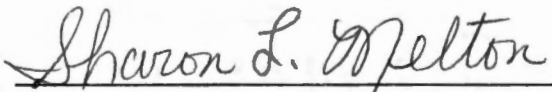
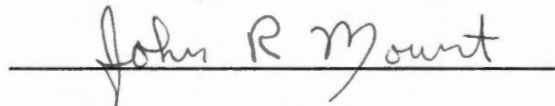


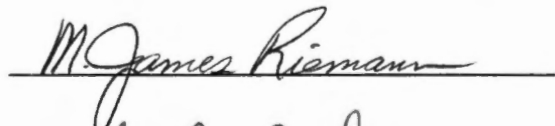
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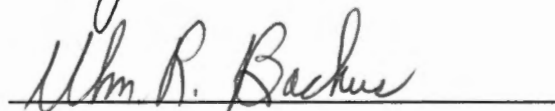
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**SENSORY AND CHEMICAL EVALUATION
OF FLAVOR IN GROUND BEEF
FROM GRASS- AND GRAIN-FED STEERS**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**James Craig Bolton
June 1987**

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DEDICATION

This thesis is dedicated to my wife Anne and my daughters Penny Elizabeth, and Leigh Anne, whose love, support, encouragement, interest, and constant attitude of concern will always be treasured. This thesis is also dedicated to my late mother-in-law Bertice J. Bradford whose love, respect and encouragement were both an inspiration and light in my life and studies.

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Most of all, I would like to thank my wife Anne Bradford Bolton, and my in-laws Carlos and Eileen Bradford for their love, friendship, inspiration, and support during my graduate studies.

ABSTRACT

A total of 48 yearling Angus, Hereford, and Charolais breeds were divided into two groups of 24 steers, and during the 1985 spring and summer, each group grazed a different pasture (PType): fescue-orchardgrass-clover or ryegrass. When each pasture no longer could sustain grazing in the summer, each group of steers was divided into 3 sub-groups of 8 steers each. One sub-group from each PType was killed directly off-pasture and represented the 0 days on feed (DOF) group. The other sub-groups were accustomed to a whole-shell corn diet over a two-week period and were fed the corn diet up to 112-DOF in a drylot at the University of Tennessee Plateau Experiment Station, Crossville, TN. At 0-, 56-, and 112-DOF, the sub-groups from each PType was transported to and slaughtered at Lay's Packing Co. Knoxville, TN. Before slaughter, fat thickness at the 12th-13th rib and steer weight were recorded along with hot carcass weight at the plant for each animal. After the carcass of each steer was chilled at 6°C for a 48-hr period, a hindquarter from each was transported to The University of Tennessee Meats Laboratory. Ground beef containing approximately 20% fat was formulated from the *biceps femoris* muscle and external fat from the round of each carcass. Ground beef from each steer was analyzed for total lipid content. From each steer, cooked ground beef patties held at an internal temperature of 55°C, were evaluated for aroma and flavor by Quantitative Descriptive Analysis (QDA). The headspace volatiles of cooked ground beef from 6 steers in each

sub-group were also analyzed. Volatile compounds from cooked ground beef held at 55°C were trapped on a Tenax GC trap, and then analyzed on a 30-m, 0.25 mm i.d. fused silica SPB-35 capillary column by gas chromatography and mass spectrometry. The relative percentage of abundance (RPA) of each volatile, intensity of each QDA flavor descriptor, total lipid content and animal measurements were statistically analyzed as a function of PType, DOF and their interaction. Factor analysis was also applied separately to the volatiles and the QDA descriptors to reduce these analyses to the lowest number of factors. The chemical volatiles were also correlated with QDA flavor analysis and the ground beef samples classified into sources by statistical procedures.

Levels of the undesirable milky-oily aroma and flavor were significantly reduced and the desirable beef fat aroma and flavor intensities increased by feeding a corn diet to beef cattle after they had grazed on pasture. Although the QDA panel used 6 different descriptors to evaluate beef flavor, factor analysis reduced all 6 to a single factor which was called "Beefy". Differences found in the flavor descriptor intensities allowed the panel to correctly classify approximately 94% of the samples into their sources of PType and DOF groups.

Forty volatile compounds, of which 29 were positively identified, were found in the headspace of the ground beef samples. Changes in the RPA of 22 volatile compounds of ground beef were found with increasing DOF. Levels of 11 volatiles (toluene, ethyl-benzene, propyl-benzene, 1-ethyl-2-methyl-benzene, pentanal, nonane, 4-methyl-3-penten-2-one, 3-penten-2-one, and 3 unknown compounds) were found to be

important in describing DOF affects for ground beef. Six of these compounds (toluene, pentanal, 1-ethyl-2-methyl-benzene, 4-methyl-3-penten-2-one, and 2 unknowns) were able to correctly classify approximately 94% of the feeding groups into the correct days on feed classification.

RPA of 16 volatile compounds were correlated with the intensities of QDA descriptors ($P < .05$). Toluene was the only compound found to be positively correlated with milky-oily flavor in ground beef. Seven compounds were positively correlated with beef fat flavor with octane having the highest correlation coefficient ($r = 0.62$). Five compounds (pentanal, ethyl-benzene, toluene, 1-ethyl-2-methyl-benzene, and an unknown) were found to account for 51% of the variation for beef fat flavor thus indicating that any of these compounds may be suitable as indicators for "Beefy" flavor.

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CHAPTER 1

INTRODUCTION

Red meat is a very desired food in America today, and its flavor is one of the most important criterion in determining the acceptability of meat as a food. Flavor is a composite experience which includes taste, smell, pressure and cutaneous sensations such as warmth, pain and cold. It is the sensation produced by a material taken in the mouth and perceived principally by the senses of taste and smell (DeMan, 1980; Holden, 1985).

Meat flavor is developed and enhanced during the cooking process. Many compounds are formed which lead to the flavor recognized by consumers as meaty. The primary reactions which occur during heating are the degradation of sugars, pyrolysis of proteins and amino acids, and degradation of lipids (DeMan, 1980; Mann, 1983).

