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**Sensory and chemical characteristics of lamb, mutton and  
mechanically deboned turkey meat patties**

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**Iowa State University, 1987**

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Sensory and chemical characteristics of lamb, mutton and  
mechanically deboned turkey meat patties

by

Abbas Mohammad Yaghi

A Dissertation Submitted to the  
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## INTRODUCTION

Ground meat combinations of various animal species are receiving more attention due to economic reasons, and because of the desire of processors to provide consumers with convenient products at a reasonable cost. Moreover, with the recent emphasis on potential health hazards, processors are concerned with marketing a safe, nutritious, palatable and desirable product.

Although mutton carcass value is relatively low compared to other competitive meat, world per capita consumption of sheep meat during the past 15 years has decreased steadily while that of other species has increased (USDA, 1976). The characteristic flavor has been cited as one reason for the low consumption of sheep meat, as well as its firm, dense, and dark red color fibers (Anderson and Kiser, 1971). Thus, any research to increase lamb/mutton consumption must focus attention on its flavor.

For the most part, lamb and mutton go to the retailers fresh and as whole carcasses. A small amount of mutton and lamb is frozen and held for a future market. Also, there is a very small quantity cured. Carcasses of the kind that are not acceptable to the trade are processed at the packaging plants (Anderson and Kiser, 1971). This gives an outlet for canner sheep, mainly old, thin ewes. These are processed and sold as prepared meat and meat food products.

Because of the minor contribution of mutton lean meat to flavor, this study was undertaken to determine if relatively low-cost lean mutton could be used as a replacement meat in processed lamb products such as

patties and hamburgers without loss in eating quality.

Mechanically deboned turkey (MDT), similar to mutton, is inexpensive and of high nutritious quality. It can be incorporated into various meat products to lower their cost (Dawson, 1975). In order to avoid introducing textural problems, MDT must not exceed a certain percentage of meat products. Deboned meat, however, presents a unique challenge in retaining consumer acceptability of the product during storage periods. Oxidative rancidity resulting in quality and nutritional loss may be the single most deteriorative reaction that occurs in food systems containing MDT (Dugan, 1968). Mechanically deboning may cause considerable cellular disruption, protein denaturation, and increased heme oxidation (Froning, 1970).

Products of oxidative rancidity would be expected to exercise the greatest influence on overall consumer acceptance of fresh meat products. Hofstrand and Jacobson (1960) noted that fat contributes to flavor and that flavor components, especially the carbonyls, were prevalent in depot fat. Investigating the components of the flavor, Jacobson and Koehler (1963) found carbonyl compounds to be important contributors to aroma. Elevated levels of alkanals due to autooxidation also were noted following an extended storage period (Sink, 1973). Concurrently, the taste panel members could discriminate between treatments with high volatiles intensity. Therefore, the relation between head-space volatiles and lipid oxidation may be interesting from a scientific point of view. This work was designed to investigate the chemical and organoleptic qualities of different proportions of mutton and a constant percentage of MDT used

for manufacture of ground lamb patties, which may have the potential to be marketed internationally. This potential exists mainly in countries that import certain types of meat products due to religious or ethnic beliefs. Also, organoleptic and gas chromatographic evaluations were done in relation to oxidative rancidity.

Since there has been no prior published research pertaining to this area of formulation differences, it is not possible to compare or relate the findings obtained by other researchers. The literature review, therefore, will discuss each meat ingredient separately in relation to its present and potential use in the food industry.

## REVIEW OF LITERATURE

## Flavor

General

Flavor has been defined by Hall (1968) as follows:

Flavor is the sensation produced by a material taken in the mouth, perceived principally by the senses of taste and smell, and also by the general pain, tactile and temperature receptors in the mouth. Flavor also denotes the sum of the characteristics of the material which produce that sensation.

Study of food flavor includes the composition of food in terms of compounds having taste or smell, as well as the interaction of these compounds with the receptors in the taste and smell organs. Following the interaction, receptor signals are produced which are carried to the central nervous system to create the impression of flavor.

Although it is true that flavor is mainly composed of taste and odor, there are other qualities contributing to the overall sensation. Texture has a very definite effect: smoothness, roughness, granularity, and viscosity can all have an influence on flavor. In addition, there are other effects such as hotness of spices, coolness of menthol, brothiness or fullness of certain amino acids and the tastes described as metallic and alkaline (DeMan, 1980).

Taste

It is generally agreed that there are only four basic or true tastes: sweet, bitter, sour and salt. According to Teranishi et al. (1971), it seems that perception of the basic taste qualities results from a pattern of nerve activity coming from many taste cells and that

specific receptors for sweet, sour, bitter and salt do not exist.

Dastoli and Price (1966) isolated a protein from bovine tongue epithelium which showed the properties of a sweet taste receptor molecule. Dastoli et al. (1968) reported the isolation of a protein having the properties of a bitter receptor. A mechanism of taste stimulation with electrolytes has been proposed by Beidler (1957) in which the time required for taste response to take place is in the order of 25 milliseconds. According to Beidler (1957), the threshold value of a substance depends on the equilibrium constant and the maximum response.

Differences in taste perception between individuals seem to be common. Peryam (1963) found that sweet and salt are usually well-recognized. However, with sour and bitter some difficulty was experienced.

Minor changes in chemical structure may change the taste of a compound from sweet to bitter or tasteless. The example of saccharin and its substitution compounds has been given by Beidler (1966). Solms et al. (1965) reported on the taste intensity, especially of aromatic amino acids. L-tryptophan is about half as bitter as caffeine, D-tryptophan is 35 times sweeter than sucrose and 1.7 times sweeter than calcium cyclamate. Experiments by Shallenberger (1971) indicated that a panel could not distinguish between the sweet taste of the enantiomeric forms of glucose, galactose, mannose, arabinose, xylose, rhamnose and glucoheptulose. As a result of these tests, it is suggested that the notion that L sugars are tasteless is a myth.

Extensive experiments with a large number of sugars by Birch and Lee

(1971) support Shallenberger's theory of sweetness and indicate that the fourth hydroxyl group of glucopyranosides is of unique importance in eliciting the sweet response.

Although it is generally recognized that the sour taste is a property of the hydrogen ion, there is no simple relationship between sour taste and acid concentration. Information on a number of the most common acids found in foods and phosphoric acid has been collected by Solms (1971) and compared with hydrochloric acid. According to Beatty and Cragg (1935), relative sourness in unbuffered solutions of acids is not a function of molarity, but is proportional to the amount of phosphate buffer required to bring the pH to 4.4. Ough (1963) determined relative sourness of four organic acids added to wine and also preference for these acids. Pangborn (1963) determined the relative sourness of lactic, tartaric, acetic and citric acid and found no relation between pH, total acidity and relative sourness.

The salty taste is best exhibited by sodium chloride. It is sometimes claimed that the taste of salt by itself is unpleasant, and that the main purpose of salt as a food component is to act as a flavor enhancer or flavor potentiator (DeMan, 1980). The taste of salts is dependent on the nature of both cations and anions. As the molecular weight of either cation or anion or both increases, the salts are likely to taste better.

The bitter taste is widely distributed and can be attributed to a great variety of inorganic and organic compounds. Some amino acids may be bitter. Solms (1971) has given a list of peptides with different

taste sensations. The best known for their bitter taste are compounds belonging to the alkaloids and glycosides.

### Odor

The olfactory mechanism is both more complex and sensitive than the process of gustation. The understanding of the mechanism of odor receptor function is very limited, and there is no single, generally accepted theory accounting for the relationship between molecular structure and odor. It has been found that most odorous compounds are soluble in a variety of solvents, but it appears that solubility is less important than the type of molecular arrangement which confers both solubility and chemical reactivity (Moncrieff, 1951).

Stoll wrote in 1957:

The whole subject of the relation between molecular structure and odor is very perplexing, as there is no doubt that there exist as many relationships of structure and odor as there are structures of odorous substances.

In 1971 (referring to Stoll, 1957), Teranishi wrote, "The relation between molecular structure and odor was perplexing then. It is now."

### Techniques of analysis of flavor

A key step towards understanding what constitutes the flavor of any foodstuff is to establish the chemical nature of the volatile constituents which act, either independently or in combination, to produce a highly characteristic aroma response for that particular substance. The analysis of flavor components includes isolation, separation, and identification of the volatile compounds. Morton and

MacLeod (1982), Teranishi et al. (1981), and Maarse and Belz (1981) provide in-depth reviews of this area.

The preparation of a sample of food-aroma volatiles may be approached in two different ways. In total volatile analysis, the investigator isolates and concentrates all of the volatile constituents that could possibly contribute to flavor (Likens and Nickerson, 1964; Huckle, 1966; Muller, 1967; Weurman, 1969; Heatherbell et al., 1971; Ryan and Dupont, 1973; Hirai et al., 1973; Peterson et al., 1975; Jeon et al., 1976; Chang and Peterson, 1977; Caporsa et al., 1977; Buttery et al., 1977; Jennings, 1978; Teranishi et al., 1981; Parliment, 1983). The second approach utilizes some suitable form of headspace analysis to isolate and examine the volatile compounds present in the vapor phase above the food.

Headspace procedures have been used extensively for monitoring changes in aroma volatiles during food processing and storage. Direct injection of a small volume (5 to 10 ml) of the vapors over the food into a gas chromatograph is the simplest form of headspace analysis and was used by McCarthy et al. (1963) to monitor the volatiles of ripening bananas. Cryogenic trapping allows for a 10- to 50-fold increase in the concentration of headspace volatiles over that obtained by direct sampling. The volatiles over the food are swept with a stream of purified carrier gas, such as helium, and condensed in a suitable liquid nitrogen-cooled trap, from which they may be subsequently volatilized by heat into a GC column (Flath et al., 1969; Teranishi et al., 1971). The use of various desiccants as precolumns to selectively remove water during trapping has been investigated by Heatherbell et al. (1971). A

very effective approach that has greatly expanded the power of the headspace technique is the trapping of large volumes of headspace vapor on porous polymer adsorbents (Jennings et al., 1972; Murray and Whitfield, 1975) of the type developed by Hollis (1966).

#### Gas chromatography (GC)

A principal concern of the flavor chemist is the choice of the type of column to be used for a particular separation and the operational parameters that will allow optimal column performance. The application of GC to the separation of flavor volatiles is discussed in detail by McFadden and Teranishi (1963) and Issenberg and Hornstein (1970).

The ability of programmed-temperature GC to give improved separation of complex mixtures is well-established. Merrit (1970) indicated one important aspect is the improved separation obtained with volatile substances when the GC is programmed in the subambient range. Techniques of cryogenic programmed temperature GC may also be used to enhance sample introduction. The introduction of a gaseous sample into a cold column results in condensation and adsorption of the components in a very narrow band at the head of the column. This type of narrow band leads to a minimum of band spreading and, consequently, to a high efficiency in the subsequent column separation. In addition, it provides a means of removing unwanted diluents and of concentrating the components to be analyzed as proposed by Rvshneck (1965). Forss et al. (1964) reported that by an appropriate choice of holding temperature on the column, cryogenic programmed-temperature can be used to concentrate sample

components from dilute liquid solutions as well as from dilute gas mixtures.

A sample injected into a GC column may be modified by means of suitable reagents incorporated within the closed system of the GC. This is a technique which simplifies the analysis of complex mixtures. Suitable reagents usually involve a physically or chemically active substance deposited on a convenient solid-support material. According to Bierl et al. (1969), the reagent contained within a coil of tubing may be placed before or after the analytical column. Clark and Nursten (1977) passed concentrated headspace samples of walnut volatiles through abstraction tubes containing boric acid,  $\alpha$ -dianisidine, and semicarbazide and, by collection and sensory examination of the treated effluents, were able to show that both aldehydes and ketones were important for walnut aroma, but alcohols were not.

### Sensory Evaluation

#### General

Once the volatile compounds have been identified, the question remains as to which are important to the flavor of the food and which are superfluous. It is only during the last 20 years that widespread and active interest has developed in sensory analysis and its relation to flavor research. Techniques for assessing the sensory significance of analytical data in flavor research generally involve statistical methods that correlate sensory and instrumental data. McLellan (1983) reported the use of microcomputers as data-collection devices in sensory analysis.

Sensory assessment of volatile components

Relative contribution to odor intensity based on thresholds      One measure of the flavor significance of a compound is the intensity of its aroma. This is measured relatively easily by determining its threshold; i.e., the minimum quantity of the compound that causes an odor detectable by a specified percentage of panel members. Even though the existence of sensory thresholds is open to question (Swets, 1961), they have great practical use in operational terms. Stone (1963) acknowledged the remarkable variability of odor and taste sensitivity among individuals; average threshold values obtained from good-sized groups of individuals have much practical value. Thresholds must be determined under carefully controlled and specified conditions. If the concentration of an odorant in a food product is greater than its threshold concentration, it is logical to suppose that the odorant contributes significantly to flavor. However, the threshold must have been determined in a medium similar in polarity to that of the food matrix.

Based on observations with mixtures of aldehydes, a sulfide, an amine, and an acid--each at a level below its own threshold--Guadagni et al. (1963) concluded that certain compounds had an additive effect at subthreshold levels. This means that even constituents present in a flavor mixture at lower-than-threshold levels may have very significant flavor or aroma effects. Guadagni et al. (1968) have determined the relative contribution of individual components to the odor intensity of the total flavor by use of an odor unit, which is the ratio of concentration to the threshold value. The number obtained is related to

the degree of importance of that chemical to the overall aroma. The difficulty with this technique is that one must be able to identify all of the individual components and then determine their thresholds too. Though appreciating the benefits of odor units, Rothe (1975) felt that mathematical calculations of this type are speculative and simplifications are made which may not apply to such a complex sensation as flavor.

Assessment by way of odor quality Flavor investigations are greatly simplified if certain volatiles in the product of interest obviously exhibit the characteristic aroma of that product. In such cases, "sniffing" the effluent of a GC column or "sniffing" fractions from silica gel columns can provide easy guidance as to the components of greatest olfactory importance (Guadagni et al., 1966; Parliment, 1980). A very serious complication in describing odors is the fact that some compounds exhibit different odor qualities at different concentrations. They may have one "character" at the threshold level and quite another at higher-than-threshold concentrations. Because of this, it is important to learn whether or how odor characteristics change for a given compound with increasing concentrations. In addition, Teranishi et al. (1971) proposed that odor comparisons must be carried out at comparable concentrations and under controlled conditions.

According to Teranishi et al. (1971), the characteristic aroma of food is due to man's integrated response to a number of flavor compounds. This was the case for irradiated beef (Wick et al., 1967). In this type of experiment, sniffing the effluent of a GC column can lead to the use

of a number of differing descriptive terms. Different people may use different terms to describe the same odor, and problems can arise in unscrambling the resulting terminology.

Statistical methods to correlate sensory and instrumental data

Multivariate statistical techniques are used to correlate GC peak areas, ratios of peaks, or combinations of peaks with variation in sensory characteristics. Two techniques commonly used are discriminant analysis and regression analysis. Powers and Keith (1966, 1968) applied discriminant analysis to coffee flavor. Qvist et al. (1976) applied this technique to the correlation of GC and sensory data of canned meat products containing soy or rapeseed proteins. An in-depth discussion of stepwise regression analysis is given by McClave and Benson (1982).

Kirton et al. (1983) experimented on pasture-fed male and female sheep ranging in age from yearling to greater than 4 years which were slaughtered at various times throughout the year. Flavor and odor of cooked meat were evaluated with three different taste-testing procedures: an analytical laboratory taste panel, an in-house consumer taste panel, and a mass consumer taste panel. None of the panels found any differences between meat from yearling rams or ewes.

Wenham (1974) reported that a trained taste panel could not identify the predominant meat in mixed species patties and showed no preference for lean beef or lean mutton patties when judging flavor and aroma. With up to 10% mutton fat added, the patties increased in acceptability, but declined to an unacceptable level at higher additions. The lean patties were improved by adding beef fat, reaching a maximum of acceptability at

the much higher fat level of 30%. This offers the prospect of upgrading lean mutton and beef fat by using them together in mixed-species products.

#### Meat Flavor

Meat flavor is developed by heating of precursors present in the meat by a Maillard-type browning reaction. The overall flavor impression is the result of the presence of a large number of nonvolatile compounds and the volatiles produced during heating. The contribution of non-volatile compounds in meat flavor has been summarized by Solms (1971). Meat extracts contain a large number of amino acids, peptides, nucleotides, acids and sugars. The presence of relatively large amounts of inosine-5'-monophosphate has been the reason for considering this compounds as a basic flavor component. In combination with other compounds, this nucleotide would be responsible for the meaty taste. Living muscle contains adenosine-5'-triphosphate which is converted after slaughter into adenosine-5'-monophosphate and this is designated to form inosine-5'-monophosphate (Jones, 1969).

Early investigators were concerned about the site and gross characteristics of the flavor precursors in beef. Howe and Barbella (1937) considered both lean and fat important and related time and temperature of heating to the quality of the flavor. Crocker (1948) concluded that heating meat fibers produced typical meat aromas and that a nontypical, low intensity flavor was obtained by heating expressed juices. Jones (1952) reported that cooking lean meat produced little

flavor and attributed the flavor to the fat. Contrary to Crocker's findings, Barylko-Piekielva (1957) stated that meat flavor was not derived solely from muscle fibers, and Kramlich and Pearson (1958) reported that heating expressed fluids from raw beef produced a typical meat aroma. Hornstein et al. (1960) blended ground lean beef with cold water at 0°C (32°F), centrifuged the slurry, and heated both the extract and residue to 100°C (212°F). On heating, the extract produced typical meaty aromas while the heated residue was essentially odorless. They concluded that regardless of the site, the flavor precursors of lean meat were water-soluble and further that the insoluble protein fraction contributed little to meaty aromas. Using the same procedures developed in their study of beef, Hornstein et al. (1960, 1963) looked at flavor precursors in lean pork and lamb. In each instance, the flavor precursors were water-soluble, nonprotein substances. Ion exchange chromatography of both pork and lamb precursors produced two subfractions, one containing amino acids and the other reducing sugars. Heating the separated subfractions produced nonmeaty aromas. Recombination of the pork and lamb subfractions followed by heating produced meaty aromas. The aromas obtained from pork and lamb were indistinguishable from and identical to that of beef. Further, gas chromatographic patterns of headspace volatiles were very similar, and the same compounds were identified in the volatiles derived from lean beef, pork, and lamb.

The similarities in beef, pork, and lamb aroma and gas chromatographic patterns reflect the results of studies by Macy et al.

(1964a,b), who analyzed the diffusates obtained from cold water extracts of beef, pork, and lamb muscle for amino-nitrogen and carbohydrate constituents. Qualitative differences in the amino-nitrogen and carbohydrate constituents of the three species were minor, and glutathione was identified in lamb but not in pork and beef. Cysteic acid and ornithine were found in pork and beef but not in lamb. In each species, ribose was completely destroyed, and fructose remained virtually unchanged. Glucose, which accounted for more than 90% of the carbohydrate initially present, was reduced to approximately 60% of initial value.

#### Meat Volatile Compounds

The volatile compounds produced on heating can be accounted for by reactions involving amino acids and sugar present in meat extract. Lean beef, pork, and lamb are surprisingly similar in flavor and this reflects the similarity in composition of extracts in terms of amino acid and sugar components. The fats of these different species may account for some of the difference in flavor normally observed. In the volatile fractions of meat aroma, hydrogen sulfide and methyl mercaptan have been found and these may be important contributors to meat flavor. Other volatiles that have been isolated include a variety of carbonyls such as acetaldehyde, propionaldehyde, 2-methyl-propanal, 3-methylbutanal, acetone, 2-butanone, n-hexanal and 3-methyl-2-butanone (DeMan, 1980).

The greatest attention has been focused on studying the volatile compounds that contribute to beef flavor. Stahl (1957) and Merrit et al.

(1959) investigated the volatile compounds recovered from raw beef. These compounds were isolated by high vacuum distillation, separated by gas liquid chromatography (GLC), and identified by mass spectrometry. Hornstein et al. (1960) and Hornstein and Crowe (1960) studied the volatiles that were obtained by heating under high vacuum a lyophilized extract of lean beef.

#### Definitions and Terms

The United States Department of Agriculture (USDA, 1960) officially describes lamb as being meat from ovines less than 12 months of age. Yearlings are animals between 12 and 24 months which have cut one pair of permanent incisor teeth, and mutton is from animals over 24 months of age which have cut two pairs of permanent incisor teeth. This specific description of the types of sheep meat, based on age, has not been used by many researchers, and is a source of confusion in the literature. To some researchers (Hoffman and Meijboom, 1968), the term mutton means the meat of all sheep, regardless of age, while others (Batcher et al., 1969) have used the official USDA definitions. However, many investigators have termed the characteristic "off" flavor in sheep meat (regardless of age) as a "mutton" flavor (Cramer and Marchello, 1962; Cramer et al., 1970; Cramer, 1974; Weller et al., 1962; Hornstein and Crowe, 1963).

Although Wasserman and Talley (1968) reported that the flavor of lamb is so characteristic it can be identified by people with little previous exposure, the distinction between the "characteristic" flavors of lamb and mutton meat has not been well-defined. People apparently

differ in their concept of what constitutes mutton flavor. Mutton meat has an entirely different flavor from that of lamb, or may merely represent a change in concentration of flavor components.

#### Lamb and Mutton Flavor

The ability to distinguish between lamb and mutton flavor varies among people. In preliminary studies on threshold tests, Batcher et al. (1969) found 3 out of 14 people tested were able to detect mutton flavor in ground lamb patties containing 15% mutton, 7 were able to detect the flavor in patties containing 15-35% mutton, and the remaining 4 people required more than 35% mutton in the patties before the presence of mutton flavor was detected.

Hofstrand and Jacobson (1960) had noted an indication that fat may contribute to the flavor of lamb and mutton broths. They observed that the depot fats contained flavor components. However, Jacobson and Koehler (1963) reported that volatile stripping, under vacuum at 80°C, resulted in a yellow oily concentrate. Infrared analysis of the concentrates showed the presence of both aliphatic and conjugated carbonyl compounds. Subsequent class separation demonstrated that the monocarbonyls (alkanals and alka-2-ones), as opposed to the polycarbonyls, predominate. Hornstein and Crowe (1963) found that lamb fat contained alkanals (0.10 µM/g lipid) and that these aliphatic aldehydes were probably responsible for the mutton-like odor.

Hornstein and Crowe (1962) studied the flavor of lean lamb. Lyophilized powders obtained from diffusates of water extracts of lean

lamb were heated in a stream of nitrogen to 100°C (212°F). Volatiles were swept from the headspace above these powders by the nitrogen gas onto a small trapping coil cooled to liquid nitrogen temperature--the coil is essentially an extension of the gas chromatographic column.

The column was then programmed from room temperature to 150°C (302°F). The effluent carrier gas was split, part going to a flame detector, part going to an observer. There was no correlation between the size of the recorded peaks and odor intensities. Further, no distinctively meaty aromas were detected for any one peak. Instead, an entire spectrum of odors was observed. However, when the volatiles in the GLC effluent emerging between room temperature and 75°C (167°F) and 150°C (302°F) were trapped as two composite fractions, the odor of the combined effluent collected above 75°C (167°F) was considerably more meaty than the collective volatiles obtained below 75°C (167°F). The similarity in aromas, GLC patterns of volatile compounds, and identified compounds reinforces the concept that the lean meat contribution to meat flavor is similar regardless of species.

#### Lipid studies

Hornstein and Crowe (1960, 1963), from their studies on lean beef, pork, and lamb, concluded that in terms of flavor, lean meats are alike. Pork, beef, and lamb do, however, have different flavors, and so they considered the fat as a source of species flavor differences. In preliminary experiments, subcutaneous fats, rendered under nitrogen, were heated to 100°C (212°F) in vacuum, nitrogen, or air. Pork and beef fat

evolved nonmeaty aromas when heated in nitrogen or in vacuum, but produced odors associated with pork and beef when heated in air. Lamb fat produced a strong characteristic lamb (or mutton) aroma when heated in vacuum, air, or nitrogen. These results suggested that lipids may indeed be responsible for the flavors that distinguish meats of different species and further that lipid oxidation may be important in the development of beef and pork flavor but not in the development of lamb flavor. Wasserman and Talley (1968) considered the hypothesis that the lean meats of various species have essentially the same basic flavor and that the specific species flavor is due to the fat. Veal was selected as the basic lean meat to which fats of other species were added. The choice of veal was made on the basis of the natural leanness of the meat and its normally bland flavor. Identification was considered correct when a panelist recognized the veal plus fat as the species of meat corresponding to the fat. The addition of beef fat did not significantly increase the number of identifications of veal as beef. Addition of pork fat resulted in a number of correct identifications of veal as pork that was significant ( $p < 0.05$ ) while the identification of veal plus lamb fat was highly significant ( $p < 0.01$ ). Hornstein and Crowe (1963), in trying to establish the origin of lamb fat flavor, isolated a polar fraction free of carbonyl compounds from unheated lamb fat that exhibited a strong typical lamblike or muttonlike aroma. This fraction was obtained by chromatographing a hexane solution of unheated lamb fat on silicic acid, using chloroform and increasing amounts of methanol as the developing solvent.

