QUALITY AND SAFETY CONSIDERATIONS FOR THERMALLY PROCESSED BLUE CRAB MEAT

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INTRODUCTION

Blue crabs comprise the largest crab fishery in the United States. U.S. landings in 1991 were 89.9 million kg (222.1 million lb), with a dock value of $73.3 million (9). Much of that supply was commercially cooked and marketed as fresh or pasteurized product. Crab meat is highly perishable and can serve as the vector for several serious food pathogens. Every crab plant must establish an effective quality control program.

Thermal processing requirements must be understood and make an integral part of any blue crab processing quality control program. The National Marine Fisheries Service (NMFS) in cooperation with the National Fisheries Institute (NFI) has developed a Hazard Analysis Critical Control Point (HACCP) quality control and inspection model for the blue crab industry. Four of seven critical control points listed by the model involve thermal processing steps or product temperature control (14).

In 1984, The National Blue Crab Industry Association (NBCIA) adopted thermal processing guidelines for the blue crab industry. NBCIA in cooperation with FDA and the state Sea Grant Advisory Programs is upgrading the guidelines to reflect HACCP principles, new processing and packaging technologies, and emerging threats from newly uncovered pathogens and spoilage organisms. Although NBCIA has delineated minimum pasteurization requirements in terms of calculated F-values, individual processing needs can result in adjusted cooking times and temperatures to achieve a given shelf life, reduce bluing, or process in newly available packaging (12, 13, 14).

The University of Georgia Marine Extension Service recently completed a study to evaluate the effects of several commercially available packaging materials on the quality of pasteurized crab meat. Stored pasteurized lump meat was held at refrigerated temperatures for 15 mo in the
following containers: steel cans, aluminum cans, plastic cans, non-barrier pouches, and barrier pouches (6). Packaging options for pasteurized meat will be discussed later in the paper.

Minimal thermal processing has been proposed as a pre-packaging or post-packaging treatment to control pathogens in freshly picked crab meat. Blue crab processors through NBCIA have established the development of proper time/temperature treatments that will destroy *Listeria monocytogenes* in freshly-picked crab meat as a leading priority.

**MATERIALS AND METHODS**

The methods followed for the study of commercial container options for the refrigerated storage of pasteurized crab meat are explained below. Freshly picked meat obtained from a cooperating Georgia processor was packed under commercial conditions into experimental and control pasteurization containers for a 15 mo refrigerated storage study. Meat was cooked at 83.3°C (182°F) to a target *F*<sub>56</sub>-value of approximately 40 min for all treatments. Lump meat was pasteurized in the following: (i) 453.6 g (16 oz) in #401 steel cans which served as the industry control (Steelein Can Company, Baltimore, MD); (ii) 226.8 g (8 oz) of crab meat in plastic cans with aluminum easy-open ends (#307 copolymer polyethylene cans with 283.5 g (10 oz) capacity, King Plastic Corporation, Orange, CA); (iii) 226.8 g (8 oz) in #307 aluminum cans (Central States Can Company, Massillon, OH); (iv) 226.8 g (8 oz) in non-barrier pouches (P640 with nylon base and low density polyethylene sealant, 16.5 cm x 22.9 cm, Cryovac Corporation, Duncan, SC); and (v) 226.8 g (8 oz) in barrier pouches (Cryovac P640B with nylon base, Saran<sup>R</sup> barrier, and low density polyethylene sealant, 16.5 cm x 22.9 cm) (6).

**RESULTS AND DISCUSSION**

Blue crab thermal processing requirements and critical control points can be illustrated by following the major operational steps found in a typical Southeastern U.S. crab plant. Specific details may vary from plant to plant, but the general process is the same.

Crabs are commonly harvested by traps and brought to the processing plant the same afternoon. Live crabs should be cooked within 1 - 2½ h of delivery or transferred to coolers. Live crabs that must be cooked the following day should be refrigerated at between 7.2°C (45°F) and 10°C (50°F). Minimum time/temperature cooking requirements must be met. To prevent cross contamination, cooked and raw crabs should not be stored in the same cooler (12, 13, 14).

Crabs are normally cooked by pressurized steam or boiled in water. Achieving proper time/temperature cooks for live crabs is the first critical control point in the NMFS model HACCP program. The dominant method is steam retorting at 1.03 bar (15 psi). Crabs are cooked for 10 min after the retort reaches 121.1°C (250°F). Boiled crabs are usually cooked for 15 min after the water resumes boiling. Ulmer (19) found that a 15 min boil produced bacterial levels comparable to 10 min of steam retorting. Internal temperatures of steamed crabs usually range from 90.5°C (195°F) to 100°C (212°F). Boiled crabs yield more meat because of their higher moisture content, but they have a shorter shelf life (12, 13, 14, 18, 19).

Retorting criteria are not uniform throughout the United States, but usually require the internal temperature of the crab to reach between 112.8°C (235°F) and 115.5°C (240°F). In 1964 Ulmer (19) determined the average internal temperature of steamed crabs reached 119.4°C (247°F) after 10 min. A record of time/temperature conditions achieved during retorting of each batch of crabs should be maintained by the plant management. Crabs are cooled for several hours after cooking. NBCIA recommendations require cooked crabs to be refrigerated at ≤ 4.4°C (40°F). Along the Georgia and Gulf Coasts, crab backs are removed and the claws and coxal are placed in refrigerated storage at between 0.6°C and 4.4°C (33°F to 40°F) before picking. The crabs are
picked the following morning. In other states, whole crabs are refrigerated before they are picked (13, 14, 18, 19).

