Food derived from muscle represent one of the largest sources of protein for humans in the United States. However, each year over 34 million pounds of meat and meat products are lost due to spoilage during processing, shipping and storage (USDA, 1975). It is apparent that new methods should be developed to reduce these losses and subsequently increase the availability and marketability of meat products.

The spoilage of muscle foods is normally controlled by the use of low temperature storage in combination with packaging. In comparison to other preservation techniques, refrigeration initially provides products having a high degree of original quality characteristics. Refrigerated products generally have a lower total degradation of color, flavor, texture and nutritive value and toxigenic microorganisms are controlled. Although freezing provides even greater preservation than refrigeration, refrigeration requires less energy and is often more desirable to the consumer. Unfortunately, the shelf-life of refrigerated products is often limited to days or even weeks as a result of the growth of psychrotrophic microorganisms and the development of autoxidative rancidity. These problems are intensified by mishandling of these products at the processing and distributor levels. The role of autoxidation versus microbial growth and the interrelationships thereof in refrigerated muscle foods has not been well defined. The following questions seem pertinent:

1. Does rancidity precede or follow microbial spoilage?
2. What are the effects of rancidity and microbial spoilage on overall quality?
3. Do microbial spoilage and rancidity influence each other?
4. How useful is a combination of antioxidants and antimicrobials in extending the shelf-life of muscle foods?

Today I would like to review recent literature on these areas and to suggest future research projects which are needed.

Several studies on several types of muscle foods have shown that both microbial spoilage and rancidity occur during refrigerated storage. Ground products appear more susceptible than whole cuts to microbial growth and rancidity. Cooked products are generally less susceptible to microbial growth but are often more susceptible to rancidity than raw products (Labuza, 1971). A representative study on raw ground beef, shown here, indicates that during storage the microbial count and TBA values (a measure of rancidity) increase while the taste panel scores decrease (Abo-gnah, 1978). After nine to 10 days of refrigerated storage, most muscle foods are rejected by taste panels due to development of a putrid flavor. Based on this data, it is difficult to determine whether rancidity or microbial spoilage were responsible for the low taste panel scores although the rejection on extended storage does appear to be directly related to microbial spoilage.

Work by Olson (1977) has indicated that addition of antioxidants to ground turkey appeared to prevent increases in TBA values (Figure 1) and maintained a higher test panel score. However, both the control and the antioxidant treated samples were rejected due to microbial spoilage after 10 days of storage. Thus, addition of antioxidants appears to be helpful in increasing acceptance of meat during early storage but the total length of storage is more dependent on microbial spoilage. It appears that when the microbial count reaches $10^9/g$, the meat is generally rejected due to the ammonia and other amine compounds produced in the meat by the microbial metabolism of proteins (Go, 1977). If the microorganisms do not metabolize the proteins, the average shelf-life at refrigerated temperatures can be extended from five days to eight to 10 days (Shelef, 1977). Color loss due to microbial growth might also influence acceptance (Bala et al., 1977).

Even when microbial growth and metabolism are controlled by use of antibiotics or other anti-micro-
bials, development of rancidity would still probably result in eventual rejection of the product. Treatments involved in the processing and handling of meat can have a positive or negative effect on the rate and extent of oxidation and are discussed in recent reviews by Labuza (1971) and Love and Pearson (1971). Cooking, drying, curing and grinding generally increase oxidation. Freezer storage in oxygen permeable packages offers the greatest protection, but frozen products will still go rancid. Rancidity does appear less objectionable to most people than does microbial spoilage and the product is generally acceptable for a longer period of time. This can be dangerous, however, since recent studies have indicated some of the products of lipid oxidation can pose potential health problems (Shamberger, 1977).

Overall, it appears that rancidity and microbial spoilage are responsible for the loss of sensory value during refrigerated storage of muscle foods. Rancidity as measured by TBA values and taste panel evaluation does appear to precede microbial spoilage in most products and results in slightly lower acceptance during the first few days of storage. However, once the level of psychrotrophic organisms has reached $10^6$, the metabolic products of these organisms, primarily amino-acid breakdown products are responsible for total rejection of the muscle foods.