Caporaso et al. (1977) identified compounds in the neutral fraction of mutton fat volatiles since olfactory evaluation indicated that the neutral fraction contained the most intense mutton odor. Olfactory evaluation was used to characterize the flavor note separated by GC and subsequently identified by MS. On the basis of the evaluation, 14 compounds (10 aldehydes, 3 ketones, and 1 lactone) were suggested as significant contributors to mutton odor.

Wong et al. (1975) identified volatile fatty acids of cooked mince mutton. Odor properties of these acids were evaluated, and the results indicated that the branched-chain and unsaturated acids having eight to ten carbon atoms contributed to the undesirable flavor of cooked mutton. The 4-methyl branched C<sub>9</sub> and C<sub>10</sub> fatty acids in particular were considered primarily responsible for the sweaty odor note described in Chinese as "sao".

Buttery et al. (1977) analyzed the basic fraction of mutton volatiles. Alkylpyridines, alkylpyrazines, and alkylthiazoles were identified. The authors indicate that pyridines may contribute to the undesirable mutton odor.

It appears as though the authors of the above three investigations are contradicting each other as each considers compounds of different chemical classes to contribute significantly to mutton flavor.

Several studies have shown that high energy diets alter the fatty acid composition of lambs' subcutaneous fat (Garton et al., 1972; Duncan et al., 1974a,b; Qrskov et al., 1974; 1975; Johnson et al., 1977; Miller et al., 1980). Sex (Cramer and Marchello, 1964; Crouse et al., 1972a;

Jacobs et al., 1972), breed (Boylan et al., 1976; L'Estrange and Spillane, 1976), slaughter weight (Tichenor et al., 1970) and environmental temperature (Callow, 1958; Marchello et al., 1967) have also been cited as factors affecting fat composition in lambs. Busboom et al. (1981) found that fat from rams was higher ( $p < 0.05$ ) in branched chain fatty acids and shorter chain fatty acids with odd numbers of carbon atoms, but was lower in 16:0 and 18:0 than was fat from wethers. Although diet does not change body composition in ruminants as much as in monogastric animals, there is evidence (Cramer et al., 1967; Ziegler et al., 1967; Miller and Rice, 1967) that some diet-induced changes in fat composition do occur. Researchers do not agree on the effect of fatty acid composition on palatability. Waldman et al. (1968) and Skelley et al. (1973), for example, found no difference in beef, whereas Dryden and Marchello (1970), with beef, and Cramer et al. (1967), with lamb, did observe differences.

Since organoleptic characteristics are influenced by feed, slaughter weight and sex, it seems logical that there would be a relationship between fatty acid composition and organoleptic characteristics.

It is widely recognized that the fine wool breeds have more mutton flavor than do meat-type breeds of sheep (Cramer et al. 1970). This is possibly so because they have a higher dietary sulfur requirement for greater wool production. More intense flavor has also been noted when lambs have been fed high concentrations of legumes (Cramer et al., 1967) and when slaughter has taken place during periods of warm environmental temperature (Cramer et al., 1961; Marchello et al., 1967). There were no

differences ( $p < 0.05$ ) between rams and wethers in mean of palatability traits. Other workers (Kemp et al., 1972) have reported less desirable flavor, aroma, tenderness and juiciness ratings for ram lambs. Although less desirable in most cases, ram carcasses were still acceptable, except for extreme heavy weight carcasses. Smith and Carpenter (1970) found total collagen in lamb muscle to be inversely proportional to tenderness, juiciness, flavor and overall satisfaction. Therefore, at older ages and heavier weights, background toughening (Purchas, 1972), due either to increased amounts of collagen and/or to increased crosslinking of collagen, may be more important than small differences in fat content. The existence of such an effect may also explain the negative overall correlation between marbling or chemical fat of the separable lean and tenderness.

#### Oxidation of Meat

##### General

Oxygen uptake by intact post-rigor muscle has been measured by Bendall and Taylor (1972) and DeVore and Solberg (1974). Mitochondrial respiration was the main element determining post-rigor oxygen consumption, and the decline of oxygen consumption rate occurred as a result of a deterioration of mitochondrial structure (Bendall and Taylor, 1972) and enzyme degradation (Grant, 1955). DeVore and Solberg (1974, 1975) reported that the respiratory oxygen consumption rate decline appeared to be related to a reduction in respiratory enzyme activity and substrate depletions.

Lipid oxidation is a major cause of quality deterioration in meat and meat products involved in the oxidation of lipid and ferrous myoglobin. Lundberg (1962) has reviewed the free radical chain mechanisms involved in autocatalytic autoxidation. Dugan (1961) indicated that hydroperoxides are the primary products of the oxidation of unsaturated lipids, the products resulting from hydroperoxide degradation responsible for the occurrence of off-flavors in oxidized lipids. Phospholipids have been shown to be the lipid component most rapidly oxidized in cooked meat (Younathan and Watts, 1960) due to their high content of unsaturated fatty acid (Lea, 1957). It is the traditional view that hemoproteins are the major catalysts of lipid oxidation in meat and meat products (Younathan and Watts, 1959). In contrast, Sato and Hegarty (1971) and Love and Pearson (1974) proposed that nonheme iron plays a major role in accelerating lipid oxidation in cooked meat. The latter authors found that metmyoglobin (MetMb) did not influence thiobarbituric acid (TBA) values in cooked meat which had been water extracted to remove prooxidants prior to cooking. Rhee (1978b) found that the rate of MetMb (a heme iron catalyst) catalysis was not proportional to MetMb concentration, whereas the rate of  $Fe^{+2}$  ethylene diamino tetra acetic acid (EDTA) catalysis increased linearly with the concentration of  $Fe^{+2}$ -EDTA complex. Liu and Watts (1970), however, indicated that both heme and nonheme iron function as catalysts of oxidative rancidity in meats, although heme was reported to be the dominant one.

In addition, Ingold (1962) reported that the heavy metals, such as

iron, cobalt, and copper, are important catalysts of oxidative rancidity due to increase in the rate of formation of free radicals.

#### Oxidation measurement techniques

A variety of methods used to measure lipid oxidation can be found in the literature, ranging from simple organoleptic evaluation to chemical and physical methods. Gray (1978) presented an extensive review of these experimental techniques, along with a discussion of the advantages and limitations associated with each method. Briefly, organoleptic methods have been used widely, with the advantage being that these are the same methods used by the consumer to evaluate a product. Questionable reproducibility, low sensitivity, and the lack of a quantitative nature of evaluations of this type are potential limitations. Of the chemical methods, peroxide value tests, which involve iodometric methods, ferric thiocyanate procedures, and 2,6-dichlorophenolindophenol methods, have been widely and successfully used. Likewise, the 2-thiobarbituric acid (TBA) test is one of the most widely used tests for measuring the extent of oxidative deterioration of lipids in muscle foods (Gray, 1978; Rhee, 1978a). This test which expresses lipid oxidation in milligrams of malonaldehyde per kilogram of sample, or TBA number, initially was reported (Sinnhuber et al., 1958) to measure only malonaldehyde. Malonaldehyde was shown to be a secondary oxidation product of polyunsaturated fatty acids containing three or more double bonds (Dahle et al., 1962; Pryor et al., 1976). However, other researchers showed that other lipid oxidation products such as the alka-2,4-dienals also

reacted with TBA to form a red complex with the same absorption maximum as malonaldehyde-TBA complex at 532 nm (Jacobson et al., 1964; Marcuse and Johansson, 1973).

There are three ways which the TBA test can be performed on muscle foods (Rhee, 1978a). It can be performed: (1) directly on the food product, followed by extraction of the colored complex (Sinnhuber and Yu, 1958); (2) on an extract of the food (Witte et al., 1970; Vyneke, 1975); or (3) on a portion of the steam distillate of the food (Tarladgis et al., 1960). The method involving the steam distillate is the most popular method for measuring the TBA number in muscle foods (Rhee, 1978a). Rhee (1978a) pointed out that use of phenolic antioxidants such as butylated hydroxyanisole (BHA) in oxidizing fats has been shown to increase the decomposition of lipid peroxides in lard and milk fat (Privett and Quackenbush, 1954; Hill et al., 1969).

Although the distillate method of Tarladgis et al. (1960) is the most popular TBA method, it doesn't necessarily mean that it is the most accurate or reproductive method. TBA values of muscle food determined by the distillate method are consistently higher than those determined by the method utilizing food extracts as observed by Witte et al. (1970) and Vyneke (1975). Furthermore, Siu and Draper (1978) reported that it was necessary to use the distillation method for samples high in fat because of turbidity of the extracts.

The Kries Test, one of the original widely used tests for lipid oxidation evaluation, and the various oxirane determination tests are also commonly used. And, of the various physical methods, the diene

conjugation procedure, fluorescence methods, infrared spectroscopy, polarographic procedures, and refractometry all have had successful applications in the assessment of lipid oxidation. For specific information regarding these methods, the reader is referred to Gray (1978).

Gas chromatographic (GC) procedures have been widely used in the detection of lipid oxidation-derived volatiles in food. Early GC procedures involved enrichment techniques, to attain adequate concentrations of compounds in the samples to meet requirements of the instrument. Various distillation procedures have been reported, although these methods tend to be complex and very time-consuming, and may even induce considerable changes in the samples. Similarly, solvent extraction may not adhere to quantitative techniques and may even introduce extraneous volatiles. Headspace vapor analysis and direct vapor analysis of food products similarly have inherent sample preparation and transfer difficulties (Dupuy et al., 1977).

Of particular importance to this study are a number of reports based on the use of a simple, direct gas chromatographic technique for eluting and resolving flavor-related volatile components (specifically, lipid oxidation-derived volatiles) for various food products and edible oils. Dupuy et al. (1973) and Dupuy et al. (1976) described the use of such a system for examining volatiles in salad oils and shortening, and in various corn oils, soybean oils, and experimentally-blended oils. These authors showed that a clear, defined relationship existed between subjective taste panel flavor scores and objective data, in that oils

with poor sensory scores produced GC profiles of volatiles with many peaks of high magnitude, and those with more desirable sensory scores had profiles of fewer peaks, with lower concentrations. They found a significant negative relationship between the summation of all peaks, and sensory flavor scores. Specifically, of those peaks identified through mass spectrometry, pentonal and hexanal were found to be very significant in this relationship.

Subsequently, Dupuy et al. (1977) modified the original technique to enhance the sensitivity and resolution, and at the same time, retain the simplicity of application. Results of this study furthermore indicated that the total volatile (TV) content, pentane, and trans-2, trans-4, decadienal components correlated significantly with sensory flavor scores.

Jackson and Giacherio (1977) also presented a modification of the original Dupuy procedure. Their method differed in that an internal standard was used, and sample collection was performed external to the GC. The authors proposed that these modifications allowed any GC with adequate sensitivity to be used, and decreased the time required per sample. Their results, based on the TV content, correlated well, once again, with flavor scores obtained from an expert panel. The authors concluded that this procedure is highly desirable, based on its "specificity, sensitivity, and reliability."

Rayner et al. (1978) applied the technique successfully to the elution and resolution of flavor-related volatile compounds from soy flour and soy protein isolates. They found highly significant

correlations between sensory flavor scores, and the concentration of volatile components. Moreover, they indicated that methanol, ethanol, acetone, and hexanal showed marked increases during the process of flavor deterioration.

Rayner et al. (1980) presented preliminary data relative to the application of the procedure to the assessment of flavor and odor quality of commercial egg products. The authors used the technique to determine the presence or absence of volatile components in the products. Chemical changes occurring during deterioration of the egg products were reflected in fluctuations of the volatiles present, with the concentration of ethanol increasing to a maximum level.

#### Sheep Lipid Oxidation and pH Measurements

In a study by Nathappan et al. (1985), longissimus dorsi samples from sheep were examined fresh or after storage at 5°C. Parameters examined were pH and thiobarbituric acid value as related to sensory odor score. The pH in fresh and stored meat was, respectively, 6.70 and 5.89, TBA 0.06 and 0.08, and odor score 9.01 and 6.64 (on a 10-point hedonic scale, where 10 was the most desirable score). Correlations between the various parameters were also discussed. Abraham et al. (1982) reported that the longissimus dorsi from sheep classified on the basis of age and weight was examined 45 min. post slaughter, for influence of chilling and subsequent freezing on pH and moisture content. Initial pH was approximately 6.22, 5.72 on chilling, 5.74 on freezing, and 6.00 on thawing (disregarding sex/age/wt. variations). Mean percentage moisture

content was correspondingly 75.98, 73.72, 70.23 and 69.20.

#### Beef and Pork Lipid Oxidation

Meat lipids exist primarily in the form of triglycerides and phospholipids. Allen and Foegeding (1981) found that in living muscle, the triglycerides (or neutral lipids) include fatty acids which are available for energy metabolism and contribute to the characteristics of the meat; the phospholipids of muscle lipids are essential to muscle because of their role in the structure and function of the muscle cell and its organelles. However, Love and Pearson (1971) concluded that lipid oxidation of meat and meat products can occur in either the stored triglycerides or the tissue phospholipids.

Phospholipid content in beef and pork muscle has been estimated to be approximately 0.5-1.0 percent (Hornstein et al., 1961; Dugan, 1971; Wilson et al., 1976). Because of numerous factors involved in adipose tissue content (age, sex, breed, feeding regime, etc.), estimates for triglyceride content in muscle are more variable, reported as being approximately 3-25 percent for pork (Hornstein et al., 1961; Luddy et al., 1970; Wilson et al., 1976; Allen and Foegeding, 1981) and 2-14 percent for beef (Hornstein et al., 1961; Wilson et al., 1976; Allen and Foegeding, 1981). Anderson (1976) stated that raw fresh pork sausage was composed of approximately 36.5 percent total lipid, which included 13.15 saturated fatty acids and 21.45 percent unsaturated fatty acids.

TBA numbers have been demonstrated to correlate highly with flavor

scores of pork lipid (Fioriti et al., 1974). Researchers have used the TBA method as reported by Tarladgis et al. (1960) to monitor lipid oxidation in pork muscle (Ordonez and Ledward, 1977), ground pork (Judge and Aberle, 1980; Lopez-Lorenzo et al., 1980; Yasosky et al., 1984) and fresh pork sausage (Drerup et al., 1981; Reagan et al., 1983).

In their review, Allen and Foegeding (1981) reported that in chicken, beef, pork and lamb, the neutral lipids (triglycerides) contain about 40-50 percent fatty acids and less than 2 percent of the most highly unsaturated fatty acids. Igene et al. (1980) reported that in the beef system, TBA numbers indicated that the phospholipids significantly contributed to oxidation from the first month of storage, while the triglycerides had an induction period before they underwent oxidation. Though the phospholipids in beef comprised 0.8 percent and the triglycerides the other 9.2 percent of the total 10 percent intramuscular lipid, the oxidized phospholipids had the greatest contribution to rancidity in the beef system. Both the phospholipids and triglycerides contributed to oxidation and their combined effects were approximately additive when compared to the total lipids. It was concluded, therefore, that the triglycerides in beef may not be important to rancidity when meat is stored frozen for a short period of time, but they could be significant after longer storage periods.

In addition, Tichivangana and Morrissey (1985) investigated various prooxidant effects on lipid oxidation of various meat species. They concluded that the rate and extent of lipid oxidation, in both raw and cooked meat, was in the order fish > turkey > chicken > pork > beef >

lamb. It was observed that in the meat systems, oxidation occurred to a much lesser degree in beef and lamb systems whereas significant increases occurred in pork, chicken, turkey and fish. They stated that rates and extent of oxidation corresponded to the level of constituent polyunsaturated fatty acids, of which beef and lamb possess relatively low levels compared to pork, chicken, turkey and fish.

Dietary fatty acids are very important in determining tissue fatty acid composition in all of the nonruminant animals (Allen and Foegeding, 1981). Swine are sensitive to their lipid intake because they are unable to hydrogenate unsaturated fatty acids to any significant degree. The result is that lipids are essentially deposited unaltered in swine adipose tissue (Allen et al. 1976). Ruminant animals, on the other hand, are not as sensitive to dietary fatty acid intake since microbial modification (e.g., hydrogenation and metabolism) of the dietary lipids occurs in the rumen (Reineccius, 1979). This unique difference would, therefore, allow less variability in unsaturated fatty acid content of beef or lamb than pork, and meat products comprised of pork would be expected to possess relatively greater variability in lipid oxidative stability.

Although phospholipids have been recognized as the major class of lipids contributing to oxidative rancidity of ruminant muscle such as beef and lamb, the triglycerides have been shown to be potentially as important as phospholipids in muscle of nonruminant muscle such as pork and poultry (Igene et al., 1980; Yamauchi et al., 1980; Tichivangana and Morrissey, 1985).

The influence of pork fat on oxidative rancidity of meat products

was demonstrated by Benedict et al. (1975), who added ground beef fat or ground pork fat to lean beef that had been trimmed free of intramuscular fat and then ground. Pigment and lipid oxidation were monitored. All samples were formulated with either type of fat to attain levels of a 25 percent fat in the products. Rate of development of TBA reactive compounds was more rapid with the pork fat samples than in samples containing beef fat.

#### Muscle pH

Many researchers have observed enhanced oxidative stability of muscle lipids with higher postmortem muscle pH values (Owen and Lawrie, 1975; Judge and Aberle, 1980; Yasosky et al., 1984). When differences in fatty acid content have been monitored, this stability has been witnessed in spite of higher polyunsaturated fatty acid levels in intramuscular triglycerides. It appears that the greatest advantages are realized when the muscle pH is above 6.1 (Olson, 1983; Yasosky et al., 1984). Greater oxidative stability has also been observed for myoglobin at higher pH values.

#### Packaging and Storage Conditions

For efficient utilization of fresh meat, a desirable product quality must be maintained during distribution and storage. Large quantities of meat spoil due to improper packaging, handling and storage conditions. Freezing and frozen storage are commonly used to prolong the shelf-life of meat, and storage life depends on the storage conditions.

Spoilage of chilled meat is retarded by storage under anaerobic

conditions because growth of the aerobic spoilage flora, usually dominated by pseudomonas, is prevented. According to Gill and Penny (1985), lactobacilli become dominant when oxygen is excluded and a high pH exists and, although their maximum cell density persists, there is no apparent spoilage. Aerobic spoilage is manifested before the maximum cell density is attained (Gill and Newton, 1978).

Although it does not produce a completely anaerobic environment, vacuum-packaging of meat in low permeability plastic film impedes the diffusion of oxygen to the meat. The growth of aerobic bacteria, such as Pseudomonas spp., has been reported (Sutherland et al., 1975; Seidman et al., 1976). The gas phase in packs will be determined by the rate gas permeates through the film, and the rates of oxygen consumption and release of carbon dioxide by the meat (Devore and Solberg, 1974). The microenvironment produced within the pack will dictate the composition of the microflora which develops. In any case, both wholesale and retail stability can be greatly improved by using vacuum packaging. The significant factor is not the absence of oxygen but rather the presence of carbon dioxide within the package that achieves microbial control as reported by Daniels et al. (1985). Cheah and Cheah (1971) reported that mitochondria consume 1-3 l of oxygen per  $\text{cm}^2$  per 24 h and remain active up to 144 h postmortem or as long as the pH remains above pH 5.5. Johnson (1974) claimed that not only meat tissue but also bacteria respire and convert oxygen to carbon dioxide.

Winger (1985) reported that storage life of vacuum packaged lamb is determined by many factors apart from frozen storage temperature. One

day of chilled storage prior to freezing reduces subsequent frozen storage life by about 25%. Animal-to-animal variability can result in differences as great as 50%. Smith et al. (1983) concluded that vacuum packaging was superior to modified atmosphere (atm) packaging for maintaining desirable appearance of wholesale loins, particularly if the atm contained a high CO<sub>2</sub> concentration.

Ground lamb (Hoshyare et al., 1982) stored for 6 months resulted in a slight increase of aerobic plate counts, psychrotrophic counts, total coliforms and fecal coliforms, as the warm months progressed (March-June). In contrast, Bhagirathi et al. (1983) found that bacterial contamination of mutton is not related to the prevailing weather conditions. Vijaya Rao et al. (1983) stated that predominant aerobic bacteria were Staphylococcus, Micrococcus, Bacillus, 3 genera of coryneforms, enterobacteria, Acinetobacter, Pseudomonas and Moraxella.

Ray and Field (1983) investigated composite samples of restructured lamb roast containing 10 or 30% mechanically deboned meat (MDM) which were analyzed for bacteriological quality before and after cooking to 62.8°C. Uncooked samples had less than  $3.0 \times 10^4$  colony forming units/g mesophilic and psychrotrophic aerobes and anaerobes including lactobacilli. In general, these groups, as well as coliforms and fecal coliforms, were present in higher numbers in uncooked roasts containing higher percentage of mechanically deboned meat. Staphylococcus aureus, Clostridium perfringens, Salmonella sp., Yersia enterocolitica and Campylobacter jejuni were not detected in uncooked samples. Cooking reduced number of aerobic and anaerobic spoilage

bacteria effectively.

### Mechanically Deboned Turkey

#### Composition and structure

Mechanical deboning alters the lipid and protein composition of the resultant meat paste rather markedly. Various workers have observed lower protein and higher fat contents in various sources of mechanically deboned poultry meat, than in hand deboned sources (Goodwin et al., 1968; Froning, 1970; Froning et al., 1971; Froning and Janky, 1971; Gruuden et al., 1972; Froning and Johnson, 1973). These investigators have further reported considerable variability in composition of mechanically deboned poultry meat. Much of this variability is likely related to factors such as age of the bird, bone-to-meat ratio, cutting methods, deboner settings, skin content, and protein denaturation. The amino acid composition of mechanically deboned turkey meat has been shown to be comparable to that of hand deboned sources (Essary and Ritchey, 1968). Therefore, mechanically deboned meat offers a high-quality protein source.

Satterlee et al. (1971) investigated the effect of skin content of chicken broiler backs on the composition of resultant mechanically deboned meat. As the skin content of the backs increased in relation to muscle and bone content, the fat content of the deboned meat increased and the moisture and protein contents decreased. The connective tissue (collagen) content of mechanically deboned meat was not affected by increasing skin content on the backs. Fat from the skin was expressed

through the screen with the meat, whereas skin collagen was passed out with the bone residue. Goodwin et al. (1968) defatted necks and backs by trimming before deboning, and observed reduced fat and increased protein in the final deboned product. These researchers further observed that removing tails slightly increased protein and reduced fat.

Another aspect affecting the composition of mechanically deboned poultry meat is the bone marrow. The mechanical-deboning process incorporates heme (Froning and Johnson, 1973) and lipid components (Moerck and Ball, 1973) from the bone marrow. The lipid components from the bone marrow account for the large increases in fat content of mechanically deboned poultry meat, and this further dilutes noticeably the protein content. Heme/lipid interaction also is an important factor affecting stability of mechanically deboned poultry meat, as will be discussed below. Moerck and Ball found that average lipid content of the bone marrow was 46.5%. Triglycerides were approximately 94.5% of the total lipid and contained primarily 16:0, 18:0, 18:1, and 18:2 fatty acids. Approximately 1.7% of the total lipids were phospholipids which had a relatively high percentage of 20:3 to 20:6 unsaturated acids. Trace amounts of glycolipids were also found.

Schnell et al. (1974) studied the ultrastructure of mechanically deboned poultry meat. A decrease in screen size (from 0.1575 cm to 0.0508 cm) caused a loss in the integrity of the myofibrils. The smallest screen size destroyed the characteristic myofibril structure, causing breaks at the Z or M lines. Once the myofibril was broken into small particles, further shearing tended to produce particles which were

spherical or oval in shape. These effects on the structural composition likely play a significant role in the functional and stability properties of mechanically deboned poultry meat.

Possible alteration of mechanically deboned poultry meat to improve quality through modification of composition has been given emphasis recently. Centrifugation has been shown to increase protein content and reduce lipid content of mechanically deboned poultry meat (Froning and Johnson, 1973; Dhillon and Maurer, 1975a). It is conceivable that commercial-scale continuous centrifugal separators could be utilized in processing plants. Centrifugation results in an aqueous layer (primarily heme components), a fat layer, and the mechanically deboned meat, with average yields of 30%, 34%, and 36%, respectively. The fat could likely be utilized in a commercial process as a food-grade fat source.

Acton (1973) modified mechanically deboned chicken neck meats by extrusion and texturizing, using a dry-heat process. The heat process resulted in a significant reduction in moisture content and significant increases in fat and protein levels as heating time increased. Texturization of mechanically deboned poultry meat possibly offers advantages for use in further-processed products.

#### Functional characteristics

Mechanically deboned poultry meat has its greatest usage in emulsified products because of its paste form. Thus, emphasis has been given to its emulsifying characteristics.

Froning (1970) studied the effect of chopping time and temperature

on mechanically deboned poultry meat. Mechanically deboned chicken meat and mechanically deboned turkey meat were found to have good emulsion stability when chopped to temperatures of 7.2-12.8°C. Mechanically deboned poultry meat chopped to temperatures greater than 12.8°C had inferior emulsion stability. Hand deboned chicken broiler meat possessed good emulsion stability at chopping temperatures in excess of 12.8°C. Histological examination indicated that mechanically deboned poultry meat had less of a protein matrix available for emulsion formation than hand deboned sources. Mechanically deboned turkey meat produced emulsions with somewhat larger fat globule size than the hand deboned counterparts. Fat coalescence was more prevalent in mechanically deboned turkey meat emulsions. The lack of a protein matrix in the mechanically deboned poultry meat emulsions was postulated to be caused by protein loss due to heat denaturation during the deboning cycle. It was concluded that a combination of hand deboned chicken or turkey meat and mechanically deboned poultry meat would therefore enhance the stability of emulsified products.

