Stabilization of the Flavor of Frozen Minced Whiting
I. Effect of Various Antioxidants

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Introduction

It is an established fact that intact fish muscle such as would exist in a fillet or whole fish is usually more susceptible to the development of oxidative rancidity during frozen storage when compared with meat or many other foods. This is due to the high content of unsaturated fatty acids and also to their relatively high degree of unsaturation compared to other natural fats and oils (Lovern, 1956; Olcott, 1962).

The lipids of marine fish contain fatty acids usually ranging in chain length from 14 to 22 carbon atoms. A high percentage (60-75) of these fatty acids are unsaturated, some having up to 6 double bonds (Stansby, 1967). The unsaturated fatty acids, and particularly the polyunsaturated ones, readily react with oxygen in the presence of an activator or catalyst, setting off a chain reaction to form hydroperoxides that degrade to carbonyl compounds which are responsible for the rancid odors and flavors. This reaction is often referred to as autoxidation (Lundberg, 1954). Another type of rancidity occurs when fatty acid-containing esters are hydrolyzed, liberating the free fatty acids. This condition is termed hydrolytic rancidity, and is readily detected by the senses when unpleasant-smelling, small-chain fatty acids such as butyric, caproic, and caprylic are involved. However, this paper will not be concerned with hydrolytic rancidity.

The rancid odors or flavors of oxidized fish oil have been described in terms such as musty, turnipy, fishy, painty, cold storage flavor, etc., and are generally distinct from rancid vegetable and animal fats which have been usually characterized as tallowy or cardboardy (Banks, 1967; Baines et al., 1969). Oxidation of lipids can also result in a yellow-to-brownish discoloration in fish, known as rusting. In carotenoid-pigmented fish, such as salmon or ocean perch, a fading of the red skin color may occur (Tarr, 1947; Dyer et al., 1956). A comprehensive review of the kinetics of lipid oxidation has been presented by Labuza (1971).

The lipids are present as phospholipids which are associated intracellularly with the mitochondria, and also as depot fats (mainly trigylcerides) stored in the muscle, mesentary, and the viscera, particularly the liver. A small portion of the lipid fraction consists of unsaponifiable matter which is predominantly sterols with lesser amounts of hydrocarbons, fat-soluble vitamins, carotenoid pigments, wax esters, etc. (Tsuchya, 1961). The susceptibility of a particular fish flesh to oxidative rancidity is related to intrinsic factors such as lipid content and degree of unsaturation, season, feed, fishing ground, stage of spawning cycle, stage of maturity, content of prooxidants and antioxidants; and to extrinsic factors such as storage temperature and partial pressure of oxygen (Castell and MacLean, 1964; Ackman, 1967; Labuza, 1971). The lean fish (≤ 1 percent lipid), although not as prone to becoming rancid compared with fatty fish (≥ 5 percent lipid), still can develop this condition because of the highly unsaturated nature of their lipids which consist predominantly of phospholipids and lipoproteins. The phospholipid content of the muscle of various marine species has been shown to range from about 0.5 to 0.7 percent (Lovern, 1962). Thus, in lean fish the phospholipids constitute the major portion of the total lipids. Fatty fish also contain phospholipids, but in addition contain deposits of depot fat usually located just beneath the skin and along the lateral line in the form of red or dark muscle which is rich in hematin compounds (hemoglobin, myoglobin, cytochromes). The latter class of compounds are known to be potent catalysts for lipid oxidation (Lew and Tappel, 1956; Watts, 1954; Brown et al., 1957). Semifatty fish (1-5 percent lipid) would be intermediate between lean and fatty fish in susceptibility to oxidative spoilage.

Some fisheries, such as the Atlantic whiting, *Merluccius bilinearis* (also known as silver hake), have not been exploited to their fullest potential because of some inherent characteristics which preclude the economical filleting of the particular species. These characteristics include excessive bones, small size, irregular shape, soft flesh, etc. With the employment of meat-bone separators, an efficient recovery of minced flesh can be attained from these types of fish (King and Carver, 1970; Miyauchi and Steinberg, 1970).