There is common belief, in this country, that cattle are raised on grain. This misconception can be dispelled by looking at the facts. Forages from grazing lands (supplemented with hay and silage) provide 63% of the feed for dairy cows, 73% of the feed for beef cattle, and 90% of the feed for sheep (Hodgson, 1974). It is obvious that the foundation of the ruminant livestock industry is forage produced by the nation's grazing lands.

Long-term population growth, higher costs for feed grains and consumer desire for leaner beef are expected to increase demands for forages. The U. S. Department of Agriculture has projected that the demand for beef will increase from 37.6 million head in 1984 to 48.1 million head in the year 2030 (Cross, 1985).

The term forage applies to those pasture grasses, legumes, hays, and silages which are characterized by a high fiber content. Forages, thus, have a lower energy content than grain or concentrates which compose the major portion of a conventional diet for finishing cattle in a drylot in this country (Bidner, 1975). Increased slaughter of pasture-finished cattle and cattle fed high concentrate diets for a shorter period of time in a drylot has caused producers, packers, purveyors, and retailers to question the adverse effect it might have upon beef flavor.

During the past few years, research at the University of Tennessee has been conducted on feeding regimes that maximize the use of Tennessee grasslands in feeding cattle to a desirable slaughter weight and grade. Results of this research show that feeding steers grain for 80-90 days after utilizing permanent fescue pasture in the summer is necessary to produce a high quality beef carcass with desirable palatability characteristics, particularly flavor (Melton *et al.*, 1982a,b; Reviere, 1982; Stockley, 1983; Yeo, 1982). While the feeding of grain for short periods of time or feeding of high quality forage diets to an animal can result in carcasses of acceptable USDA quality and yield grades, the ultimate test of a feeding regime is the sensory characteristics of the meat produced. Because of the many types of forages and feeding systems used to finish cattle, it is impossible to make

a simple conclusion concerning the effects of all forage diets on beef flavor.

Different types of forages and feeding systems appearing to affect flavor have been reported by several researchers. Bowling *et al.*, (1978), Hedrick *et al.*, (1983), Reagan *et al.*, (1977), and Wanderstock and Miller, (1948) have shown that the addition of grain in the diets of cattle on pasture increased both overall and lean flavor desirability. Other investigations also have demonstrated a significant increase in flavor desirability of beef produced by finishing cattle on grain in a drylot versus finishing on pasture (Bowling *et al.*, 1978; Dolezal *et al.*, 1982; Harrison *et al.*, 1978; Hedrick *et al.*, 1983; Meyer *et al.*, 1960; Schroeder *et al.*, 1980; Wanderstock and Miller, 1948; Westerling and Hedrick, 1979).

Several articles have been published concerning the use of the Quantitative Descriptive Analysis procedure to characterize the differences between pasture-produced and corn-produced beef (Holden, 1985; Larick, 1984; Melton *et al.*, 1982a,b). However these limited results are insufficient to allow one to make conclusions concerning flavor preferences for forage- and corn-finished beef. In addition, only one investigation has actually correlated analysis of flavor volatiles with sensory evaluation of flavor of fat from grass- and grain-fed steers (Larick, 1984).

Volatile flavor components are a result of degradation and interactions of lipid-soluble, as well as water-soluble constituents, and thermal oxidation of lipids. There has been little research reported concerning the qualitative and quantitative differences in flavor volatiles

of beef produced on grass versus grain diets. A number of compounds are believed to be associated with the undesirable flavor due to grass feeding (Bailey *et al.*, 1980; Larick, 1984; Melton *et al.*, 1982b).

Therefore, the objectives of this study were to: determine the effect of different grass pasture diets followed by a corn diet of up to 112 days on the volatile flavor components and sensory flavor characteristics of ground beef, and to determine the relationship between the volatile flavor compounds and sensory flavor characteristics of ground beef.

CHAPTER 2

REVIEW OF LITERATURE

Meat Flavor

Production of different flavors. Flavor has been described as sensations produced by a food when taken into the mouth, which are then perceived primarily by the human senses of taste and smell, along with the pain, pressure and temperature receptors found in the mouth (Hall, 1968). A second definition of flavor is all those compounds in a food which cause the two sensations of taste and smell (DeMann, 1980). The flavor of raw meat is a bloody smell and taste. Upon heating, reactions among proteins, carbohydrates, fats, salts and minerals within the meat form a number of compounds that give rise to the flavor of cooked meat.

It has long been felt that there is the same basic lean meaty aroma for beef, pork, and lamb, and that the species flavor difference in meat is because of the fatty acid composition of the lipids. Meat flavor, from different species, may be attributed to the formation of different volatile compounds such as unsaturated and saturated aldehydes, volatile fatty acids and methyl ketones produced from long chain fatty acids during cooking as well as their concentrations (Dwivedi, 1975; Sink, 1979). Hornstein and Crowe (1960) were among the first to report that fat and, more specifically, the carbonyl compounds, contributed to differences in

flavor among species. Other workers including Wasserman and Spinelli (1972) and Hornstein and Crowe (1964) have also associated fat with species flavor. Wasserman and Tally (1968) demonstrated, using a sensory panel, that the addition of fat to lean ground beef or pork increased the number of correct species identifications. According to Wasserman (1972), one of the limitations of research conducted in this area, is that the term "fat" has often not been carefully described. Adipose tissue, which is often referred to as "fat", contains, besides fatty acids and lipids, amino acids, proteins, sugars, salts, and various other constituents present in all tissues. These latter components of fat tissue also may contribute to the characteristic species flavor of meat (Wasserman and Spinelli, 1970)

The flavor precursors of lean cooked beef have been found to be water soluble, and in part, are composed of free amino acids and reducing sugars (Hornstein *et al.*, 1960; Kramlich and Pearson, 1958; Wasserman and Gray, 1965). Free amino acids of beef react with the reducing sugar present via the nonenzymatic browning reaction during cooking to produce a typical lean meaty flavor in all species of meat (DeMann, 1980). Because of this observation, one would expect the level of free amino acids in meat to decrease during cooking. However, Macy *et al.* (1970) reported that when a beef roast was cooked to 77°C, all free amino acids except threonine, serine, glutamic acid, histidine, and arginine, increased. The increases in the levels of free amino acids could have been due to hydrolysis of protein and possibly involved proteolytic enzymes in the tissue.

