Hasegawa, S.; Nagel, C. W. *J. Food Sci.* **1966**, *31*, 838.
Hasegawa, S.; Patel, M. N.; Synder, R. C. *J. Agric. Food Chem.* **1982a**, *30*, 509.
Hasegawa, S.; Pelton, V. A.; Bennett, R. D., Abstract, Citrus Research Conference, Pasadena, CA, 1982b, p 7.
Hasegawa, S.; Pelton, V. A.; Bennett, R. D. *J. Agric. Food Chem.* **1983**, *31*, 1002.
Hashinaga, F.; Itoo, S., Abstract, 4th International Citrus Congress, Tokyo, Japan, 1981, p 93.
Rouseff, R. L.; Nagy, S.; Attaway, J., Abstract, 4th International Citrus Congress, Tokyo, Japan, 1981, p 90.
Tosa, T.; Sato, T.; Mori, T.; Chibata, I. *Appl. Microbiol.* **1974**, *27*, 886.
Vaks, B.; Lifshitz, A. *J. Agric. Food Chem.* **1981**, *29*, *1258*.

Received for review May 16, 1983. Revised manuscript received October 20, 1983. Accepted January 24, 1984. This work was supported in part by the Citrus Products Technical Committee. Reference to a product name or company does not imply endorsement of that product or company by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Effect of Oxidizing and Reducing Agents on Trimethylamine *N*-Oxide Demethylase Activity in Red Hake Muscle

Linda D. Racicot, Ronald C. Lundstrom,* Kurt A. Wilhelm, Elinor M. Ravesi, and Joseph J. Licciardello

The addition of oxidizing or reducing agents to minced red hake showed that oxidizing agents reduced the rate of dimethylamine (DMA) and formaldehyde (FA) formation, while reducing agents accelerated their formation. To determine the effectiveness of different oxidizing agents, H_2O_2, NaOCl, and $KBrO_3$ were added at four levels to minced red hake. DMA, FA, and trimethylamine oxide values showed that 0.05, 0.10, and 0.25% levels of H_2O_2 were most effective in slowing the reaction rate. Although Instron measurements did not show the oxidizing agents to improve the texture greatly, the sensory panel analysis found the 0.05, 0.10, and 0.25% levels of H_2O_2 to have a better texture than the control.

Investigations into the utilization of red hake (*Urophycis chuss*) as a human food have centered around trimethylamine *N*-oxide demethylase (TMAO-ase), which is thought to contribute to the textural problems associated with this species during frozen storage. This enzyme system catalyzes the breakdown of trimethylamine oxide (TMAO) to form dimethylamine (DMA) and formaldehyde (FA) (Yamada and Amano, 1965; Tomioka et al., 1974). The FA presumably cross-links with the myofibrillar proteins, causing a toughening of the texture and loss of water holding capacity (Childs, 1973).

Various compounds have been reported to be activators or inhibitors of the TMAO-ase system. The system has been found to be catalyzed by flavin mononucleotide, methylene blue, Fe^{2+} or Fe^{3+}, ascorbic acid, and cysteine (Yamada and Amano, 1965; Tomioka et al., 1974, Harada, 1975; Parkin and Hultin, 1981; Spinelli and Koury, 1981; Lundstrom et al., 1982b). Inhibitors of the enzyme system include Cu^{2+}, EDTA, and trimethylamine (TMA) (Tomioka et al., 1974; Parkin and Hultin, 1982a). Of 32 compounds added to minced red hake, the most potent accelerators of DMA formation were phenazine methosulfate, menadione, and methylene blue, while dimethylaniline and TMA were the most potent inhibitors (Parkin and Hultin, 1982b).

The absence of oxygen has also been shown to accelerate the rate of DMA production (Lundstrom et al., 1982a). Red hake packaged in oxygen-permeable film showed decreased rates of DMA and FA formation during iced storage compared to uncooked red hake packaged in cans purged with nitrogen and stored in ice. These investigators also found that while an atmosphere of 100% oxygen gas produced low levels of DMA in minced red hake, an atmosphere of 20% oxygen/80% nitrogen also reduced the rate of DMA formation. Sectioning of blocks of fillets stored at −20 °C in an atmosphere of 100% oxygen or 20% oxygen/80% nitrogen revealed that the oxygen was able to diffuse into the blocks to reduce the DMA formation. Thin-layer sections taken from blocks stored in 100% nitrogen showed no differences in the levels of DMA production in inner and outer layers (Lundstrom et al., 1982a; Racicot and Lundstrom, 1982).

Due to the implications of redox potentiators regulating the enzyme system, one study was initiated to analyze the effects of reducing and oxidizing agents as a means to inhibit DMA and FA production and a second study was designed to determine the effectiveness of varying concentrations of oxidizing agents.