Crab meat is removed or picked by hand in most operations. Several grades of white meat based on meat size are marketed. Market grades include: Jumbo, Lump, and Special. Claw meat and cocktail claws are also picked by hand (10). Some plants use a Quik-Pik machine (Crane Research and engineering, Hampton, VA) to remove white meat. Crab cores are placed on metal racks and pre-warmed. The meat is shaken onto a belt by the rapidly vibrating machine. Only Special meat is recovered. The Harris Machine uses a hammer mill and salt brine flotation to separate claws from claw meat. The picking room is included by the second critical control point. Good sanitation methods must be maintained for both hand and machine picked meat. Fresh meat should be inspected, weighed, packaged, and iced without delay to complete the third critical control point of the crab processing operation. Fresh meat has a shelf life of 6 to 14 d. The shelf life of refrigerated crab meat can be extended to 6 mo or more by pasteurization. The product maintains the characteristics of fresh crab meat (10, 12, 13, 14, 18).

The fourth critical control point is confirmation that the pasteurization container is hermetically sealed. The traditional process would inspect the can seam of a 16-ounce steel can. Current pasteurization container options include aluminum cans, plastic pouches, and plastic cans (12, 13, 14).

NBCIA recommends that the following information be displayed on each container of pasteurized crab meat:

1. a code indicating the day, month, and year of processing
2. the words "PASTEURIZED CRAB MEAT" should appear on both the individual and shipping containers
3. the word "Pasteurized" should appear with each use of the words "Crab Meat"
4. "Perishable--Keep Under Refrigeration" should be prominently displayed on each can

At least one individual should be trained to complete can seam or container seal evaluations and in the adjustment of the seaming/sealing equipment. The plant manager should keep seam or seal records for at least 2 years (12).

Use of safe and approved time/temperature parameters for the pasteurization process comprise the fifth critical control point.

*Clostridium botulinum* has traditionally been the organism of concern for canned or other hermetically sealed foods. Thermal process requirements are usually designed around a target organism. Blue crab pasteurization requirements were developed empirically to achieve a desired refrigerated shelf life with no specific target organism. The process was designed to achieve an internal meat temperature of 85°C (185°F) for 1 minute at the geometric center of a 0.45 kg or 1 lb (401 X 301) steel can. The original empirical process requirements for 1 lb cans have been redefined by thermal lethality or total F-value to expand the concept to other container types and sizes. A z-value of 8.9°C or 16°F was picked arbitrarily in the absence of a specific target organism. A reference temperature of 85°C or 185°F was chosen. NBCIA adopted a minimum commercial pasteurization process of $F_{12} = 31$ min for their pasteurization guidelines. The process provides a wide margin of safety for the destruction of *C. botulinum* Type E spores (2, 12, 13, 14, 18). Cockey and Taitro (3) estimated that a typical commercial pasteurization process could provide an 8-D reduction in the number of *C. botulinum* spores.
$D_{55}$ values determined for Type E spores have ranged from 0.2 - 0.32 min, confirming a 96-D process at $F_{0} = 31$ min.

Each pasteurization system should have a time/temperature recording thermometer with a temperature controller and an indicating thermometer. The system should be calibrated annually. An automatically regulated steam valve is required when steam is used as the heat source for the pasteurization tank. Baskets, dividers, and cover plates should be perforated to permit circulation within and around the pasteurization baskets. The water in the bath should be mixed or agitated to achieve a uniform temperature. Compressed air or recirculating pumps are effective (12).

The pasteurization process should be standardized by qualified individuals. Subtle variations in the size and shape of the water bath, steam source, and water circulation patterns make each processing plant unique. In-plant process standardization and batch monitoring are required for any pasteurization operation. Processing boundaries should be set. Any variation in the following parameters would require restandardization of the pasteurization process:

1. Process time (both heating and cooling)
2. Water bath temperatures (both heating and cooling)
3. Initial crab meat temperature
4. Container size, shape, and material

Rapid cooling of the crab meat is as important to the final quality, safety, and shelf life of the product as the heating portion of the pasteurization process. Slow cooling rates may allow injured bacteria to recover and multiply before refrigeration temperatures are reached within the can (7, 17, 20).

The sixth critical control point requires cans to remain in an ice-water bath capable of cooling the meat at the geometric center of the can to 12.8°C (55°F) within 180 min. Cooling water should be break-point chlorinated or treated with another acceptable sanitizer. The cooled meat should be moved to refrigerated storage that is maintained between 0°C (32°F) and 2.2°C (36°F). The geometric centers of the cans must cool to 2.2°C (36°F) within 18 h or less (12, 14, 17, 18).

The seventh critical control point addresses storage temperatures. Pasteurized crab meat must be kept between 0°C (32°F) and 2.2°C (36°F) throughout the wholesale/retail distribution system. Cooling below 2.2°C (36°F) is important for both maximum shelf life and safety. C. botulinum does not produce toxin below that temperature. Accidental freezing will toughen the meat and cause drip and flavor loss. The plant manager should maintain heating and cooling records covering each batch of pasteurized meat that is processed by the crab plant. Storage temperatures should be monitored and documented throughout the wholesale and retail distribution chain (12, 13, 14, 18).