Wasserman and Spinelli (1970) further showed that adipose tissue from beef, pork, and lamb contained precursors of the characteristic aroma of the species other than fatty acids by the following experiment. They extracted adipose tissue from each specie with chloroform:methanol (2:1, v:v), heated the extracted residue and showed that it exhibited a meaty aroma characteristic of the respective specie. However, when the adipose tissue was extracted with water and the residue heated, the resulting aroma was lacking in and exhibited a greatly reduced characteristic specie note. The water extract from the adipose tissue of each specie contained amino acids and glucose.

Smith *et al.* (1983) reported that although the basic meaty flavor is non-lipid in origin, some quantity of fat is undoubtedly necessary to make beef taste rich, full, and "beefy"; the amount of fat, on or in the animal and beef, that is necessary to fulfill the appropriate flavor and aroma functions is not presently known. Fat thus may affect flavor in two ways (Hornstein, 1971). Fatty acids, upon oxidation, can produce carbonyl compounds that are potent flavor contributors themselves or can be further broken down into possible flavor contributors (Min *et al.*, 1977), and fat may act as a storage depot for odoriferous compounds that are released when heated.

Flavor volatiles from water soluble precursors in model studies.

In model studies designed to determine the role of sugars in aroma production, Herz and Shallenberger (1960) reported that when glucose was heated alone to 100°C, no aroma was produced; however, a caramel aroma was produced when glucose was heated to 180°C. Also,

Walter and Fagerson (1968) separated and identified many of the compounds produced from glucose when heated at 250°C for 30 min. Some of the compounds identified included formaldehyde, furan, 2-methyl furan, diacetyl, acetic acid, furfural, 4-hydroxy-2-pentanoic acid, 1-(2-furyl)-propane-1,2-dione, 3-methyl-cyclopentane-1,2-dione, and phenol.

Flavor volatiles from thermal degradation of fatty acids and/or lipids. Volatile flavor components from lipids are formed as a result of thermal oxidation of lipid constituents. The number of compounds arising from lipid and free fatty acids during heating is fairly large. Thermal autoxidation can occur at 60°C in the presence of a few free radicals, but most of the lipid degradation occurs at 200–300°C. At higher temperatures, such as 600°C, pyrolysis occurs with formation of bitter and acrid components (Larick, 1984).

Selke *et al.*, (1975, 1977, 1980) conducted a series of experiments to isolate the volatile components from tristearin, triolein, and trilinolein heated in air at 192°C. The volatile components from tristearin were methyl ketones (3 to 17 carbons), 38%; aliphatic (3 to 17 carbons) aldehydes, 35%; n-hydrocarbons (4 to 17 carbons), 9%; primary alcohols (4 to 14 carbons), 3%; other compounds, 15%. Each class of compounds was represented by a homologous series indicating that no specific oxidative attack occurred in the triglyceride. Rather, each methylene carbon in the fatty acyl group appeared to be susceptible to oxidation with preferential attack toward the center of the molecule (Selke *et al.*, 1975).

The thermal oxidation of triolein produced seven major compounds which were identified as heptane, octane, heptanal, octanal, nonanal, 2-decenal, and 2-undecenal. The minor volatiles produced represented homologous series in four classes: aldehydes, methyl ketones, hydrocarbons, and primary alcohols. In both the major and minor compounds, the aldehydes were the most predominate class of volatiles produced (Selke *et al.*, 1977).

The major volatiles observed from the thermal oxidation of trilinolein included: pentane; pentanal; 1-pentanol; hexanal; 2- and/or 3-hexenal; 2-heptenal; 2-octenal; 2, 4-decadienal. Minor volatiles identified from the heated trilinolein included: aliphatic acids, saturated and unsaturated aldehydes, primary and secondary alcohols, hydrocarbons and methyl ketones (Selke *et al.*, 1980). From their studies, these researchers concluded that all the aldehydes and half of the ketones produced from the thermal oxidation of the fatty acids studied, equaled or exceeded their reported taste threshold values. In some instances, the aldehydes and ketones surpassed their reported threshold levels by factors of 300 and 20, respectively. This suggests that thermally oxidized fatty acids may be precursors of odors and flavors associated with heated lipids.

Other researchers have also shown a relationship between beef fatty acids and alkyl-benzenes in beef flavor. Nonaka *et al.* (1967) found m-xylene among the oxidation products of trans, trans-2, 4-decadienal, a thermal oxidative decomposition product of lipid (particularly linoleic acid) which may form n-alkylbenzenes by a six-membered ring cyclization reaction involving the loss of H₂O. Min *et al.* (1977) has reported that

alkylbenzenes may be formed from the long chained unsaturated hydrocarbons which were derived from thermal oxidative decomposition pathways of fatty acids and then form the aromatic compounds by way of a peroxide initiated free radical decomposition. The role of alkylbenzenes and the effects they have on beef flavor have yet to be determined.

Flavor volatiles from cooked beef. Several investigators have studied the flavor volatiles of cooked beef (Herz and Chang, 1970; Hirai *et al.*, 1973; Liebich *et al.*, 1972; Watanabe and Sato, 1971). These volatiles arise from the nonenzymatic browning reaction of amino acids and reducing sugars as well as degradation of other water soluble components. However, the major portion of the volatiles arise from thermal degradation of fatty acids and lipids in the beef.