Baker et al. (1974) reported that chopping time alone did not significantly affect acceptability of frankfurters made from mechanically deboned poultry meat. Angel et al. (1974) further noted that emulsion formation was complete after a short chopping period of 1 1/2-3 min.

Froning et al. (1971) observed that mechanically deboned turkey meat exhibited higher emulsion capacity than beef, but were lower than pork on a protein-equivalent basis. This order of emulsion capacities was reversed when reported on a total-meat basis. Emulsion stability was

essentially unaffected by the inclusion of 15% mechanically deboned turkey meat to red-meat frankfurters.

Maurer (1973) found that mechanically deboned broiler backs and necks emulsified similar volumes of oils similar to those emulsified by hand deboned counterparts. Spent hen mixtures of backs, necks, and wings emulsified less oil than mixtures of breasts, legs, and thighs. Water-holding capacity was similar for mechanically deboned spent hen meat and hand deboned broiler necks and backs. Combinations of mechanically deboned spent hen backs, necks, and wings and hand deboned breasts, legs, and thighs gave high emulsion capacities and water-holding capacities. Economically and functionally, this combination of hand deboned and mechanically deboned poultry meat was found to be desirable.

Gruuden et al. (1972) reported lower apparent viscosity from deboned meat from female turkey breeder racks when compared to deboned poultry meat from other sources. Viscosity may be an indication of emulsifying ability.

Skin content has been found to markedly affect the emulsifying characteristics of mechanically deboned poultry meat (Froning et al., 1973; Schnell et al., 1973). As skin content of the meat prior to deboning was increased, emulsion capacity and emulsion stability were significantly decreased. The changes in emulsion stability and emulsion capacity (meat basis) were closely related to the higher fat content at higher skin levels. When emulsion capacity was reported as ml of fat emulsified per mg of protein, there was no significant change in emulsion capacity with increasing skin levels.

In a study conducted by Lyon et al. (1978), sensory panelists characterized mechanically deboned - hand deboned poultry meat patties with 0% structured soy protein fibers as more chewy and elastic, coarser in particle size and shape, and more moist than 8% or 16% structured protein patties. Texture, as measured by force to shear a 2.5 cm slice, increased from 2.10 to 2.57 kg as the level of structured protein fiber increased from 0 to 16%.

Firmness in poultry emulsion is generally considered to be a desirable factor (Baker et al., 1972b). A considerable amount of research had been directed at ground, stuffed, cooked poultry meat emulsions. Marshall (1964) and Baker et al. (1969, 1972a) described some of the roll and frankfurter chicken products developed at Cornell University, Ithaca, New York. Other extruded products such as a chicken breakfast sausage (Baker et al., 1967), chicken or turkey liver sausage (Mountney, 1976) and chicken summer sausage (Dawson, 1970) have followed. Although products from all poultry have been acceptable, industry experience (Pauly, 1967) and Dawson (1970) reported that combination products with other meats often rate better because of higher tensile strength. There are many variables, however, that affect the texture and firmness of the finished product. Increasing the protein level increased shear values and toughness of frankfurters (Baker and Darfler, 1975). Research by Schnell et al. (1973) found that the smaller the screen size during mechanical deboning, the more tender were the frankfurters. Hand deboned carcasses produced the firmest frankfurters. According to Young and Lyon (1973), the use of heat treated mechanically deboned meat in chicken

frankfurters caused a loss in firmness and decreased shear with levels higher than 30% heated meat.

McMahon and Dawson (1976) reported that the shear and tear values of fermented turkey sausages were significantly decreased with increasing levels of mechanically deboned meat. Similar results were reported by Dhillon and Maurer (1975b); when mechanically deboned chicken meat was mixed with ground beef or hand deboned chicken meat in various combinations up to 50%, an acceptable summer sausage with good firmness and texture was obtained. Higher percentages of mechanically deboned meat resulted in a product with soft texture (Froning et al., 1973). Collagen content was unchanged with higher skin levels, which may partially explain the emulsion capacity results reported on a protein basis.

The role of certain food additives on functional properties of mechanically deboned poultry meat has been investigated. Baker et al. (1972b) reported that Kena (food-grade phosphates, Merck) improved the stability of frankfurter emulsions, whereas sodium lauryl sulfate had little effect, and ribonucleic acid and fresh egg yolk were detrimental to emulsion stability. Schnell et al. (1973) observed that 0.5% Kena decreased the viscosity of frankfurter emulsions, while sodium caseinate increased the viscosity. Froning (1973) found that chilling spent fowl in 6% Kena prior to deboning improved the emulsion stability and emulsion capacity of the mechanically deboned product.

Froning and Janky (1971) reported that modification of mechanically deboned poultry meat through pH adjustment and/or preblending with salt

affect the emulsion stability of prepared products. Use of food-grade additives to adjust pH may have merit in controlling the variability of mechanically deboned meat. Also, salt preblending could possibly be used in conjunction with pH adjustment to improve the emulsifying ability of mechanically deboned meat sources.

Centrifugation of mechanically deboned poultry meat results in a meat fraction which has improved emulsion characteristics (Froning and Johnson, 1973; Dhillon and Maurer, 1975a,b,c). Both emulsion capacity and emulsion stability are greater in the mechanically deboned fowl meat fraction resulting from centrifugation. The better emulsification capabilities of centrifuged meat fractions is likely related to the higher protein and lower fat contents compared to the control sample.

#### Color and flavor stability

Color and flavor problems of mechanically deboned poultry meat have received considerable emphasis in recent years. Oxygen is oftentimes mixed into the mechanically deboned poultry meat during extrusion, and oxidation is a major concern as a possible prelude to development of flavor and color problems during storage of mechanically deboned poultry meat. In addition, mechanical deboning releases heme and lipid components from the bone marrow which become thoroughly mixed with the meat, and heme components have been shown to act as catalysts in autoxidation of lipids in meat (Tappel, 1955).

Workers have reported substantial quantities of heme components in mechanically deboned poultry meat (Froning et al., 1973; Froning and

Johnson, 1973; Cunningham and Mugler, 1973; Lee et al., 1975).

Mechanical deboning has been shown to triple the heme content compared to hand-deboning. This increase in heme content ultimately affects the color of the mechanically deboned poultry meat by making it redder and darker. Lee et al. (1975) observed 0.20  $\mu$ mole and 0.06  $\mu$ mole hemoglobin and myoglobin, respectively, per g of net weight in mechanically deboned chicken meat. This indicated that hemoglobin is the primary heme component, with no change in myoglobin concentration of mechanically deboned poultry meat compared to hand deboned sources.

Janky and Froning (1975) recently reported that purified myoglobin from mechanically deboned turkey meat is similar to that obtained from hand deboned sources. Myoglobin purified by DEAE-cellulose chromatography showed three distinct fractions electrophoretically. Isoelectric focusing indicated that myoglobin from mechanically deboned turkey meat had lower isoelectric points than similar fractions from hand deboned sources. These lower isoelectric points may indicate heme-protein ion binding. This is possible in mechanically deboned turkey meat because of the degree of contact of the meat with the metal surface of the mechanical deboner. Another source of ions might be the calcium and phosphorus of the bone tissue, which have been observed to act as catalytic agents in heme and lipid oxidation. If the decrease in the isoelectric points of myoglobin from mechanically deboned turkey meat is an indication of ion binding, then increased oxidation of heme proteins and lipids components may be due to ion catalysis in mechanically deboned turkey meat.

Interaction of heme and lipid components in the oxidative process has been studied recently. Lee et al. (1975) found that when hemoproteins were destroyed by prior treatment with  $H_2O_2$ , the catalytic function was decreased to less than 10% of the original activity. They concluded that hemoproteins were the predominant biocatalysts of lipid oxidation in mechanically deboned chicken meat. Furthermore, the ratio of relative concentrations of polyunsaturated fatty acids to hemoproteins was in the range where heme-catalyzed oxidation would occur at near the maximum rate.

Janky and Froning (1975) determined the oxidation rates of both heme proteins and lipids in mechanically deboned turkey meat. Heme and lipid oxidation was followed over a wide range of storage temperatures from  $-30^{\circ}C$  to  $+30^{\circ}C$ . Heme oxidation was determined by measuring the reflectance spectra for each sample at various storage periods. Bidlack et al. (1972) indicated that malonaldehyde concentration may be limited to some extent by the meat system. They also observed a leveling of malonaldehyde concentration in porcine tissue. Malonaldehyde was apparently bound in the tissue by some non-protein entity.

Schnell et al. (1971b) indicated that particle size of mechanically deboned chicken meat influenced TBA values, with smaller particle sizes inducing greater TBA values. Reducing agents decreased TBA values. Schnell et al. (1971a) further noted that the bright-red pigments associated with mechanically deboned cooked meat appeared to be oxyhemoglobin, as indicated by spectral analysis.

Numerous researchers have investigated color and flavor

deterioration in mechanically deboned poultry meat to develop practical approaches to alleviate the problem. Froning et al. (1971) incorporated fresh and stored mechanically deboned turkey meat into frankfurters at the 15% level and compared them to all-red-meat frankfurters. Flavor difference tests, preference tests, and TBA values indicated that frankfurters containing 15% mechanically deboned turkey meat were comparable to all-red-meat frankfurters in flavor stability if fresh deboned poultry meat was used. The use of mechanically deboned turkey meat which had undergone 90 days of frozen storage resulted in a significantly inferior product, as indicated by flavor evaluation and TBA values. Color evaluation showed slight fading of all frankfurter treatments during storage, with no significant differences between treatments.

Dhillon and Maurer (1975b) studied summer sausages formulated with 50% mechanically deboned chicken meat and 50% ground beef, 50% mechanically deboned turkey meat and 50% ground beef, and 100% ground beef (control). Quality measurements of these sausages indicated that the products were well-accepted, and taste panelists did not comment on any flavor differences. There was a slight decline in quality at 6 mo of storage, as indicated by TBA values and taste panel scores. The summer sausages containing mechanically deboned chicken meat showed the greatest quality loss.

Dhillon and Maurer (1975a) found that hand deboned broiler meat from whole carcasses failed to provide a satisfactory cure color in summer sausage, but incorporation of mechanically deboned chicken meat in the

formulation greatly enhanced color development. When mechanically deboned chicken meat was mixed with ground beef in various combinations up to a 50% level, an acceptable product with good color was produced. Centrifuged mechanically deboned chicken meat improved the quality of the products produced. Froning and Johnson (1973) also observed improved storage stability of centrifuged mechanically deboned turkey meat. Removal of some of the heme and lipid components by centrifugation may offer a means of improving the storage stability of mechanically deboned poultry meat.

Baker and Darfler (1975) observed no differences in preference of frankfurters made from mechanically deboned turkey meat using either pork or chicken fat.

Work has generally shown that mechanically deboned poultry meat has quite varied flavor stability in storage. Dimick et al. (1972) observed large increases in carbonyls during refrigerated storage of mechanically deboned poultry meat. In general, deboned meat from turkey frames was the least stable, followed in order by whole spent layers and broiler necks and backs. Johnson et al. (1974) noted significant flavor loss in mechanically deboned turkey meat after 12-14 weeks of frozen storage; this closely agrees with the work of Froning et al. (1971).

The utilization of various additives to maintain flavor stability of mechanically deboned poultry meat has been investigated. MacNeil et al. (1973) found a rosemary spice extractive and BHA-acid to be quite effective in maintaining the flavor stability of mechanically deboned poultry meat. Moerck and Ball (1974) reported that a mixture containing

20% BHA, 6% propylgallate, and 4% citric acid in propylene glycol (Tenox II, Eastman Chemical) added at 0.01% by weight is effective in preventing oxidation in mechanically deboned chicken meat. Froning (1973) observed that chilling of spent fowl in 6% polyphosphate increased flavor stability of mechanically deboned fowl meat in frozen storage. Polyphosphates may be effective in preventing oxidation during the deboning cycle.

Carbon dioxide snow has been used to chill mechanically deboned poultry meat rapidly for microbial control. This practice, however, has been found to increase TBA values in the products, indicating increased lipid oxidation (Uebersax et al., 1977; 1978a; Mast et al., 1979). Nitrogen in gaseous form increased lipid oxidation rates in mechanically deboned poultry meat (Uebersax et al., 1978b). However, some inert gases, such as CO<sub>2</sub>, in the presence of water in the meat tissue, might cause lowering of the meat pH. Watts (1954) stated that lowering of the pH could accelerate oxidation of hemoproteins to their oxidized forms.

#### Microbiological properties and pH

Bacteria such as Pseudomonas and Achromobacter, which have been identified in mechanically deboned poultry meat by Ostovark et al. (1971), can attack and utilize certain carbonyl compounds (Smith and Alford, 1968). Moerck and Ball (1974) suggested that high levels of microorganisms which develop in mechanically deboned poultry meat may remove malonaldehyde and other dicarbonyl compounds. Treatment with 1% Aureomycin maintained reduced the level of microorganisms, but resulted

in TBA values of 50 when stored for 15 days at 4°C.

Depending upon the type of microflora present in meat tissue and growing conditions under which the meat is stored, either increases or decreases in pH can occur (Ockerman et al., 1969; Borton, 1969), and changes in pH influence the emulsifying capacity and emulsion stability of poultry meat (Hudspeth and May, 1967; Parkes and May, 1968; Froning and Neelakantan, 1971; McCready and Cunningham, 1971; Neelakantan and Froning, 1971). These workers have shown that as the pH is elevated towards 7, corresponding increases in the emulsifying capacity and emulsion stability also occur.

Microbial populations in mechanically deboned poultry meat are quite variable and dependent upon factors such as meat source, temperature of deboning, handling, and storage. Mechanically deboned poultry meat, because of its highly-comminuted nature, lends itself to microbial problems. Ostovark et al. (1971) found that total aerobic counts of delayed-processed (held 5 days at 3-5°C before deboning) mechanically deboned chicken meat were higher than in conventionally-processed meat and remained the same throughout the storage period. In all instances, the total aerobic counts increased during storage at 3°C. The most probable numbers fecal coliforms were high for all samples and remained relatively constant throughout the storage period at 3°C. Freezing significantly reduced fecal coliforms. Six of 54 samples were contaminated with *Salmonella*, while four showed the presence of *Clostridium perfringens* and none were contaminated with *Staphylococcus aureus*. *Pseudomonas*, *Achromobacter*, and *Flavobacterium* dominated the

psychrotolerant genera isolated in this study.

Maxcy et al. (1973) found microbial counts in mechanically deboned poultry meat to range from 100,000 to 1,000,000/g, while coliform counts varied from 10 to 1,000/g.

Total microbial load, nature of microflora, and proteolytic activity of the contaminants indicated that the challenge of microbial spoilage was similar to that of red meat products, with no apparent unique microbial problems.

Young and Lyon (1973) investigated possible heat treatment to minimize bacterial loads and pathogens in mechanically deboned poultry meat. Mechanically deboned chicken meat was heated to 65°C (149°F), and frankfurters were prepared with 0, 30, 60, 80, and 100% concentrations of heated mechanically deboned chicken meat. In general, frankfurters were satisfactory when they contained up to 30% heated meat, but higher levels of heated meat produced progressively inferior frankfurters.

Since poultry meat may be a potential source of Salmonella, the processing and cooking of poultry meat products should be studied more thoroughly. While reports are available on the thermal destruction of Salmonella in some poultry meat products, ground products have received only limited attention. Bayne et al. (1965) observed that all S. typhimurium (inoculum levels of  $10^8$  per g.) cells were killed after heating ground chicken muscle for 5 min. at 60°C. Mast and MacNeil (1975) studied the effects of various pasteurization times and temperatures on bacterial counts in mechanically deboned poultry meat and constructed a thermal destruction curve.

### Concerns for the Future

One direct result of overpopulation is that we are looking for other sources of protein that can be combined with meat to make palatable, good flavor profile products, and, in effect, increase the meat supply.

While research has given the processor several alternative methods to lower the cost of production of several meat products by adding non-expensive, high quality protein ingredients to the formulation, further research is needed.

Research interest in headspace volatiles contributed by meat flavors, stimulated during this period, is likely to lead to more new developments in the area of meat combination products in the future.

## OBJECTIVES

This project had the following objectives:

1. To develop a new product utilizing lamb, mutton and mechanically deboned turkey (MDT), which may potentially be acceptable in international markets that have high lamb and mutton consumption.
2. Determine changes in fat stability, sensory characteristics and microbial profile of deboned turkey patties held under different packaging and storage conditions.
3. Evaluate relationships of sensory characteristics, gas chromatography values and lipid oxidation of lamb-mutton-MDT patties.
4. Determine the observed effect of mutton in suppressing fat oxidation when combined with other meat ingredients.

## MATERIALS AND METHODS

This study was divided into three major phases. Phase I was undertaken to study the effects of different meat combinations, packaging methods and storage conditions on rancidity development of combination lamb, mutton and mechanically deboned turkey (MDT) patties.

Phase II was begun after the completion of phase I. In this experiment, the effects of different meat combinations of lamb, mutton and MDT were evaluated for oxidative rancidity and bacterial growth on qualities related to organoleptic evaluation and flavor intensity.

Phase III was conducted to examine the effects of mutton meat, pH and storage time on rancidity development of ground beef, pork and MDT patties.

### Meat Ingredients

Mechanically deboned turkey (MDT), manufactured from large, white toms, using a Yield Master 318-3 (Kartridge Packs, Davenport, IA), was obtained in a fresh, frozen form, from Louis Rich Co., P.O. Box 288, West Liberty, IA. The MDT was transported to the Iowa State University Meat Laboratory, where the MDT was placed in a  $-35^{\circ}\text{C}$  blast freezer.

In addition to the lambs and mutton that were slaughtered at the Meat Laboratory of Iowa State University, lamb meat and fat were purchased from the University of Wyoming Meat Laboratory, while the mutton was purchased from Farm Stead, Albert Lea, Minnesota. All meat was shipped to Ames, Iowa, under frozen conditions in insulated boxes.

Beef rounds and pork ham were obtained from the Meat Laboratory of

Iowa State University.

### Experiment I

Two replications were conducted with three treatments utilizing 200 g patties. The meat treatments were: (1) 10% mutton/60% lamb/10% lamb fat/20% MDT; (2) 15% mutton/55% lamb/10% lamb fat/20% MDT; (3) 20% mutton/50% lamb/10% lamb fat/20% MDT (Table 1). All meat ingredients were analyzed for fat content (AOAC, 1980). Mutton meat was trimmed of all visible fat, and used at levels of 10, 15 and 20% in the meat formulation (Table 1).

Table 1. Experiments I and II, treatments, formulation and total fat %

| Ingredients | Treatments |      |      |     |      |         |     |
|-------------|------------|------|------|-----|------|---------|-----|
|             | Mutton %   |      |      |     | Lamb | Lambfat | MDT |
|             | 10         | 15   | 20   | 100 |      |         |     |
| Mutton      | 10         | 15   | 20   | 100 | 0    | 0       | 0   |
| Lamb        | 60         | 55   | 50   | 0   | 100  | 0       | 0   |
| Lamb fat    | 10         | 10   | 10   | 0   | 0    | 100     | 0   |
| MDT         | 20         | 20   | 20   | 0   | 0    | 0       | 100 |
| Total fat   | 20         | 19.9 | 19.8 | 9   | 11   | 85      | 20  |

All combinations of treatments contained a constant amount of 20% MDT and were adjusted to 20%  $\pm$ 1 total fat by varying the ratio of lamb fat and lamb lean meat added.

Lamb lean meat and fat, and mutton were ground once through a BIRO grinder (Model 7.5, The RIBO MFG. Co.) fitted with a 4.76 mm (3/16 inch)

plate. MDT was flaked using a Butcher Boy Flaker (Model C.M.F., Lasar MFG. Co.). After flaking, the frozen-flaked MDT trim ( $-16^{\circ}\text{C}$ ) was weighed and combined with the ground lamb lean meat and fat, and mutton into each formulation containing 10, 15 and 20% mutton meat. Each mutton formulation was then mixed for 1 minute using a Leland mixer (Model 100 DA, Leland Detroit MFG Co.), and reground (3.175 mm or 1/8 inch plate) before patty formulation.

#### Patty formulation

After preparation of the different meat combinations, three types of patties were formulated: 10, 15, and 20% mutton (Table 1). Each formulation was mechanically formed into patties with a Hollymatic (Model 500A) patty machine. Patties weighed approximately 113.5 grams with a diameter of 11.0 cm and a thickness of 1.0 cm. All patties contained approximately 20% fat. Patties were formed when MDT trim temperature was  $5^{\circ}\text{C}$ .

#### Packaging and storage

Two flexible films were used: (1) low density polyethylene film over wrap, and (2) a composite Curlon X/K-28 (nylon/saran/curpolymer/surlyn co-extrusion) vacuum packaging bags (Curwood, Inc., New London, WI). These bags have an oxygen permeability of less than 1 cc per 645 square centimeters for 24 hours at  $22.8^{\circ}\text{C}$  with 0% relative humidity, and a moisture vapor transmission of less than 0.5 gram per 645 square centimeters for 24 hours at  $37.8^{\circ}\text{C}$  and 90% relative humidity. A vacuum of 8.13 kilopascals was pulled on the Koch Multivac

(Model MG2).

Storage treatments included two temperatures: 4°C and -15°C. The meat to be stored under frozen conditions was placed in a blast freezer (-35°C) for 24 hours before storage at -15°C. Analyses were performed at 0, 2, 4, 6, 8 days of refrigeration, and at frozen storage periods of 0, 30, 60, 90, 120 days.

#### Experiment II

Similar procedures of preparation as in Experiment I were used. Two replicates with seven treatments each of 113.5 g patties. Treatment consisted of: (1) 10% mutton/60% lamb/10% lamb fat/20% MDT; (2) 15% mutton/55% lamb/10% lamb fat/20% MDT; (3) 20% mutton/50% lamb/10% lamb fat/20% MDT; (4) 100% mutton; (5) 100% lamb; (6) 100% lamb fat; (7) 100% MDT (Table 1). All combination treatments (treatments 1, 2, and 3) contained 20% + 1 total fat. In Experiment II, only vacuum packaging and frozen storage were tested at 0, 5, 10, 15, 30, 180 days of storage.

#### Experiment III

The general processing discussed in Experiment I also was used in this experiment. Three replicates with ten treatments, each of 454 g (1 lb.) patties. The treatments consisted of: (1) 15% mutton/74% beef/11% lamb fat; (2) 30% mutton/60% beef/10% lamb fat; (3) 100% beef; (4) 15% mutton/75% pork/10% lamb fat; (5) 30% mutton/61% pork/9% lamb fat; (6) 100% pork; (7) 100% mutton; (8) 15% mutton/85% MDT; (9) 30% mutton/70% MDT; (10) 100% MDT (Table 2). All treatments were vacuum packaged; however, treatments one through seven were tested at 0, 7 and 14 days of

refrigerated storage, while treatments eight to ten, at 0, 15 and 30 days of frozen storage.

Table 2. Experiment III, treatments, formulation, storage conditions and total fat %

| Treatment no. | Formulation                      | Storage conditions  | Total fat % |
|---------------|----------------------------------|---------------------|-------------|
| 1             | 15% mutton/74% beef/11% lamb fat | Refrigeration (0°C) | 15.0        |
| 2             | 30% mutton/60% beef/10% lamb fat | Refrigeration (0°C) | 15.0        |
| 3             | 100% beef                        | Refrigeration (0°C) | 4.5         |
| 4             | 15% mutton/75% pork/10% lamb fat | Refrigeration (0°C) | 15.0        |
| 5             | 30% mutton/61% pork/9% lamb fat  | Refrigeration (0°C) | 15.0        |
| 6             | 100% pork                        | Refrigeration (0°C) | 6.1         |
| 7             | 100% mutton                      | Refrigeration (0°C) | 12.6        |
| 8             | 15% mutton/85% MDT               | Frozen (-15°C)      | 19.7        |
| 9             | 30% mutton/70% MDT               | Frozen (-15°C)      | 18.5        |
| 10            | 100% MDT                         | Frozen (-15°C)      | 21.0        |

#### Chemical Evaluation

##### Thiobarbituric acid (TBA) measurement

Lipid oxidation was monitored using the TBA procedure as described by Tarladgis et al. (1960). In this TBA test procedure, triplicate 10 g samples were blended with 50 ml of distilled water, after which this mixture was transferred with 47.5 ml additional water into a Kjeldahl flask. Hydrochloric acid solution (4 N) was added in the amount of 2.5 ml in addition to 5 drops antiform and 3-4 boiling chips. The flask was connected to a cooling condenser, heat was applied, and 50 ml of distillate were collected.