One potential problem is variation in meat temperature before pasteurization. Often crab meat is packed into pasteurization cans directly from the picking table, at temperatures approaching 21°C (70°F). At other times meat may be placed in cans and held overnight in the cooler before pasteurization. A process based on an initial meat temperature of 21°C (70°F) would under process meat with a starting temperature of 0°C (32°F) or 1°C (33.8°F). We recommend that the pasteurization process be standardized with meat at the lowest initial temperatures that are expected in the plant. This method is fail-safe. A second approach would be to measure the initial meat temperature of each batch and adjust the process time accordingly (17).
Moody (11) developed a hardware and software system that utilizes a personal computer and a Strawberry Tree (Strawberry Tree Incorporated, Sunnyvale, CA) data acquisition board to calculate F-values in real time for each batch of pasteurized meat. The system will allow processors to adjust process times and temperatures to daily changes in meat quality, bacterial loads, starting temperatures, and package types.

Many processors exceed the minimum F-value level of 31 min recommended by NBCIA. Rippen of VPI has compiled industry data that associates achieved lethalties with commercial shelf life (Table 1) (16). Some processors routinely reach F-values of 60 to 120 min.

Table 1. Achieved F-value values and estimated commercial shelf life of pasteurized blue crab meat (16).

<table>
<thead>
<tr>
<th>F-value Value (Minutes)</th>
<th>Shelf Life (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 15</td>
<td>1.5</td>
</tr>
<tr>
<td>15 - 20</td>
<td>2 - 4</td>
</tr>
<tr>
<td>20 - 25</td>
<td>4 - 6</td>
</tr>
<tr>
<td>25 - 30</td>
<td>6 - 9</td>
</tr>
<tr>
<td>30 - 40</td>
<td>9 - 18</td>
</tr>
<tr>
<td>&gt; 40</td>
<td>12 - 36</td>
</tr>
</tbody>
</table>

Rippen's study determined what shelf life range should be expected for a given pasteurization F-value if can seam integrity and proper cooling schedules are maintained. Crab plant owners can tailor processing parameters to meet their marketing needs.

Pasteurized meat spoilage has been at much higher than normal levels over the last 3 years. Most of the problems have been traced to poor can seams, however a more insidious problem has presented itself. Webster et al. (23) at VPI & SU have uncovered a thermotrophic, psychrotrophic, anaerobic, non-pathogenic Clostridium that has been connected with early spoilage of pasteurized crab meat. Preliminary data indicates a D90 value of 9 min compared to 0.2 - 0.32 min for C. botulinum Type E. Fortunately the new isolate does not appear to be widely distributed. Its true impact on the crab industry is not known.

Heat processing to a F-value of sufficient lethality can provide a safe product with acceptable microbiological shelf life. However, there are other quality factors associated with blue crab meat thermal processing. Pasteurized crab meat can turn blue. Crab blood, copper-based hemocyanin, may form light grey to blue-black complexes. The discoloration is harmless, but it is not aesthetically pleasing (1). Bluing greatly reduces the meat's marketability and value. Bluing occurs during pasteurization and intensifies with storage. Bluing is temperature dependent. Meat processed above 88°C (190°F) frequently discolors. Previous studies have shown that pasteurization temperatures between 79.4°C (175°F) and 85°C (185°F) have reduced the incidence of bluing. Pasteurization at 83.3°C (182°F) to achieve a F-value of approximately 36 min and storage at -0.5°C to 6°C (31°F - 32°F) has reduced bluing levels in meat at two cooperating Georgia plants. A temperature of 83.3°C was chosen as a compromise between anticipated bluing reduction and the practical need for processors to limit increased cooking times required for lower pasteurization temperatures. Contamination of picked meat with metals, particularly iron, accelerates and intensifies bluing. The addition of
and phosphates can retard or reduce bluing levels (4, 5, 21, 22). Additional quality control steps that can help control bluing include:

(1) Reducing free liquid formation by steaming raw crabs and not washing or fluming cooked crabs.
(2) Maintaining an even circulation pattern in the pasteurization tanks. Turbulence in one area of the tank may trigger bluing.
(3) Reducing meat contact with any source of iron, including corroded steel and aluminum.
(4) Trying different package types, styles, and manufacturers until the most satisfactory container is found.

Product dryness is usually caused by cooking longer than 2 h. Dryness is not sensitive to process temperature. Dryness develops between the meat and the can’s headspace. Periodic inversion of the cans during storage can help the problem. Rapid heating and cooling reduces drying.

Moody (11) has traced the presence of small crystalline grains that are sometimes found in pasteurized crab meat to struvite, a form of magnesium ammonium phosphate. The addition of sodium acid pyrophosphate can control the problem.

Thermal processing can be used as a final treatment for "Fresh Crab Meat". Vegetative cells of pathogenic or spoilage organisms can be targeted. Plate counts can be reduced to achieve market specifications or extend shelf life in packaging that is not hermetically sealed. A specific pathogen such as Listeria monocytogenes, with a zero tolerance level enforced by FDA, can be controlled with steam or microwave heating. Greater consumer awareness has led to increased pressure to deliver pathogen free crab meat. A process to control Listeria monocytogenes would need to meet the following criteria, an average F value ≥1.0 second with a minimum value of 0.5 seconds (8, 15).

Gates et al. (6) conducted a 15 mo refrigerated storage study to determine the storage characteristics of the following previously described pasteurization containers: (i) steel cans, (ii) polyethylene cans, (iii) aluminum cans, (iv) non-barrier pouches, and (v) barrier pouches. Figures 1, 2, and 3 present heating and cooling rates for the cans. Figure 4 shows the heating and cooling curves for the pouches. Total heating times and mean F-values obtained for each type of container are shown in Table 2. Notice that the process times and shapes of the curves vary with each package type.
CRAB MEAT PASTEURIZATION

Figure 1. Time/temperature pasteurization curves showing both heating and cooling of crab meat in steel cans.