Early studies on meat flavor resulted in the identification of a number of acids, alcohols, aromatics, hydrocarbons, and carbonyl compounds. Herz and Chang (1970) reported that the most numerous members of any class of compounds identified in meat flavor preparations were carbonyls. Hirai *et al.* (1973) also found a number of carbonyls along with hydrocarbons and some aromatic compounds. All arise principally from lipids and are found in volatiles of fat or fatty meat.

Liebich *et al.* (1972) separated and identified approximately 40 volatile components of roast beef using gas-liquid chromatography and mass spectrometry. They reported that most of these volatiles arose from the lipid portion of the beef. Flavor samples were obtained by low temperature, vacuum distillation, followed by extraction of distillate with

diethyl ether. Several series of volatiles were identified including: alkanes (9 to 18 carbons), alkanals (5 to 10 carbons), alk-2-enals (7 to 13 carbons), alka-2,4-dienals (8 to 12 carbons), alka-2,3-diones (4 to 8 carbons), and several alkylbenzenes containing from one to four carbons in the alkyl side chain.

Watanabe and Sato (1971) separated the volatile compounds from beef fat heated under the cooking condition of 145°C for 10 minutes and then further separated the nonacidic compounds into five fractions by silicic acid column chromatography. The major volatiles identified consisted of several series of carbonyl compounds including alkanes (8 to 23 carbons), alkanals (5 to 9 carbons), alk-2-enals (7 to 11 carbons), and methyl alkanones (11 to 13 carbons). The odor of the nonacidic compounds resembled the heated flavor of beef fats.

The Effects of Diet on Beef Flavor

Flavor intensity and desirability. Diet of the animal before slaughter may cause a large difference in beef flavor. Because of the many types of forages and feeding systems used to finish cattle, it is impossible to make a simple conclusion concerning the effects of all forage diets on beef flavor. Different types of forages and feeding systems appear to affect beef flavor in different ways.

Research on the effects of grazing pasture *versus* supplementing grain on pasture on flavor scores of beef have been done by several investigators. Burris *et al.* (1976), and Reagan *et al.* (1981) have shown that the addition of grain in the diets of cattle on pasture has no

significant effect on either the desirability of flavor or overall flavor desirability. In contrast to these findings, Bowling *et al.* (1978), Hedrick *et al.* (1983), Reagan *et al.* (1977), and Wanderstock and Miller (1948) demonstrated an increase in both overall and lean flavor desirability by supplying grain to cattle finished on grass.

Results from several studies (Bowling *et al.*, 1978; Dolezal *et al.*, 1982; Harrison *et al.*, 1978; Hedrick *et al.*, 1983; Holden, 1985; Larick, 1984; Meyer *et al.*, 1960; Schroeder *et al.*, 1980; Wanderstock and Miller, 1948; Westerling and Hedrick, 1979) have shown that beef produced on pasture has less desirable flavor than beef in drylot grain feeding. However, two groups of investigators, Chasten *et al.* (1981) and Reagan *et al.* (1981) found no difference in the flavor intensity of grain-finished *versus* pasture-finished beef. In general, the time grain is fed to cattle in dry-lot after pasture improves the desirability of beef flavor to the American consumer. This improvement begins with any period in excess of 27 days (Dolezal *et al.*, 1982) and continues with additional feeding up to 110 to 130 days (Dolezal *et al.*, 1982; Hedrick *et al.*, 1983; Larick, 1984; Melton *et al.*, 1982a; Schroeder *et al.*, 1980; Wanderstock and Miller, 1948; Westerling and Hedrick, 1979). Research at the University of Tennessee (Melton *et al.*, 1982a; Mann, 1983; Yeo, 1982) has shown that the intensity of the beef flavor reaches a maximum at 80 to 90 days of grain-feeding of steers.

Differences in flavor desirability of the fat from cattle finished by grazing on pasture *versus* that from grain-fed cattle in a drylot have been reported by several researchers (Harrison *et al.*, 1978; Larick, 1984; Meyer *et al.*, 1960; Wanderstock and Miller, 1948). These researchers

found that the fat from grain-finished cattle had a significantly more desirable flavor than the fat from pasture-finished cattle, and that the flavor difference between grass-produced and grain-produced beef was primarily due to the flavor difference in the fat not the lean.

Melton (1983) reported that several studies which compared grain-fed animals with grass-fed animals appeared to confound the degree of animal fatness and weight with the effect of diet, since the grain-fed cattle were characteristically fatter and heavier than grass-fed animals. A few studies have been reported in which the effects of grazing on pasture and/or grain in drylot on the flavor scores of beef from cattle slaughtered at similar weights, fat thickness, fat contents, or other measures of fatness have been evaluated. When cattle were finished to yield a carcass of equivalent weight, those finished on grain in drylot had a significantly higher flavor desirability than those grazed on pasture (Bowling *et al.*, 1977; Davis *et al.*, 1981). When cattle were finished to similar fat content, as indicated by the percent intramuscular fat in the *longissimus* muscle, or overall quality grade, grain-fed samples were determined to be more desirable and possessed greater cooked beef flavor intensity than those finished on pasture (Davis *et al.*, 1981; Dolezal *et al.*, 1982; Reagan *et al.*, 1977).

When ground beef of equal fat content was prepared, using tissues from corn-fed or pasture-fed cattle, corn-produced samples had significantly more desirable flavor than pasture-produced samples (Brown *et al.*, 1979; Larick, 1984; Melton *et al.*, 1982a,b).