MATERIALS AND METHODS

The studies utilized fresh red hake procured from Gloucester, MA, and Point Judith, RI, day boats. After filleting and skinning by hand, the fillets were minced in a Yanagiya meat bone separator, Model Y-100, to obtain homgeneity. To analyze the effects of oxidizing or reducing agents, hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), sodium erythorbate, or ascorbic acid was added to the mince at a final concentration of 0.1% (w/w). In the second study, which analyzed the level of oxidizing agents required to be effective, H_2O_2, NaOCl, or potassium bromate ($KBrO_3$) was added at final concentrations of 0.01, 0.05, 0.10, or 0.25% (w/w). The additives were dissolved in distilled water and were added to the mince at a level of 20 mL/0.45 kg. A control sample containing an equivalent volume of water was also prepared. Each batch was blended with a Universal Industries Univex mixer, Model 1222, for 2 min at medium speed. Samples were

National Marine Fisheries Service, Northeast Fisheries Center, Gloucester Laboratory, Gloucester, Massachusetts 01930.

frozen overnight in 7.5-kg blocks at 600 psi in an Amerio No. 12 vertical plate freezer at −40 °C. The frozen samples were cut into 0.45-kg blocks and were placed in vacuum-sealed nylon (Curlon X/K-28) bags. The samples from the first study, which contained oxidizing or reducing agents, were stored at −6 °C. Since a freezer at −6 °C was not available, the samples from the second study containing varied levels of oxidizing agents were stored at −12 °C. The H_2O_2 part of the experiment was repeated in a third study to obtain sensory panel analysis and colorimetry data as well as chemical and physical parameters. H_2O_2 was added to minced red hake at levels of 0.01, 0.05, 0.10, or 0.25% (w/w) as described above and frozen at −12 °C.

Samples were analyzed periodically for DMA, TMA, TMAO, FA, 2-thiobarbituric acid (TBA) numbers, and peak shear force. Samples for DMA, TMA, TMAO, and FA analysis were prepared by blending the tissue with 6% $HClO_4$ (1/2 w/v) in a stainless steel blender chalice for 2 min at maximum speed. The extract was filtered gravimetrically through Whatman No. 1 filter paper. DMA, TMA, and TMAO analysis was performed by gas chromatography using *n*-propylamine or diethylamine as the internal standard (Lundstrom and Racicot, 1983). Free formaldehyde was determined by a modification of the Nash reagent method of Cochin and Axelrod (1959). The TBA number, expressed as milligrams of malonaldehyde per 1000 g, was obtained by the method of Yu and Sinnhuber (1957), which was modified by adding EDTA and propylgallate during blending. All chemical tests were performed in duplicate.

Shear force measurements were performed with an Instron Universal Testing Machine Model 1132 equipped with a Kramer Shear Press Cell modified to six blades. The crosshead speed was 5 cm/min and the chart speed was 10 cm/min. Steamed samples (internal temperature of 74 °C) were cut to standard size (6.5 × 4.25 × 1.25 cm), and the peak force measurement during compression shear was made on the Instron. A minimum of six replicates was performed for each sample. Lightness of the H_2O_2-treated samples was obtained with a Hunterlab Color/Difference Meter D25-2 by using the L scale. Values were reported for the L scale, which is based on a scale of 100 (white) to 0 (black).

Organoleptic evaluation of the samples with varying levels of H_2O_2 was performed in duplicate with five panelists experienced in sensory analysis of seafoods. The samples were cut into sticks and then steamed. The panelists evaluated the samples for appearance, odor, flavor, and texture using a nine-point scale ranging from 9 (extremely good) to 1 (inedible).

The initial rates of DMA and FA production from the oxidizing and reducing agents study were analyzed statistically by determining the linear regression slopes by using the method of least squares and comparing them for significant differences by the *t* test. Analysis of covariance was used to examine the data from the oxidizing agent study. All data were analyzed by using a Hewlett-Packard 97 programmable desk calculator.

RESULTS AND DISCUSSION

Figure 1 shows the effect of oxidizing and reducing agents on the production of DMA in red hake muscle during storage at −6 °C. The samples containing H_2O_2 or NaOCl had an inhibitory effect on DMA production ($P < 0.02$) compared to the controls and the reducing agents. Although not significant, H_2O_2 was slightly more efficient in inhibiting the reaction rate than was NaOCl. DMA was formed significantly faster in the samples containing the reducing agents ($P < 0.02$), with the ascorbic acid treatment producing the highest levels. Within the first 4 days the DMA values were 100 and 133 mg % N for the erythorbate and ascorbic acid treatments, respectively.

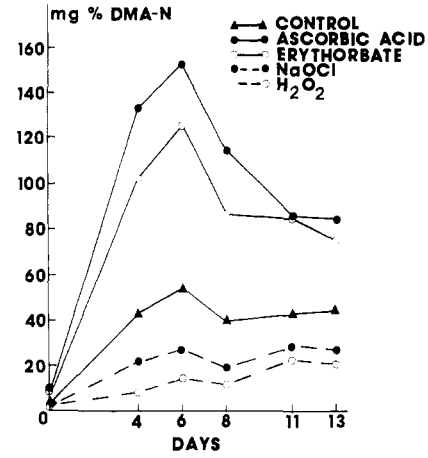

Figure 1. Effect of oxidizing and reducing agents on DMA production in red hake stored at −6 °C.

