THE EFFECT OF MODIFIED ATMOSPHERE PACKAGING (MAP) 
ON THE SHELF-LIFE OF REFRIGERATED, CUBED TURKEY THIGH MEAT

by

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I. INTRODUCTION

MODIFIED ATMOSPHERE PACKAGING (MAP) changes the gaseous environment inside the package resulting in slower respiration rate, reduced microbial growth, and decreased enzymatic spoilage with the intent of extending shelf-life (Young et al, 1988).

The three gases used most in modified atmosphere packaging of meat are oxygen, carbon dioxide, and nitrogen. These three gases impart the greatest influence in meat color and shelf-life. Also, they are relatively inexpensive and available. Oxygen is used to prevent anaerobic spoilage and to maintain the bright red color of meat. Carbon dioxide retards aerobic bacterial growth and is soluble, which means it is absorbed into meat. Nitrogen is chemically inert and is used as a filler for package integrity because of its low solubility (Bell, 1987).

To determine which gases to use, packers have to know their products, the conditions under which they are likely to be stored, and consumer perceptions about the product. In the case of fresh meat, fish and poultry, the major concerns are are enzymatic aging processes, microbial spoilage, fat oxidation, and various oxidation states of the myoglobin pigment (Wolfe, 1980). Growth of almost all aerobic microorganisms, particularly psychrophilic and
psychrotrophic, can be retarded by elevated carbon dioxide. Oxygen is usually thought to have the greatest effect on meat color. At concentrations above 5%, the myoglobin molecule becomes oxygenated to form oxymyoglobin (Williams, 1989).

Many researchers have been trying to find the best gas compositions used in modified atmosphere packaging systems for many products including poultry meat; more trials are still needed.

This research was designed with the purpose of investigating of the effect of MAP on the shelf-life of the refrigerated, cubed, raw turkey thigh meat.

The primary objectives of the research were to determine the effect of two kinds of modified atmospheres ((1) 25% CO₂ and 75% N₂ (2) 20% CO₂, 60% O₂, and 20% N₂) in the turkey thigh meat on:

1. General microbiological count of the refrigerated, cubed, raw turkey thigh meat during storage.
2. Fat rancidity of the turkey meat during storage.
3. Color changes of the turkey meat during storage.
4. Appearance and olfactory acceptability of the turkey meat at certain intervals during storage.
II. REVIEW OF LITERATURE

A. Modified Atmosphere Packaging

The primary function of a meat package is to contain the product and to prevent contamination from the external environment. More recently, packaging has been used as a means to inhibit the growth of spoilage organisms and to increase storage-life (Shay and Egan, 1987).

Modified atmosphere packaging (MAP) is one technique which can be employed to improve product shelf-life (Hintlian and Hotchkiss, 1986). It can be broadly defined as any process which changes the environment around a product. Vacuum packaging is one example. Flushing a package with a gas or gas mixture is another.

Modified atmospheres have been used since the 1800s. By the 1930s, large quantities of beef and lamb were being shipped from Australia and New Zealand to Great Britain using carbon dioxide enriched atmospheres. Interest and use faded during the 1940s and 1950s as a result of World War II, but were rejuvenated when long distance, overseas distribution of red meat products resumed. Modified atmosphere systems were used for the transoceanic, transcontinental distribution of entire carcasses and primals (Williams, 1986). The first significant packaging trials with individual portion packs rather than bulk
supplies were made in the late 1950s, when vacuum packaging of meat, fish and coffee was first introduced (Inns, 1987).

In the 1960s and 1970s, the greatest applications of MAP were the vacuum packaging of meats and cheese and the gas flushing of ground coffee. In 1981, one of the most prestigious of retailers of the United Kingdom, Marks & Spencer, introduced MAP for its complete range of fresh meats. These were packed in gas-flushed transparent plastic trays made on thermoform-fill and seal machines. This was rapidly followed by MAP for fresh fish, cooked meats and bacon. The market has since been growing at better than 20% per annum (Inns, 1987).

In order to achieve an optimum effect with MAP, five important factors must be considered: (1) the initial microbial state of the food, (2) temperature control, (3) the gas mixture (which is very product dependent), (4) the barrier film, (5) the packaging equipment used (Rice, 1987).

Carbon dioxide, nitrogen, and oxygen are the three principal gases used in MAP for meat, fish, and poultry. There is a possibility that carbon monoxide may become significant in gas mixtures as the application of the gas in MAP has been shown to stabilize the color of meat by formation of carboxymyoglobin (Wolfe, 1980). However, for the moment it has limited use and needs approval from the USDA before it can be used.
B. Principal Gases

Carbon dioxide has a powerful inhibitory effect on bacterial growth. It is particularly effective against the gram-negative, aerobic, spoilage bacteria, such as Pseudomonas spp, which cause off-odors and flavors in fresh muscle foods. Lactic acid bacteria, such as Streptococci and Lactobacilli, are more tolerant of carbon dioxide. There is a residual antimicrobial effect when foods are stored in carbon dioxide enriched atmospheres and subsequently exposed to air in that the lag phase of microbial activity is extended (Silliker et al, 1977).

The manner in which carbon dioxide inhibits growth is not fully understood. The fact that some anaerobic and facultative species are also inhibited indicates that the effect is more complex than the simple exclusion of oxygen (King and Nagel, 1975). While carbon dioxide is the most effective gas in inhibiting microbial growth, it does present some problems in other aspects of food quality and presentation. High concentrations of carbon dioxide can cause discoloration, sharp taste and pack collapse. At levels higher than 30%, purple discoloration is observed in cut chicken portions and some greyness noted in red meats (Ogilvy and Ayres, 1951). The dissolution of the gas into the surface of fresh muscle foods can reduce the pH
sufficiently to weaken the water holding capacity of the proteins. This can also have the effect of giving the food a slightly sharp and acid taste, though this disappears fairly rapidly after the pack is opened. Furthermore, carbon dioxide permeates packaging films up to thirty times faster than any other gas used for packaging of food products (King and Nagel, 1975). This, together with its dissolution into the fat and water phases of the food, can lead to pack collapse if a suitable balanced gas is not used with the carbon dioxide.

Nitrogen is inert, tasteless and is virtually insoluble in water. By excluding oxygen, nitrogen inhibits lipid oxidation and mold growth (Inns, 1987). Lipid oxidation manifests itself as rancid odors and tastes, which are caused by products derived from the attachment of oxygen molecule to the double bonds in the carbon chain of unsaturated fatty acids. Presence of as little as 0.1% unsaturated fatty acid is enough to cause the development of lipid oxidation with oxygen molecules causing rancid flavors (Leeson, 1987).

The best gas to use for the displacement of oxygen is nitrogen. It is preferred to carbon dioxide in this context because it does not dissolve into the fatty tissue of the food, as does carbon dioxide and it permeates packaging films far more slowly (Leeson, 1987).
Nitrogen is not considered an effective bacterial inhibitor. Simard et al (1985) found no difference in psychrotrophic bacteria counts between vacuum packaged beef and beef stored in 100% nitrogen. Since nitrogen is over 70% of normal atmosphere, it is readily available and relatively inexpensive, thus making it attractive as a gas dilution component (Hall et al, 1980). Atmospheres containing 80% nitrogen and 20% carbon dioxide have been shown to be effective in bulk gas flushed pork packaging systems (Hall et al, 1980).

Oxygen sustains the basic metabolism of freely respiring foods, such as fruits and vegetables, and oxygenates the pigment myoglobin in red meats to form the desirable bright, cherry-red color. It was perhaps this latter phenomenon which was the catalyst to the growth in MAP for individually packed fresh foods.

The formation of metmyoglobin, with its undesirable brown coloration, is the main limiting factor on the saleability of otherwise perfectly edible red meat. The exclusion of oxygen, as in vacuum packaging, produces the purplish red of myoglobin, while a low partial presence of oxygen enhances the rate of formation of the brownish metmyoglobin pigment. If, however, the proportion of oxygen is increased to over 50% of the surrounding atmosphere, the bright, cherry-red oxymyoglobin color, which maintains the
appeal of the product to the purchaser, is retained for longer, thus increasing the period of saleability (Leeson, 1987).

C. MAP, Poultry, and Meat

Poultry is one of the most widely accepted muscle foods in the world. From a standpoint of nutrition, poultry contains more protein and less fat, cholesterol, and calories than red meat. Also, poultry meat has more highly unsaturated fat than beef or pork according to data from the United State Department of Agriculture (USDA) (Stadelman, 1988; Mountney, 1976). The consumption of poultry meat is rising.

Despite increasing consumption of poultry meat, it was difficult to find studies done on MAP for shelf-life extension of refrigerated, raw turkey meat, and especially for the cubed turkey meat.

The system of packaging in a modified atmosphere or in a vacuum to prolong fresh meat shelf-life has been investigated by several workers (Adams and Huffman, 1972; Huffman, 1974; Silliker et al, 1977; Seideman et al, 1979B; Enfors et al, 1979; Spahl, 1981). Seiderman et al (1979A) reported that a modified atmosphere containing 20% carbon dioxide and 80% nitrogen retains the natural color of pork. Hermansen (1980) found that vacuum packed pork samples became unacceptable after 12-13 days as compared to
aerobically packed samples at 7-8 days of storage. Silliker and Wolfe (1980) have studied the safety aspects related to storage of muscle foods in carbon dioxide enriched atmospheres. The study reported that interior gas mixtures of 45% oxygen, 20% carbon dioxide, and 35% nitrogen had a good effect for modified atmosphere packaging of red meats. Clark and Lentz (1973) reported that 85-90% oxygen and 10-15% carbon dioxide showed optimum results for red meats.

Other investigators have shown that oxygen and carbon dioxide concentrations substantially higher than atmospheric concentration were useful for MAP of fresh meat especially considering of the desirable color protection (Munoz-Delgado, 1979). A study revealed that the gas composition of 50% oxygen, 25% carbon dioxide, and 25% nitrogen was appropriate for the MAP of poultry meat (Iwacha and Burland, 1987). An experiment has shown that success in storage of meat prepacked in an atmosphere of 80% oxygen and 20% carbon dioxide depends not only on the composition of the atmosphere but also on the initial bacterial load and storage temperature (Munoz-Delgado, 1979).