Qualitative description. Several articles have been published concerning the use of the Quantitative Descriptive Analysis procedure as described by Stone *et al.* (1980) to characterize the differences between pasture-fed and corn-fed beef. Melton *et al.* (1982a) reported that the corn-finished beef was more desirable than pasture-finished beef and that this increase in desirability was associated with lower intensities of milky-dairy flavor, the absence of a soured dairy flavor or other off-flavors, and higher intensities of cooked beef fat flavor. Other researchers (Holden, 1985; Yeo, 1982) have also shown that pasture produced beef has higher intensities of a milky-oily flavor than grain produced beef. Melton *et al.* (1982b), Holden, (1985) and Yeo, (1982) all observed that as cattle were fed corn in drylot after pasture, a desirable beef fat aroma and flavor, and a liver flavor increased in intensity, while the undesirable milky-oily aroma and flavor, sour aroma and flavor, and fishy flavor decreased in intensity. Berry *et al.* (1980) reported that a desirable flavor in beef steaks was associated with higher intensities of a browned flavor defined as caramelized, bouillon-like, sweet, and beefy and that an undesirable flavor was associated with higher intensities of grass and astringent flavors resulting in a puckering and dry feeling in the mouth. Schroeder *et al.* (1980) reported that grain-fed beef had a fatty flavor compared to a grassy flavor in grass-fed beef. Larick (1984) also concluded that grassy flavor of ground beef and cooked steaks decreased when steers were fed grain in drylot with the greatest decrease occurring from 0 up to 84 days of grain feeding.

Precursors. There has been little research reported concerning the qualitative and quantitative differences in flavor volatiles of beef produced on grass *versus* grain diets. Bailey *et al.* (1980) observed that fat from animals which grazed fescue produced the most total volatiles which were believed related to undesirable flavor. A peak eluting after approximately 38 minutes appeared to be associated with the undesirable flavor due to grass feeding since it was larger in samples from cattle on fescue than on a grain diet. This peak contained several volatiles including: octadecane, δ -decalactone, diethyl-phthalate, and δ -dodecalactone. Other compounds which appeared at higher concentrations in fat from grass-fed animals that appeared to be associated with grassy or oily odors include: C₅–C₁₀ aldehydes and 2, 4–decadienal.

Hexanal and 2, 4–decadienal were two of the compounds which were shown to be produced in high concentrations during the thermal oxidation of fatty acids (Selke *et al.*, 1975, 1977, 1980). Melton *et al.* (1982b) reported that trans,trans–2,4–decadienal in methanol (1 $\mu\text{g ml}^{-1}$) was selected by their Quantitative Descriptive Analysis panel as the standard for an intense magnitude of the oily aroma of the complex milky–oily flavor which they identified in beef produced on a grass diet. Park and Ford (1975) reported that organoleptic responses for oily flavor paralleled an increase in concentration of 2,4–decadienal in cooked lamb. They concluded that the aldehyde was responsible for the oily flavor.

Volatile fatty acids (C₁–C₆) have been reported to contribute positively to beef flavor (Dwivedi, 1975). Melton *et al.* (1982b) reported

that the concentration of all volatile fatty acids (VFA) analyzed in ground beef from grass-fed and grain-fed steers, except isobutyric acid, changed significantly during a period of 140 days on corn feeding. Acetic acid had the highest concentration of all VFA and was observed to increase linearly with days on corn. The other volatile fatty acids analyzed in beef had curvilinear relationships with the length of time that steers were fed corn.

Larick (1984) analyzed 72 fat samples taken from one half of 144 steers on three pastures: tall fescue, smooth brome-grass-red clover or orchardgrass-red clover, and then fed corn for a period up to 112 days over a period of two years. Fifty-three compounds were identified in the volatiles of melted subcutaneous fat by direct sampling-gas chromatography/mass spectrometry. Several classes of compounds including low molecular weight alkanals and alk-2-enals, low molecular weight acids from C₇ to C₁₀ carbon length, high molecular weight alkanes from C₁₆ to C₁₈ carbon lengths, and numerous isoprenoid hydrocarbons of C₂₀ carbon length were determined to be positively correlated with grassy flavor. Hexanal or 2,4-decadienal compounds were not found to exist in detectable levels in any of the fat samples analyzed.

Volatile components. Fatty acids are important precursors of beef flavor, since they are the primary source of carbonyl compounds (Herz and Chang, 1970), and the oxidation of the unsaturated fatty acids in beef lipids result in off flavors in meat (Pearson *et al.*, 1977).

Diet affects the fatty acid composition of beef. Beef produced on low energy diets appears to have higher levels of C_{14:1}, C_{16:1}, C_{18:0}, and C_{18:3}, and lower levels of C_{16:0} and C_{18:2} than beef produced on high energy diets fed *ad libitum* (Brown *et al.*, 1979; Melton *et al.*, 1982a). In general, beef from cattle produced on grass diets has higher concentration of C_{15:0}, C_{18:0}, C_{18:3}, C_{20:3}, C_{20:4}, and C_{22:5}, and has less C_{14:0}, C_{16:0}, C_{17:0}, and C_{18:1} fatty acids than beef from cattle produced on grain diets. The effect of diet on the concentration of C_{18:2} appears to depend on the source of the fat analyzed. Intramuscular fat from grass-fed beef had a higher concentration of C_{18:2} than that of grain-fed beef, while the C_{18:2} concentration in subcutaneous fat was higher in grain-fed beef (Melton, 1983; Westerling and Hedrick, 1979).

Lipid Composition in Beef

Type of lipids. Lipids are organic compounds that are insoluble in water but soluble in organic solvents. Quite a variety of different types of lipid compounds are found in beef tissues, all of which serve some important biochemical or physiological function. Triglycerides are the most abundant of the lipids. The typical fat molecule consists of glycerol combined with three fatty acids. There are more than 40 different fatty acids that may be esterified to the glycerol in animal fats (DeMan, 1980). These fatty acids differ in carbon chain lengths, degree of branching, and in the degree of unsaturation.

Other than glycerides and free fatty acids, beef tissues also contain phospholipids. Phospholipids are basically composed of glycerol bonded

to 2 fatty acids and phosphoric acid connected to a nitrogen containing alcohol. Examples of phospholipids are phosphatidylcholine (lecithin) and phosphatidylethanolamine (cephalin). The distribution of fatty acids in phospholipids is nonrandom, with saturated fatty acids occupying position one and unsaturated fatty acids in position two. The fatty acid composition of the phospholipid is usually different from that of a triglyceride. The acyl groups of the phospholipids are usually more unsaturated than those of the triglyceride. Sphingolipids are similar to phospholipids but have sphingosine rather than glycerol as an alcohol (DeMan, 1980; Pearson *et al.*, 1977).