After distillation, 5 ml of distillate were added to each test tube

(or 5 ml distilled water for the blank) along with 5 ml of TBA reagent. (TBA reagent was prepared with 0.1442 g 2-thiobarbituric acid in 50 ml of 90 percent glacial acetic acid.) The test tube was capped and placed in boiling water for 35 minutes, after which it was cooled. The solution was then analyzed on a Beckman model ACTA CIII spectrophotometer (Beckman Instruments Inc., San Ramon, CA) set to read absorbance at 532 nm. Standard curves were derived using TEP (1,1,3,3-tetraethoxypropane). Absorbance readings obtained were multiplied by 7.6 to arrive at a TBA number.

#### Proximate analysis

Moisture and fat percentages were determined using A.O.A.C. procedures (A.O.A.C., 1980).

#### pH analysis

The pH was determined using a Corning (model 125) meter. Fresh buffer solutions were used to standardize and calibrate the electrode.

Direct measurements on meat were taken, using a probe electrode with 5 readings at various positions within the patties utilized to obtain representative pH readings. Effort was made to ensure that proper contact occurred between the meat sample and the electrode membrane junctures.

#### Sensory Evaluation

Sensory evaluation panels were conducted to determine the presence of any detectable off-flavors of oxidative rancidity from main treatments

and/or storage effects which could then be correlated with TBA number estimates of lipid oxidation.

Meat patties were randomly selected and thawed overnight at 4°C. Cooking was done on a Wolf gas griddle measuring approximately 71 cm long by 91 cm wide. Temperature was set at 350°C; the patties were fried for 4 1/2 minutes on each side.

After removal from the griddle, the cooked patties were then cut into nine pieces. They were transferred into chafing dishes measuring approximately 30 cm x 48 cm x 9 cm that were divided into three compartments with aluminum foil; each was labeled with a 3-digit number derived from a random number table.

All sensory evaluation panels were conducted at the Iowa State University Meats Laboratory. Participants were untrained volunteer students and staff from the University, and they were specifically asked to make their selection and ratings based on flavor, texture, juiciness, and overall acceptability. The consent survey form and hedonic scale form used in sensory evaluations are demonstrated in Figures 1 and 2, respectively. A seven-point hedonic scale was used with 1 representing "dislike extremely" and 7 "like extremely"; participants were offered warm-up samples before actual testing and were allowed to freely select as many test samples as required for their decisions. Water was offered at room temperature for mouth rinsing between samples. Sensory panels were conducted until the TBA values reached 2.00 mg of malonaldehyde per gram of meat.

## SENSORY EVALUATION FORM

The taste panel for which you have volunteered will involve your evaluation of various meat products. Samples, identified by only a random number, will be presented to you for your tasting and scoring on the evaluation form provided. All samples are entirely wholesome and safe for consumption. Differences occur only in palatability characteristics with no personal risks or discomforts involved in tasting the samples. If you so desire, you may discontinue your participation on the panel at any time. We will also be available at any time to answer questions that you may have.

I have read this document and I consent to participation on the taste panel described.

DATE \_\_\_\_\_ SIGNATURE \_\_\_\_\_

-----

PLEASE FILL OUT THE QUESTIONNAIRE ABOUT YOURSELF; THEN USE THE FOLLOWING PAGES TO EVALUATE THE CODED SAMPLES.

## CONSUMER SURVEY

Please answer the following questions about yourself:

1. SEX: \_\_\_\_\_ Male \_\_\_\_\_ Female

2. Age group

\_\_\_\_\_ 1-20  
 \_\_\_\_\_ 20-30  
 \_\_\_\_\_ 30-40  
 \_\_\_\_\_ 40-50  
 \_\_\_\_\_ over 50

3. How often do you eat \_\_\_\_\_ LAMBURGER \_\_\_\_\_ ?

\_\_\_\_\_ Several times a week  
 \_\_\_\_\_ Once a week  
 \_\_\_\_\_ Several times a month  
 \_\_\_\_\_ Once a month  
 \_\_\_\_\_ Several times a year  
 \_\_\_\_\_ Never

PLEASE TAKE A WARM-UP SAMPLE FIRST, FOLLOWED BY A DRINK BETWEEN EACH SAMPLE.

Figure 1. Consent-survey form for sensory evaluation panels

| Sample Code _____ |   | Flavor | Texture | Juiciness | Overall Acceptability | Intensity Color |
|-------------------|---|--------|---------|-----------|-----------------------|-----------------|
| Like extremely    |    |        |         |           |                       |                 |
|                   |    |        |         |           |                       |                 |
|                   |    |        |         |           |                       |                 |
| Neutral           |   |        |         |           |                       |                 |
|                   |  |        |         |           |                       |                 |
|                   |  |        |         |           |                       |                 |
| Dislike extremely |  |        |         |           |                       |                 |
| Comments:         |   |        |         |           |                       |                 |

Figure 2. Hedonic scale test form for sensory evaluation panels

## GC Parameters

A Tracor Gas Chromatograph with flame ionization detector (Model 540) was used in this study. The oven was programmed from  $-15^{\circ}\text{C}$  to  $250^{\circ}\text{C}$ , increasing at rates of  $5^{\circ}\text{C}/\text{min}$  to  $-7^{\circ}\text{C}$ , then at  $2.5^{\circ}\text{C}/\text{min}$  to  $10^{\circ}\text{C}$ , and finally at  $15^{\circ}\text{C}/\text{min}$  to  $250^{\circ}\text{C}$ . A Supelco capillary column phase SE-54 (catalog #2-4001) was utilized.

Detector and injector temperatures were held at  $275^{\circ}\text{C}$  and  $251^{\circ}\text{C}$ , respectively. The range was at  $10^{-14}$  AMPS/MV. A Shimadzu-C-R3A (Shimadzu Corporation, Kyoto, Japan) integrator was used, with an attenuation of 4, a peak width of 0.04 minutes and a chart speed of 5 cm/min. The flow rate at the end of the column was 0.71 ml/min, with a split of 1:16. Methane was eluted at 2.30 minutes on the SE-54 at  $110^{\circ}\text{C}$  helium as a carrier gas.

Sample injection

A 10 ml maximum capacity gas tight Precision Sampling syringe was utilized for sample injection. An aluminum sleeve was placed around the barrel of the syringe, in order to keep the syringe temperature at  $90^{\circ}\text{C}$  so the meat volatiles would not condense on the inside surfaces upon injection. The syringe needle was inserted through the vial's septa, into the volatile layer above the meat sample ( $90^{\circ}\text{C}$ ). Care was taken not to contaminate the needle with solid sample. The syringe plunger was raised and lowered 2 times to ensure adequate flushing of the syringe and sampling of the head space before the final sample was pulled slowly into the syringe barrel. The plunger was pulled all the way up to the 10 ml

level, and the needle wiped clean with a Kimwipe. The syringe was then quickly transported to the GC, where the needle was inserted into the injection port septa, and the volatile contents emptied onto the GC column. The start button for the temperature program was pressed immediately and the integrator started. The syringe was then vacuum cleaned to remove any remaining volatiles before the next injection. Peak and peak area comparisons were examined on the resulting chromatograms.

#### Standard Plate Count

The standard plate count procedure of Gilliland et al. (1976) was performed on all samples. Thirty grams of ground meat were blended with 270 ml of 0.1% peptone solution for 2 minutes. Samples were plated onto disposable petri dishes and covered with trypticase soy agar (TSA) media. Dilutions were done according to Diagram 1. Plates were incubated at 32°C for a 48-hour period, after which colonies were counted.

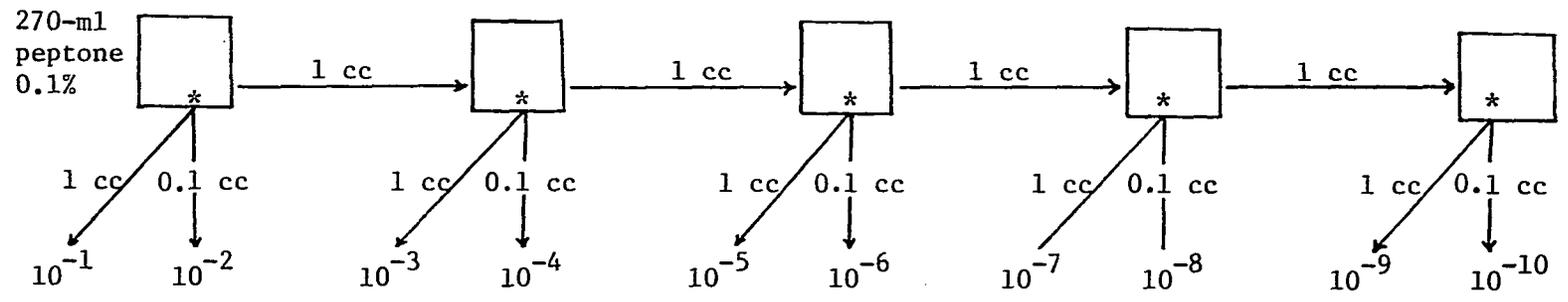
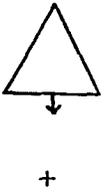
#### Psychrotrophic Count

The psychrotrophic count was determined as in standard plate count, except that incubation took place for 10 days at 5°C (Gilliland et al., 1976).

#### Presumptive Staphylococcus

The presumptive Staphylococcus were determined using the method of Baird-Parker (1962). Bacteria were counted by surface plating on Baird-Parker agar (DIFCO) and incubated at 37°C for 48 hours. Black colonies

30 g  
meat



\* = 99 ml of 0.1% peptone

Diagram 1. Dilution method for bacterial plate counts

presenting a clearing zone around them were considered to be presumptive S. aureus.

#### Coagulase test

Coagulase is an enzyme and a precursor of a thrombin-like substance which coagulates blood plasma. This test was performed on a random selection of the presumptive isolates comprising approximately 10% of the total (Hoover et al., 1983). The test: dilute citrated, oxalated or heparinized human or rabbit plasma 1 in 10 with isotonic saline or other suitable diluent; 0.5 ml of diluted plasma was pipetted into a small test tube, and 2-3 drops of a young (12-18 hours) broth culture were added. The tube was incubated at 37°C and examined every hour for 4 hours. Coagulate confirmation indicated that 57% of the presumptive colonies counted were S. aureus. Plate count data were transformed into logarithms for statistical analysis.

#### Statistical Analysis

Experiments I, II and III were designed following the split-plot technique with treatments as a whole plot unit and storage time as the split-plot unit. They were analyzed by regression analysis in accordance with procedures outlined by Snedecor and Cochran (1982).

Data collected were processed by the Statistical Analysis System (SAS) developed by the SAS Institute Inc., Cary, NC.

## RESULTS AND DISCUSSION

In a preliminary experiment, sensory taste panels were conducted to determine the effect of incorporating mechanically deboned turkey (MDT) at different levels on sensory characteristics of the meat patties. Panelists preferred the patties containing 20% MDT over the patties containing 10, 15, 25 and 30% MDT (data not presented). All patties were blended with mutton and lamb lean and lamb fat.

## Experiment I

The analysis of variance with a split-plot design in a 3x2 factorial arrangement of meat treatments x film types x storage time is shown in Table 3.

In this experiment, meat treatments (Table 3) and the interaction of meat treatments by film types and meat treatments by storage time did not have a significant ( $p > 0.05$ ) effect on thiobarbituric acid (TBA) values at 4°C or -15°C storage temperatures. All patties had the same fat and MDT content and therefore TBA values would not be expected to differ among the various meat treatments. Patties packaged in overwrap film had significantly higher ( $p < 0.05$ ) TBA values than patties packaged in composite film for both refrigerated and frozen storage conditions (Table 4). TBA values increased considerably in patties packaged in overwrap film during both refrigerated storage (Figure 3) and frozen storage (Figure 4). However, when patties were packaged under vacuum, no changes in TBA values were found for either refrigerated (Figure 3) or frozen storage (Figure 4).

Table 3. Effects of meat treatments, replicates, film type and overall storage time under refrigerated (4°C) and frozen (-15°C) storage on thiobarbituric acid<sup>a</sup> (TBA) values from analysis of variance in Experiment II

| Source                                     | d.f. | Mean squares |         |
|--|------|--------------|---------|
|  |      | Refrigerated | Frozen  |
| Meat treatments                            | 2    | 2.747        | 0.316   |
| Meat x replicates                          | 2    | 3.815        | 0.768   |
| Film types                                 | 1    | 432.715*     | 23.991* |
| Film types x meat treatments               | 2    | 2.507        | 0.278   |
| Film types x meat treatments x replicates  | 2    | 21.307       | 1.351   |
| Storage time                               | 4    | 57.310***    | 5.227** |
| Storage time x meat treatments             | 8    | 0.923        | 0.142   |
| Storage time x film types                  | 4    | 60.552***    | 3.578*  |
| Storage time x film type x meat treatments | 8    | 5.609        | 0.093   |
| Residual                                   | 25   | 5.412        | 1.015   |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.

\*,\*\*,\*\*\*p<0.05, p<0.01, and p<0.001, respectively.

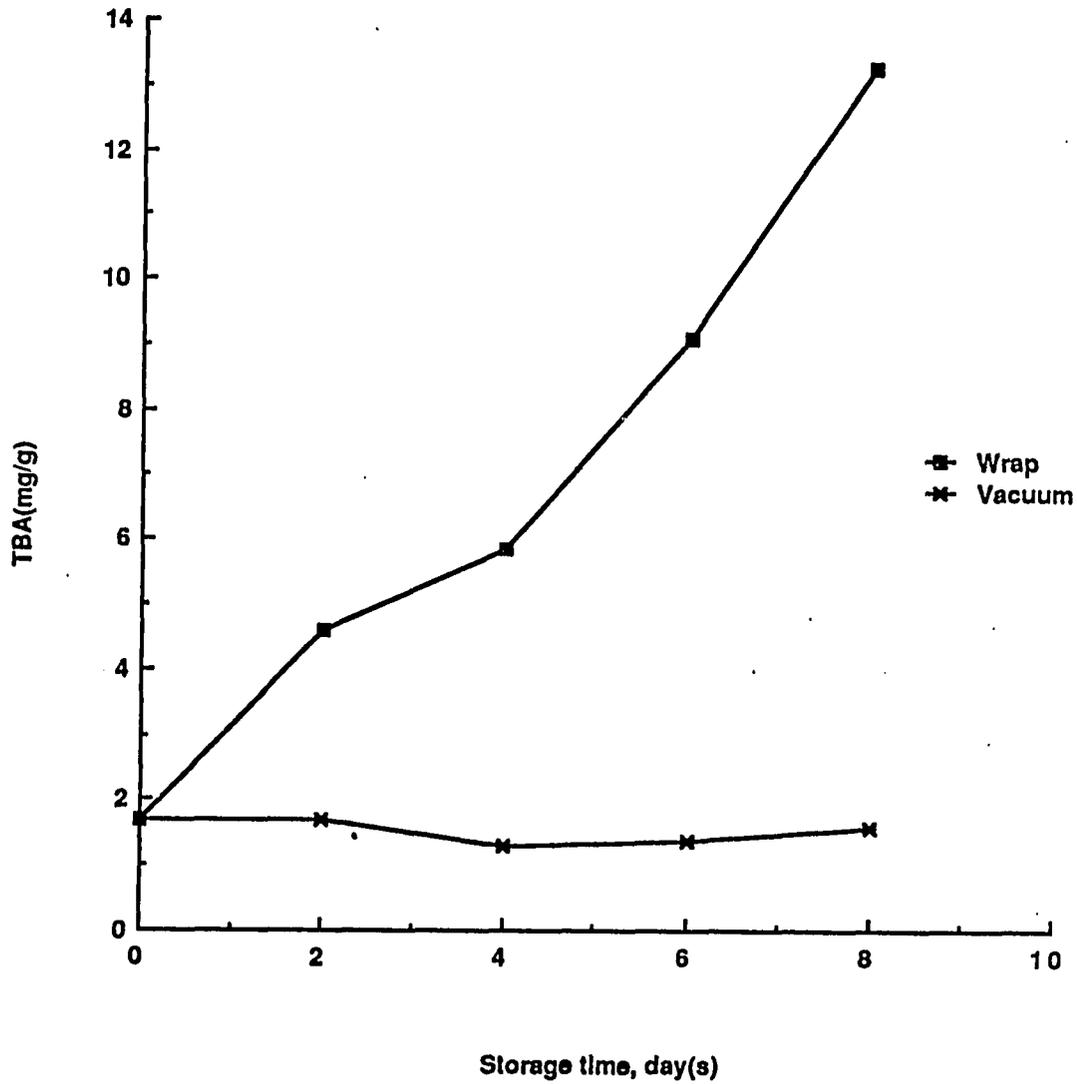


Figure 3. Effects of film type and refrigerated storage time on thiobarbituric acid (TBA) values averaged over all meat combinations, Experiment I

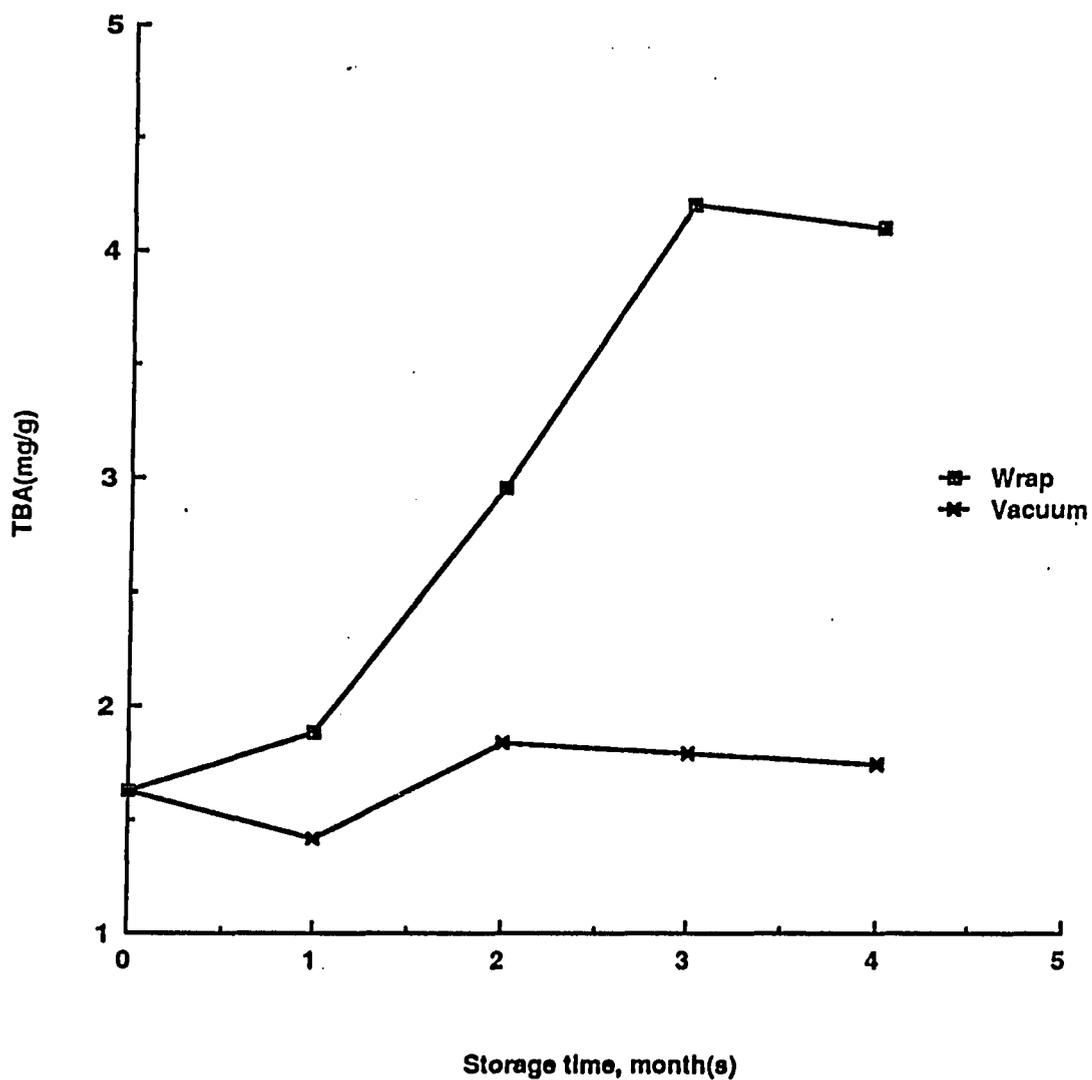


Figure 4. Effects of film types and frozen storage time on thiobarbituric acid (TBA) values averaged over all meat combinations, Experiment I

In vacuum packages, air is removed and remaining tissue respiration could convert residual oxygen to carbon dioxide. This may increase the proportion of carbon dioxide to as high as 80% of the package atmosphere (Seideman et al., 1979). However, Sander and Soo (1978) had shown that levels of 12-25% or more carbon dioxide were inhibitory to gram negative aerobes. This favors the growth of facultative anaerobes, with Lactobacillus spp. frequently dominating in vacuum packaged fresh meat as was concluded by Beebe et al. (1976). The result was an appreciable extension of shelf life compared to the highly permeable film (Sebranek, 1986).

Storage time under refrigerated ( $p < 0.001$ ) or frozen ( $p < 0.01$ ) conditions proved to be a highly significant source of variation in TBA numbers (Table 4). These TBA values could indicate a significantly inferior product (Froning et al., 1971).

As shown in Table 4 under refrigerated storage, initial and Day 2 TBA values were not significantly ( $p > 0.05$ ) different from values for Day 4, but a significant ( $p < 0.05$ ) increase in TBA values on Days 6 and 8 were observed; however, Day 8 TBA value was significantly ( $p < 0.05$ ) higher than TBA values on Days 4 and 6. In frozen storage (Table 4), initial and Month 1 TBA values were not significantly ( $p > 0.05$ ) different than Month 2 TBA value, but were significantly ( $p < 0.05$ ) lower from TBA values of Months 3 and 4. TBA values of Months 3 and 4 were not significantly ( $p > 0.05$ ) higher than TBA values of Month 2 (Table 4). Despite the contributions of vacuum packaging and film barriers to product stability, temperature is a highly critical factor in influencing flavor shelf life

Table 4. Effects of meat treatments, film type and storage time on thiobarbituric acid<sup>a</sup> (TBA) values of meat patties in Experiment I

|                       | Refrigerated<br>storage, 4°C | Frozen<br>storage, -15°C |
|-----------------------|------------------------------|--------------------------|
| <b>Meat treatment</b> |                              |                          |
| 10% mutton            | 4.406                        | 2.250                    |
| 15% mutton            | 3.782                        | 2.244                    |
| 20% mutton            | 4.439                        | 2.464                    |
| S.E.M.                | 0.437<br>(n=20)              | 0.196<br>(n=20)          |
| <b>Film type</b>      |                              |                          |
| Overwrap              | 6.895 <sup>b</sup>           | 2.952 <sup>b</sup>       |
| Composite             | 1.524 <sup>c</sup>           | 1.687 <sup>c</sup>       |
| S.E.M.                | 0.843<br>(n=30)              | 0.212<br>(n=30)          |
| <b>Storage time</b>   |                              |                          |
| Day(s)                |                              |                          |
| 0                     | 1.683 <sup>b</sup>           |                          |
| 2                     | 3.159 <sup>b</sup>           |                          |
| 4                     | 3.575 <sup>b,c</sup>         |                          |
| 6                     | 5.227 <sup>c</sup>           |                          |
| 8                     | 7.402 <sup>d</sup>           |                          |
| S.E.M.                | 0.672<br>(n=12)              |                          |
| <b>Month(s)</b>       |                              |                          |
| 0                     |                              | 1.633 <sup>b</sup>       |
| 1                     |                              | 1.65 <sup>b</sup>        |
| 2                     |                              | 2.398 <sup>b,c</sup>     |
| 3                     |                              | 2.997 <sup>c</sup>       |
| 4                     |                              | 2.918 <sup>c</sup>       |
| S.E.M.                |                              | 0.291<br>(n=12)          |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.  
<sup>b,c,d</sup>Means within each column with different letters are significantly different (p<0.05).

because of its effect on the rate of oxidation reactions.

Generally, the rate of chemical reaction is related to temperature according to the Arrhenius equation. Refrigerated storage of MDT delays or slows down the oxidation rate, and frozen storage further inhibits this reaction, but they do not stop it completely. Dawson and Gartner (1983) reported that MDT enhanced fat rancidity when added to other meat mixtures. Heme iron was believed to be the prooxidant in MDT which contributed to fat rancidity in studies by Froning and Johnson (1973) and Lee et al. (1975). The mechanism involved in heme-catalyzed lipid oxidation has been considered to be the catalytic decomposition of hydroperoxides to generate free radicals (Lee et al., 1975). This mechanism involves the formation of a coordinate between the heme compound and lipid hydroperoxide, followed by homolytic scission of the peroxide bond. There would be no change in the balance of heme iron. Thus, many food products containing mechanically deboned poultry meat can still become rancid and unappetizing when held for long periods of time in the frozen state.

#### Experiment II

In this experiment, ground meat patties of lamb, mutton and combinations of lamb, mechanically deboned turkey (MDT) and mutton with the MDT constant and varying amount of lamb and mutton were used.

