration of the shrimp muscle system enhances the water-holding capacity of shrimp meat through steam precooking. This is reflected in increased cooked meat moisture contents as post-catch ice storage is extended. The yield of cooked meat (wet weight) may not be reduced until ice storage is extended to three or more days after it is caught. Under the same steam precooking times and temperatures, meat moisture content can increase to an extent that dry matter losses are not reflected in cooked meat yield wet weight.

Heat induced solubility of the shrimp musculature is markedly increased by post-catch storage deterioration. This reflects the general solubility characteristics of tissue collagens and the action of proteolytic degradation. Steam precooking prior to mechanical peeling represents a major site for yield loss through processing.

The yield of cooked meat under commercial conditions depends on the size and age of the shrimp. Small shrimp yield less cooked meat through processing. A portion of the yield is lost through the mechanical action of the peeling unit operation strictly as a consequence of physical size. A more rapid rate of post-catch degradation forms the basis for additional yield reductions over larger shrimp.

Subjective evidence appears to support a higher level of unformed collagen (collagen not laid down as a functional tissue) in the musculature of small shrimp. In addition, the ratio of muscle collagen to muscle forming the musculature may be greater. This altered musculature would be more subject to attack by proteolytic enzymes and more unstable toward heat induced solubilization.

Methods and practices for improving shrimp meat yield can be related to two specifically identified areas of major yield loss:

1) post-catch storage and handling prior to precooking
2) steam precooking

Once shrimp are cooked, yield loss results largely from mechanical problems. The only way yield can be improved is by properly adjusting machine settings to shrimp size and characteristics.

Practice guidelines for the handling and post-catch ice storage of Pacific shrimp that will lead to improved meat yield are listed below. These guidelines are ideal goals; actual production demands as well as processing and physical plant limitations may make them difficult to attain. Movement toward the ideal, however, will lead to improved meat yield.

1) Immediately after catch, remove fish and thoroughly wash the shrimp with sea water.
2) Store shrimp quickly in the hold with ample and well-distributed ice.
3) Limit the time between catching and processing to only as much as necessary to achieve efficient mechanical shell removal.
4) Minimize exposure of shrimp to water and mechanical action.
5) Prior to steam precooking, maintain shrimp at the lowest possible temperature without freezing.
6) Do not limit process scheduling decisions only to catch date. Meat yield is also a function of post-catch storage temperature and year class composition.

Controlled experiments using a pilot scale mechanical peeler on loan from MARCO (Marine Construction and Design Co., Seattle, WA) have characterized the relationship between cooked meat yield and steam precooking time. Both solids and moisture are lost according to well defined power functions ($y = b\,x^{m}$). Yield loss through steam precooking can be reduced by adopting minimum cooking times appropriate for the year class composition of each lot of shrimp. Cooking time should be limited to only that necessary to achieve the desired degree of cooking for the largest shrimp in a particular lot.

The practice of feeding steam precookers with shrimp more than one body layer thick resulted in a reduced meat yield. Because the precooking time must be extended to achieve proper cooking for the lower layers of shrimp, the surface layer is overcooked.

Yield loss through overcooking is of significant economic importance. Observed commercial precooking times ranging from 90 to 168 seconds for the production of "ready-to-eat" cooked meat are equivalent to a yield differential of 3.1 percentage points; 31 lb of cooked meat/1000 lb of round shrimp. A differential of only 10 seconds in precooking time (100-110 sec.) for 10 machines/shift (6,800 lb/machine) is equivalent to a loss of 340 lb of cooked meat.

Condensed phosphate interacts with the proteins of the shrimp musculature to retard their solubilization and loss during steam precooking. The pretreatment of commercial quality round shrimp samples (> 2 days post-catch) in 1.5% condensed phosphate solutions for 5 minutes prior to steam precooking produced marked increases in cooked (90 sec in steam at 101°C) meat yield in laboratory process evaluations. Control samples (n=12) produced a mean yield of 23.5 ± .5%. Condensed phosphate treated samples yielded 28.6 ± 1.7% cooked meat, a yield increase equivalent to 51 lb cooked meat/1000 lb of round shrimp.