D. Effect of MAP on Meat Color

Color in poultry meat is one of the important factors which impress consumers. Although numerous studies have demonstrated that there is no direct relationship between
color and other important organoleptic properties, the packer believes the consumer associates red color with high quality (Brody, 1989).

The fresh color of muscle foods is due to the concentration and chemical state of the muscle pigment, myoglobin. Myoglobin is a water soluble protein found in red muscle fibers whose purpose in the live animal is to bind oxygen for cellular metabolism. It consists of globin, the protein portion, and a non-protein heme group with a central iron atom.

Meat color depends on the oxidative state of the central iron atom as well as the type of ligand bound at its sixth position. Undenatured myoglobin can exist in three forms. Oxygen is usually thought to have the greater effect on meat color. At low concentrations, less than 5% or below 20 mm partial pressure, oxygen may cause muscle myoglobin to become metmyoglobin which has an unappealing brown color. At concentrations above 5%, or at partial pressure above 60 - 70 mm, the myoglobin molecule becomes oxygenated to form oxymyoglobin. This results in the fresh, bloomed color which consumers expect. At atmospheric oxygen levels (20.7%) and in retail display conditions, the bloomed color is expected to last 3-4 days (Williams, 1989).

Work done by Bartkowski et al (1982) indicated that, in 50% oxygen atmospheres, retail beef cuts maintained their
bright red color for 9-10 days. Bala et al (1977) noted that in 80-85% oxygen atmospheres, fresh beef color was maintained for up to 20 days. Brooks (1935) showed that MAP which had a higher concentration of oxygen than air retarded the formation of metmyoglobin which is fastest when the partial pressure of oxygen is only about 4 mm. Thus, gas atmospheres containing low concentrations of oxygen must be avoided because of the rapid development of browning.

In many early studies using mixtures of carbon dioxide and oxygen as an atmosphere for meat storage, the oxygen concentrations used were much lower than in air, and color problems resulted (Shay and Egan, 1987). Other studies which used relatively high concentrations of carbon dioxide with moderated levels of oxygen also indicated the acceleration of darkening of meat color (Huffman, 1974; Ledward, et al, 1971; Silliker, et al, 1977). A study demonstrated that when the oxygen content of the atmosphere was raised to between 60-80%, the desirable color was maintained for much longer, thus increasing the period of salability (Inns, 1987).

Color is also a major obstacle in vacuum packaging of muscle foods, which is another form of MAP. If the color acceptance problem could be overcome, vacuum packaging would have a considerable advantage over other methods (Shay and Egan, 1987).
Other investigations have shown that fresh meat packed at oxygen and carbon dioxide concentrations substantially higher than atmospheric remained red longer than meat packed in air (Munoz-Delgado, 1979). Georgala and Davidson (1969), in conjunction with Unilever Ltd. of Great Britain, patented a process in which centrally prepared retail beef and poultry items were packed in deep, rigid barrier structures and gas-flushed with a mixture of 80% oxygen and 20% carbon dioxide. Their testing of this package indicated that from a color and bacterial standpoint, products had a shelf-life of 9 days or more.

The high amount of oxygen used in the MAP of muscle foods to develop the bright red color can also produce rancid or off-flavors as the fat undergoes oxidative deterioration (Dawson and Schierholz, 1976). Therefore, when the oxygen proportion is selected for the MAP of poultry meat, fat rancidity as well as the desirable color of the meat should be considered.

Storage temperature is important and temperature control should be kept at all times. The effectiveness of MAP is decreased as the storage temperature increases because the solubility of a gas in a liquid (or product) also decreases (Shepherd, 1987). One study indicated that above 4°C, for every 2° increase the chances of meat discoloration doubled (Bruce, 1987).
There are conflicting data on the effect carbon dioxide has on meat color. Several researchers report high levels of carbon dioxide discolor meat (Ledward, 1970; Tayor, 1972), while others (Seidman et al, 1979B) do not agree. Brown and Mebine (1969) studied the effect of a high concentration of carbon dioxide on the color of meat. They indicated the principal disadvantage in usage of high-carbon dioxide atmospheres in fresh meat storage is the development of color darkening related to metmyoglobin formation. A work (Inns, 1987) on chicken portions stored in aerobic atmospheres enriched with carbon dioxide showed that within the range 0-25% carbon dioxide, the ratio of shelf life in carbon dioxide enriched air to that in air alone was a function of the carbon dioxide concentration. Higher concentrations caused discoloration of the meat, and although there is some argument about whether this limitation exists, in practice, concentrations above 25% of carbon dioxide appear to be advantageous.

Another gas which can affect meat color is carbon monoxide. Carbon monoxide at concentrations as low as 1% has been shown to prevent the formation of metmyoglobin or brown color for extended periods time (13-15 days) (El-Badawi et al, 1964).

When carbon monoxide is present, the muscle pigment carboxymyoglobin is formed rather than the less stable
oxymyoglobin. Both result in a bright red color. The affinity of the myoglobin molecule for the carboxyl group is 30–50 times greater than that of oxygen. Carbon monoxide can also displace the oxygen molecule from oxymyoglobin and inhibit the development of rancid flavors which can easily occur in high oxygen atmospheres (El-Badawi et al, 1964).

The major concern with carbon monoxide is its toxicity to humans and the possible overlook of high bacterial growth because of the bright red color on meat for long time due to forming carboxymyoglobin. Research has indicated, however, that several pounds of carbon monoxide treated meat would have to be consumed to result in a blood carbon monoxide level equal to that resulting from smoking one cigarette (Wolfe, 1976). The use of carbon monoxide is not approved by the USDA.

E. Effect of MAP on Fat Rancidity

When a fairly high amount of oxygen is used in MAP of meat for color protection, fat rancidity may result. Because poultry lipids generally exhibit a higher degree of unsaturation compared to red meats, poultry meat is more susceptible to oxidation (Igene et al, 1979, 1980; Melton, 1983). Refrigerated, cubed, raw turkey meat has a high susceptibility to oxidative deterioration due in part to the
cubing action, which results in a highly aerated product.

Oxidation of muscle lipids involves peroxydation of the unsaturated fatty acids, in particular the polyunsaturated fatty acids (PUFA) (Allen and Foegeding, 1981). The PUFA are associated with phospholipid, which are critical to the development of off-flavor in muscle foods (Keller and Kinsella, 1973; Moreck and Ball, 1974; Igene et al, 1979).

Oxidation of these fatty acids proceeds through the following free-radical mechanisms:

Initiation \[ RH + O_2 \rightarrow R. + .OH \]
Propagation \[ R. + O_2 \rightarrow RO_2. \]
\[ RO_2. + RH \rightarrow RO_2H + R. \]
Termination \[ R. + R. \rightarrow RR \]
\[ R. + RO_2. \rightarrow RO_2R \]
\[ RO_2. + RO_2. \rightarrow RO_2R + O_2 \]

In addition to the formation of hydroperoxide (RO_2H), generally called peroxides or primary products of oxidation (Gray, 1978), other types of reactions may occur. Peroxides may break down to carbonyls, form polymers, or react with protein, vitamins, pigments, etc. (Gray, 1978; Karel, 1973).

The 2-thiobarbituric acid test or TBA test is one of the most widely used tests for measuring oxidative rancidity of meats (Gray, 1978; Rhee, 1978). This test, initially reported by Sinnhuber and Yu, in 1958, measures the quantity
of malonaldehyde in mg per kg of sample. Malonaldehyde is a secondary oxidation product of polyunsaturated fatty acids containing three or more double bonds (Dahle et al, 1962; Pryor et al, 1976).

A modified 2-thiobarbituric acid test using antioxidants to protect lipids during sample preparation has been used. In 1974, Merck and Ball added an antioxidant mixture containing 20% butylate hydroxyanisole (BHA), 6% propyl gallate (PG), and 4% citric acid in propylene glycol at the distillation stage to prevent oxidation of the chicken meat. During the TBA test of fish samples, 100 mg of propyl gallate (PG) and ethylenediamine tetracetate (EDTA), a good sequestering agent, were used to prevent further oxidation of lipid by Ke et al (1977). Rhee (1978) indicated that PG and EDTA should be added during the blending stage when the TBA assay was used for testing lipid oxidation of muscle foods. Recently, a study reported that EDTA inhibited muscle lipid peroxidation lowering TBA numbers in minced turkey muscle (Joseph, 1988).

F. Effect of MAP on Microorganisms

For many years, various naturally occurring and manufactured gases and vapors have been known to inhibit or to kill microorganisms. Several of these have been studied to determine their potential usefulness in increasing the
storage life of foods (Wagner and Moberg, 1989). One of these gases is carbon dioxide, which has been used in MAP for extending the shelf life of meat, fish, and poultry for many years.

Hotchkiss (1988) reports among the earliest work concerning the influence of carbon dioxide on bacteria was that of Pasteur and Joubert in 1877, who reported Bacillus anthraces was killed by carbon dioxide. No mention was made, however, of the media used, the length of the exposure to carbon dioxide, or the concentration of carbon dioxide required for a lethal effect (Hotchkiss, 1989).

Many researchers have shown the effect of carbon dioxide on the growth of microorganisms since the work done by Pasteur and Joubert. In 1979, Veranth and Robe demonstrated carbon dioxide enriched atmospheres (60% carbon dioxide, 25% oxygen, 15% air) doubled the shelf-life of fresh salmon. Other research done on fish by Woyewoda et al (1984) indicated fish stored in carbon dioxide had lower concentrations of ammonia and trimethylamine (TMA), with markedly retarded microbial growth as compared to samples stored in air.