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During mincing, however, changes occur or conditions are created conducive to the development of oxidative rancidity, and these include 1) a breakdown of the integrity of the musculature to a smaller particle size, 2) disruption of cells with release of enzymes and prooxidants such as the heme substances, 3) distribution of the localized dark muscle throughout the entire mass of minced flesh, and 4) intimate contact of air with an increased surface area of muscle tissue.

In a study with paired whiting fillets on the effect of mincing on oxidation of the tissues, we observed the TBA[1] number to approximately double as a result of the mincing treatment (unpublished data, NMFS Gloucester Laboratory, Gloucester, Mass.). Flink (1978) reported that this increase was prevented when the whiting was minced in a nitrogen atmosphere. However, sparging minced mullet with nitrogen immediately after mincing in the presence of oxygen was ineffective (Lee and Toledo, 1977). Apparently once oxygen becomes attached to reactive sites it becomes difficult to remove. If the deboning machine contains iron or other catalytic metal surfaces which contact the fish, the TBA value of the flesh may increase (Lee and Toledo, 1977). Silberstein and Lillard (1978) observed an increase in hemoglobin and nonheme iron in minced mullet as a consequence of mechanical deboning.

Thus, because of these changes in physical constitution, one would theoretically expect minced fish to be more readily predisposed to spoilage from oxidative rancidity during frozen storage compared with fillets. Crawford et al. (1972) confirmed this with Pacific whiting, and Hiltz et al. (1976) also reported evidence of rancidity in minced silver hake during storage at $-10\,°C$ ($14\,°F$). It should be pointed out, however, that this phenomenon was not observed with minced kipper (herring) fishsticks compared to whole kippers (Cole and Keay, 1976).

The following average lipid contents have been reported for the edible portion of Atlantic whiting: 1.2 ± 0.3; 2.0 ± 0.7; 1.9 (respectively, Sidwell et al., 1974; Brooke et al., 1962; Bean et al., 1937). Hiltz et al. (1976) found an average lipid content of 2.95 percent for fillets of summer-caught Atlantic whiting (which they stated was higher compared with winter-caught fish); however, the average lipid content of mince prepared from the same batch of fish was 2.20 percent. The lesser lipid content for the mince was attributed to removal of more subcutaneous fat by mechanical deboning, compared with hand filleted flesh.

We analyzed Atlantic whiting flesh for lipid content by methanol-chloroform extraction (Bligh and Dyer, 1959) at approximately monthly intervals over a 12-month period and found a range in mean lipid content of 1.6 to 3.2 percent (unpublished data, NMFS Gloucester Laboratory). Individual fish ranged in fat content from about 0.7 to 5.0 percent. The reasons for this natural variability have been cited (Jacquot, 1961); however, sampling errors are constantly present, due to anatomical differences in lipid composition.

In Atlantic whiting the dark muscle was found to contain 14.5 percent lipid, compared to 0.91 percent for the light muscle (Hiltz et al., 1976). Thus, unless the sample taken for analysis contains light and dark muscle in natural proportion, errors can occur in the lipid quantification. Although Atlantic whiting at times could be classified as a lean fish or fatty fish, in most instances it would be regarded as a semifatty fish and, as such, would be intermediate in susceptibility to lipid oxidation. Seventy-five percent of the fatty acids of Atlantic whiting were found to be unsaturated, and of these an abundant amount (38 percent) consisted of C20:4, C20:5, and C22:6 (Bonnet et al., 1974). Labuza (1971) indicated that the C20:5, C22:4, and C22:6 fatty acids of phosphatydyl ethanolamine are especially prone to becoming oxidized and are probably the primary cause of initial changes leading to rancidity in lean fish. Thus the necessary constituents for oxidative rancidity are present in Atlantic whiting.

There are several alternative methods for retarding lipid oxidation in frozen minced fish. Storage at low temperatures would probably be the simplest, because no additional process treatment is required and this method would be applicable to all product forms (Dyer et al., 1956; Cole and Keay, 1976). Labuza (1971) has stated that lipid oxidation proceeds rapidly at temperatures within the range of $0\,°$ to $-18\,°C$ ($32\,°$ to $0\,°F$) with a maximum oxidation rate at about $-4\,°C$ ($25\,°F$). Below $-18\,°C$, the rate of lipid oxidation decreases rapidly. However, a low storage temperature, although very effective, would not be a reliable method of stabilizing quality because of loss of temperature control once the product entered the distribution channel.

