The shelf life and safety of refrigerated fish and fish products are dictated by the presence of food spoilage and pathogenic microorganisms (Vilemure et al., 1986; Ingham, 1989; Harrison et al., 1991; Kim and Heamsberger, 1994). Temperature abuse during handling, transportation, and storage of fish without additional preservation methods allows for proliferation of these microorganisms (Barnett et al., 1982; Fey and Regenstein, 1982; Josephson et al., 1985; Scott et al., 1986; Baker et al., 1990). Growth of undesirable spoilage bacteria in refrigerated fish causes deterioration of keeping quality and reduces consumer acceptance.

Efforts to enhance the quality and safety of refrigerated foods have been primarily directed to preventing the growth of or to destroy aerobic spoilage bacteria and foodborne pathogens during storage and handling by using combinations of food additives and/or biopreservatives (Gilliland and Ewell, 1983; Lindgren and Dobrogosz, 1989). Several researchers have suggested that biopreservatives such as lactic acid bacteria or their metabolites in refrigerated foods have the ability to suppress aerobic bacteria that cause food spoilage (Raccach and Baker, 1978; Schaack and Marth, 1988; Laroia and Martin, 1990; Modler et al., 1990; Hughes and Hoover, 1991; Ray, 1992).

Phosphates have broad spectrum antimicrobial activity and are used for improving the microbiological quality of muscle foods and to improve shelf life (Molins, 1991). Molins (1991) reported that changes in pH induced by phosphate addition may play an important role in the ability of these compounds to chelate metal ions essential in bacterial metabolism and growth. He suggested that, in general, gram-positive bacteria are more susceptible to inhibition by various pyro- and polyphosphates than are gram-negative bacteria. Although there has been limited
work on combining acetates and phosphates in meat products (Mendonca et al., 1989) as antimicrobial surface treatments, this has not been studied with fish.

Lindgren and Dobrogosz (1989) observed that a combination of *Lactobacillus leuteri* and 250 mM glycerol inhibited aerobic spoilage bacteria in herring fillets stored in N\(_2\) at 5°C for 6 d. Raccach et al. (1979) and Schaack and Marth (1988) showed similar effects with lactic acid bacteria on food spoilage bacteria and pathogens in poultry meat and skim milk, respectively. Use of *Pediococcus cerevisiae* (Accel\(^R\)) and *Lactobacillus plantarum* (Lactacei\(^R\)) in refrigerated deboned poultry meat decreased the microbial population, reduced off-odor, and extended shelf-life by 2 d (Raccach et al., 1979). Kim and Heamsberger (1994) reported that combination of *Lactococcus lactis* ssp. cremoris ATCC 19257 with sodium acetate and potassium sorbate effectively inhibited growth of gram-negative bacteria on refrigerated catfish fillets. Bifidobacteria may control food spoilage bacteria and foodborne pathogens through production of lactic and acetic acids as well as other antibiotic substances (Laroia and Martin, 1990; Modler et al., 1990; Hughes and Hoover, 1991; Ray, 1992). Previous work in our laboratories has shown that sodium acetate is effective in suppressing the growth of aerobic spoilage bacteria on refrigerated catfish fillets (Kim and Heamsberger, 1994). Because there are no studies on the combined effect of sodium acetate with phosphates or bifidobacteria as an antimicrobial treatment of fish or fish products, the present study was designed to evaluate shelf-life of refrigerated (4°C) channel catfish fillets surface-treated with sodium acetate, monopotassium phosphate and/or selected bifidobacteria.

**MATERIALS & METHODS**

**Preparation of bifidobacteria cultures**

*Bifidobacterium infantis* ATCC 15697 and *B. longum* ATCC 15707 were obtained from the American Type Culture Collection (Rockville, MD). *B. adolescentis* 9H Martin was obtained from the culture collection of Dr. J. H. Martin, Mississippi State University. Stock cultures were maintained in sterile skim milk medium (SM; 10% skim milk, 0.5% yeast extract, and 0.5% glucose) at 37°C for 24 h in an anaerobic jar (Gas-Pak; BBL). For fish inoculation, the cultures were prepared by three successive 1:10 transfers at 24-h intervals into fresh SM incubated as above. Bifidobacteria cultures in SM (6.0 x 10\(^7\) to 1.0 x 10\(^8\) CFU/ml) were added at a given percentage (V/W) to fresh catfish fillets as described below. Final SM pH was 4.4-4.8.

**Catfish preparation and treatment**

Fresh channel catfish (*Ictalurus punctatus*) fillets were obtained from a commercial source, transported to MSU on ice, and used within 3 h. For each treatment, 2 kg of fillets (average weight of 110 g per fillet) were placed in a precleaned (Jetson General Purpose Cleaner, Diversy Group, Cincinnati, OH) and sanitized (hot water at 88°C) tumbler (Polymaid Model SS 350, Lax-go, FL) at room temperature. Food preservatives were added to the tumbler and fillets were tumbled
for 15 min at 18 r-pm. Untreated controls were tumbled without preservatives. The tumbler was cleaned and sanitized between treatments. Duplicate experimental trials consisted of the following treatments: (a) 0.0, 0.25, 0.5, 0.75, or 1.0% (W/W) sodium acetate (SA; Fisher Scientific Co., Norcross, GA), (b) 0.0, 0.25, 0.5, 0.75, or 1.0% (W/W) monopotassium phosphate (MKP; FMC Corp. Philadelphia, PA), (c) 0 or 2.5% (V/W) B. adolescentis, B. infantis, or B. longum (V/W), (d) 0.5% SA and 0.1, 0.2, 0.3, or 0.4% MKP, (e) 0.4% MKP and 0.3, 0.5, or 0.7% SA, (f) 0 or 2.5% of B. adolescentis, B. infantis, or B. longum combined with 0 or 0.5% SA, (g) 0 or 0.5% SA combined with 1.5%, 2.5%, 3.5%, or 4.5% B. infantis, and (h) 0 or 0.5% SA combined with 2.5% B. infantis incubated for 24, 48, or 72 h before addition. Treated catfish fillets were removed from the tumbler and stored individually in “Ziploc®” (DowBrands L.P., Indianapolis, IN) bags at 4°C. Storage bag gas transmission rate is 1.65 cc/cm² per mil in 24 h at 1 atm. Microbiological analysis was performed for each treatment over a 12 d storage period. Selected treatments were scheduled for pH measurements and sensory evaluations during storage.