There were significantly lower counts of microorganisms in carbon dioxide packaged pork samples compared to samples packaged in vacuum (Anjaneyulu and Smidt, 1986). In 1980, Christopher et al reported psychrotrophic bacterial counts
of lean and fat surfaces of loins stored in 40% carbon
dioxide and 60% nitrogen were frequently significantly lower
than counts of comparable sides of vacuum packaged loins.
Pork chops stored in air had an acceptable odor up to the
9th day, vacuum packages up to the 13th day, and up to the
16th day for carbon dioxide enriched packs (Anjaneyulu and
Smidt, 1986). These findings are consistent with the
results of Spahl et al (1981), Hermansen (1980), and

In 1984, Thomas et al indicated carbon dioxide
atmosphere storage was effective in delaying the spoilage of
poultry. Raw, cut-up poultry stored at 5°C in oxygen
permeable film, vacuum packages, and carbon dioxide flushed,
oxigen-barrier film was unacceptable by day 9, between days
9-11, and after 17 days, respectively.

The inhibitory effect of carbon dioxide on the growth
of microorganisms is fairly well documented and the effect
can be noticed even in the presence of oxygen (Brody, 1989).
The inhibitory effect of carbon dioxide on the growth of
microorganisms varies with the concentration of carbon
dioxide. Many researchers indicated higher concentrations
of carbon dioxide up to 20-30% have the best effect on the
prevention of microbial growth (Brody, 1989), although
others did not agree (King and Nagel, 1967). Work done by
Bala et al (1977) and Bartkowski et al (1982) recommended
concentrations in excess of 25%, although concentrations as low as 15% have been reported to show microbial suppression. The effect of carbon dioxide concentration on the growth of microorganisms in MAP was reviewed by Brody (1989) who concluded that the greater the concentration of carbon dioxide, the lower the respiratory rates of microorganisms. However, above 25-30% carbon dioxide, the rate of respiratory retardation was approximately the same, regardless of concentration. In 1967, King and Nagel (1967) reported generation time of *Pseudomonas aeruginosa* decreased linearly with an increased carbon dioxide concentration up to 70% (v/v). There were also studies which showed that a 10% level of carbon dioxide usually gave about a 50% inhibition on the basis of total counts after a given incubation time (Ledward et al, 1971; Clark and Lentz, 1969).

Storage temperature is important to the inhibitory effect of carbon dioxide on the microbial growth. Poor temperature control eliminates the beneficial effects of elevated carbon dioxide levels by decreasing the solubility of the gas in foods. Studies have shown the effect of carbon dioxide on microorganisms increased with decreasing temperatures (Gill & Tan, 1979). The inhibitory effect of carbon dioxide on the growth of spoilage bacteria under various storage condition is well documented by many
researchers (Baron et al, 1970; Clark and Lentz, 1969; Huffman et al, 1975; Silliker and Wolfe, 1980).

The inhibitory effect of carbon dioxide is specific to various microorganisms. Usually gram-negative spoilage bacteria are considered more sensitive to carbon dioxide. Researchers showed gram-negative spoilage flora of refrigerated meat were especially sensitive to carbon dioxide, while lactic acid bacteria were less affected (Enfors and Molin, 1984; Grau et al, 1985; Silliker and Wolfe, 1980).

Over twenty-five genera of the bacterial flora of fresh poultry have been identified in the studies of many investigators. However, when these meats undergo low-temperature storage, almost all workers agree the primary spoilage organisms belong to the genus Pseudomonas (Ayres et al, 1950; Barnes, 1968; Nagel et al, 1960). The essential feature of poultry spoilage is sliminess at outer surfaces of the carcasses or cuts. Surfaces of fresh poultry stored in an environment of high humidity are very susceptible to growth of aerobic bacteria such as Pseudomonas. These organisms grow well on the surfaces where they form minute colonies that later coalesce to produce the sliminess characteristic of spoiled poultry (Jay, 1986).

As poultry undergoes spoilage, off-odors are generally noted before sliminess, with the former being first detected
when log numbers/cm² are about 7.2-8.0. Sliminess generally occurs shortly after the appearance of off-odors with the log counts/cm² about 8 (Ayres et al, 1950). In 1980, Patterson showed Pseudomonas were invariably the predominant organisms of spoilage of chilled-stored chicken, turkeys, and ducks.

Extension of shelf-life associated with use of oxygen impermeable wrapping material results mainly from inhibition of the Pseudomonas, an effect which usually is attributed to build-up of carbon dioxide within the pack. Studies made by Coyne (1933) and Haines (1933) showed growth of Pseudomonas is delayed by 100 to 200 ml carbon dioxide/l, provided that the temperature remains below 4°C. When meat is spoiled, the predominant microflora is composed of carbon dioxide-tolerant organisms which tend to grow more slowly than Pseudomonas at chill temperatures. Escherichia coli, Streptococcus faecalis, and Lactobacillus spp show resistance to carbon dioxide (Dixon and Kell, 1989). The mechanism of the action of carbon dioxide as it prevents food spoilage has not been explained. At present there are two major theories for explaining the carbon dioxide inhibition of cell growth: (1) carbon dioxide inhibits enzymatic reactions critical for growth, e.g. carboxylation/decarboxylation reactions (King and Nagel, 1975; Krizman et al, 1977); (2) carbon dioxide affects the permeability of
the cell membrane (Sears and Eisenberg, 1961). Changes in the permeability of the cell membrane were also noticed in a study of the effects of carbon dioxide on the germination of bacterial spores (Enfors and Molin, 1978). Inhibition was suggested to be due to an increase in fluidity, causing the disturbance of the activity of a membrane-bound enzyme essential to the inhibition of germination.

Alteration in fatty acid content and fluidity of yeast cell membranes at elevated carbon dioxide pressure levels is observed (Castlli et al, 1969). One study indicated the mode of carbon dioxide action on growth of microorganisms is bacteriostatic rather than bacteriocidal. Carbon dioxide reduces the bacteria growth rate and delays onset of active growth of microorganisms which are not growing, i.e., it extends lag phases and increases generation times (Shay and Egan, 1987).

Carbon dioxide dissolves readily in water (1.71 ml carbon dioxide/ml water at 760 mm of pressure and 0°C) and hence in the juices of foods, but the absorption appears to be wholly a physical phenomenon involving no more tightly bound chemicals than carbonic acid. When absorbed in foods, the pH is lowered in proportion to the amount of carbonic acid formed and the buffering capacity of the food (Killeffer, 1930). For a satisfactory explanation of the complex inhibitory effects of carbon dioxide, further work
will be necessary to identify affected enzymes and metabolic consequences of their inhibition by carbon dioxide.

There are contradictions about the effect of nitrogen on microbial growth. Some researchers indicated that nitrogen, from a microbial viewpoint, is inert and it will exhibit antimicrobial effects only when it completely replaces oxygen; in which case the effect is in the absence of the oxygen, not the presence of nitrogen (Shay and Egan, 1987). Spoilage is the single most important safe-guard in preventing food-born disease outbreaks because it is often spoilage that warns the consumers that a given food may be unsafe (Hotchkiss, 1987). Foods that can become a hazard without concurrent indicators of spoilage are the most dangerous. The difference between spoilage and hazard must be addressed when considering the safety of MAP technology because MAP could, potentially, inhibit the development of spoilage (i.e. indicator) organisms while allowing the growth of pathogenic organisms (Hotchkiss, 1987).

In 1986, Hintlian and Hotchkiss studied the safety of MAP and suggested the growth rate of spoilage organisms to pathogenic organisms was a method to compare the relative safety of different modified atmosphere - temperature conditions. In their studies, roast beef samples were inoculated with both spoilage and pathogenic bacteria,
Pseudomonas fragi and Clostridium perfringens, and incubated at 55°F for 5 or 18 days with increasing amounts of oxygen in the atmosphere. Modified atmospheres in which oxygen was not included showed the decreased ratio of Pseudomonas fragi to Clostridium perfringens compared to the original inoculum (i.e. became more hazardous). Above 2% oxygen levels, the ratio became larger than the initial inoculum and it became less likely that the pathogens would grow without the concurrent development of the spoilage organisms.

Although gram-negative, aerobic, psychrotolerant organisms can be inhibited by carbon dioxide, most food-borne pathogens can tolerate high concentrations of carbon dioxide. Luiten et al (1982) indicated that Salmonella typhimurium and Staphylococcus aureus could tolerate a gas atmosphere of 60% carbon dioxide and 40% oxygen packaging, although organisms did not increase in number for 9 days of storage. In 1989, Brody showed the growth of Salmonella and the potential growth of psychrotrophic pathogens such as Listeria and Versinia were all possible when the time at low temperature was prolonged, even under MAP condition. Researchers have shown the hazards of the growth of Clostridium botulinum in MAP or vacuum packaging (Kautter et al, 1981; Post et al, 1985; Stier et al, 1981).

There have not been detailed studies of the safety concern of MAP and it is difficult to conclude the increased
risk of MAP with the present data. Therefore, more work is needed on the relative growth of pathogens and spoilage organisms in refrigerated MAP products.

G. Feasibility

In 1987, Hotchkiss showed two major reasons why MAP of foods gained a foothold in commercial food distribution. First, MAP offers a potential shelf-life increase of over 400% for many products. Thus many products can be distributed over longer distances or with fewer deliveries. The second reason for the success of MAP is it makes good economic sense. For many products, MAP can decrease distribution costs while also providing a high quality product.

In 1987, Leeson mentioned the benefits of MAP for manufactures, retailers, and consumers: (1) to manufacturers by enabling longer production runs, thus utilizing labor and equipment better and allowing large quantities of raw materials to be purchased, (2) to retailers by less missed sales from being out of stock, less frequent checking of sell by date enhancement of sales owing to attractive color and presentation, and obviates the need for in-store butcheries, (3) to the consumers, by the enclosed packaging, which is easy to inspect and collect, and keeps longer in the household refrigerator.
Although researchers demonstrated the advantage of MAP from an economic point of view, consumers may pay a relatively high cost because the capital outlay for the equipment of MAP alone can be significant. However, the fact that today's consumers are ready to pay a little higher price for safe and fresh foods as revealed in a survey (Sloan and McNutt, 1986) also shows a favorable aspect for MAP of raw turkey meat.
III. MATERIALS AND METHODS

A. Preparation of Sample Packages

Boneless, skinless, turkey thigh meat was prepared under commercial conditions and provided by Rocco, Inc. (Harrisonburg, Va). The turkey meat arrived at the Food Science and Technology Building, at Virginia Polytechnic Institute and State University (VT) two days after slaughter and deboning via an insulating box containing ice packs. Preliminary work was undertaken to ascertain the best preparation method of packaging with cubed turkey meat.