There does appear to be possible interactive effects of rancidity due to lipid autoxidation and microbial spoilage. It seems possible that microbial spoilage and lipid autoxidation could interact by:

1. Hydrolysis and release of free fatty acids by microorganisms which are more susceptible to autoxidation.

2. Enzymatic oxidation of the fatty acids by the microorganisms.

3. Metabolism of autoxidation products by microorganisms.

4. Formation of compounds by the microorganisms which react with autoxidation products.

5. Inhibition of microorganisms by lipid autoxidation by-products.

Several authors have reported that the microbial flora of meat products has lipolytic activity. Bala et al. (1977) reported that free fatty acid values were significantly higher in ground beef samples inoculated with Pseudomonas fragi. Free fatty acids have been shown to react with oxygen at a faster rate than when esterified to glycerol as triglycerides (Labuza, 1971) and thus autoxidation could conceivably be increased. Enzymatic oxidation of lipids also appears possible. Smith and Alford (1969) reported that of 28 microorganisms studied, Pseudomonas ovalis, Micrococcus freundii and two strains of Streptomyces were capable of increasing the concentration of peroxides and aldehydes in fresh lard. However, Smith and Alford also found certain organisms which metabolized the peroxides and aldehydes produced via autoxidation. This, of course, would result in lower concentration of autoxidation end-products and values obtained in conventional autoxidation tests such as the TBA value would be decreased. Mocek and Ball (1974) reported that in mechanically deboned chicken meat containing aeryomycin to inhibit bacteria, the TBA values attained were significantly higher than in meat showing bacterial growth during storage. Bala et al also showed that growth of P. fragi on ground beef significantly decreased the TBA values. Mocek and Ball (1974) reported that there was no increase in fatty acid autoxidation as determined by fatty acid analysis, indicating that the microorganisms removed malonaldehyde and other dicarbonyls which are TBA reactive. This seems plausible since the amine compounds produced by bacterial metabolism of proteins can directly react with aldehydes in the non-enzymatic browning reaction (Eskin et al., 1971). This could potentially lead to numerous other off-flavors.
Rancidity could also directly influence microbial growth. The peroxides and aldehydes produced during oxidation can be quite toxic to the microorganisms (Lechowich, 1971).

Overall, there does appear to be some direct interactive effects between lipid autoxidation and microbial metabolism. The exact consequences on sensory and nutritional value of meats are not known at this time. It is certain, however, that when measuring the extent of autoxidation, the extent of bacterial growth should be taken into account. Further research should be supported to further elucidate the relationship between lipid oxidation and microbial growth.

Recognizing that the growth of microorganisms and lipid oxidation limit the shelf-life of most refrigerated meats, attempts have been made to develop preservation techniques based on inhibition of these two processes. Because of the interrelationship between autoxidation and microbial growth, it should be recognized that attempts must be made to control both processes if effective preservation is to be attained. For example, if antioxidants are used to control autoxidation, the meat would still spoil due to microbial growth; and if antimicrobials were used to prevent bacterial growth, the meat would most likely be rejected because of rancidity. We have therefore been exploring the possibilities of utilizing a combination of antioxidants with antimicrobials to optimize preservation. There are only a few antimicrobials which appear useful in extending the shelf-life of fresh meats. In general, these compounds should have the ability to inhibit gram negative psychrotrophic organisms such as Pseudomonas and Achromobacter, if they are to work. Chemicals with potential usefulness are:

1. Acetic acid
2. Chlorine
3. Sorbic acid
4. EDTA
5. Polyporphates
6. Phenolic compounds
7. Naturally occurring materials

Sprays or dips of chlorine, acetic acid, iodophore, stannous chloride and hydrogen peroxide have been used to treat carcasses but acetic acid or chlorine sprays appear most effective (Spencer et al., 1968; Biemiller et al., 1973; Heitter, 1975; Stringer, 1975; Smith et al., 1976).