CRAB MEAT PASTEURIZATION

Figure 2. Time/temperature pasteurization curves showing both heating and cooling of crab meat in co-polymer polyethylene cans.
Figure 3. Time/temperature pasteurization curves showing both heating and cooling of crab meat in aluminum cans.

Figure 4. Time/temperature pasteurization curves showing both heating and cooling of crab meat in barrier and non-barrier pouches.
Table 2. Total heating times and achieved F^\omega-values for steel cans, plastic cans, aluminum cans, non-barrier pouches, and barrier pouches.

<table>
<thead>
<tr>
<th>Container Type</th>
<th>Cook Time (Minutes)</th>
<th>F^\omega-Value (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>163</td>
<td>53.8</td>
</tr>
<tr>
<td>Plastic</td>
<td>130</td>
<td>43.8</td>
</tr>
<tr>
<td>Aluminum</td>
<td>120</td>
<td>39.7</td>
</tr>
<tr>
<td>Non-barrier Pouch</td>
<td>70</td>
<td>45.2</td>
</tr>
<tr>
<td>Barrier Pouch</td>
<td>70</td>
<td>42.8</td>
</tr>
</tbody>
</table>

Pasteurized meat in plastic containers had higher sensory color and appearance scores than meat from other evaluated containers through 8 mo of refrigerated storage. Barrier pouches were the least effective package, scoring below other containers for sensory quality and whiteness. Microbiological shelf life was limited to 10 mo. Aluminum and plastic containers scored the highest sensory color and appearance ratings at 10 and 13 mo of storage. Meat from steel cans was microbiologically and chemically spoiled following 15 mo of storage. Meat in plastic and aluminum cans and non-barrier pouches maintained acceptable sensory and microbiological quality through 15 mo. Meat pasteurized in less expensive plastic and aluminum containers had better sensory and microbiological quality than meat packed in steel cans.

CONCLUSIONS

Thermal processing is an integral part of the blue crab industry. Adoption of HACCP quality control procedures, the introduction of new packaging materials, and the use of computer processing technology can provide improved quality and safety for a traditional seafood industry.

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EXTENDING SHELF LIFE OF FRESH BLUE CRAB MEAT WITH LACTATES

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Both real and perceived public health concerns about the quality and safety of seafood products may soon force the seafood industry to modify some of its traditional practices. Of special concern are previously cooked, ready-to-eat foods such as fresh blue crab meat (8). Early attempts to enhance quality and safety with additives during processing of fresh (11,13), frozen (21,22), canned (5) and pasteurized crab meat (17) were either unsuccessful (21,22,17) or not beneficial enough (11,5,13) to be adopted by seafood processors. Consequently, fresh blue crab meat is primarily sold in the traditional way, which means refrigerated with no preservatives added.

In recent years, natural lactic acid and sodium lactate have been successfully used in food processing. They are known antimicrobial agents and provide inhibitory effects on most pathogens in poultry (14,15,20,6) and red meat (18,1). Lactates are recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA) and their use in food processing is restricted to good manufacturing practices (GMP)(9). Seafood technologists have recently focused their attention on the effect of lactates on shrimp (3,4), fish and frozen crab meat (7).

The primary objective of this study was to demonstrate shelf life extension by lactic acid and sodium lactate in blue crab meat, and secondly, to determine their effects on physical and sensory qualities.
MATERIAL AND METHODS

Crab Meat

Atlantic blue crab meat (*Callinectes sapidus*) was purchased from a commercial processor (Luther Lewis & Son, Davis, NC). The crabs had been pressure cooked, and the meat had been directly picked into standard one pound plastic containers. The crab meat containers were stored in crushed ice and removed only for treatment and analyses procedures.

Treatments

Fifty-five pounds of crab meat was mixed under sanitary conditions to ensure uniformity. It was divided into five equal portions. Control samples were immediately repacked in sanitized containers. Treated samples were dipped for 30 min in either (i) water, (ii) 1% lactic acid, (iii) 4% sodium lactate or (iv) a combination of 1% lactic acid and 4% sodium lactate. They were allowed to drain for 10 min. The crab meat of all treatments, including the control, was subdivided and stored in separate containers for microbiological, physical and sensory analyses. The experiment was replicated three times.

Analyses

Physical, microbiological and sensory analyses of treated crab meat were performed during a 19-day period. Moisture content, pH value, color and texture were measured. Oven moisture and the pH values were determined, using standard procedures (24). The pH values were determined after the treatments. The crab meat (10 g) was blended in distilled water to achieve a final dilution of 1:3 (w/v) and the pH was measured, using a Fisher Accumet pH meter model 620. The texture grades were measured with an Instron universal testing machine equipped with a Kramer shear cell. The maximum force prior to rupture of triplicate 10 g samples was recorded. The color of the crab meat was measured with a Spectroguard color system. Measurements, described on the Hunter Lab scale, were taken with a tungsten filament and an average daylight source. The observer angle was 10°. Triplicate 15 g samples were prepared, and two measurements in different areas were taken.

Aerobic plate count at 35°C and the confirmed test for E. coli were performed, according to standard AOAC procedures (2).

The consumer acceptability of treated crab meat was evaluated by an in-house consumer panel of 35 panelists on days 1, 5 and 8 (16). Panelists were asked to rank appearance, odor, flavor, texture and overall acceptability. The ratings were given on a 9 point hedonic scale from dislike extremely ('1') to like extremely ('9'). All ratings were converted to numerical values.
A rating below 5 (neither like nor dislike) was considered a consumer rejection.