#### Sensory evaluation

Analyses of variance for sensory measures for meat treatments and storage time are shown in Table 5. Significant effects ( $p < 0.001$ ) of meat

Table 5. Effects of meat treatments, replicates and overall storage time on sensory characteristics from analyses of variance in Experiment II

| Source                         | d.f. | Mean squares |             |             | Overall acceptability |
|--------------------------------|------|--------------|-------------|-------------|-----------------------|
|                                |      | Flavor       | Texture     | Juiciness   |                       |
| Meat treatments                | 4    | 1035.22***   | 1076.583*** | 1149.613*** | 1180.153***           |
| 10% mutton vs. all others      | 1    | 64.465*      | 191.691**   | 148.591*    | 72.253                |
| 15% mutton vs. all others      | 1    | 224.108**    | 211.554**   | 230.736**   | 468.438**             |
| 20% mutton vs. all others      | 1    | 470.802***   | 334.460***  | 540.740**   | 325.385**             |
| 100% mutton vs. all others     | 1    | 4056.095***  | 4290.802*** | 4546.064*** | 4637.885***           |
| Meat treatments x replicates   | 4    | 4.133        | 3.758       | 11.900*     | 14.932                |
| Storage time                   | 3    | 11.459       | 12.119*     | 66.364***   | 20.311                |
| Storage time x meat treatments | 12   | 39.120***    | 29.786***   | 50.368***   | 50.732**              |
| Residual                       | 15   | 4.445        | 3.566       | 3.799       | 11.747                |

\*, \*\*, \*\*\* $p < 0.05$ ,  $p < 0.01$ , and  $p < 0.001$ , respectively.

treatments on sensory characteristics were detected. Storage time influenced texture and juiciness scores significantly ( $p < 0.05$  and  $p < 0.001$ , respectively). A significant ( $p < 0.01$ ) interaction between meat treatment by storage time was found (Table 5). The patties containing 100% mutton drastically changed in sensory qualities compared to other patties combinations across storage time (Figures 5, 6, 7, and 8).

As shown in Table 6, the patties made with 100% lamb and 20% mutton had significantly ( $p < 0.05$ ) higher flavor scores than patties made of 10% mutton or 100% mutton. The patties containing 15% mutton were not significantly ( $p > 0.05$ ) different in flavor from all other patties except the meats made of 100% mutton. These results are surprising because

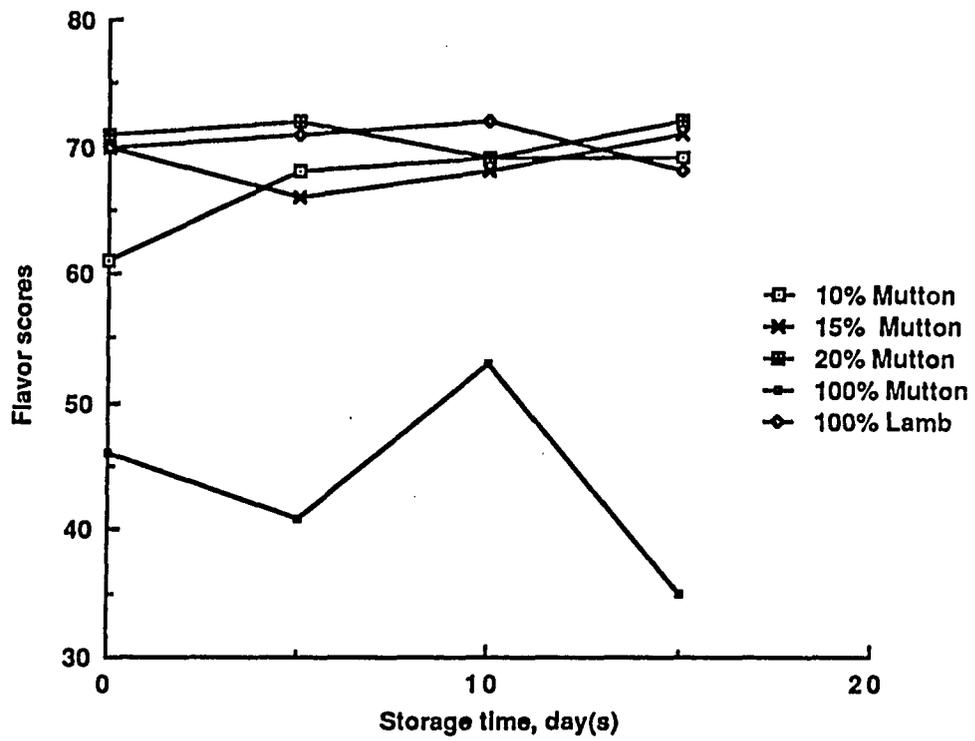


Figure 5. Sensory flavor scores of meat treatments at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

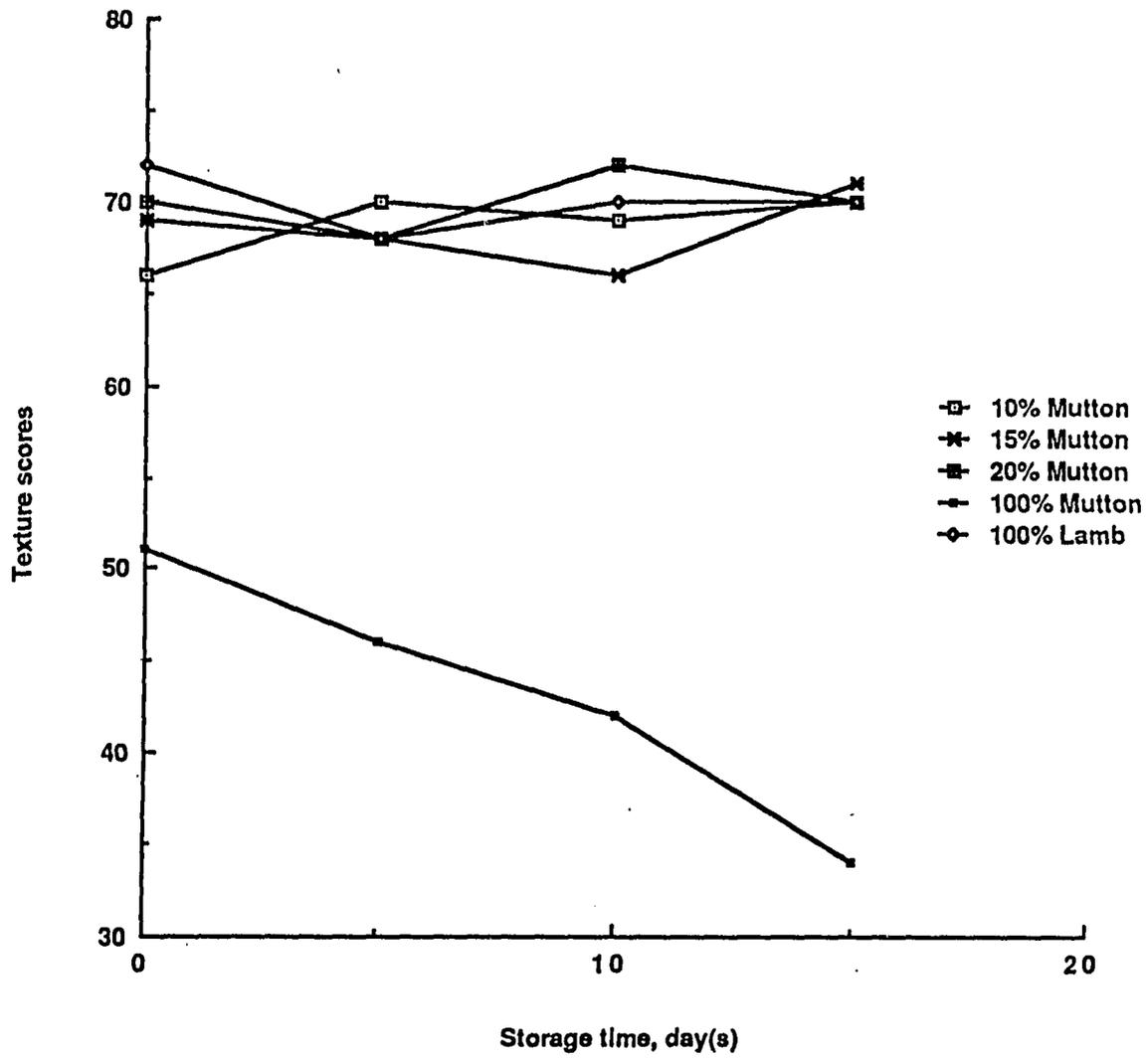


Figure 6. Sensory texture scores of meat treatments at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

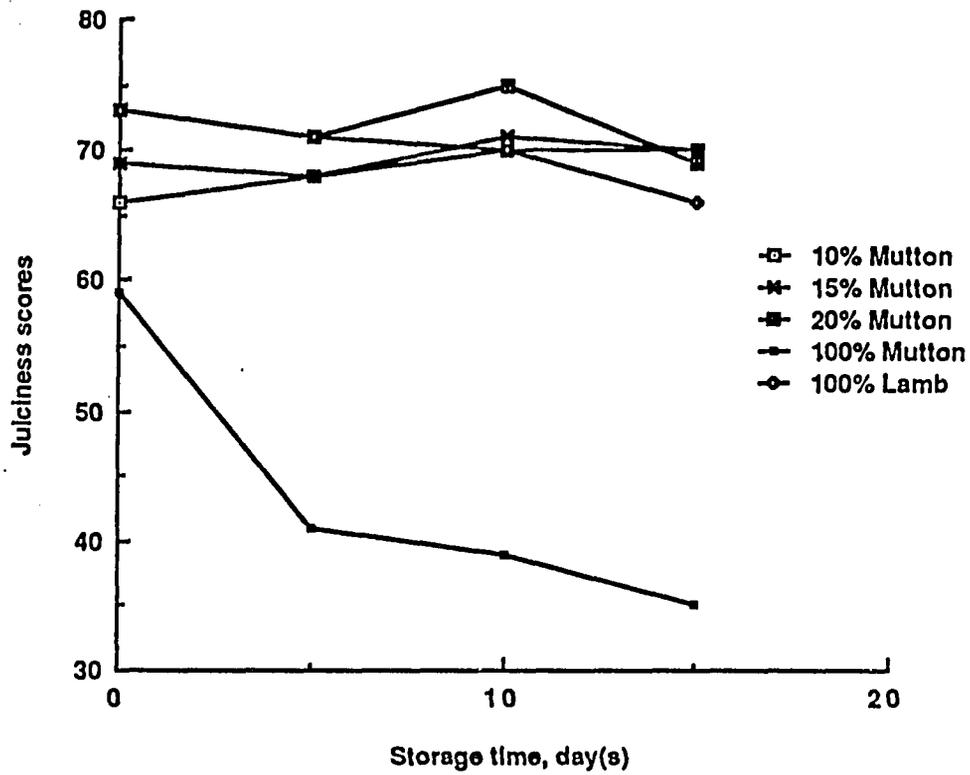


Figure 7. Sensory juiciness scores of meat treatments at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

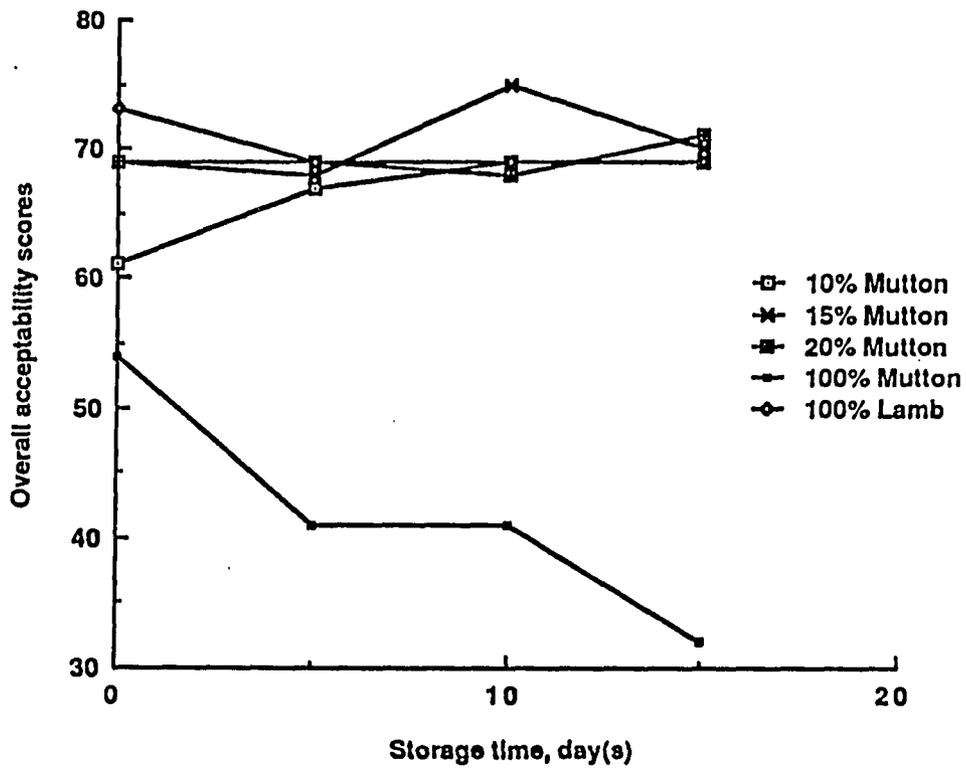


Figure 8. Sensory overall acceptability scores of meat treatments at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

the patties made with 100% mutton had the lowest flavor scores. Yet, when the amount of mutton used in the combination patties increased, the flavor scores increased. The patties containing 15% and 20% mutton were not significantly different ( $p>0.05$ ) in flavor from the patties made with 100% lamb.

In the other sensory characteristics (texture, juiciness and overall acceptability), the patties made with 100% mutton had significantly ( $p<0.05$ ) lower ratings than all other patties (Table 6). The 100% lamb patties and the combination patties were not significantly ( $p>0.05$ ) different in texture, juiciness and overall acceptability. However, the patties made with 20% mutton had the highest sensory scores compared to the other combination patties (10% and 15% mutton) and had similar scores on the 100% lamb patties. These results indicate that increasing mutton levels in the combination generally improved the sensory properties of the patties. Maybe the addition of mutton to the lamb-MDT patties gave an effective advantage in suppressing, in an unknown way, the off-flavor contributed from MDT addition to the formulation.

Sensory scores generally decreased during the 15-day frozen storage (Table 6). The scores for flavor, texture and juiciness characteristics were more significant ( $p<0.05$ ) at Day 0 than at Day 15. No significant ( $p>0.05$ ) difference was found in overall acceptability from Day 15; however, scores were the highest at Day 0 and lowest at Day 15.

The presence of MDT in combination treatments significantly increased patties' flavor, texture, juiciness and overall acceptability over 100% mutton patties mean scores averaged over storage time. MDT,

Table 6. Effects of meat treatments and storage time on sensory characteristics<sup>a</sup> in Experiment II

|                 | Flavor              | Texture             | Juiciness         | Overall acceptability |
|-----------------|---------------------|---------------------|-------------------|-----------------------|
| Meat treatments |                     |                     |                   |                       |
| 10% mutton      | 66.6 <sup>b</sup>   | 68.4 <sup>b</sup>   | 68.6 <sup>b</sup> | 66.4 <sup>b</sup>     |
| 15% mutton      | 68.7 <sup>b,c</sup> | 68.6 <sup>b</sup>   | 69.6 <sup>b</sup> | 70.5 <sup>b</sup>     |
| 20% mutton      | 70.9 <sup>c</sup>   | 69.8 <sup>b</sup>   | 72.1 <sup>b</sup> | 69.4 <sup>b</sup>     |
| 100% mutton     | 43.9 <sup>d</sup>   | 43.3 <sup>c</sup>   | 43.4 <sup>c</sup> | 42.1 <sup>c</sup>     |
| 100% lamb       | 70.0 <sup>c</sup>   | 70.0 <sup>b</sup>   | 70.1 <sup>b</sup> | 70.0 <sup>b</sup>     |
| S.E.M.          | 0.179<br>(n=8)      | 0.685<br>(n=8)      | 1.220<br>(n=8)    | 1.366<br>(n=8)        |
| Storage time    |                     |                     |                   |                       |
| Day(s)          | 65.6 <sup>b</sup>   | 65.6 <sup>b</sup>   | 68.1 <sup>b</sup> | 65.3                  |
| 5               | 63.7 <sup>b,c</sup> | 63.8 <sup>b,c</sup> | 63.8 <sup>c</sup> | 62.9                  |
| 10              | 63.6 <sup>b,c</sup> | 63.8 <sup>b,c</sup> | 65.1 <sup>c</sup> | 64.3                  |
| 15              | 63.1 <sup>c</sup>   | 63.0 <sup>c</sup>   | 62.0 <sup>d</sup> | 62.1                  |
| S.E.M.          | 0.667<br>(n=10)     | 0.597<br>(n=10)     | 0.616<br>(n=10)   | 1.084<br>(n=10)       |

<sup>a</sup>Expressed as percent preference of panelist.  
<sup>b,c,d</sup>Means within each column with different letters are significantly different (p<0.05).

when combined with mutton meat, also may enhance the texture and juiciness by increasing the softness of patties combined with mutton meat upon cooking, due to the paste like and loss of myofibril structure of MDT (Maurer, 1979) and its high unsaturated fatty acid content (Allen and Foegeding, 1981). Also, patties formulated from 100% mutton were ranked lower for all organoleptic qualities (Wenham, 1974) than other formulation, irrespective of storage period, probably due to its volatiles composition (Wong et al., 1975) and the nature of collagen crosslinking

in meat obtained from older animals (Aberle and Mills, 1983).

Perhaps no characteristic of meat and meat products, with the possible exception of tenderness, is so important to consumer acceptance as is flavor (Doty et al., 1961). Although this acceptance involves all the consumer's senses, especially taste and smell, the relative importance and contribution of each is still in doubt (Teranishi et al., 1971). The characteristic flavor of sheep meat has been cited as the reason for its low consumption, less than 1.6% of the total amount of red meat eaten (Ziegler and Daly, 1968). Although Wasserman and Talley (1968) reported that the flavor of lamb is so characteristic it can be identified by people with little previous exposure, the distinction between the "characteristic" flavors of lamb and mutton meat has not been well-defined. People apparently differ in their concept of what constitutes mutton flavor. Mutton meat may have an entirely different flavor, or may merely represent a change in concentration. The ability to distinguish between lamb and mutton flavors varies among people. In preliminary studies on threshold tests, Batcher et al. (1969) found 3 out of 14 people tested were able to detect mutton flavor in ground lamb patties containing 15% mutton, 7 were able to detect the flavor in patties containing 15-35% mutton, and the remaining 4 people required more than 35% mutton in the patties before the presence of mutton flavor was detected.

#### Gas chromatography (GC)

Chromatogram analysis typically reveals two kinds of information:

(1) identification of a compound by its retention time, and

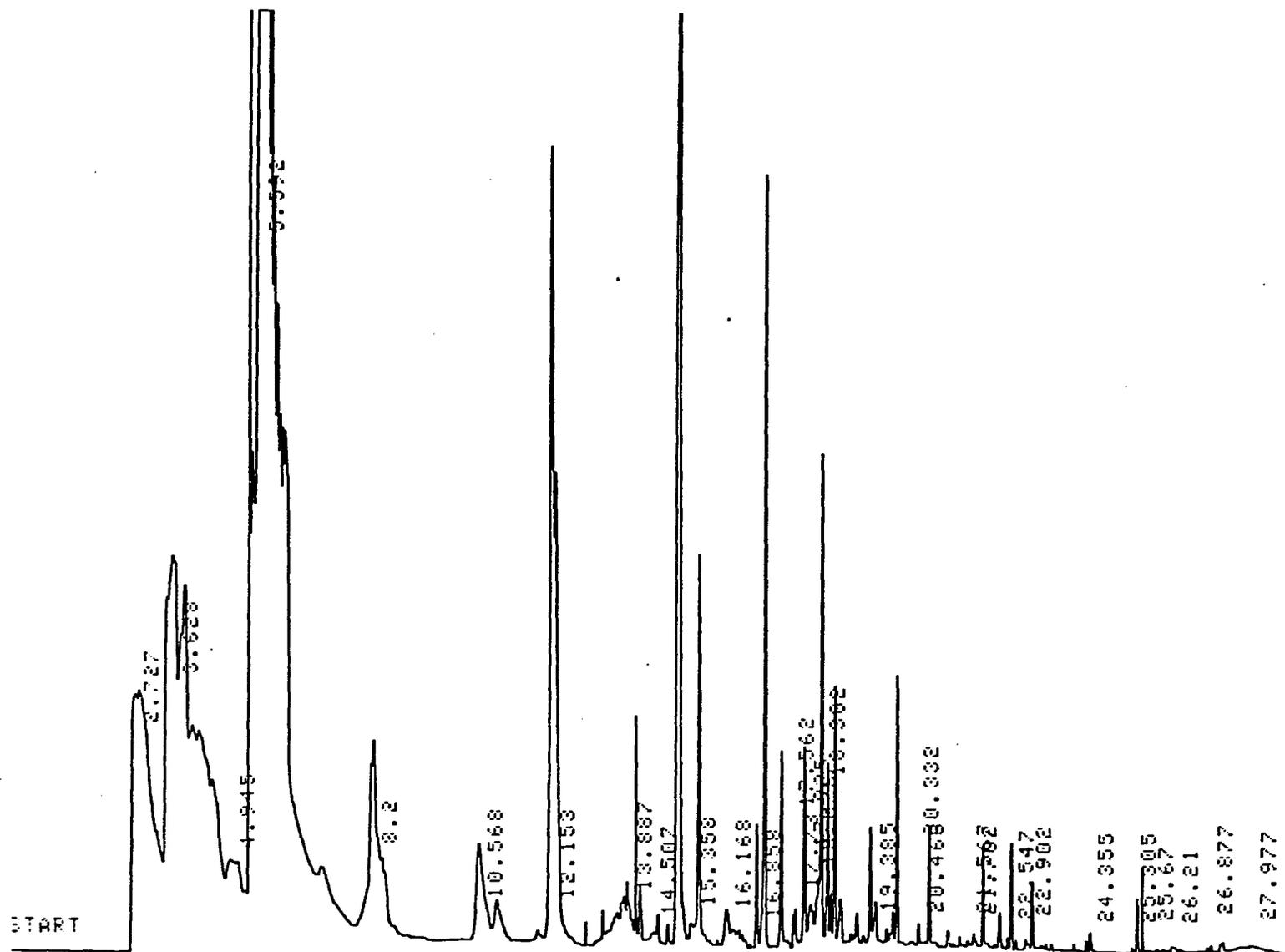


Figure 9. Sample chromatogram of patties of 20% mutton volatiles, injected on the SE-54 column

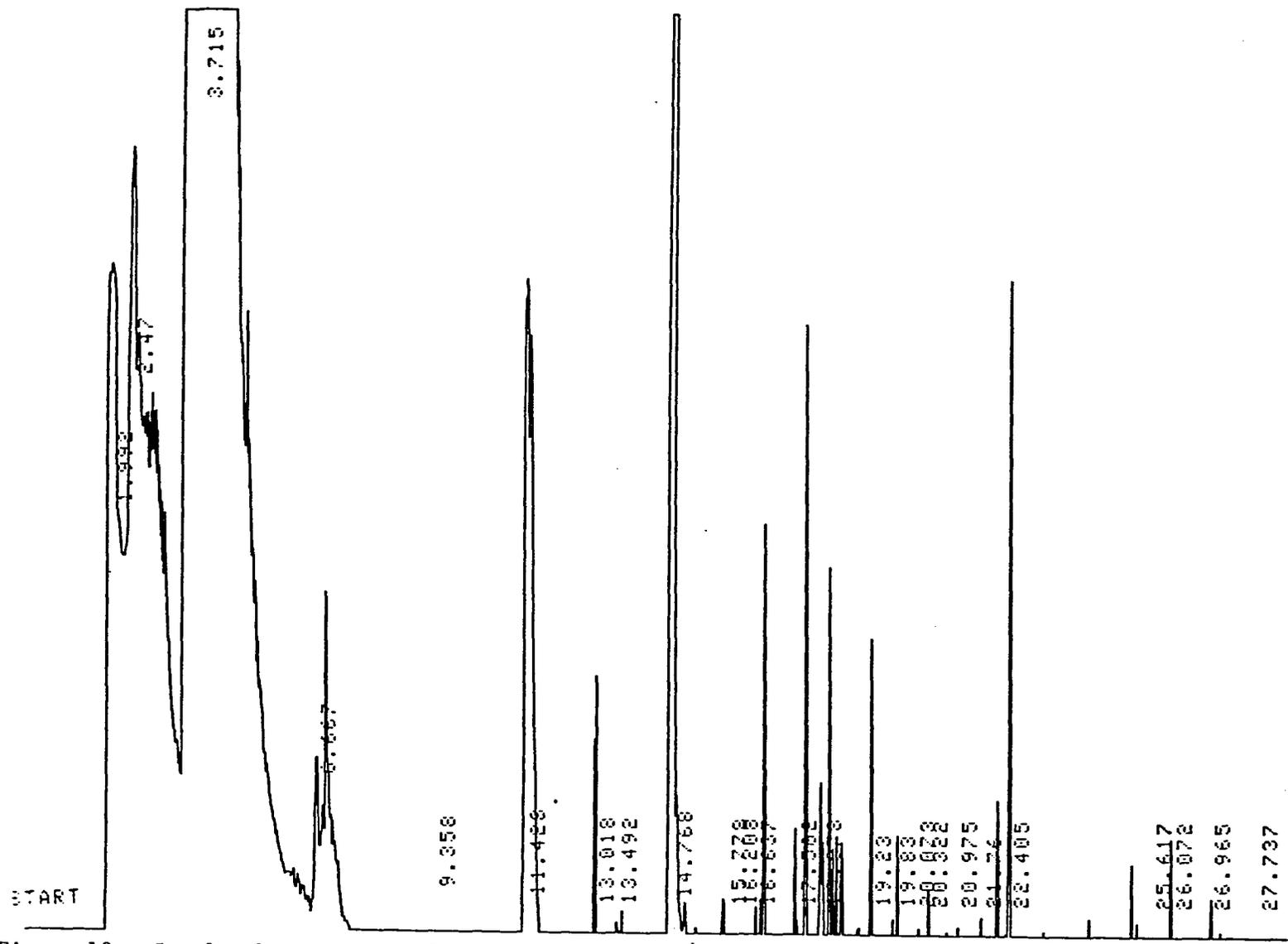


Figure 10. Sample chromatogram of patties of MDT volatiles, injected on the SE-54 column

(2) quantitation of the compound on the basis of percentage concentration, frequencies and area. Identification of the peaks of the chromatograms, based on retention time, was not made in this study.