Microbiological analyses
Each fillet was weighed and 0.1% sterile peptone water was added to make a 1:1 dilution (W/V). A Stomacher Lab Blender 400 (Tekmar, Cincinnati, OH) was used to homogenize the specimen for 2 min and then appropriate serial dilutions were made for spiral plating. Total aerobic plate counts (APC) were determined by duplicate spiral-platings (Spiral System, Inc., Bethesda, MD) on standard plate count agar (Difco Detroit, MI) incubated at 30°C for 2 d before counting (Swanson et al., 1992). APC values were expressed as mean log₅ CFU/g for 2 fillets per treatment per sampling day. Generation times were calculated as described elsewhere (Marshall and Schmidt, 1988).

Bifidobacteria were enumerated by pour plating appropriate serial dilutions in 0.1% peptone water with neomycin-paromomycin- nalidixic acid-lithium chloride agar (Teraguchi et al., 1978; Laroia and Martin, 1991) followed by incubation at 37°C for 48 h in an anaerobic jar (Gas-Pak; BBL) prior to counting colonies.

Measurement of pH
Fillet pH was measured with a standardized pH meter (Accumet®, Model 50, Fisher) by placing a surface electrode directly onto the fillet surface. Mean pH values were reported as the average of quadruplicate readings for each duplicate fillet.

Sensory evaluation
Sensory evaluation of samples was performed by an eight member untrained panel. Uncooked odor and appearance of treated fillets were evaluated every 3d during storage at 4°C. Samples were warmed to room temperature prior to analyses. Treated samples were judged against a fresh control (fresh fillets were used each analysis day) which was assigned a score of 5. Samples liked less than the control were scored 1 to 4, where 1 = most disliked. Samples liked more than the control were scored 6 to 9, where 9 = most liked. Untreated fillets also were compared with
untreated fresh fillets and treated fillets. Two fillets per treatment per sampling day were analyzed.

Statistical analyses
APC, pH, and sensory data were analyzed using ANOVA, and means were separated by the least significant difference test (SAS, 1992).

RESULTS & DISCUSSION

Combined effect of sodium acetate and monopotassium phosphate
APC of refrigerated (4°C) catfish fillets were affected by increasing levels of SA (Fig. 1). Use of 0.75% and 1.0% SA significantly lowered \( P < 0.05 \) initial APC by 0.6-0.7 log units compared to the control. Generation times (GT) of aerobic bacteria on fillets treated with SA were significantly higher \( P < 0.05 \) than the control (Fig. 2). Spoilage of most muscle foods is thought to occur when APC reach \( 10^7 \) CFU/g or greater (Ayers, 1960). Therefore, SA treatments, at 0.75% or greater, of fillets could increase shelf-life (as measured by APC) by 6 d under present experimental conditions. These results confirm previous work that demonstrated the antimicrobial potential of SA on catfish fillets, where 0.5-1.0% SA suppressed growth of gram-negative bacteria at 4°C for at least 6 d (Rim and Hearsberger, 1994).

MKP in refrigerated catfish fillets had no effect on APC values (results not shown) or generation times (Fig. 3). Treatment with MKP lowered fillet pH values by 0.5-0.9 units (results not shown). Kim and Hearsberger (1994) reported that the combined antimicrobial effects of SA, potassium sorbate, and lactic acid bacteria in refrigerated catfish fillets were not pH related. Results of the present catfish study are consistent with previous work by Molins (1991) who reported that other phosphates (sodium acid pyrophosphate or sodium tripolyphosphate) did not improve the microbiological quality of cooked, vacuum-packaged bratwurst held at 5°C for 7 d.

Combining MKP and SA effectively inhibited growth of aerobic microorganisms (Figs. 3 and 4). All samples treated with the combination had significantly \( P < 0.05 \) lower APC after 3 d of storage than the control. Combining MKP with 0.5% SA reduced numbers during latter stages of storage more than did SA alone (results not shown), which was reflected by increased generation times with increasing MKP concentration (Fig. 3). Conversely, when MKP concentration remained at 0.4%, no differences \( P > 0.05 \) in inhibition were observed with increasing Concentrations of sodium acetate (0.3-0.7%) (Fig. 4). Results indicate that the interaction between MKP and SA is likely additive.

Although MKP alone had no inhibitory effect, it may cause a decline of water activity values in treated fish fillets (Synder and Maxcy, 1979) and have indirect antimicrobial effects due to chelation of metal ions essential for bacterial metabolism and cell integrity (Scott et al., 1986). Microbial spoilage of fish is caused by gram-
Fig. 1. Total aerobic bacterial counts on catfish fillets treated with sodium acetate (SA) during storage at 4°C.

Fig. 2. Generation times of aerobic bacteria on catfish fillets treated with sodium acetate (SA) or monopotassium phosphate (MKP) and stored at 4°C. Means within the same cluster having the same letter are not significantly different (P>0.05).
Fig. 3. Generation times of aerobic bacteria on catfish fillets treated with different concentrations of monopotassium phosphate (MKP) combined with 0.5% sodium acetate (SA) and stored at 4°C. Means with the same letter are not significantly different (P>0.05).

Fig. 4. Generation times of aerobic bacteria on catfish fillets treated with different concentrations of sodium acetate (SA) combined with 0.4% monopotassium phosphate (MKP) and stored at 4°C. Means with the same letter are not significantly different (P>0.05).
Fig. 5. Aerobic plate counts of catfish fillets treated with *Bifidobacterium infantis* culture (BI) and sodium acetate (SA), either alone or combined, during storage at 4°C.

Fig. 6. Generation times of aerobic bacteria at 4°C on catfish fillets treated with *Bifidobacterium infantis* Culture (BI) and sodium acetate (SA), either alone or combined. Means with the same letter are not significantly different (p>0.05).
negative bacteria such as Pseudomonas spp. (Herbert et al., 1971; Herbert and Shewan, 1976). SA inhibits growth of gram-negative bacteria on refrigerated (4°C) catfish fillets (Kim and Hearnsberger, 1994), while gram-positive bacteria are more susceptible to inhibition by MKP than are gram-negative bacteria (Molins, 1991). This microbial specificity demonstrates that SA is a better chemical treatment than MKP to extend shelf-life of catfish. However, results indicate that a combination of SA and MKP may prolong the microbiological shelf life of catfish at 4°C by keeping counts below 10^7 CFU/g.