Statistical analyses on the means of physical, microbiological, and sensory data were performed, using the GLM procedure (19). To determine significant differences (p<0.05) between storage time and treatments, the least-square-means or the Waller-Duncan k-ratio t-test was computed.

RESULTS AND DISCUSSION

Physical Parameters

Physical effects of treatments on moisture, pH, color and texture were analyzed. Control samples had an average moisture content of about 76%. Dipping procedures elevated moisture levels in all samples (Figure 1). Water dips resulted in a 5% moisture increase while all other treatments showed an overall increase of about 2%.

The pH value of fresh handpicked crab meat was 7.8 (Figure 2). Neither distilled water nor 4% sodium lactate treatments

*Figure 1: Oven moisture of fresh blue crab meat following lactate treatment.*

*LA = lactic acid, NaL = sodium lactate.*
affected the pH of the crab meat. The pH of 1% lactic acid solution alone was 2.5 and increased to 4.4 when in combination with 4% sodium lactate. Both treatments containing lactic acid lowered the resultant meat pH to 6.2.

Visual observations of the crab meat indicated a lightening in color where lactic acid was used. This was confirmed with colorimetric measurements using a Hunter color scale. Both treatments containing lactic acid had significantly higher L values than the control (Figure 3a). The water and the sodium lactate dipped samples were lighter than the control, but significantly darker than the lactic acid samples. The a-value of all treated samples shifted to the green spectrum. This color shift was more pronounced in samples containing sodium lactate in their treatment solutions (Figure 3b). No significant differences were observed measuring the b-value (data not shown).

No significant differences in texture measurements with the Instron universal testing machine were found between lactate samples and control sample (data not shown).
Figure 3: Hunter color L-values (A) and a-values (B) of fresh blue crab meat following lactate treatments
LA = lactic acid, NaL = sodium lactate, Combo = 1% LA + 4% NaL.

Bacteriological Quality

The classification of the crab meat followed similar guidelines described by Gates (12). Therefore, crab meat samples with aerobic plate counts (APCs) less than 100,000 cfu/g were considered good quality (10). Plate counts between 100,000 and 1,000,000 cfu/g were classified as acceptable quality. Samples with APCs greater than 1,000,000 cfu/g were judged to be spoiled.

The initial quality of the non-treated control sample averaged <60,000 cfu/g (Figure 4), with bacterial growth following the natural spoilage pattern for fresh crab meat on ice. After a lag phase of 5 days, bacterial growth increased slowly. The crab meat continued to be of good quality until 10 days and was regarded as unacceptable after 14 days. The microbial quality of water-dipped crab meat, one day after treatment, indicated that
the handling process during treatment did not significantly increase the bacterial numbers. Because of the rate of spoilage, good quality shelf life was reduced to 6 days and acceptable quality to 11 days.

Bactericidal properties of the 1% lactic acid solution (1,14,15) were demonstrated (i) by lowering the initial APCs to less than 10,000 cfu/g and (ii) by extending the lag phase to 10 days. Crab meat remained in good quality (<100,000 cfu/g) for 16 days and spoiled after 19 days of storage on ice (>1,000,000 cfu/g). Sodium lactate is known to have a bacteriostatic effect (6,20). Like lactic acid, sodium lactate prolonged the lag phase in blue crab meat to 10 days before bacterial growth commenced. The treatment extended shelf life an average of 20%, to 12 days. The lower spoilage rate was consistent over 15 days but was not found to be statistically significant.

Figure 4: Log of aerobic plate count (35°C) of fresh blue crab meat following lactate treatments and storage on crushed ice.

LA = lactic acid, NaL = sodium lactate
The combination of sodium lactate with lactic acid did not offer an advantage over the sodium lactate treatment in retarding microbial spoilage. The spoilage followed a pattern similar to the sodium lactate samples, with a good quality shelf life of 12 days. However, these data were not found to be significantly different (p<0.05) from the control.

Once bacterial growth began, growth patterns were similar for all samples, as indicated by the slope of the curves. What advantage did lactic acid treatment offer? There were two effects, which led to a shelf life extension of 60%, to 16 days. First, initial plate count was reduced and second, the lag phase was extended. Lactic acid treated crab meat was still in good condition (<100,000 cfu/g) 2 days after the control samples were spoiled (APC>1,000,000 cfu/g). The differences were significant at a 0.05 level.

Finally, tests for E. coli in control and treated samples were negative during the first 10 days of storage.

**Sensory Evaluations**

All treatments improved the sensory appearance rating of crab meat (Figure 5a). This may correlate to the higher moisture content and lighter color of the crab meat after the treatments. Differences were more pronounced over time.

A slight off odor was detected by the panel in lactic acid samples and in the combination samples at the beginning of the storage time (day 1). This resulted in a lower rating for this test period (Figure 5b). However, overall odor for all treatments, including the lactic acid containing samples, was not found to differ significantly (p<0.05) from the control. The only exception was the sodium lactate sample, which was preferred by the panelists.

Panelists accepted the flavor of all samples and rated them above the rejection level of 5 (Figure 6a). Panelists rated both treatments containing lactic acid significantly less than the other treatments. Sodium lactate alone is known to enhance flavor. Panelists found a positive effect on crab flavor and preferred sodium lactate samples over control samples on day 5. The differences in flavor between all samples diminished with storage time and lost any significance after 8 days.

In terms of sensory texture ratings, no significant differences between treatments could be detected by the panelists (data not shown). This confirmed the physical data obtained with the Instron testing machine.