The unsaponifiable fraction of beef fat consists of sterols (64%), terpenic alcohols (5.5%), aliphatic alcohols (2.4%), and hydrocarbons (1.8%) (Jacini *et al.*, 1967). Sterols are compounds containing the perhydrocyclopentanophenanthrene nucleus and the most common one found in beef lipid is cholesterol (DeMan, 1980).

Location of lipids and their importance to the beef animal. Lipids found in meat can be classified as subcutaneous, intermuscular, or intramuscular. The subcutaneous lipids are found in relatively large deposits in specialized connective tissues. Intermuscular lipids are stored in the connective tissue septa which divides individual muscles and contains various amounts of the adipose tissue. Intramuscular lipids are primarily found as microscopic droplets of fat within the muscle cell, or in adipocytes (fat cells) within the perimysial connective tissue layer. The intracellular lipids exist in close association with cell wall proteins that

contain a high percentage of the total phospholipids (Love and Pearson, 1971).

The phospholipid and cholesterol portions of the muscle lipids are essential to muscle because of their role in structure and function of the muscle cell and its organelles. The neutral lipids are not essential to muscle structure but they provide fatty acids for energy metabolism in living muscle and contribute to the palatability characteristics of meat (Allen and Foegeding, 1981).

Age effect on lipid level. Link *et al.* (1970) determined the percent of total lipid, neutral lipids, and phospholipids of the *longissimus* muscle of cattle at 360, 420, and 480 days of age. The percent total lipid increased from 2.5% to 7.7% to 12.7% as age increased. The percent neutral lipids increased from 78% to 92%, while the percent phospholipids decreased from 22% to 5% as age increased.

Fatty acid composition of beef lipids. Hood and Allen (1971) determined the composition by class of both intramuscular and subcutaneous saturated and unsaturated fatty acids associated with various types of lipids. The data showed that the greatest percentages of the fatty acids found in both inter- and intramuscular beef fat were saturated or contained only one unsaturated bond. The free fatty acids and phospholipids of the intramuscular fat contained the only substantial amounts of polyunsaturated fatty acids, the fatty acids that are the most susceptible to oxidation and production of subsequent off flavors. Hornstein *et al.* (1961) concluded that phospholipids do not contribute to

desirable meat flavor, but that in excessively lean meat, they could contribute to off flavor.

Headspace Techniques for Collection of Beef Volatiles

Trapping methods. The aroma of cooked beef has been extensively studied, and about 600 volatile compounds from variously heated beef samples have been identified (Galt and MacLeod, 1984; Lee *et al.*, 1981; MacLeod and Seyyedain-Ardebili, 1981; Mottram *et al.*, 1982). Unfortunately, aroma isolation methods have usually involved multistage techniques including distillations, flash evaporation, cold trap condensation, solvent extraction, acid/base fractionation, and/or chemical derivative analysis. The long and complicated nature of several of these methods adds to the possibility of losses and artifact formation already inherent in them (Galt and MacLeod, 1984).

Recently indirect headspace methods, involving absorption and simultaneous concentration of volatiles on porous polymers, have become widely used in the analysis of beef. Advantages of absorptive techniques indicate that the volatiles are concentrated on the basis of their relative volatilities rather than affinity for or solubility in a solvent and when compared with an isolate obtained from solvent extraction, there is no solvent to interfere with the analysis of the cooked beef product (Galt and MacLeod, 1984; Mottram *et al.*, 1982; Tassan and Russell, 1974).

Tenax GC. A few researchers have reported on the use of Tenax GC as an absorbent used in indirect headspace collection of

cooked beef volatiles (Galt and MacLeod, 1984; Mottram and Edwards, 1983; Mottram *et al.*, 1982). Tenax has a very high affinity for organic compounds, which it absorbs reversibly (Galt and MacLeod, 1984). It is relatively hydrophobic, which is important in view of the large volume of water vapor produced on heating meat. It is the preferred polymer in applications where relatively high boiling compounds are of interest (Brown and Purnell, 1979; Cole, 1980), and compared with the Porapacks and Chromasorbs it has the highest temperature limit of 375°C (Galt and MacLeod, 1984; Williams *et al.*, 1978). When heat desorption is the chosen method for releasing aroma volatiles, Galt and MacLeod (1984) determined that compared with a range of Chromosorbs, Tenax (desorbed at 250°C) gave the highest recoveries of volatile compounds. For a model system of some typical food aroma components; almost quantitative desorption occurred with Tenax GC and Galt and MacLeod, (1984) found it gave the most characteristic flavor isolate by aroma judgement.

CHAPTER 3

MATERIALS AND METHODS

Experimental Design

Forty-eight yearling Angus, Angus x Hereford, and Angus x Charolais steers were randomly allotted to one of two pasture systems (24 animals per system): tall fescue (*Festuca arundinacea* IFN 2-01-920) -orchardgrass (*Dactylis glomerata* L. IFN 2-01-439)-red clover (*Trifolium pretense* L. IFN 2-01-428) (Group A), or ryegrass (*Lolium multiflorum* -variety Marshall-IFN 2-04-073) (Group B). All steers were placed on forage from September to November of 1984 and again from March to the summer of 1985. Before the spring grazing period was begun, all steers were implanted with a 36-mg pellet of Zeranol (Ral-Gro™). All steers were wintered on the fescue-orchardgrass-clover pasture and were fed hay composed of tall fescue and various legumes when snow covered the ground. At designated times during the summer, the steers on each pasture type were divided into three sub-groups, placed in the feedlot and fed a whole shelled corn diet (Table 1). Efforts were made to have equal amounts of steers of same breed, body size, and weight in each sub-group. After being placed into the feedlot, the steers were serially slaughtered at 0, 56, and 112 days (Table 2). Weight and fat thickness were recorded for each steer at of pasture and again after the completion of 56 or 112 days on feed. Fat