Chromatograms were obtained by GC analysis of patties made from combinations of lamb, mutton and MDT and from the raw materials used in these patties. Figures 9 and 10 depict typical chromatograms from two of the various treatment combinations. GC was included as part of this study in an attempt to determine the effect of different meat combinations and storage time on chromatograms area values and observe their relationships to sensory scores and oxidative rancidity development. Sample replication had a very high reproducibility of peak area values. Sub-ambient ( $-15^{\circ}\text{C}$ ) temperature was utilized by using liquid nitrogen to lower the column temperature in order to trap the highly volatile compounds and to be able to account for their contribution to the overall area values. Chromatogram data were analyzed by section (section I, 10 min retention,  $-15^{\circ}\text{C}$  to  $10^{\circ}\text{C}$ ; section II, 10 min retention,  $11^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ ; section III, 10 min retention,  $151^{\circ}\text{C}$  to  $250^{\circ}\text{C}$ ) to test for the effect of time by temperature programming on the intensity of the volatile's peaks area development of different meat treatments.

Percentage volatiles concentration (PVC)      The analysis of variance of meat treatments x storage time x chromatogram sections is shown in Table 7. Patties PVC were significantly different for meat treatments ( $p < 0.05$ ) and chromatogram sections ( $p < 0.001$ ). Interactions of chromatogram sections by meat treatments and chromatogram sections by

Table 7. Effect of meat treatments, storage time and chromatogram sections on volatiles concentration, peaks frequency and area from analysis of variance in Experiment II

| Source                                 | d.f. | Mean squares      |               |                              |
|--|------|-------------------|---------------|------------------------------|
|  |      | Concentration (%) | Frequency (n) | Area (uv.sec $\times 10^5$ ) |
| Treatments                             | 6    | 2.882*            | 5.505         | 54802913**                   |
| 10% mutton vs. all others              | 1    | 1.880             | 3.051         | 5970460                      |
| 15% mutton vs. all others              | 1    | 9.717**           | 12.801        | 8074576                      |
| 20% mutton vs. all others              | 1    | 0.354             | 2.401         | 8491085                      |
| 100% mutton vs. all others             | 1    | 0.359             | 15.334        | 9337054                      |
| Lamb fat vs. all others                | 1    | 6.575*            | 0.667         | 11885352                     |
| MDT vs. all others                     | 1    | 0.352             | 1.029         | 332150084***                 |
| Treatments x replicates                | 6    | 0.686             | 7.394         | 6579908                      |
| Storage time                           | 4    | 0.532             | 45.102***     | 7599327                      |
| Storage time x treatments              | 24   | 1.570             | 3.414         | 5082748                      |
| Storage time x treatments x replicates | 24   | 1.856             | 4.945         | 8420131                      |
| Sections                               | 2    | 28111.893***      | 421.748***    | 45067413**                   |
| Sections x treatments                  | 12   | 856.435*          | 5.198         | 29186557***                  |
| Sections x storage time                | 8    | 2193.397***       | 36.117***     | 3940724                      |
| Sections x treatments x storage time   | 48   | 1419.165          | 6.157         | 4586894                      |
| Residual                               | 74   | 386.152           | 7.271         | 6513581                      |

\*,\*\*,\*\*\* $p < 0.05$ ,  $p < 0.01$ , and  $p < 0.001$ , respectively.

storage time were significant ( $p < 0.05$  and  $p < 0.001$ , respectively), while interaction of chromatogram sections by meat treatments by storage time was not significant for PVC. This indicates that meat treatments and storage days had an effect on the appearance of PVC in the different chromatogram sections.

In this experiment, there was a significant ( $p < 0.05$ ) difference in PVC between patties of lamb fat, and patties of 100% mutton and MDT

(Table 8). No significant ( $p>0.05$ ) difference in PVC between patties of 100% lamb, and patties of 100% mutton, lamb fat and MDT were detectable. Although patties of 15% mutton were lowest in PVC, they were not significantly ( $p>0.05$ ) different from patties of 10% mutton, but were significantly ( $p<0.05$ ) different from patties of 20% mutton. However, patties of 20% mutton were not significantly ( $p>0.05$ ) different in PVC from patties of 10% mutton. Storage time did not have any significant ( $p>0.05$ ) effect on PVC. All 3 chromatogram sections were significantly ( $p<0.05$ ) different from each other in PVC.

PVCs were highest in chromatogram section I followed by sections II and III, respectively (Figure 11). A concurrent increase in PVC and mutton addition to the meat combination treatments was observed.

Volatiles peaks frequencies (VPF) Volatiles peaks frequencies (VPF) were not affected by meat treatments (Tables 7, 8). Storage time and chromatogram sections had a highly significant ( $p<0.001$ ) effect on VPF. No significant ( $p>0.05$ ) interaction between storage time by meat treatments was found. Interactions of chromatogram sections by meat treatments and chromatogram sections by meat treatments by storage time were not significant ( $p>0.05$ ), while interaction of chromatogram sections by storage time were significant ( $p<0.001$ ) for VPF. This shows that storage of meat treatments for different periods of time had an effect on the number of peaks appearing on each section of the chromatogram.

VPFs from patties at Days 5 and 10 were not significantly ( $p>0.05$ ) different from Days 0 and 15, but VPF from Days 5 and 10 were significantly ( $p<0.05$ ) different from Day 30 (Table 8). Differences in

Table 8. Mean values of concentration, peaks frequencies and area of volatiles of meat treatments, storage time and chromatogram sections in Experiment II

|                              | Concentration<br>(%)   | Frequency<br>(n)     | Area<br>(uv.sec $\times 10^5$ ) |
|------------------------------|------------------------|----------------------|---------------------------------|
| <b>Meat treatment</b>        |                        |                      |                                 |
| 10% mutton                   | 33.001 <sup>a, b</sup> | 10.00                | 127398 <sup>a</sup>             |
| 15% mutton                   | 23.760 <sup>a</sup>    | 9.10                 | 106117 <sup>a</sup>             |
| 20% mutton                   | 33.334 <sup>b, c</sup> | 9.96                 | 102249 <sup>a</sup>             |
| 100% mutton                  | 33.334 <sup>b, c</sup> | 10.37                | 94674 <sup>a</sup>              |
| 100% lamb                    | 33.069 <sup>a, b</sup> | 9.40                 | 69702 <sup>a</sup>              |
| Lamb fat                     | 32.800 <sup>a</sup>    | 9.57                 | 73728 <sup>a</sup>              |
| MDT                          | 33.333 <sup>b, c</sup> | 9.53                 | 1232172 <sup>b</sup>            |
| S.E.M.                       | 0.151<br>(n=30)        | 0.496<br>(n=30)      | 148098<br>(n=30)                |
| <b>Storage time, day(s)</b>  |                        |                      |                                 |
| 0                            | 33.146                 | 8.55 <sup>a</sup>    | 122739                          |
| 5                            | 33.377                 | 9.43 <sup>a, b</sup> | 181134                          |
| 10                           | 33.333                 | 9.24 <sup>a, b</sup> | 295766                          |
| 15                           | 33.140                 | 10.00 <sup>b</sup>   | 222873                          |
| 30                           | 33.166                 | 11.31 <sup>c</sup>   | 467518                          |
| S.E.M.                       | 0.210<br>(n=42)        | 0.343<br>(n=42)      | 141590<br>(n=42)                |
| <b>Chromatogram sections</b> |                        |                      |                                 |
| Section I                    | 55.907 <sup>a</sup>    | 6.87 <sup>a</sup>    | 456616 <sup>a</sup>             |
| Section II                   | 25.898 <sup>b</sup>    | 11.06 <sup>b</sup>   | 156890 <sup>b</sup>             |
| Section III                  | 17.894 <sup>c</sup>    | 11.19 <sup>b</sup>   | 70511 <sup>b</sup>              |
| S.E.M.                       | 2.349<br>(n=70)        | 0.322<br>(n=70)      | 96463<br>(n=70)                 |

<sup>a, b, c</sup> Means within each column with different letters are significantly different (p<0.05).

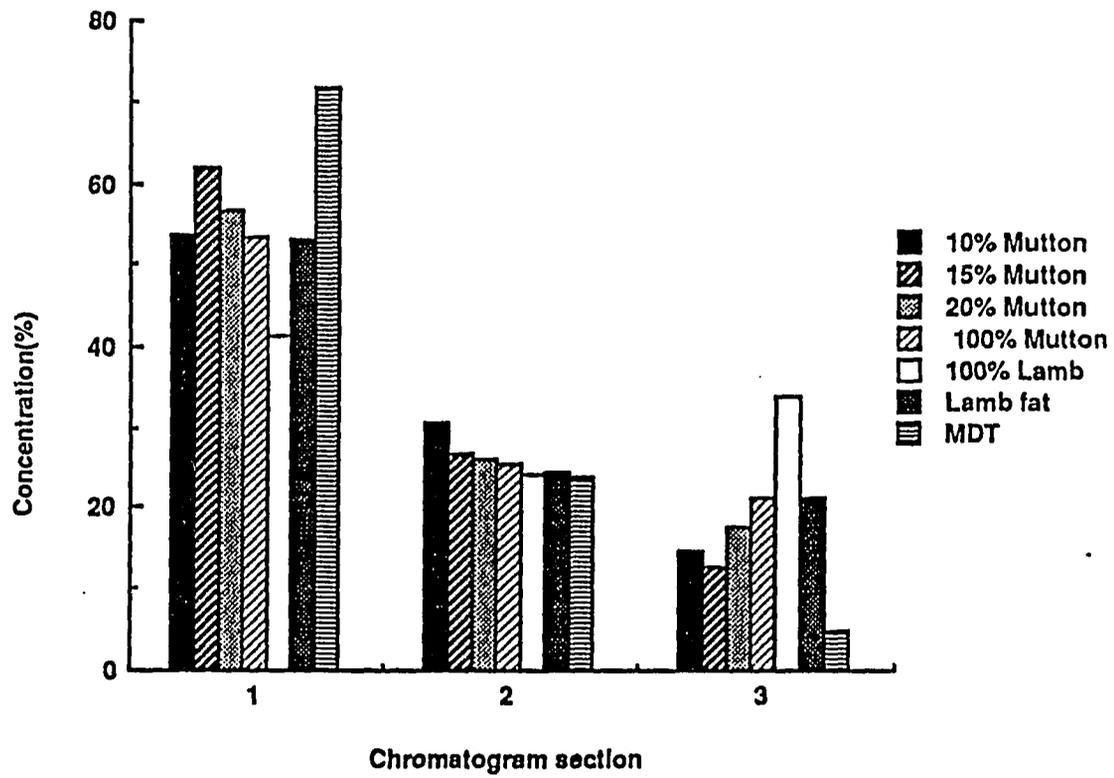


Figure 11. Effect of meat treatments on the concentration of volatiles in different chromatogram sections, Experiment II

VPF were significant between Day 0, 15 and 30, respectively.

Chromatogram section I was significantly ( $p < 0.05$ ) greater than chromatogram sections II and III, while no significance ( $p > 0.05$ ) was found between chromatogram sections II and III in VPF.

VPF of meat combination treatments were lowest in chromatogram section I, followed by sections II and III, respectively (Figure 12).

Volatiles area intensity (VAI) Patty VAIs were significantly ( $p < 0.01$ ) different for meat treatment and chromatogram sections, but not for storage time (Table 7). Interactions of chromatogram sections by meat treatments had a significant ( $p < 0.001$ ) effect on VAI, reflecting the effect of meat treatments on the VAI of different chromatogram sections.

All meat treatments except MDT were not significantly ( $p > 0.05$ ) different in VAI from each other (Table 8). No significant ( $p > 0.05$ ) effect of storage time on VAI were detected. However, chromatogram section I was significantly ( $p < 0.05$ ) different from sections II and III, but section II and section III were not significantly ( $p > 0.05$ ) different in VAI values averaged over all meat treatments.

VAIs were highest in chromatogram section I, followed by sections II and III, respectively (Figure 13). Mutton addition inversely decreased VAI in meat combination treatments. It appears that at high temperatures, the volatiles intensity of mutton and MDT faded, probably because VAI consisted mainly of low molecular weight and medium polar compounds.

Volatiles area ratio of different meat treatments (R) by section was determined by the following formula:  $R = A^*/A_7$ , where  $A^*$  is the area of

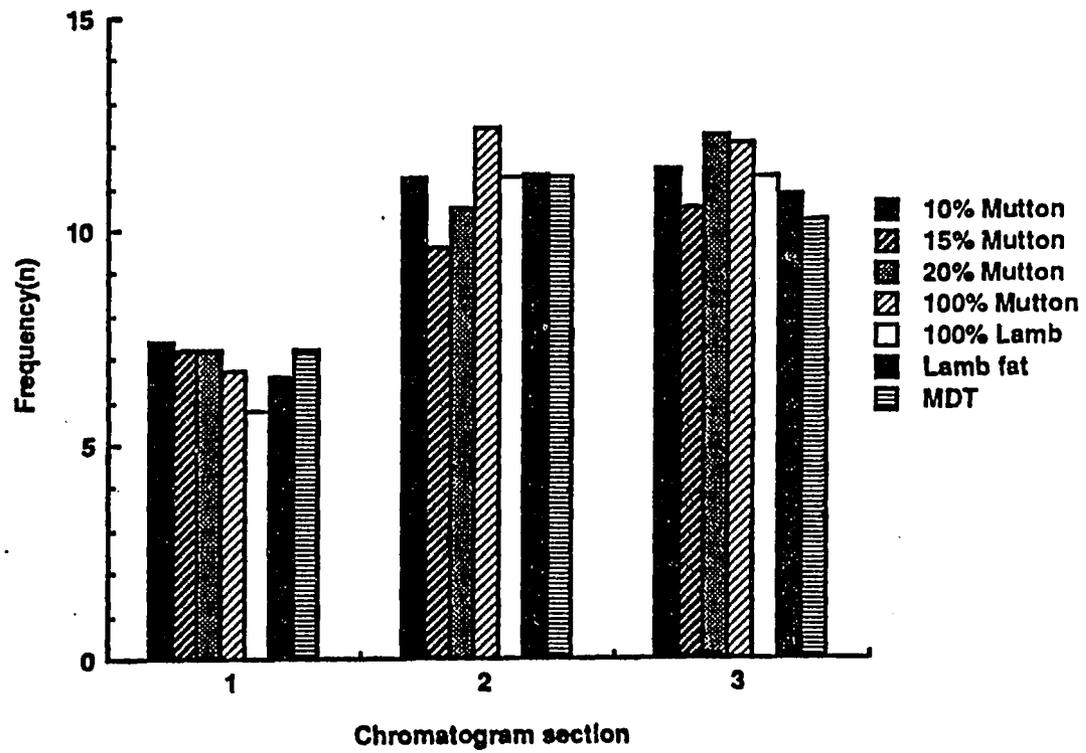


Figure 12. Effect of meat treatments on frequency peaks of volatiles in different chromatogram sections, Experiment II

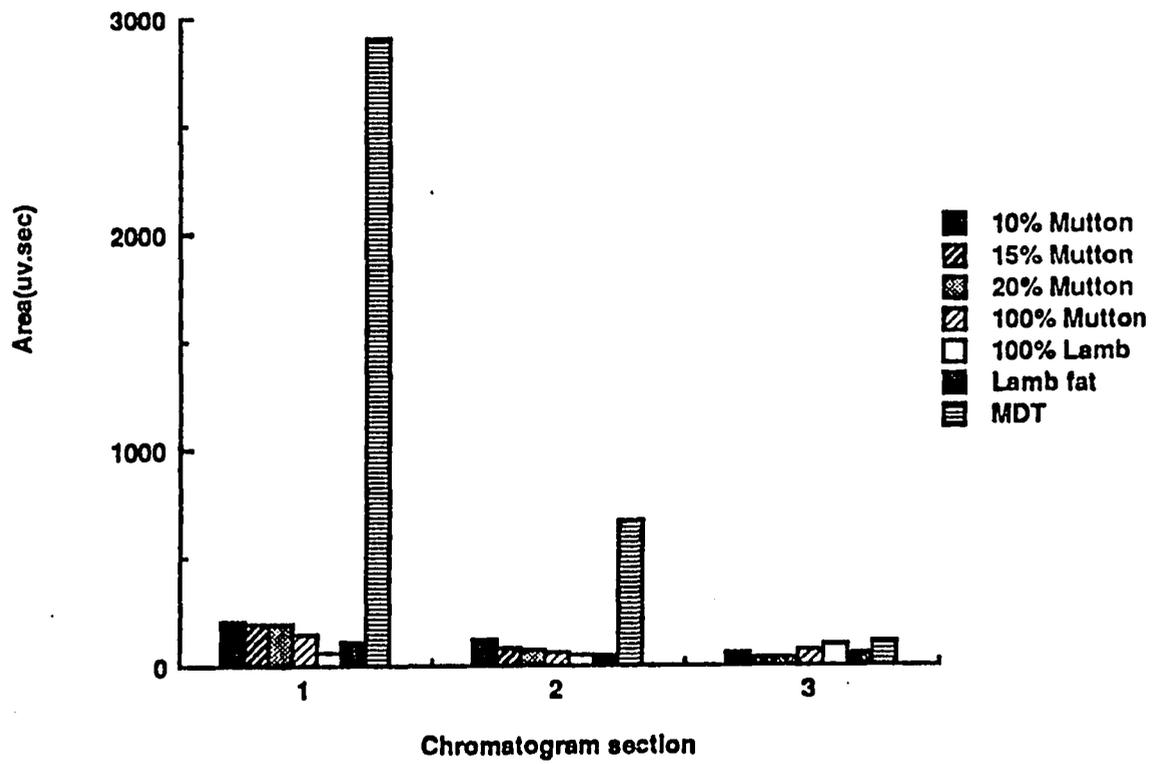


Figure 13. Effect of meat treatments on the area of volatiles in different chromatogram sections, Experiment II

volatiles of meat treatments averaged over storage time, and  $A_7$  is the total area of volatiles of treatments averaged over storage time (Table 9, Figure 14). In chromatogram sections I and II, patties of MDT were

Table 9. Volatiles area ratios<sup>a</sup> of meat treatments in different chromatogram sections in Experiment II

| Meat treatment | Area      |            |             |
|----------------|-----------|------------|-------------|
|                | Section I | Section II | Section III |
| 10% mutton     | 0.053     | 0.106      | 0.124       |
| 15% mutton     | 0.052     | 0.073      | 0.085       |
| 20% mutton     | 0.051     | 0.063      | 0.084       |
| 100% mutton    | 0.039     | 0.058      | 0.143       |
| 100% lamb      | 0.017     | 0.040      | 0.202       |
| Lamb fat       | 0.028     | 0.048      | 0.126       |
| MDT            | 0.759**   | 0.613***   | 0.234       |

<sup>a</sup>Ratios expressed as area column value per total area.

\*\*,\*\*p<0.01 and p<0.001, respectively.

significantly different in volatiles area ratio from the other meat treatments. Ratios of 10%, 15%, 20% and 100% mutton patties ranked in VAI 2nd, 3rd, 4th and 5th, respectively. Although chromatogram section III volatiles area ratio of MDT patties were not significantly ( $p>0.05$ ) different from the other treatments, it had the highest numbers. Ratios of 10%, 15%, 20% and 100% mutton patties ranked in VAI 5th, 6th, 7th and 3rd, respectively. It was probably the mutton meat volatiles which blocked the effect of MDT meat volatiles, as shown in section III

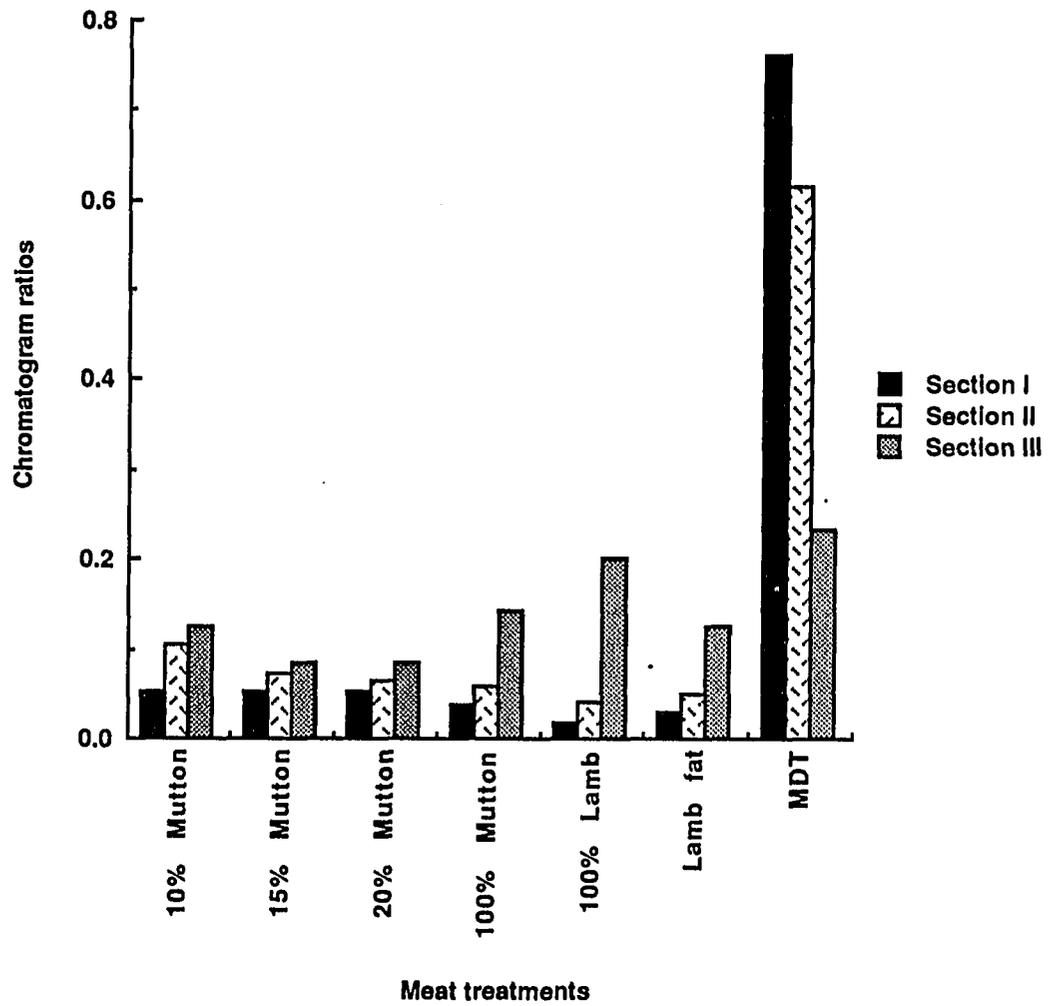


Figure 14. Volatiles area ratios of meat treatments in different chromatogram sections, Experiment II

(Table 9). In comparing chromatogram sections I and II, ratios of mutton meat volatiles ranked the same in contrast with other meat treatment ratios. This sharp increase in area volatiles ratios of patties of 100% mutton, 100% lamb and lamb fat, and the decrease in MDT patties in chromatogram section III is probably due to the molecular weights of compounds that contributed to their VAI. Mutton meat volatiles contain 46 carboxylic acids, mostly of high molecular weights, while in turkey meat, volatiles are composed mainly of low molecular weight carboxylic acids, which have a low evaporation temperature (Shahidi et al., 1986). The origin of the peculiar mutton flavor such as branched chain acids in mutton tissues, logically lies most likely in the characteristic metabolic processes in the sheep rumen. Garton et al. (1972) have recently suggested that branched acids with methyl substituted at even numbered carbon atoms result from the incorporation of methylmalonyl-CoA (arising from propionate metabolism) in the place of malonyl CoA during chain lengthening. The site of this branched chain acid synthesis is considered to be the liver.