Turkey meat was processed in a 0.5°C room to remove a lump of external fat and then cubed using a cubing machine, Model 705 (Berkel Inc., La Porte, Indiana) on the day of arrival. One hundred g of cubed turkey meat was layered into a container made from crystallized polyester terphthalate (CPET). The tray was put in a multilayer pouch of polypropylene /biaxially oriented nylon/polyethylene (Cryovac, Duncan, South Carolina) and heat sealed (Multivac A300/52, Wolfertschwenden, W-Germany). Two kinds of modified atmospheres were made using a gas partitioner (Fisher Co., Pittsburgh, Pennsylvania) and a gas mixer (Brunner Eng. & MFG. Inc., Bedford, Indiana):

(1) \( \text{CO}_2: \text{O}_2: \text{N}_2 = 25\%:0\%:75\% \), and (2) \( \text{CO}_2: \text{O}_2: \text{N}_2 = 20\%:60\%:20\% \)
Each package was evacuated and then filled with the desired gas mixture or air for Air Control before sealing.

The tray was approximately 10 cm x 14 cm x 3.5 cm. The pouch was about 15 cm x 25 cm and 0.07 mm thickness of one layer.

B. Storage of Sample Packages

All sealed packages were stored in a cooler, maintained at 0.5°C. Samples were analyzed for headspace gas composition, 2-thiobarbituric acid test (TBA test), aerobic plate count (APC), color, and sensory evaluation. These tests were done after 2, 7, 9, 12, 16, and 21 days of storage.

C. Headspace Gas Analysis

Gas samples were drawn from the headspace of modified atmosphere packages and air control packages into a syringe with a needle (Becton, Dickinson & Co., Rutherford, New Jersey) inserted through adhesive foam plastic tape on the pouch. Composition of the gas was measured using a gas partitioner and an integrator, HP 3396A (Hewlett-Packard Co., Avondale, Pennsylvania). Duplicate readings from each package were taken.

D. Color Measurement

Color of the cubed, raw turkey thigh meat from three
different packages for each treatment was evaluated using a color meter, Chroma Meter CR-200 (Minolta Camera Co., Ramsey, New Jersey).

Hunter L value (lightness), Hunter a (green or redness), Hunter b (blue or yellowness), and Hunter ΔE value (total color difference) were recorded for each treatment. Hunter L values (black and white) range from 0 to 100. Hunter a values and Hunter b values go from -80 to 100 and -80 to +70, respectively. Total color difference (ΔE) can be expressed as $\Delta E = \sqrt{\Delta L^2 + (\Delta a)^2 + (\Delta b)^2}$ (Pomeranz, 1987). Triplicate readings were taken.

E. Sensory Evaluation

Cubed turkey thigh meat stored at 0.5°C was evaluated at 2, 7, 9, 12, 16, and 21 days after storage. A sensory panel of 7-12 people was used to evaluate 3 treatments at each sampling period. Reference packages, which were sealed with air and kept frozen, were thawed on test day. The panel was instructed to refer to the reference package during their evaluations of sample packages.

The Quantitative Descriptive Analysis (QDA) method, one of descriptive analysis test methods describing the perceived sensory characteristics, usually in the odor of their occurrence, was used for the sensory evaluation of cubed turkey meat samples. A line scale for QDA was
selected to see the sequential preferences of the panelists among samples (Johnson, 1990).

Panel members were instructed to compare the packages to each other and to the reference pack and then to mark a small vertical line on a 15 cm long horizontal line (Appendix). A mark in the left side, near to 0, corresponded to "very desirable" and a mark in the right side, near to 15, indicated the package was "very undesirable." The distance of each vertical line was measured with a ruler for the statistical analysis (Stone, and Sidel, 1985). Judges were asked to evaluate the characteristics of the color and appearance without opening the packages and then, to rate the smell with opened sample packages.

F. Microbiological Tests

Aerobic plate count (APC) was used to determine the microbial growth on the turkey sample meat. Eleven g of cubed turkey meat from each package was sampled aseptically and randomly on test days: 2, 7, 9, 12, 16, and 21 of storage.

Samples were prepared by stomaching with 0.1% peptone dilution blanks for 2 minutes in a Model S10-400 Stomacher (Tekman Co., Cincinnati, Ohio). Homogenates were serially diluted with 0.1% peptone and used for pour plates with
Standard Methods agar (Bacto, Difco Lab, Detroit, Michigan) in duplicate. Plates were incubated at 30°C for 48 hours (Johnston and Tompkin, 1984). Bacterial counts were also done on the day of arrival to determine the turket meat's quality.

G. 2-Thiobarbituric Acid Test (TBA Test)

TBA values of cubed turkey meat from three sample packages were determined on each test day: 2, 7, 9, 12, 16 and 21 days of storage. The distillation method described by Tarladgis et al (1960) and modified by Ockerman (1981) was used with another modification using antioxidants. One hundred mg of each antioxidant, propyl galate (PG) and ethylene diamine tetracetic acid (EDTA), was added at the blending state to protect lipids during sample preparation (Ke et al, 1977; Rhee, 1978). Tests were done in duplicate for each treatment at each sampling period.

1. Preparation of the Samples

Ten gram of each sample from two modified atmosphere treatments and one air control were mixed with 50 ml of distilled water and 100 mg of each PG and EDTA and homogenized in a blender for 2 minutes at the highest speed. The homogenate was then transferred to a 500 ml Kjeldahl flask to which 47.5 ml of distilled water and 2.5 ml of 4N
hydrochloric acid (HCL) solution were added. This mixture was distilled with a Model 55110 high temperature heating mantle (Precision Co., Chicago, Illinois) until 50 ml of the distillate was collected in a flask. Five ml of the distillate was used to continue the TBA assay.

2. Preparation of the Standard Curve

A standard curve was prepared with each TBA determination by using a 10⁻⁴ M stock solution of 1,1,3,3, tetraethoxy propane (TEP) (Sigma, Chemical Co., ST. Louis, Missouri). TEP solutions of 0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0 7.0, 8.0, and 9.0 ml were pipetted into 50 ml volumetric flasks and diluted to 50.0 ml. Five ml of each solution was transferred to a test tube for the assay. Absorbance was plotted versus concentration and the slope of the curve was calculated using regression analysis.

3. Determination of Percent Recovery

Percent recovery was determined for each TBA test. Standard solutions to be distilled were prepared using 10⁻⁴M stock solution of TEP. One, two, three, four, and five ml of these stock solutions were added to 100 ml volumetric flasks. Two and one-half ml of 4N hydrochloric acid (HCL) solution was added to each flask after which all solutions were made up to a 100 ml volume with distilled water. These
solutions were then distilled. Five ml of the distillates was transferred into test tubes for the assay.

4. TBA Assay

Five ml of 0.02M 2-thiobarbituric acid (Sigma, Chemical Co., ST. Louis, Missouri) solution was added to each of the sample tubes to be assayed. Test tubes were capped, immersed in a boiling water bath for 35 min, and cooled in tap water for 10 min. Absorbance was then read at 530 nm against a blank using a Spectronic 20 spectrophotometer (Bausch & Lomb, Rochester, New York).

5. Calculation of TBA Numbers

Absorbance values of distilled standards, which were prepared for percent recovery determination and obtained after the TBA assay, were divided by the absorbance values of the undistilled standards, which were prepared for the standard curve. The average of these five quotients multiplied by 100 was taken as the percent recovery.

The regression line slope was used in calculating the constant (K). The K value was calculated using the following equation:

\[ K = \frac{\text{Moles of Non-distilled MA}}{\text{O.D. of Non-distilled MA}} \times \frac{1000 \text{ g}}{\text{Sample weight}} \]
\[
\frac{100}{\text{Total Volume of Distillate (ml)}} \times \frac{\% \text{ Recovery}}{\text{Aliquot Volume of Distillate (ml)}}
\]

The TBA value, expressed as mg of malonaldehyde per kilogram of sample, was calculated by multiplying the absorbance of each sample by the calculated \( K \) value determined for each sample. This analysis was performed in duplicate for each treatment at each sampling period.

H. Data Analysis

The split-plot design was used for data analysis. Each of the three treatments and the three replications were considered a whole-plot. Each of 2, 7, 9, 12, 16, and 21 days after storage within each treatment was considered the split-plot. The general linear model (GLM) procedure in Statistical Analysis System (SAS) software was used for statistical computation (SAS, 1985).
IV. RESULTS AND DISCUSSION

A. Headspace Gas Analysis

Headspace gas composition can gradually change depending on the permeability of the packaging material, the evolution and/or absorption of gases from the food, and the integrity of the seal of the package (Leeson, 1987). In this study, the headspace gas compositions of three different treatments, two modified atmosphere packages (MAP) and one Air Control, were analyzed as described in Section III C, on each test day. Results of gas composition are presented in Table 1, with gas compositions at 0 day storage showing the ratio of gases used in each treatment when it was sealed.

Carbon dioxide showed increasing trends in MAP2 (CO$_2$:O$_2$:N$_2$ = 20%:60%:20%) from 20.3% on sealing day to 26.9% on the 21st day of storage. Air Control treatments also showed increasing trends of carbon dioxide during storage; from 0% to 17% (Fig. 1). The amounts of carbon dioxide in MAP1 (CO$_2$:O$_2$:N$_2$ = 25%:0%:75%), which had high initial levels of carbon dioxide (25%), showed fluctuations between 25% and 20.2% with a general trend to decrease (Fig. 1). Carbon dioxide of MAP1 (CO$_2$:O$_2$:N$_2$ = 25%:0%:75%) and MAP2 (CO$_2$:O$_2$:N$_2$ = 20%:60%:20%), which had the gas initially when they were sealed, showed decreases by day 2 from 25% to 21.6% in MAP1.
and from 20.3% to 19.5% in MAP2.