Table I. Formaldehyde Production in Red Hake Muscle Stored at −6 °C

	formaldehyde, mg/100 g, for days of storage at −6 °C					
treatment[a]	0	4	6	8	11	13
control[a]	0.6	10.8	13.3	19.7	19.2	20.7
ascorbic acid[b]	4.5	38.7	43.7	42.1	41.2	35.1
erythorbate[b]	2.8	27.2	33.1	33.2	33.7	27.7
H_2O_2[c]	0.0	0.7	1.9	3.1	8.4	7.1
NaOCl[ac]	0.1	5.0	4.4	6.9	12.1	10.4

[a] Levels for treatments with different superscripts are significantly different from one another ($P < 0.01$).

FA analysis followed the same pattern as the dimethylamine values (Table I). The control sample had initial FA values of 0.6 mg/100 g, which rose to 20.7 mg/100 g by day 13. The reducing agents promoted the FA levels to exceed those of the control samples ($P < 0.01$), while treatments containing H_2O_2 produced significantly lower levels of FA ($P < 0.01$). The rate of FA production in the NaOCl treatment was not significantly different from the control but followed the trend of the H_2O_2 treatment.

Parkin and Hultin (1982b) reported accelerated DMA production during frozen storage when ascorbic acid or erythorbate was added to minced red hake. Licciardello et al. (1982) found red hake dipped in a solution of erythorbate and citrate to have accumulated a higher DMA content than the untreated control during frozen storage. Kelleher et al. (1981) also reported increased rates of DMA formation during frozen storage of red hake fillets that had been dipped in a mixture of erythorbate and sodium triphosphate. They found the samples to have a higher shear force compared to the controls, and the samples were characterized as tough by the taste panel.

Figure 2–4 show the effect of varying the concentration of oxidizing agents on DMA production in red hake mince at −12 °C. All treatments produced significantly less DMA than the control samples ($P < 0.005$). H_2O_2 was significantly more effective at inhibiting DMA formation than either NaOCl or $KBrO_3$ at corresponding concentrations ($P < 0.005$). The levels of 0.05, 0.1, and 0.25% H_2O_2 were more inhibitory to DMA production than any of the treatments at any concentration ($P < 0.005$). The free FA data also showed samples treated with oxidizing agents to have significantly lower ($P < 0.005$) levels of FA than that found in the control samples (Table II). The control

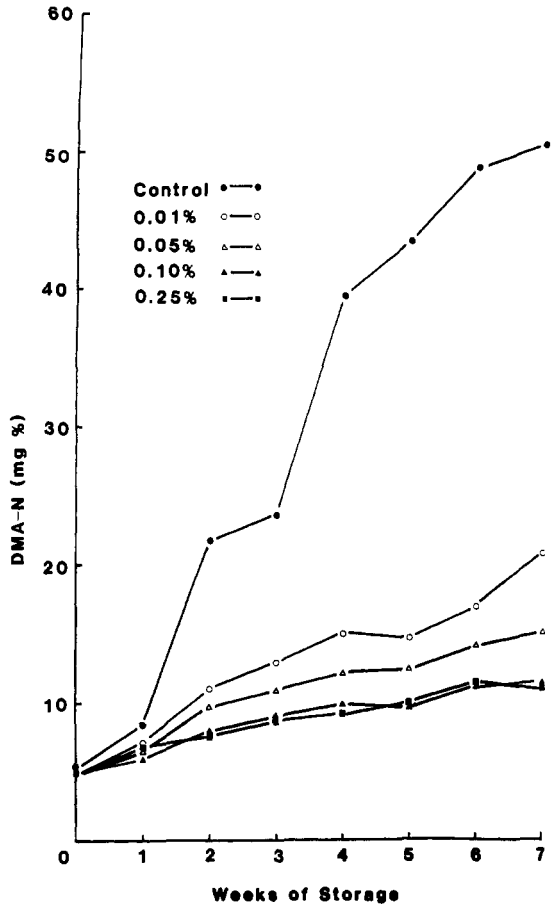

Figure 2. Effect of hydrogen peroxide on DMA production in red hake stored at −12 °C.

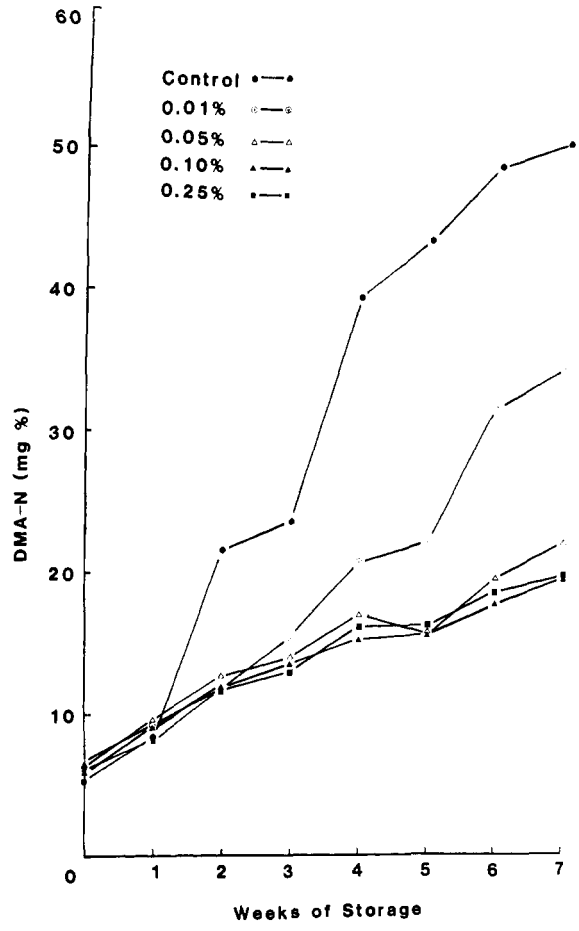

Figure 3. Effect of sodium hypochlorite on DMA production in red hake stored at −12 °C.