Combined effect of sodium acetate and bifidobacteria

The effects of various concentrations and species of BIF and SA on the shelf-life of refrigerated catfish fillets were studied on the basis of aerobic plate counts (APC) and sensory data. When a 2.5% culture of B. infantis was used alone, little impact on APC was noted with the exception of a significant (P<0.05) extension of the lag phase (Fig. 5). Once growth began, GT of aerobic microorganisms on fillets treated with B. infantis were not significantly different (P>0.05) from control fillets (Fig. 6). Similar (P>0.05) extended lag phases and GT were noted for fillets treated with 2.5% cultures of B. adolescentis or B. longum (results not shown). Hence, further results only will report data from B. infantis treatments. Lag phase increases of psychrotrophic populations were observed in ground poultry treated with Lactobacillus plantarum or Pediococcus cerevisiae (Raccach et al., 1979). It was assumed that inoculated BIF do not grow on refrigerated fish fillets and the extension of lag phase may be due to compounds produced during culturing, i.e. acetic and/or lactic acid, that were inhibitory to aerobic spoilage bacteria (Gilliland and Speck, 1975; Ray, 1992). Other reasons for inhibited aerobic growth might include nutrient competition, unfavorable changes in oxidation reduction potential, or production of other antimicrobial compounds.

Fillets treated with 0.5% SA had APC significantly lower and GT significantly higher (P<0.05) than control or BE-treated fillets (Fig. 5 & 6). The microbiological shelf-life (i.e. time to reach APC of 10^7 CFU/g or greater (Ayers, 1960)) of SA-treated fillets was prolonged by 3 d compared to untreated and BIF-treated fillets. Combining 2.5% BIF with 0.3% SA resulted in significant (P<0.05) lag phase extension and increased GT values approximately 8 h higher than controls (results not shown). No differences (P>0.05) among species was noted. When 2.5% B. infantis was combined with 0.5% SA, significant (P<0.05) decreases in APC and increases in GT were observed (Fig. 5 & 6). No significant difference (P>0.05) in GT was seen between this treatment and 0.5% SA alone, resulting in a 3d microbiological shelf-life extension. B. infantis behaved similarly (P>0.05) as the other two cultures when combined with 0.5% SA (results not shown). The combined treatments could increase GT by approximately 20 h. A previous report on SA combined with potassium sorbate or lactic acid culture has attributed antimicrobial effects primarily to SA (Kim and Hearnsberger, 1994). The present study shows that an additive interaction occurs when BIF are combined with SA.
Efforts to increase antimicrobial activity of the BIF-SA treatment proved unsuccessful. Increasing the amount of B. infantis culture had no influence (P>0.05) on APC (results not shown). Likewise, increasing the amount of time the B. infantis culture was incubated prior to application had no influence (P>0.05) on APC (results not shown). Reddy et al. (1970) reported that addition of 10% cultures of Leuconostoc citrovorum was effective in inhibiting the growth of aerobic spoilage bacteria in ground beef stored at 7°C for 7 days. In a later study, Reddy et al. (1983) found that when cultivation was prolonged from 24 to 48 h, growth and antibiotic production of Lactobacillus bulgaricus in skim milk was enhanced.

Catfish pH and sensory scores

Addition of SA decreased pH of fillets by 0.2-0.3 units (results not shown). Fillets treated with both SA and MKP had initial pH values 0.25-0.3 units lower than the control (Table 1).

Table 1. Mean pH values of catfish fillets treated with combinations of sodium acetate (SA) and monopotassium phosphate (MKP) during storage at 4°C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage Time (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>6.45&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.3% SA-0.4% MKP</td>
<td>6.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.5% SA-0.4% MKP</td>
<td>6.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.7% SA-0.4% MKP</td>
<td>6.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means in the same column with different superscripts are significantly different (P<0.05).

This decline was attributed to SA. After 3 d of storage, pH values changed little and did not differ (P>0.05) from the control. Initial pH values of fillets treated with 0.5% SA and 2.5% BIF, either alone or combined, were 0.4-0.5 units lower than untreated control fillets (results not shown). Other work has shown that SA-treated catfish fillets do not necessarily have lower pH values than controls, but remain inhibitory to growth of aerobes (Kim and Heamsberger, 1994). Hence, inhibitory results seen in the present study are likely due to changes in pH and to the action of SA itself.

Sensory results of SA-MKP experiments clearly showed panel preference for treated samples over stored untreated controls (Table 2). Sensory assessment of untreated controls was halted after 3 d of storage because of excessive off odor. Fillets treated with SA alone or combined with MKP had odor scores that were statistically indistinguishable (P>0.05) from fresh controls for up to 9 d (Table 2). However, appearance scores of fillets were significantly lower (P<0.05) after 3 d, likely due to a brownish and watery appearance (Table 2). Microbial spoilage of fish muscle is due to production of volatile nitrogen compounds, volatile acids, H₂S, and mercaptans (Miller et al., 1973; Reineccius, 1977). Sensory data indicate that SA
concentrations up to 1% could be used on catfish without contributing a typical acetic acid (vinegar) odor.

Table 2. Mean sensory evaluation scores of catfish fillets treated with sodium acetate (SA) and monopotassium phosphate (MKP), either alone or combined, during storage at 4°C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Odor Score</th>
<th>Appearance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 3 6 9 12</td>
<td>0 3 6 9 12</td>
</tr>
<tr>
<td>Fresh Control</td>
<td>5.0a 5.0a 5.0a 5.0a 5.0a</td>
<td>5.0ab 5.0a 5.0a 5.0a 5.0a</td>
</tr>
<tr>
<td>1.0% SA</td>
<td>5.2a 4.5a 4.4a 4.0a 3.7b</td>
<td>5.4a 5.2a 4.3b 3.4b 3.6b</td>
</tr>
<tr>
<td>0.3% SA-MKP</td>
<td>4.8a 5.0a 4.0a 3.8b 3.0b</td>
<td>4.6b 4.8a 4.4b 3.3b 3.9b</td>
</tr>
<tr>
<td>0.4% MKP</td>
<td>4.4a 4.6a 4.7a 5.2a 2.9b</td>
<td>5.3a 4.6a 4.1c 4.0a 3.5b</td>
</tr>
<tr>
<td>Untreated</td>
<td>5.0a 1.5b ND ND ND</td>
<td>5.0ab 2.9b ND ND ND</td>
</tr>
</tbody>
</table>

Means within the same column with different superscripts are significantly different (P<0.05).