Packaging under vacuum (Liljemark, 1964; Sacharow, 1969; Hansen, 1972; Bilinski et al., 1979) or in an inert gas (Tarr, 1948) in an oxygen-impermeable film has been demonstrated to be an effective means of suppressing rancidity development in frozen fish; however, this treatment does not provide any protective carry-over when the primary product is converted into secondary products. The economics of vacuum-packing processed products such as breaded fish sticks could also be prohibitive. Glazing whole fish, fillets, or steaks has been used with success and is especially effective if the glaze contains an antioxidant (Tarr, 1948; Bilinski et al., 1979). The deficiency with this control method is that the glaze has to be periodically replenished because of sublimation, and cracks in the glaze due to freezing rate could also reduce its effectiveness (Flink, 1978). In addition, glazing would not be compatible with batter/breaded products. Saberizing or deep-skinning to remove the subcutaneous fatty tissue along the lateral line has been found effective for stabilizing hake fillets (Licciardello et al., 1980). However, applying this treatment to

[1]Abbreviations used in this manuscript: TBA = Thiobarbituric acid; EDTA = Ethylenediamine-Tetraacetate; BHA = Butylated hydroxyanisole; TBHQ = mono-tertiary-butylhydroquinone.

underutilized fish species destined to be minced would defeat the original purpose of mincing from an economic standpoint. Washing to remove lipids, blood, and other prooxidants has aided in improving color and flavor stability of minced fish (Miyauchi et al., 1975), but there is a loss of soluble protein from this treatment and, some researchers believe, adverse texture changes during frozen storage. Application of oxygen scavengers such as the glucose oxidase-glucose system (Liljemark, 1964; Kelley, 1971; Atkinson and Wessels, 1973) or the scavenger pouch, Maraflex[2] 7 F (Zimmerman et al., 1974), has been advocated; however, there is a paucity of information on the efficacy of the scavenger pouch, and the glucose-oxidase treatment requires a certain processing protocol that raises doubts as to its economic feasibility for stabilizing flavor of minced fish.

There are numerous reports in the scientific literature on the efficiency of antioxidants for minimizing effects of lipid oxidation in frozen fish (Tarr, 1947, 1948; Tarr and Cooke, 1949; Banks, 1952; Farragut, 1972; Sweet, 1973). Controlling oxidative flavor changes in frozen minced fish through addition of antioxidants offers several advantages. The antioxidant could be incorporated into the mince by slowly mixing in a food mixer or applied as a controlled spray inside the drum of the deboner as the minced fish is being extruded through the perforations on the drum. This treatment should not be as costly as vacuum packaging and would provide carry-over protection into secondary products prepared from the mince.

Therefore, the purpose of this investigation was to compare the efficacy of several antioxidants in stabilizing the flavor of frozen minced Atlantic whiting.

Experimental Methods

Freshly landed Atlantic whiting, *Merluccius bilinearis,* were obtained from a Gloucester processor. The fish were scaled and then passed through a Model 22 LaPine gutting machine which had been modified (Mendelsohn et al., 1977) to automatically process whiting by heading, gutting, removing kidney and black belly membrane, and washing the gut cavity. Minced whiting was produced by passing the dressed fish through a Bibun mechanical deboner equipped with a drum having 5 mm perforations. When not being machine-processed, the fish or mince were kept well-iced to maintain a low product temperature.

Twenty-two pounds (10.0 kg) of minced fish were placed in a 28-quart (26.5 l) stainless steel mixing bowl of a Univex Mixer Model M1222. One-half pint (220 ml) of an antioxidant solution was sprayed on the fish with an atomizer over a 3-minute period while the mixing blade was rotating in an orbital path at the low speed setting.