Table II. Formaldehyde Production in Red Hake Muscle Stored at −12 °C

treatment[a]	formaldehyde, mg/100 g, for weeks of storage at −12 °C							
	0	1	2	3	4	5	6	7
control[a]	1.7	2.7	7.3	8.5	15.5	24.6	20.9	26.8
H_2O_2								
0.01%[b]	0.6	1.1	2.2	1.5	4.2	3.2	3.0	5.5
0.05%[b]	0.6	1.2	1.2	1.2	3.5	2.6	2.3	2.8
0.10%[b]	0.7	0.9	1.1	0.6	2.2	1.4	1.4	1.4
0.25%[b]	1.0	1.5	1.6	0.6	2.7	1.6	1.4	0.9
NaOCl								
0.01%[b]	0.8	1.6	3.8	3.7	7.7	10.7	9.5	17.5
0.05%[b]	1.3	1.5	1.4	2.1	5.6	4.1	4.6	6.2
0.10%[b]	1.4	2.0	2.1	3.2	6.3	3.4	4.2	7.2
0.25%[b]	1.8	2.3	2.3	2.3	3.8	3.4	2.3	6.1
$KBrO_3$								
0.01%[b]	2.2	1.9	2.0	2.9	5.8	6.6	9.8	16.6
0.05%[b]	3.1	2.6	3.1	3.1	6.3	6.9	4.5	9.1
0.10%[b]	2.9	2.6	4.2	3.0	5.1	5.3	4.4	7.7
0.25%[b]	4.7	2.7	4.2	5.7	7.8	5.0	6.1	11.3

[a] Levels for treatments with different superscripts are significantly different from one another ($P < 0.005$).

Table III. TMAO Levels in Red Hake Muscle Stored at −12 °C

treatment[a]	TMAO, mg % N, for weeks of storage at −12 °C							
	0	1	2	3	4	5	6	7
control[a]	64.2	56.4	49.8	46.5	30.5	20.8	20.2	17.7
H_2O_2								
0.01%[b]	61.5	58.0	58.2	55.2	57.1	51.7	51.4	48.7
0.05%[b]	62.1	61.0	59.7	58.2	60.5	57.2	55.2	55.2
0.10%[b]	64.0	61.7	58.8	59.8	63.9	59.6	57.5	57.9
0.25%[b]	63.1	66.8	60.9	61.4	62.9	60.4	59.1	57.8
NaOCl								
0.01%[b]	63.1	63.5	55.5	54.0	53.0	42.7	39.2	31.4
0.05%[b]	61.9	62.4	59.4	57.8	56.8	53.4	50.5	49.3
0.10%[b]	59.5	61.4	58.2	56.6	57.6	54.8	52.3	48.2
0.25%[b]	60.5	63.4	58.2	54.4	58.2	56.0	54.0	52.6
$KBrO_3$								
0.01%[b]								
0.01%[b]	63.4	64.6	57.9	56.3	53.3	47.9	39.5	33.2
0.05%[b]	64.6	64.3	58.5	58.0	58.5	52.8	50.5	52.6
0.10%[b]	65.8	63.9	58.5	59.1	59.4	53.6	49.5	52.7
0.25%[b]	64.0	64.4	59.3	57.9	58.8	54.1	50.6	51.8

[a] Levels for treatments with different superscripts are significantly different from one another ($P < 0.05$).

samples showed an increase in FA content during the 7-week storage period, ranging from 1.7 to 26.8 mg/100 g. Within the H_2O_2-treated samples, the 0.01% level had the fastest rate of FA production, rising from 0.6 to 5.5 mg/100 g, while the 0.25% level had the slowest rate, which ranged from 1.0 to 1.4 mg/100 g. The 0.01% NaOCl treatment had a FA content that rose from 0.8 to 17.5, while the 0.25% NaOCl treatment had a slower rate of FA production of 1.8–6.1 mg/100 g during the 7-week experiment. The $KBrO_3$ treatments were not different from each other. The 0.01% treatment produced 2.2–16.6 mg of FA/100 g, while the 0.25% level had values of 4.7–11.3, with rates for the 0.05 and 0.1% levels falling in between those of these two treatments. The TMAO data reflected the degradation of TMA to FA and DMA (Table III). Except for the 0.1% level, the H_2O_2 treatments maintained higher levels of TMAO than any of the other treatments although this was not statistically significant. TMAO values for the control samples dropped from 64.2 to 17.7 mg % N. In contrast, the 0.05, 0.1, and 0.25% H_2O_2 treatments had values ranging from 55.2 to 57.9 at the end of the 7-week study. The TMA values, which are also a