#### Thiobarbituric acid (TBA) test

Analysis of variance for TBA values for meat treatments and storage time are shown in Table 10. Oxidative changes during storage of meat treatments patties have been measured spectrophotometrically by means of the reaction of 2-thiobarbituric acid with an oxidation product,

Table 10. Effect of meat treatments and storage time on thiobarbituric acid<sup>a</sup> (TBA) numbers from analysis of variance in Experiment II

| Source                     | d.f. | Mean squares<br>TBA (mg/kg) |
|----------------------------|------|-----------------------------|
| Treatments                 | 6    | 720.75**                    |
| 10% mutton vs. all others  | 1    | 1.084                       |
| 15% mutton vs. all others  | 1    | 4.023                       |
| 20% mutton vs. all others  | 1    | 24.903                      |
| 100% mutton vs. all others | 1    | 484.05*                     |
| Lamb fat vs. all others    | 1    | 182.14                      |
| MDT vs. all others         | 1    | 3890.72***                  |
| Treatments x replicates    | 6    | 50.93                       |
| Storage time               | 5    | 18.67***                    |
| Storage time x treatments  | 30   | 5.23***                     |
| Residual                   | 35   | 0.97                        |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.

\*,\*\*,\*\*\*p<0.05, p<0.01, and p<0.001, respectively.

malonaldehyde. Significant effects (p<0.01) of meat treatments on TBA numbers were detected (Table 10). Storage time significantly (p<0.001) influenced TBA values.

The effects of the 7 treatments and 6 months of storage on TBA numbers are shown in Table 11. There were no significant differences between treatments except for the MDT treatment, which varied significantly (Table 11). TBA numbers for Days 0, 5, 15 and 30 were significantly (p<0.05) different from Day 180, while no significant (p>0.05) differences were found in TBA values of patties at Day 10 and the patties at other storage days.

TBA values decreased as percentage of mutton increased in combination treatments (Figure 15). However, MDT treatment had the

Table 11. Effects of meat treatments and storage time on thiobarbituric acid<sup>a</sup> (TBA) values of meat patties in Experiment II

|                      | TBA<br>number        |
|----------------------|----------------------|
| Meat treatment       |                      |
| 10% mutton           | 4.405 <sup>b</sup>   |
| 15% mutton           | 3.954 <sup>b</sup>   |
| 20% mutton           | 3.499 <sup>b</sup>   |
| 100% mutton          | 0.843 <sup>b</sup>   |
| 100% lamb            | 0.880 <sup>b</sup>   |
| Lamb fat             | 2.188 <sup>b</sup>   |
| MDT                  | 13.456 <sup>c</sup>  |
| S.E.M.               | 2.060<br>(n=12)      |
| Storage time, day(s) |                      |
| 0                    | 3.774 <sup>b</sup>   |
| 5                    | 4.557 <sup>b</sup>   |
| 10                   | 4.019 <sup>b,c</sup> |
| 15                   | 4.836 <sup>b</sup>   |
| 30                   | 4.655 <sup>b</sup>   |
| 180                  | 3.287 <sup>c</sup>   |
| S.E.M.               | 0.263<br>(n=14)      |

<sup>a</sup>Expressed as mg malonaldehyde.

<sup>b,c,d</sup>Means within each column with different letters are significantly different ( $p < 0.05$ ).

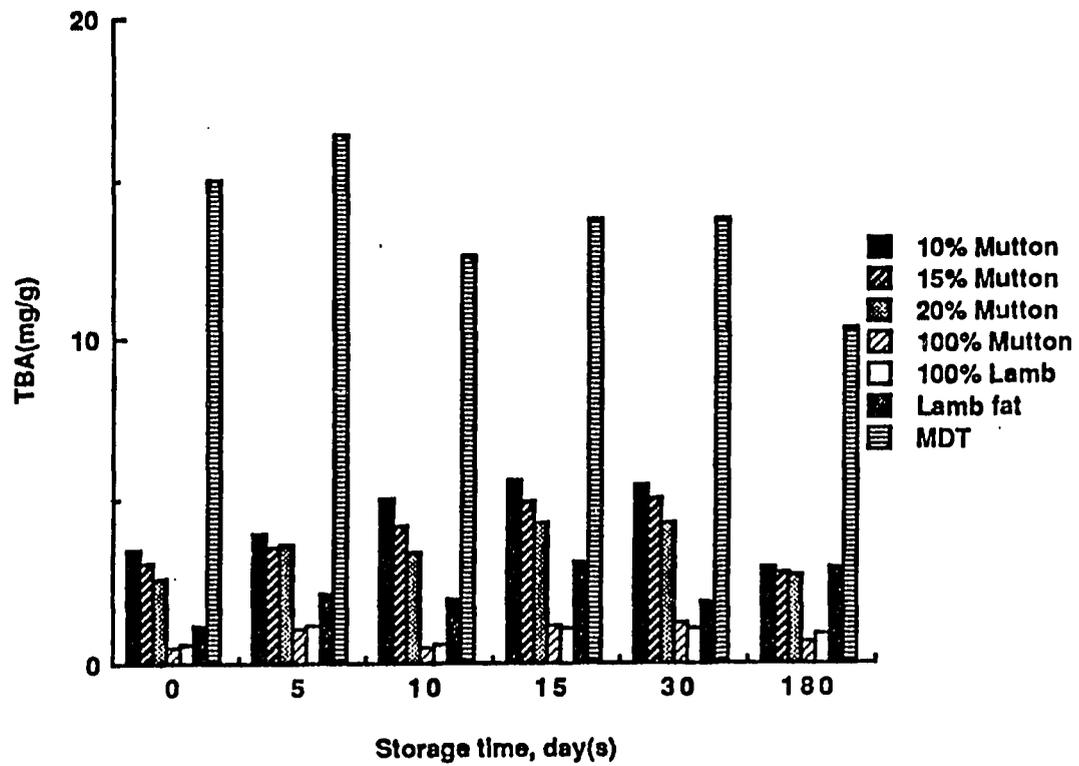


Figure 15. Oxidative rancidity of meat treatments at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

highest TBA values across all storage times.

Researchers showed that other lipid oxidation products such as the alka-2,4-dienals also reacted with TBA to form a red complex with the same absorption maximum as the malonaldehyde-TBA complex at 532 nm (Jacobson et al., 1964; Marcuse and Johansson, 1973). Herz and Chang (1970) have indicated that the most numerous members of any class of compounds identified in meat flavor concentrates are the carbonyls. Although there are both water- and fat-soluble carbonyls, Sanderson et al. (1966) indicated that those involved in meat flavor are primarily lipid-soluble. Since the degradation of lipid compounds has been associated with flavor development (Hornstein et al., 1961) and with the aging of meat (Lea, 1962), it seems reasonable to suggest a relationship between the two. The now classical work of Patton et al. (1959) established the unsaturated C:18 fatty acids as precursors of carbonyls. Hofstrand and Jacobson (1960) had noted that monocarbonyls (alkanals and alka-2-ones) predominate, as opposed to the polycarbonyls. Hornstein and Crowe (1963) reported finding alkanals in lamb fat and these aliphatic aldehydes were probably responsible for the mutton-like odor. Analysis of the monocarbonyl fractions in mutton by Riely et al. (1971) revealed 2 components, alkanals and the alka-2-enals. He noted that the alka-2,4-dienals and alka-2-ones are apparently not present in the fat of this animal species. Jacobson et al. (1964) also reported that the absorbance of the TBA complex with alkanals and alka-2-enals at 452 nm was of value in assessing the oxidized flavor of red meat fat. The low amount of C:18 unsaturated fatty acids, particularly the polyunsaturates,

that were observed in sheep fat (Ziegler et al., 1967) can probably explain the low concentration of alka-2-enals and the absence of alka-2,4-dienals.

Lazarus et al. (1977) reported no differences in fatty acid composition of phospholipids of lamb muscle stored at 4°C for up to 9 days. Reasons for the lack of change in fatty acid composition vary. Kunsman et al. (1978) reported that the molar ratio of polyunsaturated fatty acids to hemoprotein in their study was in the range in which hemoprotein acts as an antioxidant.

MDT is characterized by its paste-like consistency and high susceptibility to deteriorative changes which occur during storage. The extreme stress and aeration during the process and the compositional nature (bone marrow, heme, and lipids) of the product contribute to its high oxidative potential. Poultry meat is composed of relatively high levels of unsaturated fatty acids and low levels of natural tocopherols, making it relatively unstable (Dawson and Gartner, 1983).

The carbonyl content of MDT was reported by Dimick et al. (1972). The major monocarbonyls present were alka-2-ones, alkanals, and alka-2-enals. No consistent patterns in the levels of total carbonyls and monocarbonyls were shown to occur during the refrigerated storage. The action of heat on lipids during cooking can accelerate autoxidation and thus increase the amount of carbonyl compounds (Thomas et al., 1971). Elevated levels of alkanals also were noted following the extended storage period.

TBA values decreased as percentage mutton meat increased in meat

combination treatments 10%, 15% and 20% mutton, respectively (Table 11). A possible explanation is that mutton meat contributed a specific protein which might possess high reactivity rates with oxidation compound products, especially peroxides (Gardner, 1979).

A positive significant ( $p < 0.001$ ) correlation was found between TBA numbers and area of chromatogram in sections I and II (0.956 and 0.965, respectively), indicating that the higher the TBA value, the larger the area of peaks (Kakuda et al., 1981). A logarithmic relationship between TBA values and volatiles area intensity were also found,  $y = 0.002x + 4.852$  for section I, and  $y = 0.085x + 4.6$  for section II, with a probability of  $p < 0.0002$  and  $p < 0.0001$ , respectively. However, Kakuda et al. (1981) reported a linear relationship, with an  $r^2$  of 0.946, between the TBA absorbance at 532 nm and the HPLC peak height of malonaldehyde. Not taking into account the presence and the production of other compounds that will be affected by the oxidation reactions, also the free radicals generations are logarithmic in nature (Chipault, 1962).

Because of the undesirability of including the 100% lamb fat and 100% MDT patties in the taste panels, no significant correlation could have been established between sensory evaluation data and TBA numbers or GC analysis. In addition, contrary to expectation on the basis of TBA values, sensory scores for the meat combination patties were higher than for the pure mutton patties.

Microbiological analysis

Analysis of variance for microbial counts for meat treatments and storage time are shown in Table 12.

Table 12. Effects of meat treatments and storage time on mesophiles, psychrotrophs and presumptive Staphylococcus bacteria<sup>a</sup> from analysis of variance in Experiment II

| Source                    | d.f. | Mean squares |               | d.f. | Mean squares                      |
|---------------------------|------|--------------|---------------|------|-----------------------------------|
|                           |      | Mesophiles   | Psychrotrophs |      | Presumptive <u>Staphylococcus</u> |
| Treatments                | 5    | 2.962        | 3.566         | 5    | 0.854                             |
| Treatments x replicates   | 5    | 2.199***     | 2.612***      | 5    | 1.038***                          |
| Storage time              | 5    | 0.360***     | 0.197**       | 4    | 1.423                             |
| Storage time x treatments | 25   | 0.031        | 0.038         | 20   | 0.126                             |
| Residual                  | 30   | 0.045        | 0.057         | 24   | 0.107                             |

<sup>a</sup>Expressed as Log<sub>10</sub> CFU/g.

\*\*,\*\*p<0.01 and p<0.001, respectively.

Storage time was the major source of statistical variation in microbial counts. Colony forming units (CFU) of mesophiles, psychrotrophs and presumptive Staphylococcus of meat treatments are shown in Figures 16, 17 and 18, respectively. Meat treatments did not have any significant (p>0.05) effect of CFU of mesophiles, psychrophiles and presumptive Staphylococcus (Table 13). Storage time influenced growth of

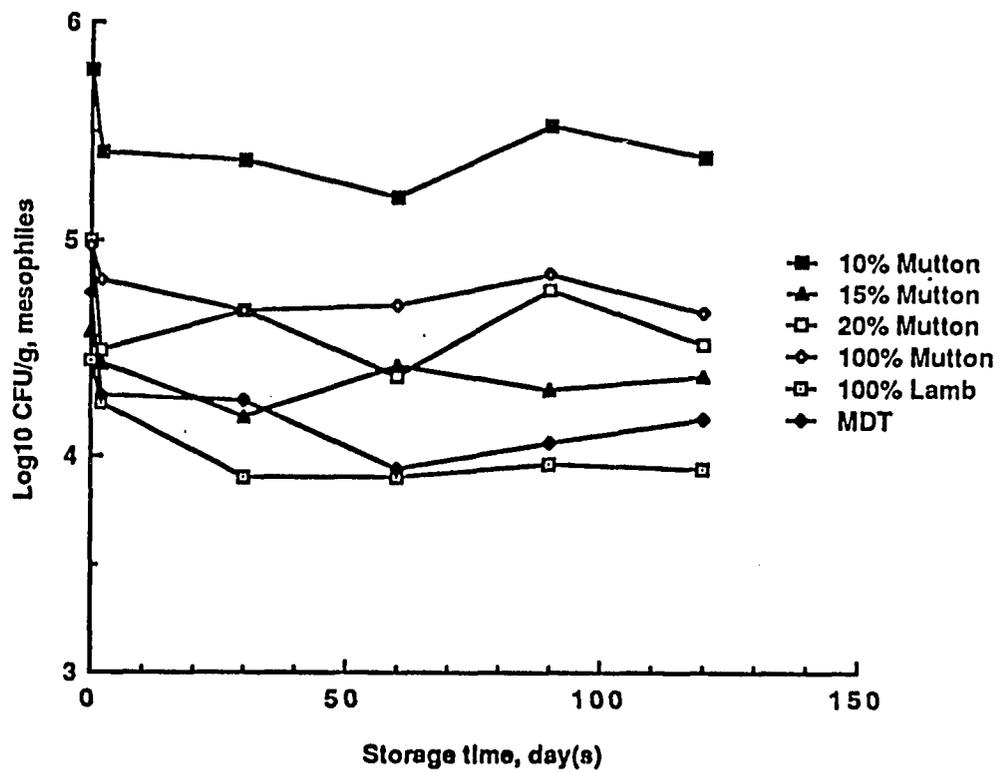


Figure 16. Mesophilic growth curve on different meat combinations at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

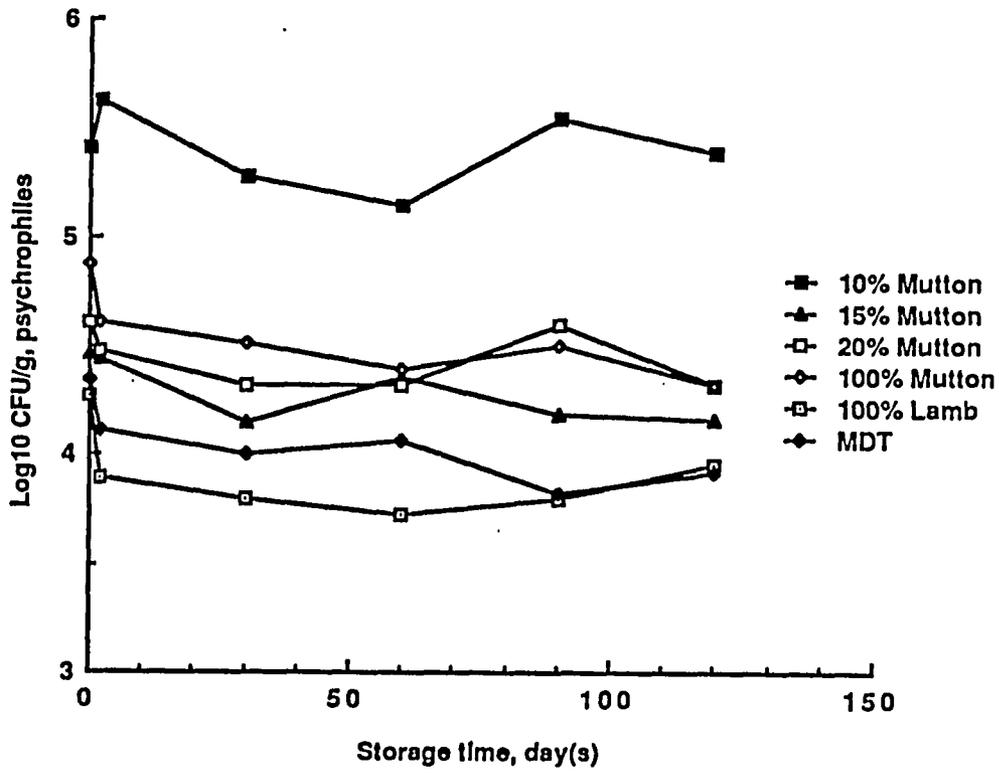


Figure 17. Psychrotrophic growth curve on different meat combinations at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

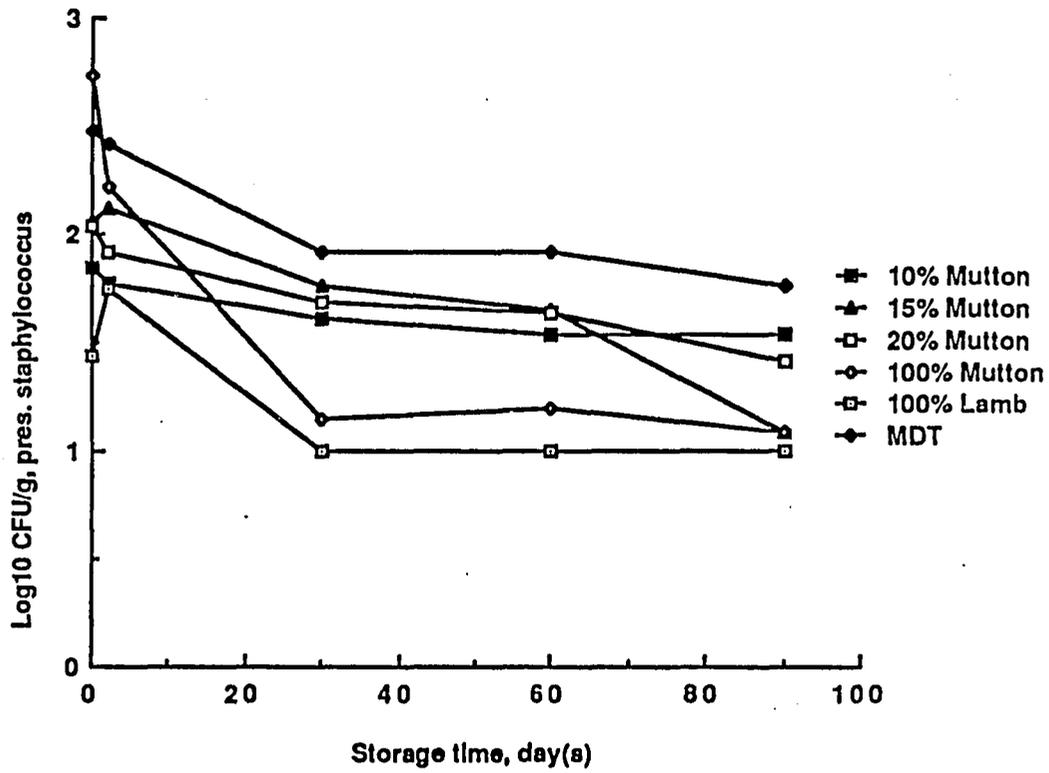


Figure 18. Presumptive Staphylococcus growth curve on different meat combinations at different storage times at  $-15^{\circ}\text{C}$ , Experiment II

Table 13. Effects<sup>a</sup> of meat treatments and storage time on microbial counts<sup>a</sup> in Experiment II

|                    | Mesophiles           | Psychrotrophs        | Presumptive<br><u>Staphylococcus</u> |
|--------------------|----------------------|----------------------|--------------------------------------|
| Meat treatment     |                      |                      |                                      |
| 10% mutton         | 5.46                 | 5.442                | 1.666                                |
| 15% mutton         | 4.38                 | 4.292                | 1.732                                |
| 20% mutton         | 4.63                 | 4.437                | 1.742                                |
| 100% mutton        | 4.77                 | 4.536                | 1.677                                |
| 100% lamb          | 4.06                 | 3.904                | 1.236                                |
| MDT                | 4.24                 | 4.041                | 2.155                                |
| S.E.M.             | 0.428<br>(n=12)      | 0.466<br>(n=12)      | 0.294<br>(n=12)                      |
| Storage time, days |                      |                      |                                      |
| 0                  | 4.918 <sup>b</sup>   | 4.662 <sup>b</sup>   | 2.098 <sup>b</sup>                   |
| 2                  | 4.611 <sup>c</sup>   | 4.526 <sup>b,c</sup> | 2.031 <sup>b</sup>                   |
| 30                 | 4.505 <sup>c,d</sup> | 4.339 <sup>c</sup>   | 1.519 <sup>c</sup>                   |
| 60                 | 4.417 <sup>d</sup>   | 4.332 <sup>c</sup>   | 1.541 <sup>c</sup>                   |
| 90                 | 4.571 <sup>c,d</sup> | 4.405 <sup>c</sup>   | 1.314 <sup>c</sup>                   |
| 120                | 4.527 <sup>c,d</sup> | 4.390 <sup>c</sup>   |                                      |
| S.E.M.             | 0.061<br>(n=12)      | 0.069<br>(n=12)      | 0.103<br>(n=10)                      |

<sup>a</sup>Expressed as Log<sub>10</sub> CFU/g.

<sup>b,c,d</sup> Means within each column with a different letter are significantly different (p<0.05).

mesophiles significantly ( $p < 0.001$ ). Mesophiles CFU of patties at Day 30, 90 and 120 were not significantly ( $p > 0.05$ ) different from each other nor were CFU at Days 2 and 60 different, but CFUs of patties were significantly ( $p < 0.05$ ) different at Day 0 than on all other storage days.

The CFUs for psychrotrophs in patties on Day 2 were not significantly ( $p > 0.05$ ) different from patties at other storage times, while significant ( $p < 0.05$ ) differences were found in patties stored on Day 0, and on Days 30, 60, 90 and 120, respectively (Table 13).

As would be expected, presumptive Staphylococcus CFU decreased steadily throughout the storage period. Significant ( $p < 0.05$ ) differences in presumptive Staphylococcus CFU of patties were found between two sets of storage times at Days 0 and 2, and Days 30, 60 and 90.

However, no significant ( $p > 0.05$ ) differences were found in CFU of patties stored between Days 0 and 2, or among Days 30, 60, and 90, respectively (Table 13).

Carbonyl compounds can also be produced by microorganisms, particularly Pseudomonas (psychrotrophs), which is one of the dominant genera found on animal carcasses and cuts. Pseudomonas can produce copious amounts of alkanals, alka-2-enals and alka-2-ones, but apparently can completely destroy the alka-2,4-dienals (Smith and Alford, 1968). Staphylococcus aureus has been observed to decrease the alkanal and alka-2-enal, but increase the alka-2,4-dienals content in meat (Bothast et al., 1973). Such action could explain the carbonyl production pattern observed in this experiment. MDT had the highest presumptive Staphylococcus CFU during the whole storage time, but no significant

( $p > 0.05$ ) differences were found in comparison with other treatments. This could explain why MDT had a relatively high TBA value.

### Experiment III

The relationship between oxidative rancidity and the addition of mutton to lamb-MDT mixtures was ambiguous in the previous experiments. Two objectives of Experiment III were to monitor pH and TBA measurements of mutton lean meat added to other meat mixtures throughout a refrigeration and frozen storage period, and to determine the correlation between pH and TBA values.

#### Refrigeration storage

Beef and pork patties made with different amounts of mutton lean meat (0%, 15% and 30%) were vacuum packaged and stored at 4°C for 15 days.

Meat treatments and storage time showed a highly significant ( $p < 0.01$ ) effect on pH values (Table 14). The pH values of meat treatments on different storage days are shown in Figure 19. No significant ( $p > 0.05$ ) differences in pH values were found between patties of 100% beef, 15% mutton + beef and 100% pork, as compared with patties of 30% mutton + beef, 15% mutton + pork, 30% mutton + pork and 100% mutton (Table 15). However, significantly different ( $p < 0.05$ ) pH values were found between patties of 30% mutton + beef or 100% mutton, and patties of 15% mutton + pork. Lamb fat had significantly ( $p < 0.05$ ) higher pH values than patties of 100% beef, 15% mutton + beef, 100% pork, 15% mutton + pork, 30% mutton + pork, but lamb fat patties were not

Table 14. Effects of meat treatments and refrigeration storage time on acidity and oxidative rancidity measurements from analysis of variance in Experiment III

| Source                           | d.f. | Mean squares |                  |
|----------------------------------|------|--------------|------------------|
|                                  |      | pH           | TBA <sup>a</sup> |
| Treatments                       | 7    | 0.235**      | 0.419***         |
| 100% beef vs. all others         | 1    | 0.029        | 0.002            |
| 15% mutton + beef vs. all others | 1    | 0.021        | 0.603***         |
| 30% mutton + beef vs. all others | 1    | 0.045        | 0.024            |
| 100% pork vs. all others         | 1    | 0.125        | 0.441***         |
| 15% mutton + pork vs. all others | 1    | 0.796**      | 0.428***         |
| 30% mutton + pork vs. all others | 1    | 0.002        | 0.147***         |
| 100% mutton vs. all others       | 1    | 0.088        | 0.178***         |
| Treatments x replicates          | 14   | 0.059        | 0.007            |
| Storage time                     | 2    | 0.461**      | 0.321***         |
| Storage time x treatments        | 14   | 0.064        | 0.03***          |
| Residual                         | 32   | 0.0611       | 0.005            |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.