The various antioxidant treatments included: 1) 500 ppm disodium EDTA, 2) 0.84 percent FP-88E (Freez-Gard), 3) 0.15 percent sodium erythorbate, 4) 15 or 75 ppm Tenox A (BHA + citric acid in propylene glycol, 5) 30 or 150 ppm Tenox 20 (TBHQ + citric acid in propylene glycol, and 6) 30 or 150 ppm Tenox S-1 (propyl gallate + citric acid in propylene glycol).

The two different concentrations for each of the phenolic antioxidant treatments represent the maximum permissible level and five times that amount. The maximum permissible level is 0.02 percent based on the fat content which for whiting was regarded as 3 percent. The water-soluble antioxidants were dissolved in distilled water. The phenolic antioxidants (BHA, TBHQ, and propyl gallate) had to be emulsified in a mixture of propylene glycol and distilled water (1:3) by means of a blender. Two different control samples were included in the study: One was prepared directly from the mince with no further treatment; for the other control, the mince was subjected to a 3-minute water spray-mixing process to determine the effect of the agitation received during mixing on the development of rancidity. One final test sample was prepared with 0.5 percent crab seasoning (Baltimore Spice Co.) and 3.2 percent dry, textured vegetable protein.

For each treatment a 16.5-pound (7.5 kg) block and several 5-pound (2.3 kg) blocks were formed under pressure in an Amerio plate freezer. The larger block was cut into sticks which were batter/breaded, blanched for 30 seconds in vegetable oil at 400 °F (204.5 °C), frozen, then packaged in 1-pound (0.45 kg) waxboard cartons and stored at 20 °F (−6.7 °C). The smaller blocks were stored intact in a waxboard carton at 20 °F (−6.7 °C) and processed into breaded sticks for organoleptic evaluation at the time of testing.

At periodic intervals the sticks or blocks were removed from storage and tested by both sensory and chemical methods for degree of rancidity. All chemical analyses were conducted in duplicate on the flesh of the uncooked fish stick after the breading was removed.

Sensory Evaluation

The frozen sticks were cooked for 15 minutes in a convection oven at 400 °F (204.5 °C), and with breading removed were rated by a 6-member trained panel for flavor (rancidity) on a scale of 1 to 5. Descriptive terms corresponding to numerical scores were as follows: 5 = not rancid, 4 = barely detectably rancid, 3 = slightly rancid, 2 = moderately rancid, 1 = strongly rancid. A reference control stored at −22 °F (−30 °C) was included in each taste test.

Peroxide Value

Peroxide value was determined on a chloroform-anhydrous sodium sulfate extract of the flesh by an iodine titration procedure described by Riemenschneider et al. (1943).

TBA Number

For determining TBA reactive substances, the method of Yu and Sinnhuber (1957) was modified by the addition of EDTA and propyl gallate to prevent oxidation during blending. TBA number was calculated by the procedure reported by Sinnhuber and Yu (1958).

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Statistical Analysis

All analyses were performed on a Hewlett-Packard 97 programmable desk calculator.

Results

Tables 1 and 2 present average peroxide values and TBA numbers of the minced whiting sticks as effected by the various additives during storage at 20°F. For most treatments the decrease in flavor score (or increase in rancidity) during storage progressed at two different rates—that is, a rapid rate during the first several weeks followed by a slower rate during the remainder of the storage period. With the controls, the flavor scores reversed their downward trend and began to increase during this second phase, whereas with the samples treated with those additives that proved to be ineffective, the flavor scores remained relatively stationary during this period. A possible explanation for this phenomenon is that some particular compound that was chiefly responsible for the rancid flavor had reached its maximum concentration during the early weeks of storage and was later either entering into other reactions or was somehow being dissipated, possibly during cooking. It should be noted, however, that for those treatments that exhibited this flavor score inversion, the peroxide values and TBA numbers increased steadily throughout storage. A rational explanation for this anomaly is that the chemical analyses were performed on uncooked samples, whereas the sensory evaluation was carried out on cooked samples.

Table 1.—Effect of various additives on peroxide value of breaded minced whiting sticks stored at 20°F.