These decreases may be explained by the dissolution of carbon dioxide into the turkey meat or the permeation of carbon dioxide to the outside environment. Fluctuations found in carbon dioxide amounts of MAP1 \((\text{CO}_2:\text{O}_2:\text{N}_2 = 25\%:0\%:75\%)\) could have resulted from the production of carbon dioxide due to microbial growth, the permeation of inside carbon dioxide to the outside environment, and the adjusted factor in percent calculation of the machine, gas partitioner, to give a total 100% due to changes of other gases, mainly oxygen.

Consistent trends of decrease were observed in the amount of oxygen, with the concentrations from 58.9% to 49.8% in MAP2 and from 21.1% to 0% in the Air Control. The only exception of increasing from 43.5% to 49.8% found in MAP2 on day 21 could not be explained (Fig. 2). The decreasing trends of oxygen from 58.9% to 49.8% in MAP2 and from 21.1% to 0% in Air Control could have resulted from the consumption of oxygen by aerobic microorganisms. Permeation of oxygen to the outside environment through the pouch also could be thought of as another reason of the decrease, especially in MAP2 which contained higher initial amounts of oxygen (60%) than air.

Oxygen was not found during storage in MAP1 which did not have any initial oxygen. Some amounts of oxygen from
air might have permeated the pouch which has oxygen permeability of 3 - 5 cc/m² for 24 hours at 1 atm. pressure and 4°C. Aerobic psychrotrophic microorganisms, mainly *Pseudomonas*, could have used the oxygen for their respiration, resulting in no residual oxygen inside the pack.

Nitrogen concentrations did not show noticeable changes in all treatments. Only slight increases of 3.6%, 2.5%, and 4.1% N₂ in MAP1, MAP2, and Air Control were found with exceptions of decreases on day 12 in MAP1 and days 9 and 21 in MAP2 (Fig. 3). Nitrogen is virtually insoluble in water and those slight changes of the gas might result from the adjusted factor in percent calculation of gas partitioner to give a total 100% due to changes of oxygen and carbon dioxide. Permeation of nitrogen into the sample packages from air could also be a reason, especially in MAPs which contained lower amounts of nitrogen than air.

General trends of increase in carbon dioxide, 6.6% CO₂ in MAP2 and 17% CO₂ in Air Control, with the exception of MAP1 which showed fluctuations, were found in this study. Oxygen showed decreases from 58.9% to 49.8% in MAP2 and from 21.1% to 0% in Air Control. These observations of decreasing oxygen concentrations agreed with the results of other researchers (Brody, 1989) who concluded the rate of oxygen consumption by the contained product usually exceeds
Ridgepacking was sealed.

Headspace gas compositions of 0 day storage show the actual ratio of gases used when each

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>N₂</th>
<th>O₂</th>
<th>CO₂</th>
<th>N₂</th>
<th>O₂</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0'Days</td>
<td>88.0</td>
<td>83.9</td>
<td>82.8</td>
<td>81.7</td>
<td>80.1</td>
<td>79.4</td>
</tr>
<tr>
<td>0'Days</td>
<td>17.0</td>
<td>13.4</td>
<td>12.2</td>
<td>13.2</td>
<td>12.2</td>
<td>16.9</td>
</tr>
<tr>
<td>0'Days</td>
<td>23.3</td>
<td>23.4</td>
<td>23.2</td>
<td>23.6</td>
<td>23.8</td>
<td>22.1</td>
</tr>
<tr>
<td>0'Days</td>
<td>26.9</td>
<td>26.9</td>
<td>25.5</td>
<td>24.6</td>
<td>22.9</td>
<td>78.6</td>
</tr>
<tr>
<td>0'Days</td>
<td>78.6</td>
<td>78.5</td>
<td>77.5</td>
<td>77.5</td>
<td>77.7</td>
<td>77.6</td>
</tr>
<tr>
<td>0'Days</td>
<td>21.4</td>
<td>21.2</td>
<td>22.5</td>
<td>22.4</td>
<td>23.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The numbers are the average of three replications.

Table 1. Headspace gas compositions of three packaging treatments of cubed, raw turkey meat
Figure 1. Changes of carbon dioxide in three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Carbon dioxide of 0 day storage shows the initial amount of carbon dioxide in each treatment. Initial amounts of carbon dioxide of 25%, 20%, and 0% were used in MAP1, MAP2, and Air Control, respectively.
Figure 2. Changes of oxygen in three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Oxygen of 0 day storage shows initial amount of oxygen in each treatment. Initial amounts of oxygen of 0%, 60%, and 21% were used in MAP1, MAP2, and Air Control, respectively.
Figure 3. Changes of nitrogen in three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Nitrogen of 0 day storage shows initial amount of nitrogen in each treatment. Initial amounts of nitrogen of 75%, 21%, and 79% were used in MAP1, MAP2, and Air Control, respectively.
the rate of oxygen permeation from the external air to the package interior. These results were consistent with other studies (Taylor et al, 1990; Taylor and Mac Dougall, 1973) demonstrating oxygen concentration in MAP decreases with time, from initial 75% to approximately 50% at 21 days after packing, while the level of carbon dioxide remained at 25-30% throughout storage.

B. Color Measurement

Hunter L, a, b, and ΔE values were taken using a Chroma Meter to determine color differences among treatments. Results are presented in Table 2, Table 3, Table 4, and Table 5. The higher Hunter a value represents a redder color. General trends of redness (Hunter a value) agreed with the color preferences judged by the panelists in sensory evaluation. MAP2 (CO₂:O₂:N₂ = 20%:60%:20%), which had high amounts of oxygen, showed higher Hunter a values than those of MAP1 and Air Control; the average Hunter a value of storage days by 12 was 19.4 in MAP2, 16.5 in MAP1, and 14.7 in Air Control. However, later in the study MAP1 showed higher average Hunter a values on storage days, 16 and 21, 16.6 compared to 12.1 of MAP2 and 9.3 of Air Control. MAP1 was also more preferred by the panelists in the color evaluation than MAP2 and Air Control on the same storage days (Fig. 4).
Microbial counts (APC), redness (Hunter a value), and sensory evaluation of color were found to have similar tendencies; Air Control which averaged the highest APC among treatments were rated worst in the color evaluation and overall showed the lowest scores in Hunter a values. Interestingly, Air Control which showed redder color was rated better than MAP1 in sensory evaluation of color, and it had the lowest bacterial count on day 2. Considering these relationships, the results of lower Hunter a values of 13.6 and 10.7 on days 16 and 21 in MAP2 compared to 17.8 and 15.3 of MAP1 could be thought of as results of bacterial growth and oxidation of iron atom of oxymyoglobin to brownish red color of metmyoglobin due to prolonged exposure to oxygen.

Statistical analysis on the redness among treatments showed significant differences (P<0.05), especially between MAPs and Air Control. There was no significant difference between MAP1 and MAP2. Therefore, results obtained in this experiment illustrated that high amounts of oxygen could give red color to the turkey meat samples only before microbial growth affected the color of the meat and oxidation of oxymyoglobin occurred to metmyoglobin, storage day 12 in this study. Hunter b values show blue or yellowness with corresponding values of -80 to +70.
Table 2. Measurements of Lightness (Hunter L value) of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1&lt;sup&gt;2&lt;/sup&gt;</th>
<th>MAP2&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Mean&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>48.92</td>
<td>2.03</td>
<td>48.31</td>
</tr>
<tr>
<td>7</td>
<td>52.30</td>
<td>1.14</td>
<td>49.25</td>
</tr>
<tr>
<td>9</td>
<td>48.43</td>
<td>0.70</td>
<td>48.00</td>
</tr>
<tr>
<td>12</td>
<td>48.14</td>
<td>1.43</td>
<td>49.44</td>
</tr>
<tr>
<td>16</td>
<td>46.40</td>
<td>1.21</td>
<td>50.22</td>
</tr>
<tr>
<td>21</td>
<td>47.53</td>
<td>0.52</td>
<td>52.77</td>
</tr>
</tbody>
</table>

<sup>1</sup>Hunter L values show lightness (black and white) with correspondent values 0 to 100 (Pomerantz, 1987).

<sup>2</sup>MAP1 (Modified Atmosphere Packaging1) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 25%:0%:75%

<sup>3</sup>MAP2 (Modified Atmosphere Packaging2) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 20%:60%:20%

<sup>4</sup>SE=Standard Error

<sup>5</sup>Sample mean and SE were obtained from 3 replications (n=3).
Table 3. Measurements of Redness (Hunter a value) of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1$^2$</th>
<th>MAP2$^3$</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SE$^4$</td>
<td>Mean SE</td>
<td>Mean SE</td>
</tr>
<tr>
<td>2</td>
<td>15.63 1.77</td>
<td>20.86 3.00</td>
<td>16.70 1.87</td>
</tr>
<tr>
<td>7</td>
<td>18.18 1.38</td>
<td>20.80 1.34</td>
<td>16.21 1.51</td>
</tr>
<tr>
<td>9</td>
<td>17.59 1.64</td>
<td>20.81 0.81</td>
<td>14.40 2.03</td>
</tr>
<tr>
<td>12</td>
<td>14.55 2.07</td>
<td>15.10 2.12</td>
<td>11.55 3.43</td>
</tr>
<tr>
<td>16</td>
<td>17.81 1.61</td>
<td>13.61 2.92</td>
<td>10.85 0.71</td>
</tr>
<tr>
<td>21</td>
<td>15.34 3.25</td>
<td>10.66 1.87</td>
<td>7.78 1.17</td>
</tr>
</tbody>
</table>

$^1$Hunter a values show greenness and redness with correspondent values -80 to 100.