ND: Not determined.

Note: Fresh control assigned 5, with samples liked less than the control scored 1 to 4 (1 = most disliked) and samples liked more than the control scored 6 to 9 (9 = most liked).

Sensory scores of SA-BIF experiments indicate that treated fillets were in the "liked less" to "typical" category in appearance and odor compared to fresh control fillets (Table 3). Stored untreated control fillets were considered organoleptically unacceptable (associated with spoiling fish) by 6 d of storage and were discontinued from sensory evaluation. Odor and appearance of fillets treated with 0.5% SA and 2.5% *B. infantis* either alone or combined, was the same (p>0.05) as fresh fillets up to 6 d. Fillets treated with SA and BIF or SA alone were rated higher than fillets with BIF alone after 9 d. APC of fillets treated with BIF alone rapidly increased after 3 d of storage, yet the fillets were not considered spoiled by the panel until after 6 d.

**CONCLUSIONS**

SA alone or combined with MKP or BIF inhibited growth of aerobic spoilage bacteria on refrigerated (4°C) catfish fillets. MKP or BIF had little activity alone, but could increase effectiveness of SA. Therefore, use of MKP or BIF alone has trivial value in extending shelf-life of refrigerated catfish fillets. SA alone or combined with MKP or BIF is recommended to extend the microbiological shelf-life of refrigerated catfish fillets with high (10⁶ CFU/g) initial microbial loads.
Table 3. Mean sensory evaluation scores of catfish fillets treated with sodium acetate (SA) and *Bifidobacterium infantis* culture (BI), either alone or combined, during storage at 4°C.

<table>
<thead>
<tr>
<th>STORAGETIME (d)</th>
<th>Odor Score</th>
<th>Appearance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>0 3 6 9 12</td>
<td>0 3 6 9 12</td>
</tr>
<tr>
<td>Fresh Control</td>
<td>5.0a 5.0a 5.0ab 5.0a 5.0a</td>
<td>5.0a 5.0a 5.0a 5.0a 5.0a</td>
</tr>
<tr>
<td>2.5% BI</td>
<td>4.7a 4.8a 4.5b 3.1bc 1.4c</td>
<td>4.5a 4.5a 5.1a 3.2b 1.5c</td>
</tr>
<tr>
<td>0.5% SA</td>
<td>4.6a 4.4a 5.4a 3.7b 2.2b</td>
<td>4.6a 4.5a 5.3a 3.3b 2.5b</td>
</tr>
<tr>
<td>2.5% BI-0.5% SA</td>
<td>5.4a 5.0a 5.0ab 3.4bc 2.4b</td>
<td>4.5a 4.8a 5.2a 3.3b 2.6b</td>
</tr>
<tr>
<td>Untreated Control</td>
<td>5.0a 5.1a ND ND ND</td>
<td>5.0a 5.3a ND ND ND</td>
</tr>
</tbody>
</table>

* Means within the same column with different superscripts are significantly different (P<0.05).

ND: Not determined.

Note: Fresh control assigned 5, with samples liked less than the control scored 1 to 4 (1 = most disliked) and samples liked more than the control scored 6 to 9 (9 = most liked).

ACKNOWLEDGMENTS

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REFERENCES


Effect of Tray Design and Packaging Type on Microbial Growth, Surface pH and Sensory Ratings of Refrigerated Channel Catfish Fillets

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INTRODUCTION

Gram negative spoilage bacteria such as *Pseudomonas*, *Moraxella*, *Acinetobacter*, *Flavobacterium*, and *Cytophaga* species are the major contributors to deterioration of fish and seafood products (Farber, 1991). Modified atmosphere packaging (MAP) using mixtures of carbon dioxide, oxygen, nitrogen, or other gases has been studied extensively to prolong shelf-life of fishery products (Silva et al, 1993; Wang and Ogaryzak, 1986; Stenstrom, 1985; Gray et al., 1983; Parkin et al., 1981; Wolfe, 1980) and thus, extend marketable life of the products. Studies by Gray et al. (1983) in fish products and Sander and Soo (1978) in chicken products, showed that MAP systems were better in extending shelf-life than ice or vacuum packaging systems.

Carbon dioxide is the major gas used in MAP because of its effectiveness in retarding microbial growth in refrigerated, perishable foods. It is especially effective against gram negative spoilage microorganisms by extending lag phase and decreasing growth rate during log phase (Farber, 1991). To achieve the greatest extension of shelf-life, low temperature, close to 0°C (Farber, 1991; Gray et al, 1983), low initial microbial load (Lannelongue, 1982), and high concentrations of carbon dioxide (Blickstad and Molin, 1983) are necessary.

Shelf-life and keeping quality of raw channel catfish fillets have been reported to be 19 d for tray packed/chilled (2°C) products, 7 d for ice-packe d fillets (Reed et al., 1983), up to 28 d under 80% CO₂ in barrier bags at 2°C (Silva and White, 1994), and about 16 d for fillets exposed to CO₂ for 6 d and transferred to trays wrapped with HDPE and held at 2°C (Silva et al., 1993). Initial counts on fish for those studies were 3.9 log CFU/cm², 3.9 log CFU/cm², 6 log CFU/g, and 5.8 log CFU/g, respectively. One MAP technology is the Master-Pack System. It consists of placing small product units (prepackaged or not) into a larger package units (Brody, 1989) which could then be evacuated and backflushed with a gas mixture. The products remain in this system until strict temperature control is not feasible or until ready for consumer display or use.