When asked to judge overall acceptability, panelists rated both lactic acid containing treatments lower than the control (Figure 6b). The 4% sodium lactate treatment was judged equal or superior to the control (p<0.05).
Figure 5: Sensory evaluations of appearance (A) and odor (B) of fresh blue crab meat following lactate treatments. Means of the same day marked with different letters were significantly different at a 0.05 level. *) F-value too small.

LA = lactic acid, NaL = sodium lactate, combo = 1%LA + 4%NaL,
9 = like extremely
1 = dislike extremely

BLUE CRAB MEAT
SENSORY EVALUATIONS
APPEARANCE

HEDONIC SCALE

(A)

TREATMENTS
◆ CONTROL ◇ WATER ◐ 1% LA ◐ 4% NaL ◐ COMBO

BLUE CRAB MEAT
SENSORY EVALUATIONS
ODOR

HEDONIC SCALE

(B)

TREATMENTS
◆ CONTROL ◇ WATER ◐ 1% LA ◐ 4% NaL ◐ COMBO
Figure 6: Sensory evaluations of flavor (A) and overall acceptability (B) of fresh blue crab meat following lactate treatments. Means of the same day marked with different letters were significantly different at a 0.05 level. *) F-value too small.
LA = lactic acid, NaL = sodium lactate, combo = 1% LA + 4% NaL
9 = like extremely
1 = dislike extremely

BLUE CRAB MEAT
SENSORY EVALUATIONS
FLAVOR

HEDONIC SCALE

(A)

TREATMENTS

CONTROL WATER 1% LA 4% NaL COMBO

DAY 1
DAY 5
DAY 8

BLUE CRAB MEAT
SENSORY EVALUATIONS
OVERALL ACCEPTABILITY

HEDONIC SCALE

(B)

TREATMENTS

CONTROL WATER 1% LA 4% NaL COMBO

DAY 1
DAY 5
DAY 8

*
CONCLUSIONS

Shelf life of fresh blue crab meat was extended 20% by sodium lactate (4%), 60% by lactic acid (1%) and 30% by the combination of both (1% lactic acid and 4% sodium lactate) treatments.

Elevated moisture content and an increase in lightness were observed in all treated samples. Lactic acid containing treatments showed reduced pH values. No treatment effects on texture were detectable with either sensory or physical evaluations.

Panelists judged lactate samples better in appearance with no differences found overall in odor and texture. Panelists found both lactic acid and sodium lactate treated crab meat to be acceptable with sodium lactate judged best in flavor and overall acceptability.

REFERENCES


ACKNOWLEDGEMENTS

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EXTENDING SHELF LIFE OF REFRIGERATED SEAFOOD PRODUCTS

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INTRODUCTION

Seafood products are widely known for their high degree of perishability. For the most part, U.S. seafood processors have relied on good sanitation and proper time and temperature controls for slowing decomposition and spoilage in refrigerated seafood products. Other food processing industries have employed traditional food preservation concepts for extending shelf life of refrigerated foods (29). These concepts (Table 1) include control of water activity (a\textsubscript{w}), pH, irradiation (ultraviolet/ionizing), preservatives and altered atmospheres (MAP, CAP or vacuum). More recently, new technologies such as ohmic heating, ultra high pressure, microwave pasteurization and natural and innovative preservatives have become available to food processors. This paper examines current technologies used in processing blue crab, health regulations impacting the U.S. blue crab industry and opportunities to apply new technologies for increasing value and extending shelf life of refrigerated blue crab products.

THE U.S. BLUE CRAB PROCESSING INDUSTRY

Current technologies used in processing blue crab involve traditional time and temperature controls and sanitation programs. Cooked, ready-to-eat refrigerated and pasteurized crab meat are the primary product types. Frozen crab meat has been a traditional type for use in value-added products (e.g., crab cakes and deviled crabs). Market interest in both live and frozen (cooked) whole crab, crab portions and vacuum-packed crab meat has increased recently (32). This interest, coupled with natural fluctuations in blue crab supply, has made for volatile market conditions.

A critical point in the processing of blue crab is cooking. Cooking times, temperatures and methods affect yield and subsequent shelf life of refrigerated products (6,9). Traditional time and temperature controls for cooking blue crab were based on industry practice and research during the 1950s to 1970s (7,20,33). The products fall under Current Good Manufacturing Practices (CGMPs) as required of all U.S. food processors engaged in interstate commerce (5). Specific time and temperature controls in production of refrigerated (24,34) and pasteurized (12,21,27) crab meat are available.

Still, good sanitation programs are required for the low bacterial levels necessary to protect the processor from losses due to spoilage and to ensure the safety of the product to the consumer (18,30,31). During processing, crab meat can be exposed to a wide variety of microorganisms. Therefore, it is vitally important that sanitation programs be rigorously applied, processes carefully managed to eliminate cross-contamination and refrigerated storage routinely monitored.
Table 1. Food Preservation Concepts for Extended Refrigerated Foods