	Weeks in storage										
Additive	0	2	4	6	8	10	12	14	16	18	20
Control	3.5	5.5	4.7	3.3	6.2	9.7	9.1	6.6	16.4	10.9	14.5
Water control	2.9	2.7	4.2	6.3	3.8	5.3	4.9	6.6	7.2	8.1	8.3
0.15% Erythorbate	2.8	3.8	3.7	4.3	2.2	1.9	1.2	0.6	1.7	2.5	3.0
500 ppm EDTA	3.6	3.5	5.1	7.5	11.1	7.6	9.2	10.1	9.8	9.6	11.2
0.84% FP-88E	3.3	4.1	2.9	4.9	5.5	2.7	2.9	2.8	2.8	5.9	3.6
15 ppm TENOX-A	2.7	2.2	4.3	5.2	5.5	5.9	7.3	7.7	8.7	11.6	11.2
75 ppm TENOX-A	3.0	3.3	2.8	3.3	10.0	13.3	10.3	11.4	12.6	15.1	15.5
30 ppm TENOX-20	3.9	4.7	4.1	3.9	6.0	5.2	7.5	7.8	9.8	14.1	16.0
150 ppm TENOX-20	3.6	3.5	1.7	3.0	5.4	2.9	2.9	4.3	5.6	5.9	8.8
30 ppm TENOX-S-1	3.0	4.7	1.8	2.9	4.6	6.5	8.5	9.1	11.5	14.7	14.4
150 ppm TENOX-S-1	3.8	3.0	2.7	2.5	2.9	4.0	4.9	5.2	8.7	10.1	10.0
Crab seasoning	3.5	5.5	4.7	2.4	5.6	7.1	8.6	6.6	16.4	10.9	14.5

Table 2.—Effect of various additives on TBA number of breaded minced whiting sticks stored at 20°F.

	Weeks in storage												
Additive	0	2	4	5	6	8	9	10	12	14	16	18	20
Control	2.73	4.23	7.52	5.65	5.69	6.20	7.80	7.66	7.53	7.14	8.65	8.55	8.08
Water control	4.94	5.17	5.83	5.22	6.20	6.53	6.95	10.72	5.13	7.43	8.27	8.88	7.00
0.15% Erythorbate	2.59	1.18	0.61	1.32	1.08	1.69	2.82	2.30	2.11	2.21	2.87	3.01	2.54
500 ppm EDTA	1.22	3.34	9.35	6.77	6.76	5.69	6.44	4.75	5.03	5.88	7.52	5.78	6.49
0.84% FP-88E	2.59	2.82	3.62	1.65	2.35	3.67	3.39	2.26	3.43	4.51	7.38	6.49	4.28
15 ppm TENOX-A	3.76	4.23	5.31	4.55	6.02	7.38	6.82	6.63	7.16	8.51	10.25	10.39	8.23
75 ppm TENOX-A	2.12	1.93	2.16	3.05	3.38	4.84	4.23	5.31	5.78	6.39	8.32	8.41	7.47
30 ppm TENOX-20	0.75	3.06	4.32	5.41	3.67	5.83	7.05	5.50	8.85	7.00	7.47	9.64	7.05
150 ppm TENOX-20	1.18	1.55	1.88	1.74	1.03	1.60	2.77	3.29		3.59	5.36	5.69	4.28
30 ppm TENOX-S-1	0.52	2.59	3.71	4.33	2.59	4.61	5.69	4.70		7.47	11.05	9.49	11.99
150 ppm TENOX-S-1	0.94	2.16	1.97	2.40	1.41	2.30	3.10	2.30	2.68	4.51	5.50	4.84	5.78
Crab seasoning	3.06	4.98	6.96	4.09	4.04	6.67	8.26	7.38	7.90	10.53	9.87	10.58	11.61

Ke et al. (1976) stated that "rancidity could be defined as the presence of off-flavors which makes the fish unacceptable to the consumer. However, many different mechanisms operative in fish muscle produce various types of off-flavors, and the responsible compounds which develop in frozen mackerel have not been fully developed." This sentiment is applicable to many other species including whiting. The taste panelists, after having rated the samples for rancidity, were requested to indicate on the score form whether the samples were acceptable, borderline, or unacceptable. In most cases the samples were considered of marginal quality when rated 3, which corresponded to slightly rancid. In accordance with this criterion, the most effective antioxidant treatments were judged to be 150 ppm Tenox S-1, crab seasoning, 0.15 percent sodium erythorbate, and 150 ppm Tenox 20.