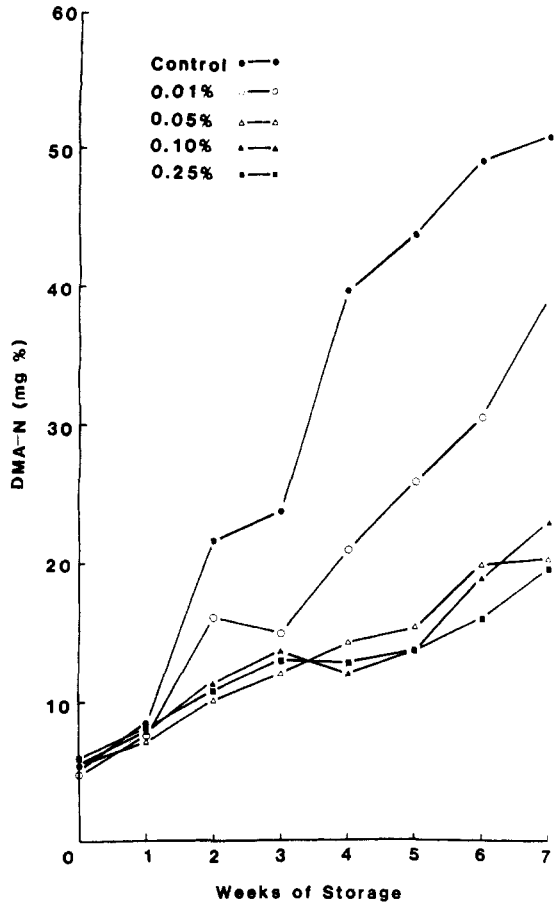

Figure 4. Effect of potassium bromate on DMA production in red hake stored at −12 °C.

Table IV. Instron Shear Press Force (N/g) of Red Hake Mince Stored at −12 °C

treatment[a]	Instron shear press force, N/g, for weeks of storage at −12 °C							
	0	1	2	3	4	5	6	7
control[a]	12.4	15.4	14.8	17.4	20.1	25.4	28.4	37.7
H_2O_2								
0.01%[NS]	16.3	15.8	17.6	18.4	19.3	22.5	22.7	23.3
0.05%[NS]	15.4	17.2	19.3	18.3	19.0	22.0	23.0	25.9
0.10%[NS]	16.0	17.4	17.5	17.6	19.0	22.3	21.6	24.5
0.25%[NS]	14.1	15.5	17.5	16.6	17.7	18.9	21.4	26.1
NaOCl								
0.01%[NS]	13.5	17.1	16.1	18.0	19.2	22.6	21.4	29.4
0.05%[NS]	16.5	18.7	19.7	20.1	22.1	25.3	24.9	24.5
0.10%[NS]	19.4	21.5	24.3	21.5	21.8	26.2	24.7	24.8
0.25%[NS]	15.0	17.6	19.0	19.3	17.7	21.6	22.2	26.7
$KBrO_3$								
0.01%[b]	16.6	18.1	21.4	22.4	26.4	20.8	21.7	26.5
0.05%[bc]	20.2	25.1	24.9	24.1	25.1	27.4	29.8	33.0
0.10%[bc]	19.7	25.4	25.5	24.8	30.0	27.8	29.1	29.8
0.25%[bc]	23.0	24.8	25.9	27.5	28.4	26.3	29.9	34.2

[a] Forces for treatments with different superscripts are significantly different: a and b ($P < 0.025$); bc ($P < 0.005$); NS, not significant.

degradation product of TMAO, remained at a neglibible level (0.1–0.6 mg % N) throughout the study.

TBA numbers for the control ranged from 0.80 to 1.36, while those for the treated samples ranged from a low of 0.33 to a high of 1.53. None of the values were indicative of excessive rancidity. Sinnhuber and Yu (1958) reported canned and frozen fish of good quality to have values less than 3, while products of poorer quality had values ranging from 4 to 27. Apparently, the oxidizing agents did not have an effect per se on the formation of malonaldehyde. Other researchers have reported that H_2O_2 added to fish mince

Table V. Formaldehyde Production in H_2O_2 Treated Red Hake Stored at −12 °C—Study B

treatment[a]	formaldehyde, mg/100 g, for weeks of storage at −12 °C							
	0	1	2	3	4	5	6	7
control[a]	0.6	3.3	8.1	16.9	20.5	18.4	19.3	16.4
H_2O_2								
0.01%[a]	0.5	5.7	11.6	15.4	12.6	15.4	14.7	14.8
0.05%[b]	0.4	2.3	3.2	5.3	2.5	4.4	4.2	4.1
0.10%[b]	0.4	0.9	2.4	3.1	1.2	1.7	2.0	0.9
0.25%[b]	0.4	0.7	1.0	2.2	0.9	1.2	1.1	0.9

[a] Levels for treatments with different scripts are significantly different from one another ($P < 0.005$).