Sorbic acid appears to be one of the most promising antimicrobials for application to meats. Perry et al. (1964) first reported on the effectiveness of sorbic acid for extending shelf-life of cut-up fresh poultry. Robach (1978) has verified this earlier work and has shown that sorbic acid can effectively inhibit certain strains of Pseudomonas. Sorbic acid has also been used in the recent patent by Monsanto to lower the requirements for nitrite in a curing solution used for bacon (Robach, 1978). Sorbic acid is an effective inhibitor of Clostridium botulinum. Certain chelating agents have also been reported to have antimicrobial activity. Ethylenediamine-tetraacetic acid (EDTA) and polyphosphates have shown promise in prolonging the shelf-life of fish and meat products due to their antimicrobial actions (Kuusi and Loytomaki, 1972; Ellinger, 1973). Both EDTA and the polyphosphates also have antioxidant activity which would allow these compounds to have a dual function in refrigerated meat products (Stucky, 1972). Certain phenolic antioxidants also appear to have antimicrobial activity. Butylated hydroxyanisole (BHA) is the most effective and has been found to inhibit several molds as well as Streptococcus aureus, Escherichia coli, Salmonella typhimurium, Clostridium perfringens and botulinum and Vibrio paraahemolyticus (Chang and Branen, 1975; Ahmad and Branen, 1976; Ayaz et al., 1977; Shih and Harris, 1977; Robach et al., 1977; Klindworth et al., 1977). It should be pointed out that BHA is not very effective towards most gram negative bacteria and its activity is decreased in food systems. This would thus limit its activity in meat products in preventing spoilage by psychrotrophic organisms. It would, however, appear useful as an adjunct to sorbic acid. Klindworth (1977) has indicated synergistic antimicrobial activity of sorbic acid and BHA towards Clostridium perfringens. The parabens might also be useful in antimicrobials in meat (Chichester and Tavart, 1972) however, the antioxidant activity of BHA plus its antimicrobial activity makes it advantageous over the parabens.

Several naturally occurring compounds appear to be useful for preserving meats (Marth, 1966). Antibiotics produced from non-food fermentation have been found to be effective in extending the shelf-life of meat products (Elliot and Michener, 1965; Marth, 1966; Njoku-Obi et al., 1957; Eklund et al., 1961). Despite their effectiveness against gram negative organisms, these antibiotics are not legal for use (Chichester and Tanner, 1968). Certain compounds produced by lactic cultures may be acceptable because of their widespread consumption in fermented foods. Lactic cultures were utilized by Reddy et al. (1970) to preserve ground beef held at refrigerated...
temperatures and by Daly et al. (1973) to control *S. aureus* in sausage. Reddy et al. (1970) found that the addition of 1% lactic culture prevented the growth of aerobic organisms, and cultured meat with 450 ppm of ascorbic acid was consistently preferred for flavor and aroma over uncultured meat. The use of cultures, however, is not normally acceptable because of the overall increase in microbial counts due to the culture and the development of off-flavors and colors. Recently the principals responsible for inhibition of gram-negative organisms by lactic cultures was partially purified (Branen et al., 1975). This partially purified material appears to be effective in preventing putrefactive spoilage of beef and fish products. The effectiveness of these materials against spoilage by pseudomonads can be increased by combining them with a proteolytic enzyme inhibitor from potatoes. The enzyme inhibitor has been purified by Ryan et al. (1973) and is quite effective against the extracellular proteolytic enzymes produced by *Pseudomonas* species (Go, 1976).

It should be mentioned that packaging would appear to provide an important adjunct to the chemicals described above. Many workers have found increased shelf-life of meat and poultry packaged in impermeable films or cans, especially when evacuated (Elliot and Michener, 1965; Carpenter et al., 1975; Wells et al., 1958). The effects have been attributed to retention of CO₂ formed by respiration or to exclusion of oxygen (Elliot and Michener, 1965).