\*\*,\*\*p<0.01 and p<0.001, respectively.

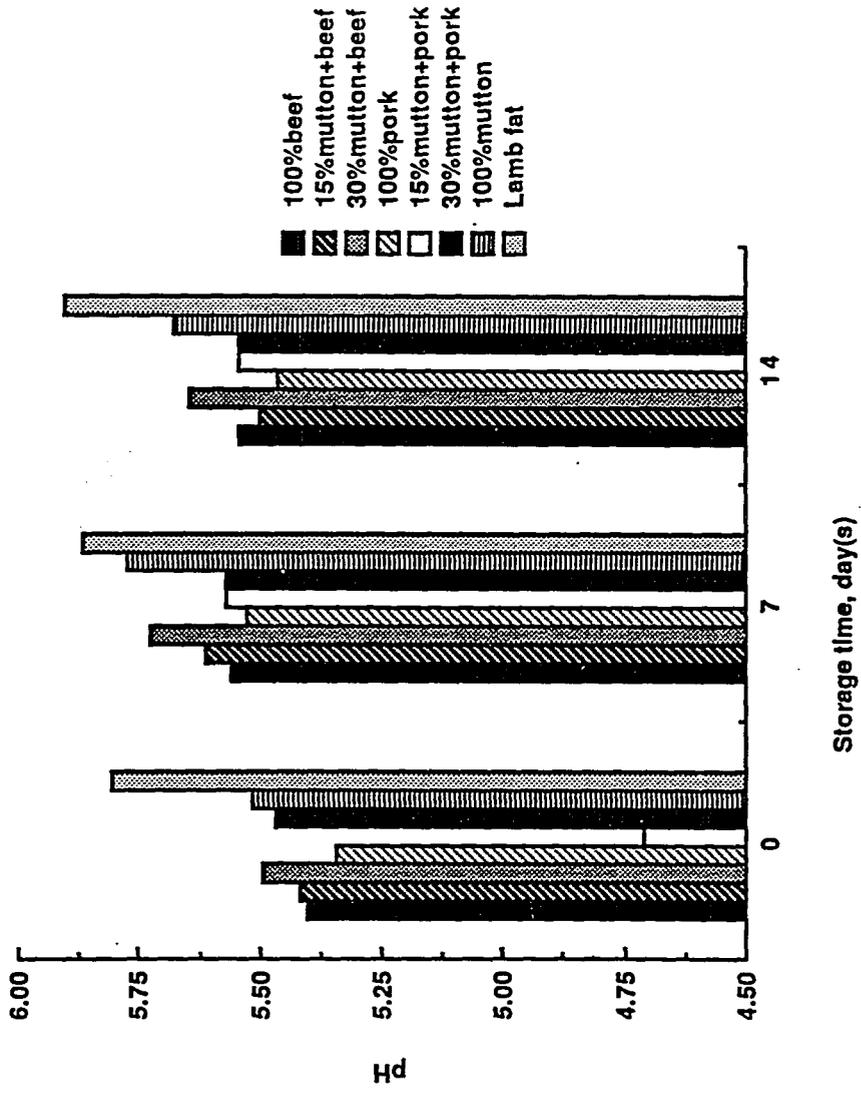


Figure 19. Effects of meat treatments and refrigeration storage time on acidity measurements in Experiment III

Table 15. Effects of meat treatments and refrigeration storage time on acidity and oxidative rancidity measurements in Experiment III

|                      | pH                    | TBA <sup>a</sup>      |
|----------------------|-----------------------|-----------------------|
| Meat treatment       |                       |                       |
| 100% beef            | 5.501 <sup>b, c</sup> | 0.641 <sup>b</sup>    |
| 15% mutton + beef    | 5.509 <sup>b, c</sup> | 0.897 <sup>c</sup>    |
| 30% mutton + beef    | 5.621 <sup>c, d</sup> | 0.704 <sup>b</sup>    |
| 100% pork            | 5.443 <sup>b, c</sup> | 0.448 <sup>d</sup>    |
| 15% mutton + pork    | 5.274 <sup>b</sup>    | 0.451 <sup>d, e</sup> |
| 30% mutton + pork    | 5.568 <sup>c</sup>    | 0.536 <sup>e</sup>    |
| 100% mutton          | 5.653 <sup>c, d</sup> | 0.524 <sup>d, e</sup> |
| Lamb fat             | 5.857 <sup>d</sup>    | 1.041 <sup>f</sup>    |
| S.E.M.               | 0.081<br>(n=9)        | 0.028<br>(n=9)        |
| Storage time, day(s) |                       |                       |
| 0                    | 5.394 <sup>b</sup>    | 0.788 <sup>b</sup>    |
| 7                    | 5.660 <sup>c</sup>    | 0.604 <sup>c</sup>    |
| 14                   | 5.606 <sup>c</sup>    | 0.574 <sup>c</sup>    |
| S.E.M.               | 0.050<br>(n=24)       | 0.014<br>(n=24)       |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.  
<sup>b, c, d, e, f</sup>Means within each column with different letters are significantly different (p<0.05).

significantly different ( $p < 0.05$ ) from patties of 30% mutton + beef or 100% mutton (Table 15).

The pH values of meat treatments on Day 0 were significantly different from the pH values of Days 7 and 14. Even though pH values increased from Days 0 to 7, the pH values did not change significantly ( $p > 0.05$ ) from Days 7 to 14 (Table 15).

Meat treatments and storage time showed a highly significant ( $p < 0.001$ ) effect on TBA values (Table 14). Interaction of storage time by meat treatments on pH values was not significant ( $p > 0.05$ ); however, there was a highly significant ( $p < 0.001$ ) interaction on TBA values. This indicates that TBA values of meat treatments varied differently, depending upon the length of refrigerated storage. The TBA values of different meat treatments are represented in Figure 20.

Although the TBA values of 100% beef patties were not significantly ( $p > 0.05$ ) lower than those for the 30% mutton + beef patties, they were significantly ( $p < 0.05$ ) lower than the TBA value of 15% mutton + beef patties (Table 15). TBA values for lamb fat were significantly ( $p < 0.05$ ) higher than those for all of the other meat treatments. TBA values of 100% pork patties were significantly ( $p < 0.05$ ) lower than the TBA values of the 30% mutton + pork patties; however, they were not significantly different ( $p > 0.05$ ) from the TBA values of 15% mutton + pork patties or 100% mutton patties.

TBA values of patties on Day 0 were significantly ( $p < 0.05$ ) higher than on Days 7 and 14 (Table 15). No significant ( $p > 0.05$ ) differences in TBA values were found between Days 7 and 14.

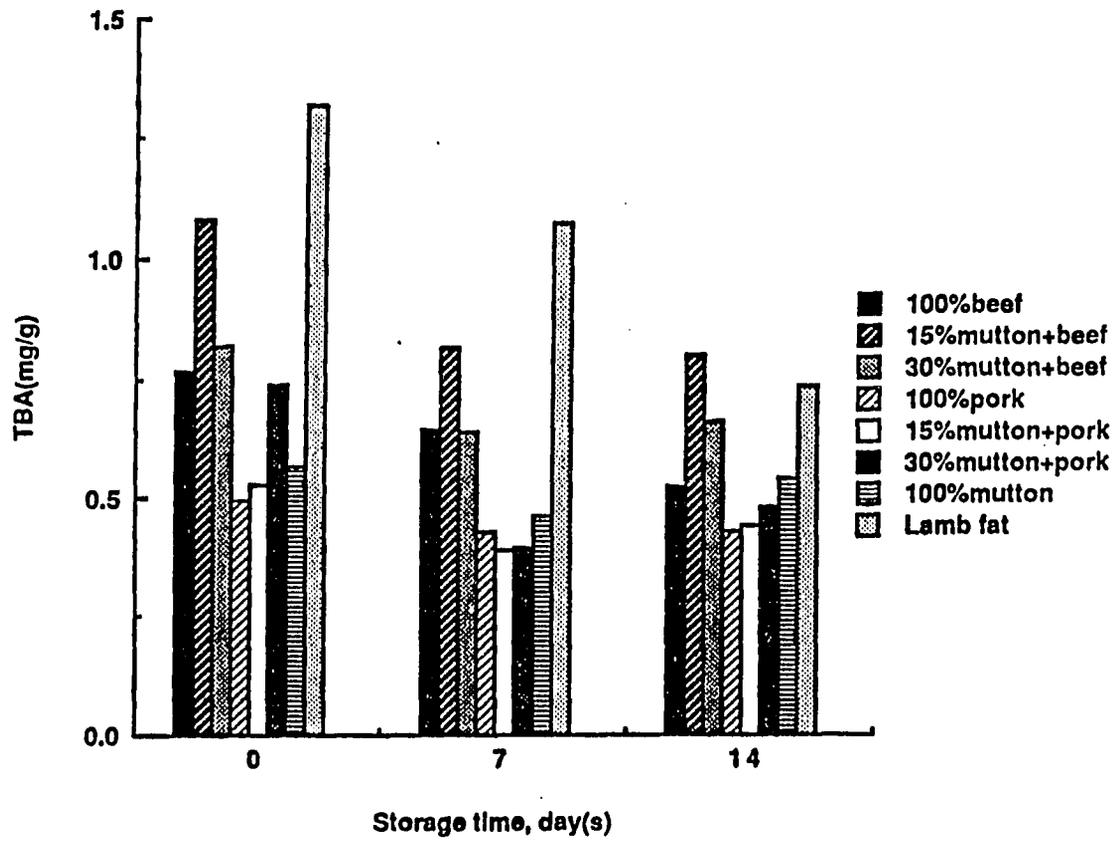


Figure 20. Effects of meat treatments and refrigeration storage time on oxidative rancidity measurements in Experiment III

### Frozen storage

MDT patties made with different amounts of mutton lean meat (0%, 15% and 30%, respectively) were vacuum packaged and stored at  $-15^{\circ}\text{C}$  for 30 days.

Meat treatments and storage time showed a significant ( $p < 0.01$  and  $p < 0.001$ , respectively) effect on pH values (Table 16). Interaction of storage time by meat treatments on pH values was significant ( $p < 0.001$ ), which indicated that pH values of meat treatments varied differently upon frozen storage. The pH values of meat treatments at different storage days are shown in Figure 21.

The pH values of MDT patties were significantly ( $p < 0.05$ ) higher than other meat treatment (Table 17). Combination treatments were not significantly ( $p > 0.05$ ) different from one another. The pH values of meat treatments on Day 0 were significantly ( $p < 0.05$ ) different from pH values on Days 15 and 30. Although pH values decreased from Days 0 to 15, the pH values did not change significantly ( $p > 0.05$ ) from Days 15 to 30 (Table 17).

TBA measurements did not vary significantly ( $p > 0.05$ ) between meat treatments (Table 16). Storage time showed a highly significant ( $p < 0.001$ ) effect on TBA values, and interaction of storage time by meat treatments was significant at  $p < 0.01$  level. The TBA values of meat treatment at different storage days are represented in Figure 22.

TBA values of patties on Day 15 were significantly ( $p < 0.05$ ) lower than on Days 0 and 30. No significant ( $p > 0.05$ ) differences in TBA values were found between Days 0 and 30.

Table 16. Effects of meat treatment and frozen storage time on acidity and oxidative rancidity measurements from analysis of variance in Experiment III

| Source                          | d.f. | Mean squares |                  |
|---------------------------------|------|--------------|------------------|
|                                 |      | pH           | TBA <sup>a</sup> |
| Treatments                      | 2    | 0.016**      | 0.008            |
| MDT vs. all treatments          | 1    | 0.027**      | 0.001            |
| 15% mutton + MDT vs. all others | 1    | 0.001        | 0.014            |
| 30% mutton + MDT vs. all others | 1    | 0.018**      | 0.008            |
| Treatments x replicates         | 4    | 0.0006       | 0.01             |
| Storage time                    | 2    | 0.02***      | 0.16***          |
| Storage time x treatments       | 4    | 0.011***     | 0.042**          |
| Residual                        | 12   | 0.001        | 0.005            |

<sup>a</sup>Expressed as mg malonaldehyde/kg food.

\*\*,\*\*p<0.01 and p<0.001, respectively.

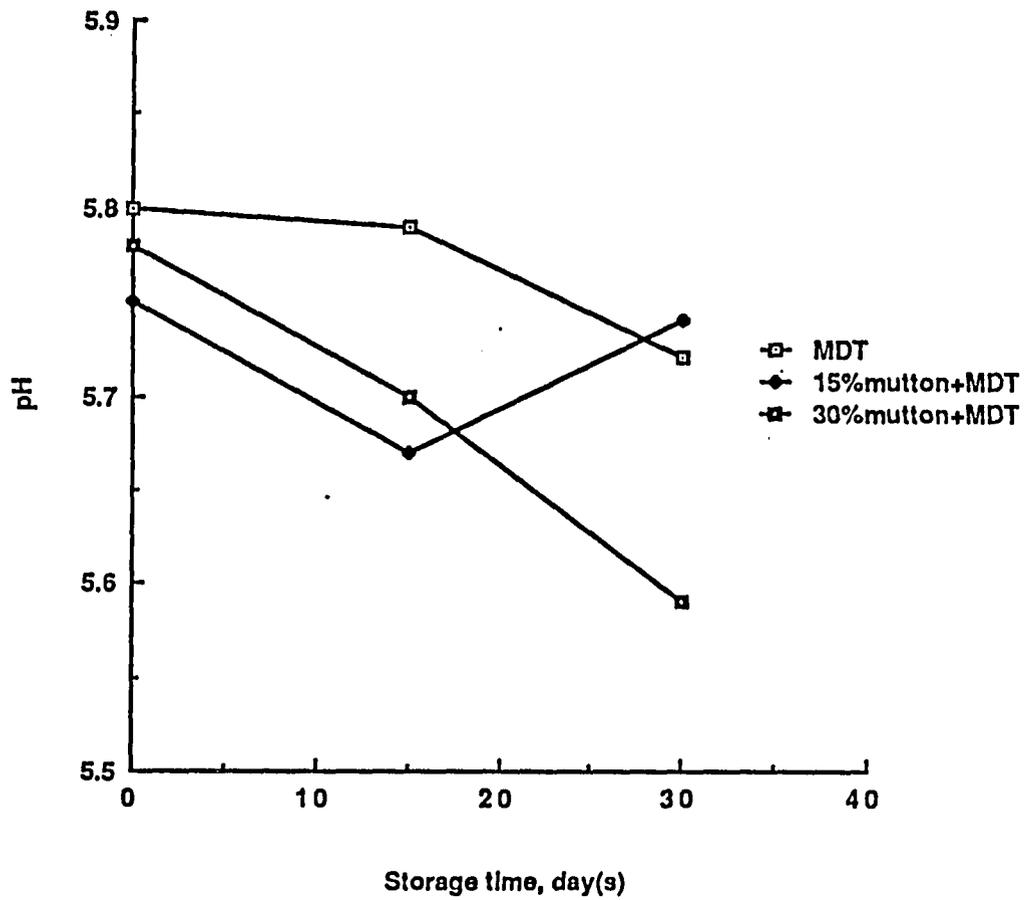


Figure 21. Effects of meat treatments and frozen storage time on acidity measurements in Experiment III

Table 17. Effects of meat treatments and frozen storage time on acidity and oxidative rancidity measurements in Experiment III

|                      | pH                 | TBA <sup>a</sup>   |
|----------------------|--------------------|--------------------|
| Meat treatment       |                    |                    |
| MDT                  | 5.770 <sup>b</sup> | 0.989              |
| 15% mutton + MDT     | 5.717 <sup>c</sup> | 0.951              |
| 30% mutton + MDT     | 5.689 <sup>c</sup> | 1.008              |
| S.E.M.               | 0.008<br>(n=9)     | 0.033<br>(n=9)     |
| Storage time, day(s) |                    |                    |
| 0                    | 5.777 <sup>b</sup> | 1.090 <sup>b</sup> |
| 15                   | 5.716 <sup>c</sup> | 0.833 <sup>c</sup> |
| 30                   | 5.683 <sup>c</sup> | 1.024 <sup>b</sup> |
| S.E.M.               | 0.011<br>(n=9)     | 0.024<br>(n=9)     |

<sup>a</sup> Expressed as mg malonaldehyde/kg food.

<sup>b,c</sup> Means within each column with different letters are significantly different ( $p < 0.05$ ).

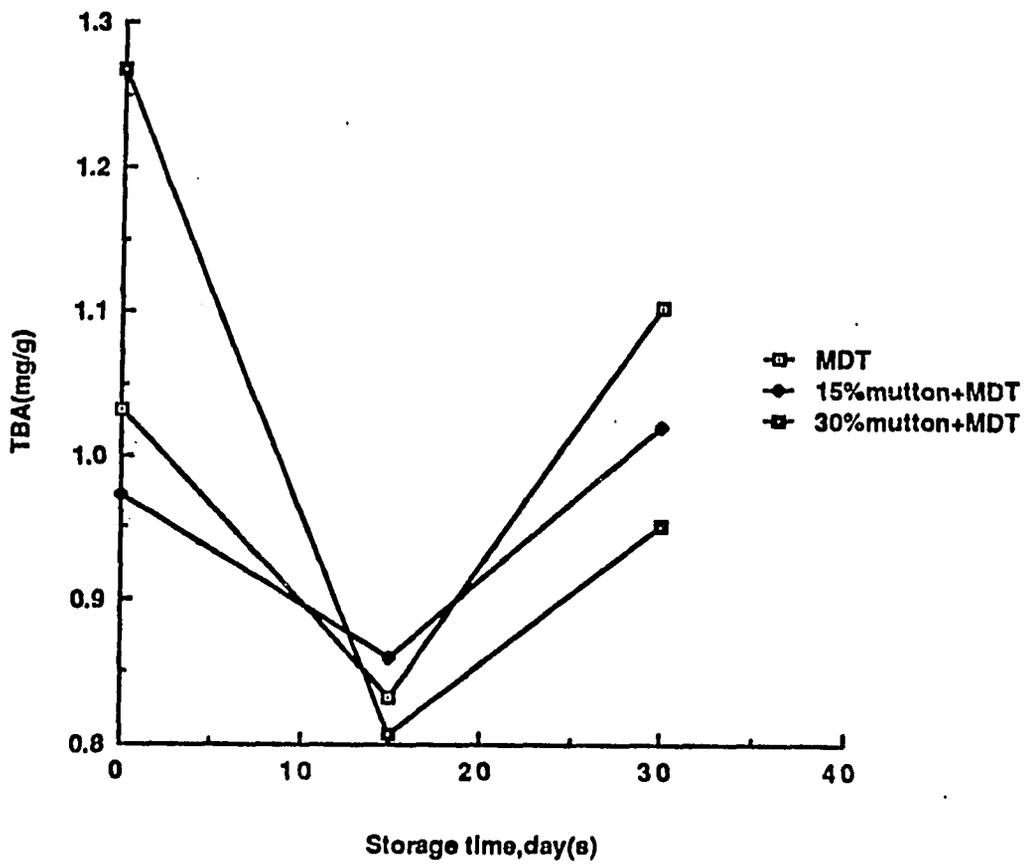


Figure 22. Effects of meat treatments and frozen storage time on oxidative rancidity measurements in Experiment III

Correlations were calculated between TBA and pH measurements to determine the usefulness of pH values in estimating rancidity in mutton combination treatments. No significant correlation between pH and TBA for the refrigeration (0.142) or frozen (0.302) storage were calculated.

It could not be established whether or not there was correlation between pH and TBA measurements in this experiment. This may be due to the following: (1) Oxidative stability of muscle lipids may be greater when muscle pH is above 6.1 (Olson, 1983; Yasosky et al., 1984), and the addition of mutton to the formulation did not greatly elevate pH. (2) Differences in fatty acids content have not been monitored between different combination treatments, and therefore oxidation rates for different fatty acids could have been an important variable influencing the results (Keskinel et al., 1964; Kwoh, 1971). Mutton meat addition at the levels used in this experiment had no effect on oxidative rancidity development.

Brown and Mebine (1969) investigated the oxidation of extracted oxymyoglobin in model systems. A strong linear dependency of oxidation rates on pH between pH 5 and pH 7 was discovered; rates decreased steadily as pH was increased. Dependencies above and below these pH values appeared reduced.

Elevated pH values have also been observed to maintain the naturally occurring enzymatic reducing activity in raw meat, maintaining myoglobin in the reduced state for various lengths of time in fresh meat.

## SUMMARY

Three experiments were performed to investigate the use of ground meat of various animal species in different formulations. Mutton and mechanically deboned turkey (MDT) are inexpensive and can be incorporated into lamb meat products to lower their cost of production.

In the first experiment, different levels of mutton meat (10%, 15% and 20%) and a constant percentage (20%) of MDT were mixed with lamb lean and fat. All formulations were adjusted to 20% fat. The effects of wrap and vacuum packaging, as well as storage conditions (refrigeration and frozen) and storage time (8 days and 4 months, respectively) were assessed. Oxidative rancidity was monitored by TBA numbers. Although TBA values were not affected significantly by meat combinations, they increased significantly in meat patties packaged in overwrap film during refrigeration and frozen storage.

In the second experiment, vacuum packaging and frozen storage were utilized for seven different formulations of ground lamb patties as follows:

- 1) 10% mutton/60% lamb/10% lamb fat/20% MDT
- 2) 15% mutton/55% lamb/10% lamb fat/20% MDT
- 3) 20% mutton/50% lamb/10% lamb fat/20% MDT
- 4) 100% mutton
- 5) 100% lamb
- 6) 100% lamb fat
- 7) 100% MDT

All formulations were adjusted to 20% fat. The evaluations included: proximate analysis, oxidative rancidity, organoleptic evaluation, bacterial counts and quantitative measurement of head-space volatiles.

Sensory panels rated higher flavor values for the formulation with 20% mutton and 100% lamb, as compared with formulations with 10% and 15% mutton during storage, but were unable to detect differences in texture, juiciness and overall acceptability. Patties formulated with 100% mutton were ranked lower in flavor, texture, juiciness and overall acceptability when compared to 10%, 15%, 20% mutton and 100% lamb. The sensory scores showed that the addition of up to 20% mutton, 20% MDT and 60% lamb lean and fat to the patties' formulation had no significant effect on the patties' quality traits.

Gas chromatography showed that concentration and area of volatiles were affected significantly by the type of meat treatments and the volatilization temperature (chromatogram sections) but not by storage time. Frequency of peaks of the seven meat treatments were not to be significantly different from one another, while storage time and chromatogram sections resulted in consistent significant differences.

Meat treatments had significant effects ( $p < 0.01$ ) on thiobarbituric acid (TBA) numbers. MDT treatments had the highest TBA values across all storage times. Although TBA values were not affected significantly by meat combinations, TBA values of 10% mutton patties were the highest numerically, followed by patties of 15% and 20% mutton, respectively.

Microbial growth curves were significantly ( $p < 0.05$ ) affected by storage time. Microbial counts of meat treatments proved not to be

significantly ( $p>0.05$ ) different.

In the third experiment, different levels of mutton lean meat (15% and 30%) were mixed with ground beef, ground pork and MDT, separately. Beef-mutton and pork-mutton combinations were stored under refrigeration conditions (14 days), while MDT-mutton combinations were stored under frozen conditions (30 days). All treatments were vacuum packaged. Relationships between TBA determinations and pH were determined.

TBA values were not affected significantly ( $p>0.05$ ) by meat treatments stored under frozen conditions. However, refrigerated conditions showed a significant ( $p<0.05$ ) increase in TBA values over time. Meat combination and storage time significantly ( $p<0.05$ ) decreased pH values in refrigeration and frozen storage.

## CONCLUSIONS

1. The patty formulations of lamb-MDT with 20% mutton had the highest sensory scores of all the combination treatments, and do not differ significantly from the 100% lamb patties.
2. Vacuum packaging and frozen storage appreciably extended the shelf life of lamb-mutton-MDT patties compared to over-wrap packaging and refrigerated storage.
3. Storage time and temperature influence flavor shelf life, especially in products containing MDT.
4. Mutton addition to the lamb-MDT patties suppressed off-flavor contributed from MDT, while MDT generally improved the sensory properties of lamb-mutton patties by enhancing textural and juiciness properties.
5. GC analysis showed that volatiles area intensity and percentage volatiles concentration were significantly affected by meat treatments. At high temperature programming, the volatiles' intensity of mutton and MDT faded.
6. TBA values decreased as percentage of mutton increased in combination treatments. However, sheep fat may generate other oxidative products or protein derived compounds that will lead to low TBA values which are not indicative of oxidative changes.
7. Storage time and temperature affected microbial counts on meat patties the most, and meat patties made of MDT had the highest presumptive Staphylococcus counts.

8. Correlation between TBA and pH were not significant in either refrigeration or frozen storage conditions.

#### Future Research

More research on headspace volatiles using gas chromatography should be done by introducing internal standards and utilizing mass spectrophotometry techniques to identify specifically the compounds generated upon refrigeration or frozen storage of meat products. A promising area of meat combination products development can be foreseen, if care in educating the consumer about the new flavors and texture is administered. Also, the usage of meat combinations in further processed products (frankfurters, salami, sausage, bologna, etc.) is appealing for further studies.

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