In-plant process evaluations utilizing control/treatment lots of shrimp ranging from 500 to in excess of 4000 lb supported laboratory results. Under a variety of processing conditions, seven control lots produced yields of 20.2 ± 3.2%. Shrimp treated with 1.0 - 1.5% condensed phosphate solution produced yields of 24.1 ± 2.6%; an increase in cooked meat yield equivalent to 39 lb/1000 lb of round shrimp.

Extensive flavor panel evaluations of fresh frozen cooked shrimp meat derived from condensed phosphate treated samples have shown no significant difference in judgment scores from control samples. These evaluations included replicate round shrimp lots with wide quality variations treated with 0.0, 1.5, 3.0 and 6.0% condensed phosphate for 5 minutes prior to processing under identical conditions.

The application of condensed phosphate (1.5% solution for 5 min) results in small increases in the cooked meat moisture content. Replicate control/treatment samples (n=7) showed a 0.30 ± .79 g moisture/100 g wet weight increase over control samples. This may reflect either the general characteristic of proteins exposed to condensed phosphate to increase their water retention through cooking, or the higher moisture content of connective tissue proteins retained through precooking.

The yield enhancing action of condensed phosphate depends on the concentration of the condensed phosphate rather than the length of exposure time. Round shrimp exposed to condensed phosphate solution just prior to steam precooking only retain finite quantity of occluded solution. Concentration dependency is mediated by possible contact time with musculature proteins regulated by washing action of wet steam within the precooker.

Post-catch ice storage and shrimp year class composition modify the relationship between pretreatment solution concentration and resulting meat yield response over an untreated control sample. The effectiveness of condensed phosphate application is improved by post-catch degradative changes in shrimp musculature proteins. Very fresh shrimp require a stronger pretreatment solution than shrimp that have undergone post-catch ice storage to achieve the same yield increase over comparable control samples. This dependency on post-catch deterioration is further modified by the marked difference in the stability of shrimp year classes. Large shrimp stored three days in ice may require a solution three times as strong to achieve a yield increase over comparable untreated control samples than small shrimp stored in ice for only two days.

The quantity of phosphate added by a pretreatment to cooked meat compared to an untreated control sample is directly related to the increment of yield increase for a specific lot of shrimp. Variability among lots of shrimp is modified by post-catch time and temperature history which markedly alters the effectiveness of the action of condensed phosphates (increment of phosphorus added/increment of yield increase over a control).

The phosphorus content of untreated shrimp meat expressed as P_2O_5 can vary from 537 to 727 mg/100 gm wet weight, a variation of 190 mg. Samples (n=7) pretreated for 5 min in 1.5% condensed phosphate produced a 81 $\pm$ 39 mg P_2O_5/100 gm wet weight increase over respective controls. Pretreatment solutions as high as 6% have produced added phosphorus levels less than 110 mg P_2O_5/100 gm wet weight over control samples. Generally, the quantity of phosphorus added to cooked meat derived from pretreated round shrimp is somewhat less than the range of phosphorus naturally occurring in shrimp.

The precise concentration of condensed phosphate that will produce optimum yield from all lots of shrimp cannot be recommended. Short term exposure of shrimp to condensed phosphate solutions approximating 3.0% just prior to steam precooking will produce marked yield increases for most lots of average commercial quality. Very fresh and large shrimp of high quality require stronger concentrations of up to 6.0% to achieve smaller increments of yield increase over respective controls.

Ideally, round shrimp should receive a short (3 to 5 min) exposure to condensed phosphate just prior to being fed into the steam precooker. Exposure of treated shrimp to large quantities of untreated water prior to steam precooking washes occluded phosphate from shrimp, diminishing the possibility for their action. Exposure of shrimp to the basic conditions of a condensed phosphate solution for extended periods of time prior to steam precooking may not produce optimum efficiency. These basic conditions favor protein stabilization. Although not confirmed by experimental data, it is believed this factor could be responsible for the considerable difference between the yield increase observed under laboratory and inplant processing conditions.