The objective of the present study was to compare storage life of channel catfish fillets held in different environments (air, vacuum and MAP - Master-Pack) and tray types (single or double-bed) at 2°C by measuring anaerobic, psychrotrophic, and Lactobacilli plate counts, pH, moisture and sensory scores (odor and appearance rating) every 4 d for 28 d.
MATERIALS AND METHODS

Materials
Live channel catfish *Ictalurus punctatus* were processed into fillets at a commercial catfish processing operation and packed in a walk-in cooler at 2°C in single-(S) or double-(D) bed Styrofoam trays with a moisture absorbant pad. The tray-packed fillets (2 per tray) were wrapped with a 2.7 mil polyethylene (HDPE) film and heat-sealed. The trays were packed in ice chests and covered with ice until further treatment at the Mississippi State University Food Science laboratories (not more than 6 h).

One third of the trays were stored as packed (AIR); one third were unwrapped and placed individually in permeable ETM bags (Cryovac Corp., Duncan, SC), vacuumized, and heat-sealed (VAC); and the other third were packed 5 trays to a bag in a barrier B700TM Master-Bag, air evacuated, and back flushed with CO2 to reach 90% CO2, 3% O2, and 7% N2 (MAP). The properties of each of the films are given in Table 1. All products were held at 2°C for up to 28 d and sampled periodically.

Each treatment was replicated twice and analyses were performed in duplicates. Treatments were tray-type (D or S), gas environment (AIR, VAC, or MAP), and storage time (up to 28 d) at 2°C.

Methodology
Anaerobic (AnPC), psychrotrophic (PPC) and lactobacillii (LAC) plate counts were performed following AOAC methods (FDA, 1992). Standard plate count agar (DIFCO Labs.) was used for AnPC (pour plates) and PPC (spread plates) with plates incubated at 25°C for 72 h in an anaerobic chamber and 21°C for 72 h in a temperature controlled chamber for AnPC and PPC, respectively. Rogosa agar (DIFCO Labs) was used for LAC, using pour plating technique and incubating aerobically at 25°C for 72 h.

Surface pH was measured using a flat-head electrode on the fish flesh as outlined by Silva and white (1994). Moisture was measured by shredding 5 g of fillet and heating at 100°C for 18 h (AOAC, 1990).

Appearance and odor ratings were conducted on the packaged products after sampling for microbial counts, by seven trained panelists. A 5-point rating scale for appearance and odor was used as follows: Appearance: 5 - fresh appearance 3 - slightly dry or slimy surface, 1 - slimy and off-colored surface, Odor: 5 - fresh, sweet odor, 3 - slightly spoiled (spoilage threshold rating), and 1 - totally spoiled/putrid.

RESULTS AND DISCUSSION

Initial anaerobic counts (AnPC) of fillets in double-(D) bed trays were lower than in single-(S) bed trays regardless of environment (Fig. 1). By the eighth day, AnPC were above 7 log CFU/g for all treatments except S/MAP, D/VAC, and D/MAP. By the 12 d, D/VAC products exceeded 7 log CFU/g, thus the product had spoiled (Handumrongkul and Silva, 1993; Martin and Hearnsberger, 1993; Anonymous, 1992). Products packed under 90% CO2 in single-bed trays (S/MAP) exceeded 7 log CFU/g after 16 d, whereas those packed in double-bed trays (D/MAP) did not exceed 7 log CFU/g until after 24 d.
Table 1. Properties of films used for packaging study.

<table>
<thead>
<tr>
<th>Film/Bag Type</th>
<th>Source</th>
<th>Thickness (mm)</th>
<th>WVTR (cm³/m²/24h/atm)</th>
<th>OTR</th>
<th>CO₂TR (cm³/m²/24h/atm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>Dow Chem Co.</td>
<td>0.069</td>
<td>10.08 (0.65°C 100% RH)</td>
<td>1,070</td>
<td>3,350</td>
</tr>
<tr>
<td>E™️ bag</td>
<td>Cryovac Corp.</td>
<td>---</td>
<td>4,000 (22.8°C)</td>
<td>16-</td>
<td>20,000</td>
</tr>
<tr>
<td>B700 bag</td>
<td>Cjovac Corp.</td>
<td>0.5-0.6</td>
<td>3-6</td>
<td>15-30</td>
<td></td>
</tr>
</tbody>
</table>

WVTR - water vapor transmission rate, OTR - oxygen transmission rate, CO₂TR - carbon dioxide transmission rate
FIGURE 1. ANAEROBIC PLATE COUNTS IN CHANNEL CAT FISH FILLETS AS AFFECTED BY TRAY TYPE (SINGLE OR DOUBLE BED) AND ENVIRONMENT.
Psychrotrophic plate counts (PPC) were below 7 log CFU/g for single-bed or double-bed tray packed products in MAP (Fig. 2) for over 12 d. The PPC of fish packed under other treatments exceeded 7 log CFU/g after 4 d except for S/AIR which took about 6 d.

Lactobacilli counts (LAC) were lower in fillets packed in double-bed trays (Fig. 3), but reached the same levels as for other treatments after the 16th day, between 4-5 log CFU/g. It is well known that gram negative spoilage bacteria population is replaced by gram positive Lactobacillus in meat products under anaerobic or modified atmospheres (Farber, 1991; Gray et al., 1983).

Surface pH of fillets tended to be lower for products in double-bed trays for the first 12 d (Fig. 4). After the 16th day, pH of products packed under VAC or MAP in single-bed trays was near 5.0. This is probably due to carbonic acid and lactic acid formation (Brody, 1989).

Initial moisture content of fillets ranged from 72 to 81% (Fig. 5). Even though there was more visual drip in vacuum-packed products (data not shown), moisture content was not significantly affected. However, D/MAP fillets had lower moisture than S/MAP fillets after 28 d. This may be the result of the pad not being in direct contact with the fish in D trays.

Odor ratings of fillets in D/MAP and S/MAP were above spoilage level, 3 for at least 24 d (Fig. 6). Vacuum and air packed products were rated below 3 after 6 to 8 d at 2°C except for D/VAC, which were rated below 3 by the 12th day.

Appearance ratings of fillets followed closely the trends of odor ratings. Ratings for MAP fillets did not reach below 3 until the 28th day (Fig. 7), whereas the other treatments reached 3 between the 6th and 16th day.