Flavor score (rancidity rating) was correlated with TBA number and also with peroxide value on pooled data for all treatments up to and including the first 8 weeks of storage. It was not considered valid to include data beyond 8 weeks in view of the drastic change in flavor scores for some treatments during that period. The correlation coefficient (r) for regression of TBA number on flavor score was determined to be 0.70 for $n=60$. The TBA number corresponding to borderline acceptability was determined from the regression line to be 5. This numerical value is in accord with a TBA number of 4 reported for marginal quality seafood (Sinnhuber and Yu, 1958) and a number of 6 for mackerel which has lost quality (Ke et al., 1975).

Flavor score was also correlated with peroxide value over the first 8 weeks of storage, and a correlation coefficient of 0.60 was obtained. The regression line predicted a peroxide value of about 5 to be associated with a flavor score of 3.

Table 3 compares various antioxidant treatments on the basis of induction period and times to reach a peroxide value of 5, a TBA number of 5, and a flavor score of 3. The efficacy of

an antioxidant treatment is usually derived from its ability to extend the induction period. In this study, induction period was defined as the time in weeks during storage at which the curve for peroxide value showed a definite change (increase) in slope. With some treatments, there did not appear to be a definitive induction period—that is, the peroxide values progressively increased from the start. On the basis of the four parameters under comparison, the most effective flavor-stabilizing treatments were considered to be 0.15 percent erythorbate, 150 ppm Tenox 20, 150 ppm Tenox S-1, and 0.84 percent FP-88E. The mixing operation did not seem to enhance the development of rancidity, since both controls became unacceptable at approximately the same time.

The phenolic antioxidants were generally ineffective when used at the maximum permissible level, but were effective at 5 times that concentration. The problem with using phenolic antioxidants as flavor protectors in foods is not necessarily rooted in their efficacy, but rather in the uniformity of incorporation. In a nonhomogenous food mass such as minced fish, it is difficult to evenly disperse a very small amount of antioxidant, especially when the solubility in the substrate is not favorable. On the basis of sensory analysis, the crab seasoning seemed to stabilize flavor during storage; however, the chemical tests indicated that these treated samples became rancid at a time comparable to the controls. The seasoning apparently masked the rancid flavor.

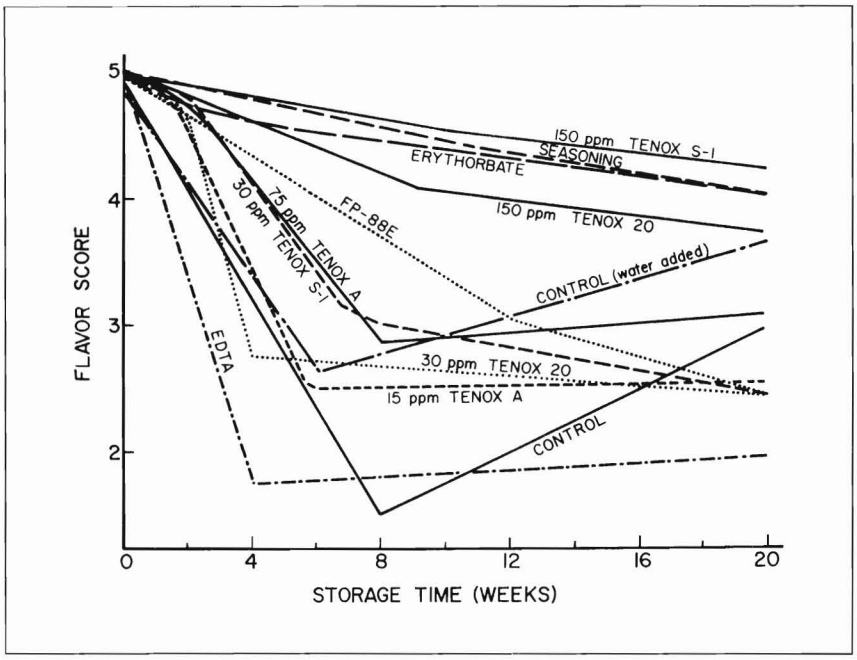

Figure 1.—Effect of various antioxidant treatments on flavor score of minced whiting sticks during storage at 20 °F.