$^2$MAP1 (Modified Atmosphere Packaging1) CO$_2$:O$_2$:N$_2$ = 25%:0%:75%

$^3$MAP2 (Modified Atmosphere Packaging2) CO$_2$:O$_2$:N$_2$ = 20%:60%:20%

$^4$SE = Standard Error

$^5$Sample mean and SE were obtained from 3 replications (n=3).
Table 4. Measurements of Blueness or Yellowness (Hunter \( b^* \) value) of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1(^2)</th>
<th>MAP2(^3)</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE(^4)</td>
<td>Mean</td>
</tr>
<tr>
<td>2</td>
<td>8.15</td>
<td>0.40</td>
<td>13.50</td>
</tr>
<tr>
<td>7</td>
<td>10.99</td>
<td>0.10</td>
<td>13.43</td>
</tr>
<tr>
<td>9</td>
<td>9.34</td>
<td>0.06</td>
<td>13.37</td>
</tr>
<tr>
<td>12</td>
<td>6.15</td>
<td>1.66</td>
<td>12.83</td>
</tr>
<tr>
<td>16</td>
<td>8.30</td>
<td>0.56</td>
<td>13.20</td>
</tr>
<tr>
<td>21</td>
<td>9.21</td>
<td>1.62</td>
<td>15.06</td>
</tr>
</tbody>
</table>

\(^1\)Hunter \( b^* \) values show blueness and yellowness with correspondent values -80 to +70.

\(^2\)MAP1 (Modified Atmosphere Packaging1) \( \text{CO}_2:O_2:N_2 = 25\%:0\%:75\% \)

\(^3\)MAP2 (Modified Atmosphere Packaging2) \( \text{CO}_2:O_2:N_2 = 20\%:60\%:20\% \)

\(^4\)SE=Standard Error

\(^5\)Sample mean and SE were obtained from 3 replications (\( n=3 \)).
Table 5. Total Color Difference (Hunter ΔE value) of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1(^2)</th>
<th>MAP2(^3)</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean(^4)</td>
<td>Mean(^5)</td>
<td>Mean</td>
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<tr>
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<td>SE</td>
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<td>SE</td>
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<tr>
<td>2</td>
<td>52.06</td>
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<td>52.39</td>
</tr>
<tr>
<td></td>
<td>2.38</td>
<td>1.70</td>
<td>0.55</td>
</tr>
<tr>
<td>7</td>
<td>50.18</td>
<td>54.47</td>
<td>53.31</td>
</tr>
<tr>
<td></td>
<td>1.31</td>
<td>1.48</td>
<td>0.70</td>
</tr>
<tr>
<td>9</td>
<td>39.63</td>
<td>40.84</td>
<td>54.14</td>
</tr>
<tr>
<td></td>
<td>13.50</td>
<td>14.20</td>
<td>2.38</td>
</tr>
<tr>
<td>12</td>
<td>52.41</td>
<td>52.22</td>
<td>51.21</td>
</tr>
<tr>
<td></td>
<td>0.70</td>
<td>0.56</td>
<td>2.48</td>
</tr>
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<td>16</td>
<td>55.15</td>
<td>51.13</td>
<td>52.35</td>
</tr>
<tr>
<td></td>
<td>1.24</td>
<td>1.79</td>
<td>2.30</td>
</tr>
<tr>
<td>21</td>
<td>53.77</td>
<td>48.45</td>
<td>47.28</td>
</tr>
<tr>
<td></td>
<td>1.21</td>
<td>2.41</td>
<td>2.69</td>
</tr>
</tbody>
</table>

\(^1\)Hunter ΔE values show total color difference with the formula; 
\[ ΔE = \sqrt{(-ΔL)^2 + (Δa)^2 + (Δb)^2} \]

\(^2\)MAP1 (Modified Atmosphere Packaging1) CO\(_2\):O\(_2\):N\(_2\) = 25%:0%:75%

\(^3\)MAP2 (Modified Atmosphere Packaging2) CO\(_2\):O\(_2\):N\(_2\) = 20%:60%:20%

\(^4\)SE=Standard Error

\(^5\)Sample mean and SE were obtained from 3 replications (n=3).
Figure 4. Hunter a values of three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Hunter a values show greenness and redness with correspondent values -80 to 100. MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
Hunter b values were higher in MAP2 ranging from 12.83 to 15.06 than MAP1 and Air Control which had Hunter b values from 6.15 to 10.99 and 9.76 and 14.8, respectively. Thus, MAP2 showed more yellowish color than MAP1 and Air Control. It was difficult to find tendencies in Hunter b values over storage in all treatments because of fluctuations except the fact that Hunter b values increased from day 2 to day 21 by 1.06, 1.56, and 3.4 in MAP1, MAP2, and Air Control, respectively. Lightness (black and white) and total color differences (ΔE) measured as Hunter L and Hunter ΔE values showed fluctuations with no apparent trends among samples and/or storage days.

Statistical significance was found only in Hunter b values between MAP1 and MAP2 and between MAP1 and Air Control. There were no significances in the lightness and total color differences among treatments and storage days.

C. Sensory Evaluation

Cubed turkey meat samples of three different treatments were evaluated as described in section III E. Scores range from 0 to 15 corresponding 0 to "very desirable" and 15 to "very undesirable." Results are presented in Table 6, Table 7, and Table 8.

When three variables, color, appearance, and odor, were compared in each treatment, generally odor and color were
rated better than appearance in all three treatments with exceptions of day 12 in MAP1 and MAP2; the total average score of odor, color, and appearance was 3.66, 4.80, and 5.28, respectively. The preferences for odor and color to appearance was clear in Air Control (Fig. 5). Panelists did not perceive the odor difference among treatments at day 2, and rated similar scores of 1.17, 1.03, and 1.15 to MAP1, MAP2, and Air Control. When evaluations of the three variables were analyzed for days storage, fluctuations were found in all treatments. These fluctuations may be from the inherent limitations of organoleptic tests, such as the panelist's preference, physiological condition, acuity, mood, as well as environmental and atmospheric conditions (Shaw, 1981).

Each variable was compared among treatments. Color preference was significantly different among treatments (P<0.05). Color of MAP2 was rated better than those of MAP1 and Air Control by day 12 with the exception of a marginal difference from MAP1 on day 7; the panelists evaluated MAP2 as best in color with scores from 1.6 to 3.7 compared from 2.95 to 3.73 on MAP1 and from 3.23 to 8.2 on Air Control up to day 12. Panelists generally preferred the color of MAP2 by storage day 12. However, MAP1 which did not contain oxygen but had 25% carbon dioxide and 75% nitrogen was evaluated better than MAP2 and Air Control on days 16 and
21; MAP1 was rated from 3.81 to 3.99, MAP2 from 5.69 to 5.61, and Air Control from 11.09 to 8.99. These observations agreed with results of other researchers who demonstrated that carbon dioxide could give darker redder color on meat samples (Jantawat and Dawson, 1980; Uebersax et al, 1978).

Visual color evaluated by panelists showed similar tendencies to Hunter a value (redness) measured using a chroma meter. Appearance evaluation showed similar trends with the evaluation of color (Fig. 7). The appearance of MAP2 which ranged from 1.76 to 2.93 was preferred to MAP1 and Air Control which showed scores from 3.43 to 4.42 and from 4.24 to 3.63, respectively by day 9. After 12 days of storage, the judges evaluated MAP1 with a more favorable appearance than MAP2 and Air Control rating MAP1 from 3.43 to 4.42, MAP2 from 4.06 to 6.66, and Air Control from 8.65 to 11.73. There were statistically significant differences between treatment packages and control packages (P<0.05). No significance was found between MAP1 and MAP2, yet panelists rated MAP2 slightly more desirable at days 2, 7, and 9.

The trend found in evaluations of color and appearance was not found in the evaluation of odor; the panelists evaluated Air Control as the worst in color and appearance over storage except day 2 and MAP2 as the best on days 7
and 9. MAP1 was the best in same variables on all other days. However, the odor evaluation revealed MAP1 to have a more preferable odor than the two other treatments from day 7 to 21 (Fig. 8). Scores showed MAP2 had worse odor at days 7 and 9, Air Control at days 12, 16, and 21. These observations could result from fat rancidity in MAP2 and bacterial growth in Air Control. The odor caused from microbial growth may effect the panelists more strongly than the odor of oxidative deterioration of fat in the turkey meat. Statistical analysis showed significant differences between MAP1 and Air Control (p<0.016).

Evaluations of the three treatments showed decreasing trends in preference as the storage days go with exceptions in color and appearance. The differences of variables according to storage days were statistically significant (p<0.05). The favorable trends of appearance found in all three treatments and of color found in MAP2 and Air Control on day 21 were difficult to explain and random variation might be reason.

In summary, sensory evaluation of three different treatments showed general preferences in color and appearance for MAP2 to day 12. MAP1 was preferred from day 16 in the same variables; color and appearance. The odor evaluation showed high preference for MAP1 over the storage days.
Table 6. Sensory Evaluation of Color for Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>Color(^1)</th>
<th>MAP1(^2)</th>
<th>MAP2(^3)</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean(^4)</td>
<td>Mean(^5)</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SE</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3.53 1.30</td>
<td>1.60 0.27</td>
<td>3.23</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>2.95 0.26</td>
<td>3.09 0.53</td>
<td>5.49</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>3.23 1.15</td>
<td>2.68 1.24</td>
<td>5.91</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>3.73 1.04</td>
<td>3.70 0.46</td>
<td>8.20</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>3.81 0.64</td>
<td>5.69 1.74</td>
<td>11.09</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>3.99 0.96</td>
<td>5.61 2.27</td>
<td>8.99</td>
</tr>
</tbody>
</table>

\(^1\)Color was evaluated on a 15 cm horizontal line corresponding 0 to "very desirable" and 15 to "very undesirable".