Results show that fillets packed under 90% CO₂ (MAP) will have lower bacterial counts than those packed under vacuum or air. Lactobacillus counts show that spoilage bacteria are not rapidly replaced by Lactobacillus under MAP in double-bed trays but the latter grow rapidly in single-bed trays under MAP or VAC. The double-bed trays have a foam, porous layer between the product and the pad, thus isolating the product from the drip, and the bacterial flora accumulated away from the product. Lower pH is thought to be from the conversion of CO₂ to carbonic acid and the production of lactic acid by lactobacilli (Daniels et al., 1985; Lannelongue et al., 1982). Odor (Fig. 6) and appearance (Fig. 7) ratings of fillets followed anaerobic (Fig. 1) counts (AnPC) very closely, and correlated somewhat with PPC (Fig. 2). A slimy, whitish appearance of the fish surface and an ammonia, putrid smell were the signs of fish spoilage, although MAP products also had a sour smell towards the end of their storage (24-28 d).

This work shows that not only products packed under 90% CO₂ in a Master-Bag will have a longer shelf-life, but also products packed in double-bed trays may have longer keeping quality. Also it shows that AnPC may follow better the microflora of fish fillets held at 2°C as compared to PPC.
FIGURE 2. PSYCHROTROPHIC PLATE COUNTS IN CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
FIGURE 3. LACTOBACILLI PLATE COUNTS IN CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
FIGURE 4. CHANGES IN pH OF CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
FIGURE 5, CHANGES IN MOISTURE CONTENT OF CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
FIGURE 6. ODOR RATING OF CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
FIGURE 7. APPEARANCE RATING OF CHANNEL CATFISH FILLETS AS AFFECTED BY TRAY TYPE (Single or Double bed) AND ENVIRONMENT.
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REFERENCES


STABILITY OF FROZEN MINCE FROM CHANNEL CATFISH FRAMES

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INTRODUCTION

The demand for farm-raised channel catfish (*Ictalurus punctatus*) has grown tremendously in recent years due to year round availability, consistent quality, and healthy attributes of catfish. In 1993, over 459 million tons of catfish were produced in the United States (Anon., 1994). As this industry has grown, so has the amount of offal, trimmings, and other solid waste generated and the need to provide effective means of waste removal and disposal.

According to the USDA (Anon., 1992) 47% of catfish sold is in the form of fillets, 32% is whole fish, and the remaining 21% includes steaks, nuggets, and value added products. Only 68% of the fish is sold for food with the remainder being waste, including skeletons (frames), which account for 18% of the fish (Woodruff, 1984).

Currently, most catfish producers do not have the necessary equipment to use fish frames other than converting them into fish meal Income processors receive for catfish offal, about $.05/lb, just covers the cost of transporting the waste materials to rendering plants.

These frames could be utilized more effectively. About 50% of frames is meat, which can be recovered by various means (deboning, cooking, and separating). There are several advantages to finding better uses for even a portion of this waste. Less waste and more useable product means less cost for discharging waste into waste treatment systems, reduces water pollution and strain on the environment. A profit could also be made on the additional muscle meat recovered (McAlpin et al., 1994).

By passing the catfish frames through a mechanical deboner, approximately 25-50% of the weight of the frame is removable meat (Ammerman, 1985). Once removed, methods to process and preserve this mince become important.
Antioxidants can be added to increase shelf-life. Several food-grade antioxidants and metal chelators such as sodium citrate, phosphates and sodium erythorbate or in combination may be used to maintain quality of fish mince. Sodium citrate protected ocean trout against lipid oxidation (Shenouda et al., 1979). Citric acid can inactivate enzymes and sequester trace metals (Anon., 1985). Brifisol™, a phosphate mix, can be a useful antioxidant in finely ground meats (Anon., 1990).

Phosphates have been shown to prevent rancidity in fish (Gordon, 1971), and sodium erythorbate has been found to have protective effects on various fish species (Bilinski et al., 1979, Hwang and Regenstein, 1988, Santos and Regenstein, 1990, Licciardello et al., 1977, 1980, 1982). Erythorbates are comparable to ascorbates in antioxidant effectiveness, but cost less (Anon., 1982).

The present research was conducted (1) to explore the feasibility of producing a mince from channel catfish frames and, (2) to study methods of maintaining the overall quality of the frame mince during frozen storage.

MATERIALS AND METHODS

Sample preparation

Catfish frames were transported from a commercial processor in Mississippi to the Mississippi State University/National Marine Fisheries Experimental Seafood Processing Laboratory in Pascagoula, MS. Frames were packed on ice (1 to 3 days) prior to transportation and kept on ice until used. Once unloaded, frames were rinsed with filtered water using a rotary fish washer (Model GL300 Ryan Engineering Inc., Seattle, WA) that allowed them to drain as they tumbled. Frames were then passed through a deboner with 5mm holes in the cylinder (Model NDX13 Bibun Machine Construction Co. Ltd., Japan).

Mince used in unwashed treatments (U) was covered with plastic and stored at 3 ± 1 °C until used. Washed mince (W) was prepared by placing mince in wash tanks containing 1 part mince to 4 parts water (5°C). This slurry was stirred for 10 min and allowed to settle for 5 min before water was decanted. This procedure was repeated 3 times to remove lipids, some pigments, and water soluble proteins. Mince slurry was pumped to a rotary screen rinser (Model F32LW, Bibun Machine Construction Co., Ltd., Japan) to remove loose water and then transferred to a screw press (Model YS200, Bibun Machine Construction Co., Ltd., Japan) to remove remaining excess water and reduce the moisture content to 78%.