Table 1

Diet For Steers Fed In Drylot

Ingredient	Amount by weight ^a
Whole shelled corn	<i>ad libitum</i>
Supplement(36% Protein) CO-OP Ration 433 (contains 300g ton ⁻¹ Sodium Monensin)	1.1 lbs Head ⁻¹ Day ⁻¹
Minerals	<i>ad libitum</i>

^a Dry matter basis

Table 2

Slaughter Schedule For Steers On Pastures A and B in 1985

Slaughter group ^b	Pasture type ^a	
	A	B
0-DOF	July 29	July 01
56-DOF	Oct 07	Sept 09
112-DOF	Dec 02	Nov 04

^a A = Fescue, Orchardgrass, Clover Pasture; B = Ryegrass Pasture

^b 0-DOF samples from steers slaughtered directly off of pasture;
 56-DOF samples from steers slaughtered after 56 days on feed;
 112-DOF samples from steers slaughtered after 112 days on feed.

thickness was measured over the 12th–13th rib 10.2–cm from the mid–line ultrasonically on the live animal.

Slaughter and Processing

The steers were slaughtered at Lay's Packing Company, Knoxville, TN. After slaughter, the carcasses were weighed and hot carcass weights recorded, chilled at 5 to 6°C for a 48–hr period, and graded; then a hindquarter was purchased, removed, and transported to The University of Tennessee, Department of Food Technology and Science Meats Abattoir. The USDA carcass quality and yield grades were determined (Official United States Standards for Grades of Carcass Beef, 1975) by a USDA grader at the plant.

At the meats laboratory, each hindquarter was fabricated at which time 2.5–kg of the *biceps femoris* muscle and at least 1.25–kg of external round fat were obtained from each hindquarter. The muscle and the fat from each steer were then vacuum packaged in a 20.5–cm x 61.5–cm Cryovac barrier bag, with an O₂ transmission rate of 30–50 cc @ 23°C [m², 24 hr., 1 atm] and a H₂O vapor transmission rate, 0.5–0.6–g @ 38°C 100% R.H. (100 sq. in., 24 hr.), using a Cryovac double chamber vacuum packaging machine (Model 8210). The bag was then heat shrunk by immersion for approximately 2 sec in a 91°C water bath and then stored in a 2°C cooler for aging.

The packaged muscle and fat were aged ten days in the cooler; then each was ground separately through a 1.3–cm plate on a Biro™ 5–hp grinder (Model 5–42–48–52). The fat content of the ground muscle

and ground fat were determined by a modified Babcock fat analysis (Ockerman, 1969). The ground beef was formulated to contain approximately 20% fat by the Pearson Square Method (Terrell, 1971) and was prepared from the lean and the fat by mixing them thoroughly and grinding through a .32-cm plate twice on the Biro™ grinder. After grinding, ground beef from each steer was divided into 250-g and 350-g portions, vacuum packaged in a 18-cm x 36-cm Cryovac barrier bag, and stored at -32°C. These samples were used for chemical (250-g) and volatile (350-g) analysis. The remaining portion of ground beef from each steer was made into 12, 100-g patties using a hand-patty press for sensory evaluation. Packaging and storage were the same as for the chemical analysis samples.

Chemical Analysis

Six months after the last fabrication, the 250-g sample of ground beef was thawed, and powdered in liquid nitrogen (Mann, 1983). The powdered sample from each carcass was stored at -18°C, and the following analysis was run within one week.

Total lipids and lipid soluble compounds were extracted from 15-g of the powdered ground beef sample by the chloroform-methanol procedure described by Melton *et al.* (1979) with the BHT (butyl hydroxy toluene) addition described by Holden (1985) to prevent oxidation of the polyunsaturated fatty acids. After extraction and isolation of the chloroform solution of the lipid extract, the total lipid content of each sample was determined as described by the same authors. Total lipid

and lipid soluble compounds are expressed as mg of lipid 100 g⁻¹ of ground beef.

Sensory Analysis

A Quantitative Descriptive Analysis (QDA) panel trained as described by Melton *et al.* (1982b) and under the conditions reported by Melton (1983), with two exceptions, was used to evaluate the flavor of a 100-g ground beef patty from each sample by the QDA method on the modified score sheet shown in Figure 1 (Mann, 1983). The exceptions were that the beef for sensory evaluation was kept at 55°C in ceramic bowls as described by Sanders (1985) and the QDA score sheets' 150mm horizontal line for each flavor descriptor was segmented into 10 equal units with a range of 0 to 100. The flavor of the patty was evaluated within six months of the last fabrication.

Headspace Volatile Analysis

An analysis of headspace volatiles was undertaken using the 350-g sample of ground beef from six steers randomly selected from each feed group and pasture type (n=36). A volatile entrainment similar to the method described by Mottram *et al.* (1982) was used with modifications including using a totally stainless steel containment and nitrogen line system to handle the pressure needed for entrainment, a 55°C hold temperature of the sample during the collection process, and a 30 min collection time. Prior to cooking, a 350-g sample of ground beef from

QDA Score Sheet

Name _____

Sample # _____

Date _____

First smell and then taste each sample individually and determine quantitatively the flavor characteristics listed below by placing a mark on the line beside the descriptor term which would represent that intensity. Rinse your mouth between samples.

Aroma

Cooked Beef Fat	0	10	20	30	40	50	60	70	80	90	100
Milky-oily (grass-fed beef)	0	10	20	30	40	50	60	70	80	90	100

Taste

Cooked Beef flavor (fat)	0	10	20	30	40	50	60	70	80	90	100
Milky-oily (grass-fed beef)	0	10	20	30	40	50	60	70	80	90	100
Off-Flavor (Liver etc.)	0	10	20	30	40	50	60	70	80	90	100
Sour	0	10	20	30	40	50	60	70	80	90	100

Describe any off-flavor present:

Can you attend the next taste panel at _____?