Table VI. TMAO Levels in Minced Red Hake Treated with H_2O_2 Stored at −12 °C—Study B

treatment[a]	TMAO, mg % N, for weeks of storage at −12 °C							
	0	1	2	3	4	5	6	7
control[a]	54.9	47.1	37.6	29.7	20.2	16.1	18.8	9.5
H_2O_2								
0.01%[a]	56.1	44.9	34.7	31.0	29.1	23.1	18.7	13.7
0.05%[b]	55.1	49.1	47.7	45.2	47.2	42.9	42.7	40.0
0.10%[b]	54.6	51.1	50.5	50.0	47.5	47.3	46.3	47.4
0.25%[b]	55.2	52.2	49.9	53.0	51.7	50.3	47.9	49.5

[a] Levels for treatments with different superscripts are significantly different from one another ($P < 0.005$).

did not promote oxidative rancidity as measured by peroxide and epoxide values (James and McCrudden, 1976; Young et al., 1979).

Initially the shear force measurements showed the samples containing oxidizing agents to be tougher than the control (Table IV). However, the control sample became progressively tougher to the point where it was tougher than the treated samples. The control sample was significantly different than the $KBrO_3$ treatments at all weeks and with all treatment levels ($P < 0.025$). The 0.01% level of $KBrO_3$ had a significantly lower force requirement than the 0.05, 0.1, or 0.25% levels ($P < 0.005$). There were no differences within the H_2O_2 or NaOCl treatments.

The four levels of H_2O_2 were reexamined in the third study to determine sensory panel evaluation and color measurements as well as the chemical analysis and Instron evaluation. In this study the mince treated with 0.1% H_2O_2 had a faster initial rate of DMA production than did the control sample until week 3 when the control sample produced more DMA than any of the other treatments (Figure 5). The differences in the 0.01% level of H_2O_2 in comparison to the previous study may have been due to a heavier load of catalase-producing bacteria. However, no microbiological examinations were made during this study. The control and 0.01% levels produced significantly more DMA than any of the other treatments ($P < 0.005$). The 0.05% level also produced more DMA than the 0.1 and 0.25% legvels ($P < 0.005$). The FA and TMAO data also reflected this trend. The FA values for the control samples rose from an initial value of 0.6 to 16.4 mg/100 g at week 7, while the samples with 0.05, 0.1, or 0.25% H_2O_2 had significantly lower levels of FA (Table V). The TMAO values for the control dropped from 54.9 to 9.5 mg % N at the end of the experiment (Table VI). In comparison, the 0.05, 0.1, and 0.25% H_2O_2 treatments resulted in higher levels of TMAO throughout the study ($P < 0.005$) with values ranging from 40.0 to 49.5 mg % N for the three treatments at week 7. The higher concentrations of 0.05, 0.1, and 0.25% H_2O_2 were effective in inhibiting the rate of TMAO breakdown to FA and DMA ($P < 0.005$). As in the previous study, the TBA numbers did not show evidence of excessive rancidity. Instron analysis showed no

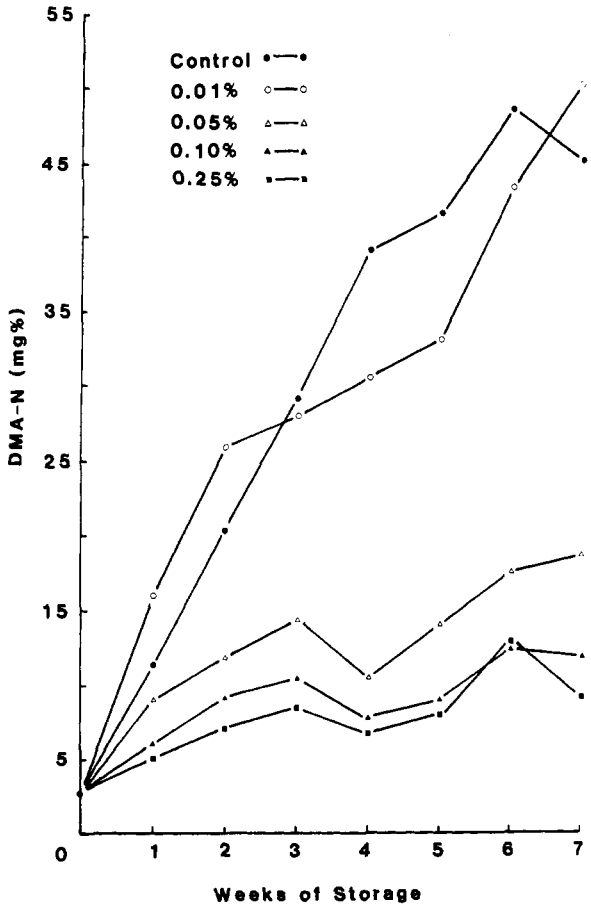

Figure 5. Effect of hydrogen peroxide on DMA production in red hake stored at −12 °C—study B.