Treatments

The mince was held in a refrigerated room (3°C ± 1 °C) until used. There were 5 treatments for both washed and unwashed mince, consisting of four antioxidant combinations and one control. The following antioxidants and combinations of antioxidants were added to the mince: (1) 0.15% sodium citrate - CI (Haarmann and Reimer Corp., Elkhart, IN); (2) 0.15% sodium erythorbate - ER Pfizer New York, NY); (3) 0.15% sodium citrate and 0.15% sodium erythorbate (CE); (4) 0.15% sodium citrate, 0.15% sodium erythorbate, and 0.4% Brifisol™ 414 (BR) - a mixture of sodium acid pyrophosphate, sodium pyrophosphate, and sodium polyphosphate, glassy (BK Ladenburg, Cresskill, NJ); and, (5) mince alone or control (CO). Sodium citrate and sodium erythorbate were calculated (w/w) based on acid equivalents.
Antioxidants were dissolved in a small amount of water added to unwashed mince and were added to the washed mince in powdered form. All treatments including controls were mixed for 3 min to evenly disperse the antioxidants. Replication 1 used a household mixer (Model K45 Kitchenaid Division, Hobart Manufacturing Co., Troy OH) and replications 2 and 3 used an industrial size mixer (Model A200, Hobart Manufacturing Co.). Mince was then placed in 20 0.45 kg wax coated cardboard boxes (Packaging Production Corp., New Bedford, MA) and frozen to -40°C in a plate freezer (Dole Freeze-Cell Model 2735-6A, Dole Refrigerating Co., Lewisburg, TN). Frozen mince was stored in a storage freezer overnight (-20°C), packed in dry ice, and transported to Mississippi State University for chemical analyses. Samples were stored at -14°C ± 2°C for the duration of the study.

Analyses

Oxidative rancidity was determined by the 2-thiobarbituric acid reactive substances (TBARS) test (Tarladgis et al, 1960). Optical density was multiplied by a factor of 7.8 to express the results as mg malonaldehyde/kg mince according to Sinnhuber and Yu (1958). Enzymatic rancidity (free fatty acids, FFA) was determined by the method described by Woyewoda et al (1986). Color was determined by a Hunterlab Model D25 Color Meter (Hunter Associates Laboratory, Inc., Reston, VA), standardized with a white plate standard no. LS-13601. All preceding tests were performed in duplicate after 0, 1, 2, 3, and 4 mo. of frozen storage.

Moisture, fat, protein, ash, copper, iron, phosphorus, and erythorbate contents were determined at time 0 for each experimental observations by the Mississippi State Chemical Laboratory. All analyses, with the exception of erythorbate, used AOAC (1990) methods. A standard curve was set up to evaluate erythorbate results using Vitamin C (ascorbate) procedures (Strohecker and Henning, 1966). In addition to AOAC methods, the phosphate analysis used procedures from Clesceri et al. (1989).

Statistical Analysis

The data were analyzed using analyses of variance for a split-plot in a randomized complete block design. Wash treatment (w and u), whole plot and antioxidant treatment (5), and storage time (0 to 4 mo.) were the subplots. Data was analyzed using PROC GLM of the Statistical Analysis System (SAS, 1985). If significant differences were found, means were separated using Fisher’s Protected least significant difference (LSD) (Steel and Torrie, 1980) at the 5% level of significance.

RESULTS AND DISCUSSION

washed mince had lower (P<0.05) fat, phosphorus, and ash, but higher (P<0.05) moisture and Protein (Table 1). Washing removes lipids, blood, and other prooxidants along with water soluble proteins (Miyauchi and Steinberg, 1970). Proximate composition of the unwashed mince was similar to that reported by Silva and Ammerman (1993) for catfish muscle and by Freeman and Hearsberger (1993) in the skin side and lateral portion of catfish fillets; washed mince was in composition to the internal portion and visceral side of fillets.
Table 1. Effect of wash treatment on proximate composition and selected nutrients (wet basis) in catfish mince averaged over antioxidant treatment.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Washed</th>
<th>Unwashed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous (%)</td>
<td>0.22 b</td>
<td>0.30 a</td>
</tr>
<tr>
<td>Copper (mg/kg)</td>
<td>0.65 a</td>
<td>0.58 a</td>
</tr>
<tr>
<td>Iron (mg/kg)</td>
<td>5.29 a</td>
<td>5.21 a</td>
</tr>
<tr>
<td>Erythorbate (mg/g)</td>
<td>0.57 a</td>
<td>0.58 a</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>82.20 a</td>
<td>74.25 b</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3.24 b</td>
<td>14.09 a</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.51 b</td>
<td>0.66 a</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>14.20 a</td>
<td>11.22 b</td>
</tr>
</tbody>
</table>

ab - Means within row not followed by same letter differ (P<0.05).
There were differences (P<0.05) between washed and unwashed minces in phosphorus, iron, erythorbate, and ash due to antioxidant treatment (Table 2). Mince containing Brifisol™ (BR) was higher in phosphorus and ash, due to Brifisol TM phosphates. Erythorbate levels were higher (P<0.05) in minces containing added erythorbate (ER, CE, BR), as would be expected. Iron levels were higher (P<0.05) in minces containing citrate (CI, CE, BR) and was lower (P<0.05) in the control (CO) and erythorbate (ER) treated minces.

**Color**

Washed minces had higher (P<0.05) “L” (lighter product) and lower (P<0.05) “a” and “b” values than the unwashed mince (Table 3). Miyauchi and Steinberg (1970) noted that washing leads to improved color and flavor stability of mince by removing blood and heme pigments.

Though “b” values differed (P<0.05) between wash treatments, both washed and unwashed mince were more Yellow in hue than blue. There was also a difference (P<0.05) in “b” values among antioxidant treatments, regardless of wash treatment or storage time (data not shown). Mince containing Brifisol™ had higher (P<0.05) “b” value than the other treated minces.

There was a gradual (P<0.05) decrease but significant shift in “b” values over storage time, regardless of wash or antioxidant treatment (Fig. 1). Nakayama and Yamamoto (1977) noted a shift toward yellowness in unwashed minces made from unskinned short spine thornyhead, turbot and dogfish. Oxidation of dark muscle lipids can result in yellow-to-brownish discoloration in fish known as rusting (Licciardello, et al., 1982). Gordon (1971) reported that phosphate treatments in fish retards rancidity and prevents development of yellow appearance.

There were no changes in Hunter “L” values over time. Moledina et al (1977) found “L” values to decrease over time in mechanically deboned flounder meat, and found that preservatives could greatly minimize this. Minced turbot darkens while minced pollock lightens during storage (Nakayama and Yamamoto, 1977). Fish should have an off white to cream color, a whiter, less red color is desired (Jahncke et al. 1992).

**TBARs**

Washed mince had lower (P<0.05) TBARs than unwashed mince regardless of antioxidant treatment or storage time (Fig. 2). This was probably due to lower lipid and heme pigment contents (Table 3). Fischer and Deng (1977) indicated heme iron as the major catalyst of lipid oxidation in mullet dark muscle. Hiltz et al. (1976) attributed variations in TBARs of silver hake to varying amounts of the lipid-rich red muscle. Silberstein and Lillard (1978) found hemoprotein content to influence prooxidant activity in extracts of minced mullet.