<table>
<thead>
<tr>
<th>Traditional Technologies</th>
<th>New Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Water Activity (a_w)</td>
<td>* Ohmic Heating</td>
</tr>
<tr>
<td>* pH (acidity)</td>
<td>* Ultra High Pressure</td>
</tr>
<tr>
<td>* Irradiation</td>
<td>* Microwave Pasteurization</td>
</tr>
<tr>
<td>- Ultraviolet</td>
<td>* Natural Preservatives</td>
</tr>
<tr>
<td>- Ionizing</td>
<td>* Innovative Preservatives</td>
</tr>
<tr>
<td>* Preservatives</td>
<td></td>
</tr>
<tr>
<td>* Altered Atmosphere</td>
<td></td>
</tr>
<tr>
<td>- MAP (modified)</td>
<td></td>
</tr>
<tr>
<td>- CAP (controlled)</td>
<td></td>
</tr>
<tr>
<td>- Vacuum</td>
<td></td>
</tr>
<tr>
<td>* Time and Temperatures</td>
<td></td>
</tr>
<tr>
<td>* Sanitation (prevention)</td>
<td></td>
</tr>
</tbody>
</table>

HEALTH REGULATIONS IMPACTING BLUE CRAB PRODUCTS

All cooked, ready-to-eat blue crab products will be affected by new health regulations, including HACCP-based inspection, microbiological criteria, adulteration and economic fraud and labeling. Industry along with the U.S. Food and Drug Administration (FDA) and the U.S. National Marine Fisheries Service (NMFS), has worked cooperatively to implement a Hazard Analysis Critical Control Point (HACCP) inspection program. This approach will improve the quality and safety of cooked, ready-to-eat blue crab products.

Critical steps for control of microbial levels in refrigerated blue crab products are shown in Figure 1. Cooking, picking and packing are identified as critical control points under the blue crab HACCP regulatory model (26). Current industry practices for cooking of blue crab include steam pressure, atmospheric steam (partial cook) and boiling (Table 2). Specific process schedules have been incorporated into most state health regulations in the United States. Picking and packing represent additional critical control points (Table 3) where potential bacterial contamination of product is prevented through good manufacturing practices and proper sanitation.

Microbiological criteria (Table 4) for cooked, ready-to-eat crab meat and shrimp have been recommended for process verification (3,25). They include specific tolerance levels for Salmonella, Listeria monocytogenes, Staphylococcus aureus and thermal tolerant coliforms.
Figure 1. Flow chart for processing of blue crab products.
<table>
<thead>
<tr>
<th>METHOD</th>
<th>HAZARD</th>
<th>PREVENTIVE MEASURES</th>
<th>MONITORING</th>
<th>RECORDS</th>
</tr>
</thead>
</table>
| Steam pressure             | Microbial survival           | Adequate time and temperature         | Pressure monitoring | Annual cooker retort certifi-
|                            | Decomposition (short shelf life) | Approved scheduled process             | Temperature monitoring | cation                      |
| Steam atmospheric          | Microbial survival           | Adequate steam distribution and venting | Time in retort      | Annual cooker retort certifi-
| (partial cook only)        | Decomposition (short shelf life) | Approved scheduled process             | Venting             | cation                      |
| Boiling                    | Microbial survival           | Adequate time and                      | Cooking time        | Approved scheduled process   |
|                            | Decomposition (short shelf life) | Approved scheduled process             | Boiling of water    | Approved scheduled process   |
Table 3. CRITICAL CONTROL POINTS (PICKING AND PACKING) IN BLUE CRAB PROCESSING

<table>
<thead>
<tr>
<th>STEP</th>
<th>HAZARD</th>
<th>CONTROL POINTS</th>
<th>PREVENTIVE MEASURES</th>
<th>MONITORING</th>
<th>RECORDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking (hand and machine)</td>
<td>Bacterial contamination</td>
<td>Picking station</td>
<td>Good manufacturing practice</td>
<td>Supervisory checks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Foreign material</td>
<td>Machine</td>
<td>Personal hygiene</td>
<td>QA checks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Excessive shell</td>
<td></td>
<td>Clean and sanitize equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decomposition</td>
<td></td>
<td>Pest control</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Short hold time</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Immediate icing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pack/weigh and seal fresh meat</td>
<td>Incorrect weight</td>
<td>Packing weighing station</td>
<td>Scale check</td>
<td>Supervisory checks</td>
<td>Annual scale certification</td>
</tr>
<tr>
<td></td>
<td>Foreign material</td>
<td></td>
<td>Employee training</td>
<td>Scale calibration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bacterial contamination</td>
<td></td>
<td>Sanitation</td>
<td>QC checks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time/temperature control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. RECOMMENDED MICROBIOLOGICAL CRITERIA FOR PROCESS VERIFICATION IN COOKED, READY-TO-EAT SHRIMP AND COOKED, READY-TO-EAT CRAB MEAT

<table>
<thead>
<tr>
<th>MICROORGANISM</th>
<th>CRITERIA</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SHRIMP</td>
<td>CRABMEAT</td>
</tr>
<tr>
<td>Salmonella</td>
<td>n = 30</td>
<td>n = 30</td>
</tr>
<tr>
<td></td>
<td>c = 0</td>
<td>c = 0</td>
</tr>
<tr>
<td></td>
<td>m = M = 0</td>
<td>m = M = 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analytical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unit = 25 g</td>
</tr>
<tr>
<td>Listeria monocyto genes</td>
<td>n = 5</td>
<td>n = 5</td>
</tr>
<tr>
<td></td>
<td>c = 0</td>
<td>c = 0</td>
</tr>
<tr>
<td></td>
<td>m = M = 0</td>
<td>m = M = 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unit = 50 g;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>analytical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unit = 25 g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>through compositing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of 5-g portions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>from 5 sample units</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>n = 5</td>
<td>n = 5</td>
</tr>
<tr>
<td></td>
<td>c = 2</td>
<td>c = 2</td>
</tr>
<tr>
<td></td>
<td>m = 50/g</td>
<td>m = 100/g</td>
</tr>
<tr>
<td></td>
<td>M = 500/g</td>
<td>M = 1000/g</td>
</tr>
<tr>
<td>Thermal Tolerant Coliforms</td>
<td>n = 5</td>
<td>n = 5</td>
</tr>
<tr>
<td></td>
<td>c = 2</td>
<td>c = 2</td>
</tr>
<tr>
<td></td>
<td>m = 100/g</td>
<td>m = 500/g</td>
</tr>
<tr>
<td></td>
<td>M = 1000/g</td>
<td>M = 5000/g</td>
</tr>
</tbody>
</table>

n number of sample units examined from a lot to satisfy plan

c maximum allowable number of defective units (class 2) or marginally acceptable units (class 3)

m microbiological limit in class 2, separates good from defective quality
in class 3, separates good from marginally acceptable quality