\(^2\)MAP1 (Modified Atmosphere Packaging1) \(\text{CO}_2:\text{O}_2:\text{N}_2 = 25\%:0\%:75\%\)

\(^3\)MAP2 (Modified Atmosphere Packaging2) \(\text{CO}_2:\text{O}_2:\text{N}_2 = 20\%:60\%:20\%\)

\(^4\)SE= Standard Error

\(^5\)Sample mean and SE were obtained from 3 replications \((n=3)\).
Table 7. Sensory Evaluation of Appearance for Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1&lt;sup&gt;2&lt;/sup&gt;</th>
<th>MAP2&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Air Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SE&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Mean SE</td>
<td>Mean SE</td>
</tr>
<tr>
<td>2</td>
<td>4.24 1.67</td>
<td>1.76 0.31</td>
<td>3.93 0.60</td>
</tr>
<tr>
<td>7</td>
<td>3.50 0.58</td>
<td>3.26 0.31</td>
<td>5.92 0.56</td>
</tr>
<tr>
<td>9</td>
<td>3.63 1.13</td>
<td>2.93 1.81</td>
<td>6.56 0.80</td>
</tr>
<tr>
<td>12</td>
<td>3.43 0.79</td>
<td>4.06 0.29</td>
<td>8.65 1.73</td>
</tr>
<tr>
<td>16</td>
<td>4.42 0.29</td>
<td>6.66 1.89</td>
<td>11.73 1.05</td>
</tr>
<tr>
<td>21</td>
<td>4.16 0.83</td>
<td>6.03 2.66</td>
<td>10.18 2.05</td>
</tr>
</tbody>
</table>

<sup>1</sup>Appearance was evaluated on a 15 cm horizontal line corresponding 0 to "very desirable" and 15 to "very undesirable".

<sup>2</sup>MAP1 (Modified Atmosphere Packaging1) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 25%:0%:75%

<sup>3</sup>MAP2 (Modified Atmosphere Packaging2) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 20%:60%:20%

<sup>4</sup>SE=Standard Error

<sup>5</sup>Sample mean and SE were obtained from 3 replications (n=3).
Table 8. Sensory Evaluation of Odor for Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>MAP1&lt;br&gt;Mean</th>
<th>SE&lt;sup&gt;4&lt;/sup&gt;</th>
<th>MAP2&lt;br&gt;Mean&lt;sup&gt;5&lt;/sup&gt;</th>
<th>SE</th>
<th>Air Control&lt;br&gt;Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.17</td>
<td>0.21</td>
<td>1.03</td>
<td>0.22</td>
<td>1.15</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>1.91</td>
<td>0.35</td>
<td>3.27</td>
<td>0.23</td>
<td>3.02</td>
<td>0.25</td>
</tr>
<tr>
<td>9</td>
<td>2.13</td>
<td>0.31</td>
<td>3.72</td>
<td>1.15</td>
<td>2.88</td>
<td>0.44</td>
</tr>
<tr>
<td>12</td>
<td>3.59</td>
<td>0.86</td>
<td>4.50</td>
<td>1.23</td>
<td>5.05</td>
<td>2.27</td>
</tr>
<tr>
<td>16</td>
<td>2.78</td>
<td>0.24</td>
<td>4.80</td>
<td>0.97</td>
<td>7.95</td>
<td>1.15</td>
</tr>
<tr>
<td>21</td>
<td>3.98</td>
<td>0.69</td>
<td>4.94</td>
<td>1.33</td>
<td>8.03</td>
<td>0.77</td>
</tr>
</tbody>
</table>

<sup>1</sup>Odor was evaluated on a 15 cm horizontal line corresponding 0 to "very desirable" and 15 to "very undesirable".

<sup>2</sup>MAP1 (Modified Atmosphere Packaging1) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 25%:0%:75%

<sup>3</sup>MAP2 (Modified Atmosphere Packaging2) CO<sub>2</sub>:O<sub>2</sub>:N<sub>2</sub> = 20%:60%:20%

<sup>4</sup>SE=Standard Error

<sup>5</sup>Sample mean and SE were obtained from 3 replications (n=3).
Figure 5. Sensory evaluations of Air Control treatment of cubed, raw turkey meat stored at 0.5°C over 21 days for three variables: color, appearance, and odor. Scores range from "0" to "15" in all three variables. "0" corresponds to "very desirable" and "15" corresponds to "very undesirable."
Figure 6. Sensory evaluations of color for three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Scores range from "0" to "15", "0" corresponds to "very desirable" and "15" corresponds to "very undesirable." MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
Figure 7. Sensory evaluations of appearance for three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Scores range from "0" to "15". "0" corresponds to "very desirable" and "15" corresponds to "very undesirable." MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
Figure 8. Sensory evaluations of odor for three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. Scores range from "0" to "15". "0" corresponds to "very desirable" and "15" corresponds to "very undesirable." MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
D. Microbiological Analysis

Growth of almost all aerobic microorganisms, particularly the psychrophilic and psychrotrophic, can be retarded by elevated carbon dioxide (Brody, 1989). The principal cause of deterioration of meats is the action of psychrotrophic microorganisms (Bruce, 1989). Carbon dioxide is quite effective in inhibiting the growth of a number of the spoilage organisms (Hays et al, 1959; Hintlian and Hotchkiss, 1986; Leeson, 1987).

In this study, aerobic plate counts (APC) were examined to determine the difference of bacterial growth in three treatments (Table 9). There were significant differences in microbial counts among treatments (p<0.01). Air Control showed the highest APC with the log number from 3.36 to 9.18 over the storage days except the storage day 2 (Fig. 9). APC of MAP1 ranged from 3.61 to 7.26 and that of MAP2 was from 3.77 to 7.71 from day 7 to 21. The higher APC in MAP1 and MAP2 compared to Air Control on day 2 could result from the longer stay of MAP treatments in the cooler room before they were sealed and the time needed for carbon dioxide to be dissolved into the meat to have inhibitory effects on the microbial growth. APC of MAP2, which had 20% of carbon dioxide with high amounts of oxygen (60%), ranged from 3.77 to 7.71. The microbial number of MAP2 was between APCs of Air Control and MAP1 which showed the counts from 3.36 to
9.18 and from 3.61 to 7.26, respectively. This observation was consistent with the conclusion of the study of Wolfe (1980). MAP1, containing the highest amounts of carbon dioxide (25%), showed the lowest APC. The differences of APC among treatments were statistically significant (p<0.05). The noticeable differences were found between MAP treatments and Air Control (p<0.016). There was no statistical significance between MAP1 and MAP2, although MAP2 had a little higher APC than MAP1; from 3.77 to 7.71 versus from 3.61 to 7.26.

Storage temperature used in this study was fairly low, 0.5°C, and obviously it was thought to help carbon dioxide deter microbial growth. The combination of high carbon dioxide concentration and low temperature gives the greatest increase in the lag phase (Coyne, 1933; Enfors and Molin, 1980; Gill and Tan, 1980; Eklund and Jarmund, 1983; Baker et al, 1986).

Rapid increases in bacterial count were evident between days 2 and 7 in Air Control, 9 and 12 in MAP2, and 12 and 16 in MAP1. Rates of rapid increase in APC were 1.79 in Air Control, 1.23 in MAP2, and 1.63 in MAP1. Ayres et al (1950) indicated off-odors are generally noted before sliminess is first detected when log numbers/cm² are about 7.2-8.0, and sliminess generally occurred shortly after the appearance of off-odors with the log counts/cm² about 8 as poultry
undergoes spoilage. The off-odor of Air Control, MAP2, and MAP1 started between day 10 and 11, 18 and 19, and 20 and 21, respectively. Sliminess of sample packages appeared between day 11 and 12 in Air Control, 20 and 21 in MAP2, and sliminess was not found in MAP1 up to 21 day storage.

Results obtained in these experiments illustrated that carbon dioxide had an obvious inhibitory effect on the microbial growth and these results are now well documented by many researchers (Veranth and Robe, 1979; Christopher et al, 1980; Thomas et al, 1984). This study also revealed the higher concentrations of carbon dioxide used in MAP had the stronger effect on the prevention of microbial growth. This observation agreed with results of other researchers (King and Nagel, 1967; Bala et al, 1977; Enfors and Molin, 1980; Bartkowski et al, 1982) who concluded that as carbon dioxide concentration increased, an enhanced bacteriostatic effect was observed.

E. Thiobarbituric Acid Test (TBA test)

Poultry lipids generally exhibit a higher degree of unsaturation compared to red meats; thus poultry meat is more susceptible to oxidation (Igene et al, 1979, 1980; Melton, 1983). Within the same species of poultry, dark meat (thigh) was found to generate higher TBA values than white
Table 9. Aerobic Plate Count (APC) of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>APC(^1) (log number/g sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAP(^1)(^2)</td>
</tr>
<tr>
<td></td>
<td>Mean^5</td>
</tr>
<tr>
<td>0^4</td>
<td>3.23</td>
</tr>
<tr>
<td>2</td>
<td>3.61</td>
</tr>
<tr>
<td>7</td>
<td>3.93</td>
</tr>
<tr>
<td>9</td>
<td>4.10</td>
</tr>
<tr>
<td>12</td>
<td>4.64</td>
</tr>
<tr>
<td>16</td>
<td>6.27</td>
</tr>
<tr>
<td>21</td>
<td>7.26</td>
</tr>
</tbody>
</table>

\(^1\)APC=Aerobic Plate Count

\(^2\)MAP1 (Modified Atmosphere Packaging1) \(\text{CO}_2:\text{O}_2:\text{N}_2 = 25\%:0\%:75\%\)

\(^3\)MAP2 (Modified Atmosphere Packaging2) \(\text{CO}_2:\text{O}_2:\text{N}_2 = 20\%:60\%:20\%\)

\(^4\)APC of 0 day storage shows the initial bacterial number of turkey meat samples.