Freeman and Hearnberger (1993) found the flesh located along the lateral line of catfish fillets to have higher TBARs than flesh from other parts of the fillets. Absence of the lateral line in catfish frames would produce mince with less heme pigments and could partially explain the relatively low TBARs reported here for both washed and unwashed mince.

There was an increase (P<0.05) in TBARs during storage (Fig. 2). Woodruff (1987) reported slightly higher TBARs values in catfish fillets during frozen storage as did Silva and Ammerman.
Table 2. Effect of antioxidant treatment on proximate composition and selected nutrients in catfish mince averaged over wash treatment.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>CO</th>
<th>CI</th>
<th>ER</th>
<th>CE</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous (%)</td>
<td>0.20a</td>
<td>0.20a</td>
<td>0.22a</td>
<td>0.18a</td>
<td>0.50b</td>
</tr>
<tr>
<td>Copper (mg/kg) NS</td>
<td>0.47</td>
<td>0.62</td>
<td>0.54</td>
<td>0.49</td>
<td>0.97</td>
</tr>
<tr>
<td>Iron (mg/kg)</td>
<td>3.67a</td>
<td>7.05b</td>
<td>3.12a</td>
<td>5.23ab</td>
<td>7.18b</td>
</tr>
<tr>
<td>Erythorbate (mg/g)</td>
<td>0.03a</td>
<td>0.03a</td>
<td>0.94b</td>
<td>0.95b</td>
<td>0.94b</td>
</tr>
<tr>
<td>Moisture (%) NS</td>
<td>78.32</td>
<td>78.53</td>
<td>78.22</td>
<td>78.16</td>
<td>77.89</td>
</tr>
<tr>
<td>Fat (%) NS</td>
<td>8.68</td>
<td>8.39</td>
<td>8.49</td>
<td>9.03</td>
<td>8.73</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.48a</td>
<td>0.53a</td>
<td>0.51a</td>
<td>0.49a</td>
<td>0.93b</td>
</tr>
<tr>
<td>Protein (%) NS</td>
<td>12.70</td>
<td>12.46</td>
<td>12.80</td>
<td>12.96</td>
<td>12.65</td>
</tr>
</tbody>
</table>

ab-Values within row not followed by the same letter differ (P<0.05).

NS - No significant differences.

1 CO = Control, CI = sodium citrate, ER = erythorbate, CE = citrate + erythorbate, BR = brifisol™.
Table 3. Effect of wash treatment on TBARs and Hunter Color of catfish mince averaged over antioxidant treatment and storage time.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Washed</th>
<th>Unwashed</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBARs (mg malonaldehyde/kg fish)</td>
<td>0.20b</td>
<td>0.30a</td>
</tr>
<tr>
<td>Hunter L value</td>
<td>66.42a</td>
<td>61.35b</td>
</tr>
<tr>
<td>Hunter a value</td>
<td>-0.25a</td>
<td>1.87b</td>
</tr>
<tr>
<td>Hunter b value</td>
<td>8.36b</td>
<td>9.48a</td>
</tr>
</tbody>
</table>

ab - Means within row not followed by the same letter differ (P<0.05).
Ciarlo et al. (1985) found initial TBARs values to be lower in minced hake than hake fillets. There were no differences (Pr0.05) in TBARs due to antioxidant treatment (Table 4). TBARs reactive material is generally produced in substantial amounts only from fatty acids containing three or more double bonds (Nawar, 1985) found in relatively low concentrations in channel catfish (Silva et al., 1993; Worthington et al., 1972).

FFA

Among antioxidant treatments, BR offered more protection (Ps0.05) against the formation of free fatty acids than CO regardless of storage time or wash treatment (Table 4).

There was an interaction (Ps0.05) between wash treatment and storage time (Fig. 3) for free fatty acids. In both washed and unwashed mince, free fatty acids increased (Ps0.05) over storage time. After the first month there was also a difference (Ps0.05) between washed and unwashed mince each month. These increases in free fatty acids are very similar to those found in catfish fillets over the same storage time (Nguessan, 1992). Hiltz et al. (1976) found the rate and extent of free fatty acid increase to be the same for fillets and minced silver hake.

Silva et al. (1993) found oxidation to occur primarily in phospholipids but not neutral lipids of catfish fillets. Eun et al. (1993) reported an active system of peroxidases in catfish microsomes, and concluded that phenolic antioxidants, followed by phosphates and finally natural antioxidants were more effective in preventing oxidation of catfish muscle during storage.

Both the unwashed and washed mince made from catfish frames had acceptable color and low TBARs and FFA values during frozen storage. In future experiments, other quality parameters such as sensory and microbiological evaluations would be necessary to determine overall acceptability.

ACKNOWLEDGMENTS

The authors wish to acknowledge the aid of Ms. Sabrina Hunt in preparing this manuscript.

REFERENCES


Table 4. Effect of antioxidant treatment on TBARs and free fatty acid (FFA) values in catfish mince averaged over wash treatment and storage time.

<table>
<thead>
<tr>
<th>Antioxidant</th>
<th>TBARs Value (mg malonaldehyde/kg fish)</th>
<th>FFA Value (µmol/log fish)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (CO)</td>
<td><strong>0.33</strong>&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>3.39 a</td>
</tr>
<tr>
<td>Citrate (CI)</td>
<td>0.28</td>
<td>3.33 a</td>
</tr>
<tr>
<td>Erythorbate (ER)</td>
<td>0.25</td>
<td>3.53 a</td>
</tr>
<tr>
<td>Citrate + Erythorbate (CE)</td>
<td>0.19</td>
<td>3.40 a</td>
</tr>
<tr>
<td>Brifisol + Citrate + Erythorbate (BR)</td>
<td>0.20</td>
<td>3.05 b</td>
</tr>
</tbody>
</table>

ab - Means within column followed by different letter differ (**P<0.05**).

NS - No significant differences.


Nguessan, F. 1992. Unpublished data Department of Food Science and Technology, Mississippi State University, Miss. State, MS.


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