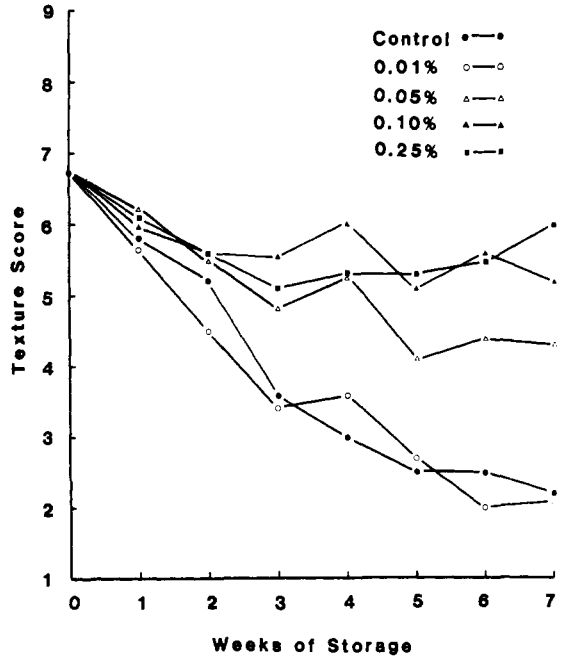

Figure 6. Sensory panel evaluation of texture of red hake treated with hydrogen peroxide stored at −12 °C.

differences among the treatments and the control sample. All samples exhibited an increase in toughening.

In contrast to the Instron data, the sensory panel evaluation of texture showed the control and 0.01% level to be significantly different from the higher concentrations of H_2O_2 ($P < 0.005$) (Figure 6). The control and 0.01% treatment levels dropped from scores of 6.6 (good) to 2.5 and 3.0 (very poor), respectively. The 0.1 and 0.25%

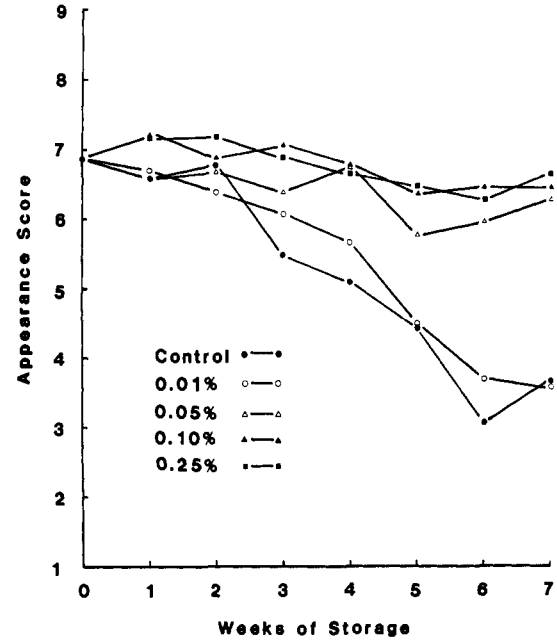

Figure 7. Sensory panel evaluation of appearance of hydrogen peroxide treated red hake stored at −12 °C.

treatment levels remained in the range of 6.6 (good) to 4.0 (fair). Apparently the sensory panel is measuring other attributes of mouth feel that are not being analyzed by the Instron test.

Colorimetric analysis showed the levels of 0.05, 0.1, and 0.25% H_2O_2 to be lighter in intensity than those of the 0.01% and control treatments. The initial value using the L scale was 68 for all of the samples. The 0.1 and 0.25% treatments had values of 67.5 at the close of the study, while the 0.05% level had a value of 65.5. There was a steady decline in the readings of the control and 0.01% treatments to a value of 58.5. The darkening of the control and 0.01% treatments was also noted by the sensory panel (Figure 7). The panelists were instructed to judge the appearance of the samples as to variations in color. The appearance of the samples containing higher concentrations of H_2O_2 was rated significantly higher than the control or 0.01% level of H_2O_2 ($P < 0.005$). The control and 0.01% H_2O_2 samples dropped in appearance from a rating of 7 (good) to 4.5 (slightly poor). The other treatments ranked in the region of 7 (good) to 6 (fair). The lighter color of the higher concentrations of H_2O_2 is presumably due to a bleaching effect. H_2O_2 has been shown to be an effective bleaching agent for cod, mackerel, and marinated herring (Sims et al., 1975; James and McCrudden, 1976; Young et al., 1979). The sensory panelists also noted a slight decrease in the flavor of the samples during the study. The control and 0.01% samples decreased in rankings from an initial value of 6.7 (good) to 4.7 (slightly poor), while the other samples rated 7 (good) to 5.8 (fair) during the study ($P < 0.05$). There were no differences in odor.

These studies indicate that there may be some potential in the use of oxidizing agents for inhibiting DMA and FA production in red hake muscle. The choices available for maintaining acceptable texture in red hake during frozen storage are currently quite limited. Licciardello et al. (1982) has clearly shown that lower frozen temperatures are very effective in preventing textural toughening. This should be the preferred method of handling red hake during frozen storage. However, given the economic constraints of operating colder than normal storage facilities, the search has continued for an alternative method.