Levels of 15-20% CO₂ in the package appear to inhibit the pseudomonads which are largely responsible for surface spoilage of meat under aerobic conditions (Carpenter et al., 1975). Controlled atmosphere may provide the best preservation of fresh meat (Carpenter et al., 1975; Wolfe et al., 1976). According to Smith et al. (1976), vacuum packaging does not appear feasible for preservation of wholesale or carcass beef in the 7 to 10 day range, but is commercially feasible after about 10 days if a good vacuum is maintained. Various films or laminates have been used for cured meat, but these meats finally spoil from growth of lactic acid bacteria (if evacuated) or by yeasts and molds if oxygen is permitted access (Elliot and Michener, 1965).

The role of antioxidants in the preservation of the quality of muscle foods has been studied for several years even though their utilization in these products has not been extensive. Antioxidants (i.e., butylated hydroxyanisole, butylated hydroxytoluene, propyl gallate and tocopherols) and chelating agents (ethylene-diaminetetraacetic acid and polyphosphates) have been introduced into muscle foods through feeding, injection or direct addition to the product in order to retard oxidative changes (Pool et al., 1950; Line-weaver et al., 1952; Klose et al., 1956; Greene, 1969; Jacobson and Koehler, 1970; Love and Pearson, 1971; Webb et al., 1972a, b; Olson and Rust, 1973; Spencer and Verstrate, 1975; Lindsey et al., 1975; Haymon et al., 1976; Govindarajan et al., 1977). These studies have shown that antioxidants (particularly BHA, BHT and TBHQ) are effective in controlling the autoxidation of the lipids in muscle foods from various species and under various handling, processing and preservation methods. A new development in antioxidant technology has been the development of functionally active polymeric forms which are both useful in stabilizing dietary lipids and which are virtually nonabsorbed from the gastrointestinal tract (Furia and Bellanca, 1976). Though not yet approved for use in human foods, preliminary studies in our lab have shown them to be equal to TBHQ in stabilizing odor and flavor deterioration in refrigerated ground turkey. According to Karle (1973) the addition of antioxidants also greatly reduces the loss of the biological value of proteins. However, extensive studies have not been initiated to determine the effect of antioxidants upon retarding lipid oxidation and the resultant preservation of the biological value in frozen, non-frozen and cooked muscle foods.

The extent of oxidation in muscle foods can also be reduced by anaerobic storage, but control of lipid oxidation by removal of oxygen and use of gas-impermeable packaging is difficult to achieve (Love and Pearson, 1971).

Overall, it would appear that a combination of antioxidants and antimicrobials would be beneficial in extending the shelf-life of refrigerated meat products. Because of the greater susceptibility to microbial growth and autoxidation of processed products which have been ground prior to refrigeration. Such a preservation system would appear most beneficial in processed products rather than whole cuts. However, further research may indicate usefulness with whole cuts or carcases and cooked meats. We have found that a combination of the *S. diacetilactis* cell-free filtrate with TBHQ does effectively extend the shelf-life of ground turkey (Salminen and Branen, 1978). Taste panel evaluations, microbial counts and TBA values indicate that the refrigerated shelf-life of ground turkey can be extended by at least five days. Other combinations of antioxidants and antimicrobials may prove even more useful, but little has been done in this regard.

As mentioned earlier, the exact roles of lipid autox-
Both antioxidants and antimicrobials will be needed. Adaptation.

It is certain that both limit the shelf-life of meat products and thus a combination of both antioxidants and antimicrobials will be needed. To effectively select the optimum combination, further research will be needed to accomplish the following:

1. Delineate the exact roles of, and interrelationships between, microbial growth and lipid autoxidation.

2. Evaluate the capability of various antioxidants to prevent rancidity of various meat products subjected to various preparation and storage conditions.

3. Evaluate the usefulness of various antimicrobials against food spoilage and poisoning organisms in various muscle foods.

4. Evaluate the effectiveness and synergistic action of combinations of antioxidants and antimicrobials in preservation of muscle foods.

This research should provide a basis for developing a practical method for extending the shelf-life of meat products. The total marketing chain would benefit from such a method since it would aid in improving and increasing the utilization of one of our most nutritious foods, meat products.

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