Treatment of shrimp in the precooker feed tank represents the quickest means of applying phosphate under present common physical plant conditions. All water supplies to the feed tank must be shut-off and the precooked feed tank charged with condensed phosphate solution from a make-up tank. If fluming is used to move shrimp, the shrimp must be dewatered prior to their addition to the feed tank. A continuous supply of phosphate solution is then added to the feed tank to replace solution occluded to shrimp being fed into the precooker. It would be advantageous for the fresh solution to be added to the feed tank through a spray directed on the exposed layer of shrimp just as they enter the precooker. This spray should be adjusted to a rate that will, at a minimum, maintain the solution in the tank at a level appropriate for efficiently feeding shrimp into the precooker.

Operation of the above described basic system with the addition of a minimum of added fresh solution results in a buildup of material in the tank and a warming of the solution during production. Bacterial buildup does not represent a problem. The phosphate solution is a very hostile environment for bacterial survival. Feed tank solutions over a 4-hour production period have shown a reduction in bacterial numbers. Use of this basic system should involve the complete replacement of feed tank solution every half shift to remove solid material.

The warming of the feed tank solution by the feed belt and by condensed steam from the precooker represents a special problem. The warmer feed tank solution promotes protein solubilization and decreases the yield-enchancing effectivensss of condensed phosphates. Operational and/or physical changes in the described basic system can minimize this problem.

The flow of fresh phosphate solution into the tank can be increased to provide an overflow which will moderate solution temperature. Under this type of operation, complete replacement of feed tank solution after each half shift would not be necessary. Alternatively, ice can be added to the feed tank with shrimp to lower feed tank solution temperature. This practice would require the use of a more concentrated phosphate solution.

Both of these procedures would not result in the most efficient use of condensed phosphate and, in the latter case, would not produce effective concentration control. The cost effectiveness of these two procedures would have to be proven under actual process practice.

The most effective means to eliminate solution heating and achieve maximum use of treatment phosphate would be to incorporate some means of removing solid material and of chilling feed tank treatment solution. The solution could be continuously circulated from the feed tank through a simple screening system and chiller to a makeup tank. Fresh solution would be added to the makeup tank to maintain system volume and condensed phosphate concentration. Chilled solution recirculated back to peeler feed tanks would provide concentration conditions for optimum meat yield.

The requirement for fresh phosphate solution would be reduced and amount to only that lost on shrimp going into the precooker and that needed to adjust concentration resulting from dilution by condensed steam. Chilling the feed tank solution to 34 to 40°F could raise the 3.9 percentage point yield increase observed for in-plant investigations.

The cost/benefit of a phosphate pretreatment can be roughly estimated based upon the phosphate requirements to operate the described basic system using a defined set of actual inplant operational parameters.

Operational Parameters

1. Production capacity = 6800 lb/machine/8 hr shift.
2. Solution requirement:
   Initial tank charge = 200 gal (1,667 lb).
   Half-shift tank replacement charge = 200 gal (1,667 lb).
   Process use (55 gal/1,000 lb) = 374 gal (3,118 lb).
   Total = 774 gal (6,452 lb)/machine/shift.
3. Condensed phosphate requirement:
   Feed tank charges (3% wt/wt) = 100 lb.
   Process use (4.5% wt/wt) = 140 lb.
   Total = 240 lb/machine/8 hr shift.

Cost:Benefit Relationship

1. Phosphate cost @ $0.42/lb (10,000 lb lots)
   (Brifisol D510; BK-Ladenburg Corp. 11312 Hartland St., North Hollywood, CA 91605: Jan 80)
   $100.80/machine/shift.
2. Enhanced yield (based upon 3.9 percentage points) = 265.2 lb.
3. Value of increased yield increment wholesale ($4.00/lb; Jan 80) = $1,068.00
4. Cost:benefit = 1:10.6

The incorporation of a reuse system which includes a chiller would reduce phosphate requirements by 50 lb/machine/shift and potentially increase the increment of yield increase to 5.0 percentage points producing a direct cost benefit ratio of 1:17.0.

OREGON STATE UNIVERSITY
EXTENSION
SERVICE

Extension Service, Oregon State University, Corvallis, Henry A. Wadsworth, director. This publication was produced and distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914. Extension work is a cooperative program of Oregon State University, the U.S. Department of Agriculture, and Oregon counties.

Extension's Marine Advisory Program is supported in part by the Sea Grant Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Extension invites participation in its programs and offers them equally to all people, without discrimination.