Landolt and Hultin (1982) have investigated washing of red hake fillets to remove TMAO, the substrate from which DMA and FA originate. While washing is effective in removing TMAO, other soluble compouonds that may be desirable (i.e., flavor components, vitamins, soluble proteins, etc.) could be removed in the process. The search for a chemical additive that would prevent textural changes in red hake has been largely unproductive. Compounds such as Cu^{2+}, TMA, and dimethylaniline (Tomioka et al., 1974; Parkin and Hultin, 1982a,b) are effective in inhibiting DMA formation, but no specific data are available on their effect on actual texture changes. These compounds would not be acceptable as a food additive, whereas chemical oxidizing agents such as H_2O_2, NaOCl, and $KBrO_3$ do have a history of use in food products. All three oxidizing agents were found to inhibit DMA and FA production with H_2O_2 being the most effective. The H_2O_2 were also effective in slowing the textural toughening, lending further support to the theory that FA cross-linking of the proteins is responsible for the textural changes. A chemical agent such as H_2O_2 is easily incorporated into a minced fish matrix, but substantial difficulties would be expected in using H_2O_2 to treat red hake fillets. Although our experiments were performed at temperatures higher than those normally used in commerical facilities in order to accelerate the experimental period, a combination of an oxidizing agent and lower temperature would enhance the shelf life of minced red hake blocks and could possibly make the red hake commercially feasible with improved texture, whiter appearance, and lower DMA and FA contents. It has been reported by Stout and Carter (1983) that Pacific whiting treated with H_2O_2 was not mutagenic as determined by the Ames test. Even so, other potential hazards resulting from the use of H_2O_2 have not been examined, and caution should be used to avoid the wide and indiscriminate use of H_2O_2 by the industry. These initial results suggest that further investigation of treatment temperature, oxidizer concentration, residual oxidizer, nutritional changes, toxic compounds, and mutagenic effects are warranted and must be performed before oxidizing agents can be added to products intended for human consumption. Since redox compounds have been shown to have an effect on DMA and FA production in other gadoid species as well, the investigation of oxidizing agents in other species should be undertaken.

Registry No. DMA, 124-40-3; FA, 50-00-0; TMAO, 1184-78-7; TMAO-ase, 9076-66-8; H_2O_2, 7722-84-1; NaOCl, 7681-52-9; $KBrO_3$, 7758-01-2; ascorbic acid, 50-81-7; sodium erythorbate, 6381-77-7.

LITERATURE CITED

Childs, E. A. *J. Food Sci.* **1973**, *38*, 1009.

Cochin, J.; Axelrod, J. *J. Pharmacol. Exp. Ther.* **1959**, *25*, 105.

Harada, K. *J. Shimoneseki Univ. Fish.* **1975**, *23*, 163.

James, A. L.; McCrudden, J. E. In "Proceedings: The production and utilization of mechanically recovered fish flesh"; Torry Research Station: Aberdeen, Scotland, 1976; p 54.

Kelleher, S. D.; Buck, E. M.; Hultin, H. O.; Parkin, K. L.; Licciardello, J. J. ; Damon, R. A. *J. Food Sci.* **1981**, *47*, 65.

Landolt, L. A.; Hultin, H. O. *J. Food Biochem.* **1982**, *6*, 111.

Licciardello, J. J.; Ravesi, E. M.; Lundstrom, R. C.; Wilhelm, K. A.; Correia, F. F.; Allsup, M. G. *J. Food Qual.* **1982**, *5*, 215.

Lundstrom, R. C.; Correia, F. F.; Wilhelm, K. A. *J. Food Biochem.* **1982a**, *6*, 229.

Lundstrom, R. C.; Correia, F. F.; Wilhelm, K. A. *J. Food Sci.* **1982b**, *47*, 1305.

Lundstrom, R. C.; Racicot, L. D. *J. Assoc. Off. Anal. Chem.* **1983**, *66*, 1158.

Parkin, K. L.; Hultin, H. O. In "Advances in the Refrigerated Treatment of Fish"; International Institute of Refrigeration: Boston, MA, 1981; p 475.

Parkin, K. L.; Hultin, H. O. *FEBS Lett.* **1982a**, *139*, 61.

Parkin, K. L.; Hultin, H. O. *J. Food Process. Preserv.* **1982b**, *6*, 73.

Raciot, L. D.; Lundstrom, R. C., presented at the 27th Atlantic Fisheries Technological Conference, Portland, ME, Sept 20–23, 1982.

Sims, G. C.; Cosham, C. E.; Anderson, W. E. *J. Food Technol.* **1975**, *10*, 497.

Sinnhuber, R. O.; Yu, T. C. *Food Technol. (Chicago)* **1958**, *12*, 9.

Spinelli, J.; Koury, B. J. *J. Agric. Food Chem.* **1981**, *29*, 327.

Stout, V.; Carter, G. *J. Food Sci.* **1983**, *48*, 492.

Tomioka, K.; Ogushi, J.; Endo, K. *Bull. Jpn. Soc. Sci. Fish.* **1974**, *40*, 1021.

Yamada, K.; Amano, K. *Bull. Jpn. Soc. Sci. Fish.* **1965**, *31*, 1030.

Young, K. W.; Newmann, S. L.; McGill, A. S.; Hardy, R. In "Advances in Fish Science and Technology"; Connnell, J. J., Ed.; Fishing News Books, Ltd.: Farnham, Surrey, England, 1979; p 242.

Yu, T. O.; Sinnhuber, R. O. *Food Technol. (Chicago)* **1957**, *11*, 104.

Received for review October 3, 1983. Accepted February 1, 1984. Mention of names or companies does not imply endorsement by NMFS-NOAA. This research was supported in part by a grant from the New England Fisheries Development Foundation. This paper was presented at the Atlantic Fisheries Technological Conference, Quebec City, Quebec, Aug 21–24, 1983, Abstract 36.