\(^5\)SE = Standard Error

\(^6\)Sample mean and SE were obtained from 3 replications (n=3).
Figure 9. Aerobic plate counts (APC) of three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
meat (breast) (Wilson et al, 1976). There was a direct relationship between total lipid levels and TBA values (Dawson and Schierholz, 1976). Lipids from raw breast muscles contained significantly higher amounts of malonaldehyde (MA) compared to thigh muscle, but thigh muscles had 2.5 times more total lipids than breast muscles. Therefore, thigh muscles had a significantly higher TBA number than breast muscles (Pikul and Kummerow, 1990).

A thiobarbituric acid assay (TBA test), measuring the amount of MA produced in the fat during storage, was used to determine the oxidative stability of cubed turkey meat samples in this study. The results are presented in Table 10. As expected, MAP2, which contained high amount of oxygen(60%), had higher TBA values with statistical significance (p<0.016) compared to MAP1 over the storage period (Fig. 10); TBA values of MAP2 showed 1.014 on storage day 2 and 13.574 on the storage day 21 while the numbers of MAP1 were 0.365 and 0.475 and those of Air Control were 1.063 and 8.340. However, the panelists evaluated MAP2 as having the worst odor on days 7 and 9. On days 12, 16, and 21, the worst odor was from Air Control. This evaluation could result from microbial growth in Air Control. The bad smell from the putrefaction of turkey meat due to microorganisms might be judged as worse than the smell from fat rancidity.
Observations of high TBA numbers in MAP2 agreed with the result of the study done by Dawson and Schierholz (1976), who demonstrated fat oxidation, as measured by TBA values, was influenced by time and oxygen availability. MAP1, which had 25% carbon dioxide and 75% nitrogen, showed noticeable lower TBA values than MAP2 (p<0.016) and Air Control (p=0.052); total average TBA values of MAP1, MAP2, and Air Control were 0.584, 7.75, and 4.686, respectively. A relationship was found among TBA values, microbial counts and sensory evaluations of odor. MAP1, which had the lowest TBA values, showed the lowest microbial counts and was evaluated as the best in sensory evaluation of odor. Low TBA values of MAP1 found in this study agreed with studies done by Jurdi et al (1980) and Ubersax et al (1978). The study done by Jurdi et al (1980) found that mechanically separated poultry meat stored in a nitrogen flushed package had lower TBA values during refrigerated and frozen storage. Ubersax et al (1978) reported that mechanically separated turkey meat mixed under nitrogen showed less change in TBA values.

Studies done by Jantawat (1979) and Jurdi et al (1980) illustrated that carbon dioxide could increase TBA numbers. However, it was difficult to see carbon dioxide effect alone on the TBA values in this study because the treatment package (MAP1), which had high amounts of carbon dioxide
(25%), also contained high amounts of nitrogen (75%).

TBA numbers observed in MAP2 and Air Control showed more obvious increasing trends than that of MAP1 during storage (Fig. 12); the average values of increasing rates in TBA numbers of MAP1, MAP2, and Air Control were 0.432, 2.62, and 1.535, respectively. The increasing rates of TBA numbers shown in MAP1 was not noticeable with the exception of between day 7 and 12, which could not be explained.

Analysis of variance of TBA numbers showed significant treatment effects. The significant difference was found between MAP1 and MAP2 (p<0.016).
Table 10. TBA Values of Three Packaging Treatments of Cubed, Raw Turkey Meat Over 21 Day Storage at 0.5°C.

<table>
<thead>
<tr>
<th>Days of Storage</th>
<th>TBA Values (mg MA(^1)/kg Sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAP(^1)(^2)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>0(^4)</td>
<td>0.358</td>
</tr>
<tr>
<td>2</td>
<td>0.365</td>
</tr>
<tr>
<td>7</td>
<td>0.476</td>
</tr>
<tr>
<td>9</td>
<td>1.198</td>
</tr>
<tr>
<td>12</td>
<td>0.492</td>
</tr>
<tr>
<td>16</td>
<td>0.495</td>
</tr>
<tr>
<td>21</td>
<td>0.475</td>
</tr>
</tbody>
</table>

\(^1\)MA = Malonaldehyde

\(^2\)MAP\(^1\) (Modified Atmosphere Packaging1) CO\(_2\):O\(_2\):N\(_2\) = 25%:0%:75%

\(^3\)MAP\(^2\) (Modified Atmosphere Packaging2) CO\(_2\):O\(_2\):N\(_2\) = 20%:60%:20%

\(^4\)TBA value of 0 day storage shows the initial quality of turkey meat samples.

\(^5\)SE = Standard Error

\(^6\)Sample mean and SE were obtained from 3 replications (n=3).
Figure 10. TBA values of three packaging treatments of cubed, raw turkey meat stored at 0.5°C over 21 days. TBA number of 0 day storage shows the quality of turkey meat used in this experiment. MAP1 is composed of 25% CO₂ and 75% N₂. MAP2 is composed of 20% CO₂, 60% O₂, and 20% N₂.
V. CONCLUSIONS

The effect of MAP was investigated with regard to the shelf-life extension of refrigerated, cubed turkey thigh meat. The modified gas compositions of 25% carbon dioxide and 75% nitrogen (MAP1) and 20% carbon dioxide, 60% oxygen, and 20% nitrogen (MAP2) were used for two treatments. Air was used as a control. All sample packages were stored at 0.5°C.

Headspace gas composition, oxidative deterioration of fat (TBA test), aerobic plate count (APC), color differences (Hunter L, a, b, and ΔE), and sensory qualities of color, appearance, and odor were evaluated.

Analysis of headspace gas composition showed general tendencies of increase in carbon dioxide and decrease in oxygen in MAP2 and Air Control. Air Control showed higher rates of those tendencies than MAPs. Generally, a decreasing trend of carbon dioxide was found in MAP1 which had high amounts of initial carbon dioxide (25%). Slight increasing trends were found in amounts of nitrogen in all treatments with higher rates in Air Control.

Effects of MAP on the color of turkey meat samples were observed in Hunter a values (green and redness) and Hunter b values (blue and yellowness). MAP1 and MAP2 showed redder
color than Air Control on days 16 and 21 and by day 12, respectively. Other color measurements such as Hunter L, and total color difference (ΔE) did not show noticeable differences among treatments.

Sensory evaluation showed a statistically significant preference for MAP1 and MAP2 in all three variables: color, appearance, and odor.

Aerobic plate count showed significantly higher numbers in Air Control. Between MAP1 and MAP2, MAP2 showed higher APC than that of MAP1. The addition of carbon dioxide at a level of 25% resulted in a marked delay in the growth of bacteria as compared to Air Control.

Results of TBA tests demonstrated the effect of MAP on the fat rancidity of turkey meat samples. MAP1 which did not have oxygen showed the lowest TBA numbers, while MAP2 which contained high amounts of oxygen (60%) had the highest numbers in TBA tests.

MAP was effective on the extension of turkey meat shelf-life. However, MAP2 had the highest TBA values because of high amounts of oxygen. Generally, MAP1, which had the lowest numbers in microbial counts and TBA values was rated favorably by the panelists in sensory evaluations of appearance and odor. Two MAP treatments showed redder color both as measured by chroma meter and by sensory evaluation of color with MAP2 by day 12 and MAP1 on days 16
and 21 of storage.

Therefore, MAP1, which had 25% carbon dioxide and 75% nitrogen, had the best effect on extending the shelf-life of refrigerated, cubed turkey thigh meat among treatments used in this study.
LIST OF REFERENCES


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CUBED TURKEY THIGH MEAT SENSORY SCORECARD

Name: ___________________  Date ________________

Instructions:

Please rate the following samples for color and overall appearance without opening the package; then, open the package and rate the odor of each sample. Place a vertical line that best describes the property of the sample (e.g. --|-------|--). A reference of fresh cubed turkey thigh meat considered to be of good quality has been provided. Please evaluate the reference first. The reference should be compared as needed during your evaluation of the other samples.

1. Color

|__________________________________________________________|__________________________________________________________|
|Very desirable                                           | Very undesirable                                       |

2. Appearance

|__________________________________________________________|__________________________________________________________|
|Very desirable                                           | Very undesirable                                       |

3. Odor

|__________________________________________________________|__________________________________________________________|
|Very desirable                                           | Very undesirable                                       |
VITA

InSook Ahn was born on August 16, 1959, in Busan, Korea. In March 1978, she entered Ewha Women's University and graduated in February 1982 with a Bachelor of Science in Education of Science (chemistry). In September of 1984 she was accepted at Yonsei Graduate School and in June of 1986 received her master's degree in Food and Nutrition. She was a member of the Korean Home Economics Association and is the author of the following publication: "A Study on Dietary Behaviors in Middle-aged Women." I.S. Ahn, S. J. Moon and Y. M. Lee. J. Korean Home Economics. (1988) 26 (1).

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THE EFFECT OF MODIFIED ATMOSPHERE PACKAGING (MAP)
ON THE SHELF-LIFE OF REFRIGERATED, CUBED, TURKEY THIGH MEAT

by

InSook Ahn

(ABSTRACT)

This research was designed to investigate the effect of Modified Atmosphere Packaging (MAP) on the shelf life of refrigerated, cubed, turkey thigh meat. Modified atmospheres of 25% carbon dioxide and 75% nitrogen and 20% carbon dioxide, 60% oxygen, and 20% nitrogen were used for MAP1 and MAP2 respectively. All sample packages, MAP1, MAP2, and Air Control, were stored at 0.5°C. Headspace gas analysis, color measurement, sensory evaluation, aerobic plate count, and oxidative deterioration of fat were examined over 21 day of storage.

Microbiological spoilage was significantly delayed by modified atmosphere treatments. MAP1 delayed fat rancidity while MAP2 increased rancidity because of the high amount of oxygen. The redness of turkey thigh meat was increased in both MAPs. MAP2 showed the highest a values up to storage day 12 and then MAP1 had the highest a values on storage days 16 and 21. Sensory evaluations showed preferences for MAPs in all variables: color, appearance, and odor. Thus, modified atmosphere treatment 1 (MAP1) demonstrated the best effect on the extension of the shelf life of turkey meat in this study.