M microbiological limit in class 3, separates marginally from unacceptable quality
One criteria, zero tolerance for *Listeria monocytogenes*, has proven to be quite a challenge for industry. The organism is widespread in nature and the primary concern is for its growth under refrigerated storage conditions (13,14). Of significant interest has been detection of *Listeria* in processing plants generally recognized as having better designed sanitation programs, i.e., a cleaner working environment (1).

Another issue affecting refrigerated blue crab products is adulteration and economic fraud. Concerns have led U.S. processors to petition the FDA for increased surveillance of imported products and use of tamper-evident packaging in domestic markets (15). The fraudulent mixing of domestic and foreign meats and slacking out of frozen product to be sold as fresh have added to the economic instability of traditional blue crab markets. In an effort to thwart fraudulent practices and address health concerns for refrigerated crab products in distribution, North Carolina processors have agreed with state health authorities to use tamper-evident packaging for all North Carolina produced crab products. This new state health regulation (28) will take effect April 1, 1993.

Another area impacting refrigerated blue crab products is labeling. Historically, use of the descriptor "fresh" has referred to cooked blue crab meat that has not undergone any further processing or freezing. Industry anxiously awaits the FDA's decision on continued use of this descriptor for packaging of refrigerated blue crab products. In addition, mandated nutrition labeling will force blue crab processors to redesign packaging materials and deplete present stocks of packaging as early as May of 1993.

**OPPORTUNITIES FOR NEW PRODUCTS AND NEW MARKETS**

Now that we have reviewed current practices and listed challenges facing blue crab processors, let's discuss some opportunities for applying new technologies to refrigerated blue crab products. Broadly speaking, chilled foods are extended shelf life products that exhibit shelf lives longer than those traditionally associated with the food and rely mainly on refrigeration for safety (29). Examples of extended shelf life products are Oscar Mayer's Lunchables with cured cooked chicken, sodium lactate and MAP, a Contadina pasta that uses $A_w$ MAP and heat treatment after extrusion to destroy psychrophiles and Sara Lee's Bilmar deli meats process that packages, pasteurizes and chills without headspace, i.e., sous vide.

What about seafood products? Ionizing irradiation is approved for use in over 30 nations to extend shelf life of a variety of foods (10). Research on seafood products, including blue crab, has demonstrated positive effects on quality and freshness (11,16,17). Presently, low-dose gamma irradiation is not approved for use in the U.S. by the FDA in processing of refrigerated seafood products. Its approval would greatly enhance the value, safety and consumer confidence for pathogen-free fresh seafood in the marketplace (10).

Altered atmospheres are traditional technologies used to extend shelf life of a wide variety of refrigerated foods including fresh fish and shellfish (19). Its use in the blue crab industry has been limited primarily to vacuum packaged, frozen hand-picked meats. Currently, MAP does not have U.S. FDA endorsement for seafoods although several European countries have accepted this technology for commercial use (4). Limited use of MAP under specified conditions was approved under the previous voluntary U.S. NMFS inspection program.

What about extended shelf life blue crab products? Natural and innovative preservatives represent a new technology so far untapped by traditional seafood processors. An example is use of the natural preservative sodium lactate to extend the shelf life of blue crab meat (22). Lactates are just one of a variety of GRAS approved substances that may be used as direct or indirect additives in seafood products.
BENEFITS OF INCREASED VALUE AND EXTENDED SHELF LIFE

What are the benefits for industry to incorporate new technologies into current practice? Short term benefits are increased value and greater consumer confidence in refrigerated products. Longer term, the benefits are new forms and markets for extended shelf life products. The blue crab industry traditionally has been a commodity-based industry at the mercy of supply and demand economics. Application of new technologies in development of refrigerated blue crab products would alleviate restraints on growth and open the door to the modern food era.

Any new development must be properly planned and cautiously scrutinized to ensure its safety. For industry, this development usually is in cooperation with university and regulatory personnel. One approach is the barrier concept which employs a combined technologies approach to shelf life extension and safety [23]. Under this approach, all new products should be abuse tested and challenged with various bacteria to check for the effectiveness of the barrier system. Protocols for verifying the effective control of specific pathogens have been proposed [2,8].

SUMMARY

In summary, regulatory guidelines for processing of cooked, ready-to-eat crab meat are well defined. The successful implementation of the HACCP-based inspection program for blue crab will greatly enhance the quality and safety of blue crab products. While the U.S. blue crab industry is undergoing some significant changes, opportunities do exist for applying innovative approaches to extend the shelf life of blue crab products. Establishment of HACCP-based inspection and microbiological criteria may provide industry with the proper mechanism to apply new technologies, add value and develop new markets. The challenge before all of us here today is to develop a new generation of extended shelf life seafood products.

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