EDTA at the level used behaved as a prooxidant. Variable results have been reported in the literature on the efficiency of EDTA in combatting oxidative rancidity. Some investigators have found it to be effective (Farragut, 1972; Sweet, 1973); others concluded it to be ineffective (Deng et al., 1977; Iredale and York, 1977). It is generally considered that EDTA is only useful in controlling rancidity when trace catalysts such as iron or copper are present, and in their absence EDTA exerts no protective action. There is also evidence to suggest that EDTA may form complexes with increased catalytic activity, and this phenomenon could account for the prooxidant effect observed in this study.

It would thus appear that of the various antioxidants examined in this study the erythorbate and the FP-88E were the most effective from a practical standpoint. FP-88E is a commercial preparation containing sodium erythorbate, polyphosphates, and sodium chloride. However, the latter compound is considered to be a prooxidant. Therefore, sodium erythorbate was selected as the antioxidant of choice for further investigation on the basis that it is on the FDA's GRAS list, is water soluble and, therefore, easily incorporated, and is highly efficient for the intended purpose. Whereas the phenolic antioxidants are probably true antioxidants in that they interrupt free-radical chain reactions by donating electrons or hydrogen, sodium erythorbate or ascorbate function as an oxygen scavenger (Cort, 1974). The application of sodium erythorbate for controlling rancidity development in fish has been reported (Iredale and York, 1977; Bilinski et al., 1979); however, more feasibility studies have been conducted with ascorbic acid or sodium ascorbate (Tarr, 1947, 1948;

Table 3.—Effect of various additives on three parameters relating to quality (flavor) deterioration in frozen minced whiting sticks

Treatment	Induction period (weeks)	Time (weeks) to reach: P.V.[1] = 5	TBA[2] no. = 5	Flavor score = 3
Control	0	7	3	4-5
Control (water added)	2	8	1	4-5
0.15% Erythorbate	>20	>20	>20	>20
500 ppm EDTA	0	2-3	3-4	2-3
0.84% FP-88E	>20	>20	15-16	12
15 ppm TENOX-A	2	6-7	3	4-5
75 ppm TENOX-A	6	7	10	7-8
30 ppm TENOX-20	6	8	7	4-5
150 ppm TENOX-20	12	15-16	18	>20
30 ppm TENOX-S-1	6	8	8	7-8
150 ppm TENOX-S-1	9	12-13	17	>20
Crab seasoning	0	8	3	>20

[1]P.V. = peroxide value
[2]TBA = Thiobarbituric acid

Andersson and Danielson, 1961; Liljemark, 1964; Greig et al., 1967; Greig 1967a,b; Bauernfeind and Pinkert, 1970; Orthoefer, 1973; Deng et al., 1977). Sodium erythorbate (d-isoascorbate) has been shown to have equivalent antioxidant activity compared to sodium ascorbate (Yourga et al., 1944; Tarr, 1948). Its only advantage over sodium ascorbate is lower cost.

The results presented thus far have been for studies with oil-blanched breaded sticks. In the case of minced blocks the results paralleled those with sticks except the degree of rancidity which had developed at the end of 20 weeks of storage was much less. This is understandable, since it has been demonstrated that oxidative rancidity in fish products occurs principally at the surface (Sweet, 1973; Nakayama and Yamamoto, 1977; Licciardello et al., 1977), and there was a sizeable difference in surface-to-volume ratio of the sticks and blocks used in this study.

The concentration of 0.15 percent sodium erythorbate applied in this investigation was an arbitrary selection based on reported usage levels of about 0.05 to 0.25 percent. In a future communication, the effect of concentration will be reported.

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