Yes _____ No _____

Figure 1. QDA Score Sheet

each steer was removed from the freezer, and allowed to thaw at 5–6°C for 16 hr. Two beef patties, each weighing 125–g were prepared using a hand patty press and cooked as reported by Melton (1983) to an internal temperature of 70°C. The patties, after cooking, were ground using a hand mill (.32–cm plate), and weighed, and a 200–g sample was placed on a ceramic plate resting on the bottom of a 4 qt aluminium pressure saucepan for volatile entrainment of the headspace compounds.

(Figure 2) A sodium sulfate (Na_2SO_4) trap was fitted to the pressure saucepan using .64–cm Swagelock™ tube fittings to remove water from the volatile constituents. Sodium sulfate (200–g) was used in each trap with a glass wool plug at each end to prevent movement of the chemical into the Tenax trap or the sample area. The container was maintained at a constant temperature of 55°C by the use of a free standing heating plate that was electronically controlled by a variable power transformer from Staco (Model 3PN2210). The pot was allowed to equilibrate over a 30 min period with the N_2 flow set at 50 ml min⁻¹ without the pre-column attached. The 200–g sample of cooked ground beef was then placed in the pot and allowed to equilibrate for an additional 10 min before attachment of the pre-column. After each sample run, the system was cleaned using the procedures outlined in Table 3. Cleaning procedures were developed during preliminary studies to reduce the level of residual volatiles to undetectable levels.

A 108–mm in length x 4–mm internal diameter glass pre-column was packed with 100–mg of Tenax GC, 60/80 mesh, and conditioned 16 hr at 250°C with an He flow rate of 50 ml min⁻¹ in the pre-column injector of the gas chromatograph–mass spectrometer(GC–MS). An

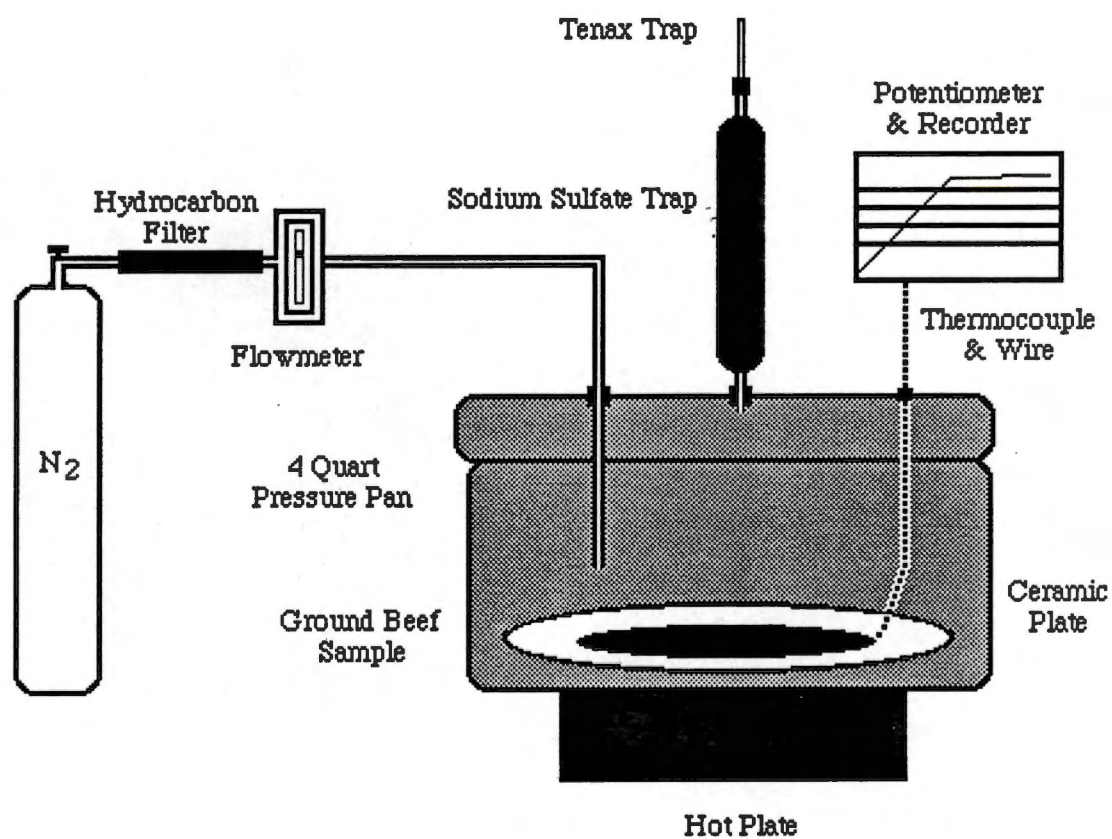


Figure 2. Headspace Collection Unit

Table 3

Cleaning Procedure

Procedure		Solution	Removal of
1.	Wash	Chlorinated soap and water	Excess organic material
2.	Rinse	Distilled water	Soap
3.	Wash	20:1(v/v)Chloroform: methanol	Residual fats
4.	Rinse	Acetone	Chloroform:methanol
5.	Rinse	Distilled water	Acetone
6.	Wash	4% Glacial acetic acid: distilled water(v/v)	Any siliclated, and other polar compounds
7.	Rinse	Distilled water	Acetic acid

internal standard (1 μg of methyl caprate) was added to the trap through the syringe injector port prior to volatile collection with the method described by Mottram *et al.* (1982). The pre-column was then attached to the holder by a .64-cm x .32-cm stainless steel Swagelok™ reducing union (#400-6-2) using a graphite ferrule. Trapping of volatiles was performed at ambient temperature. Purified N_2 (50 ml min^{-1}) was passed over the sample for 30 min to sweep the headspace volatiles into the Tenax trap. After sampling, the trap was removed and immediately placed on to GC-MS pre-column injector for analysis. During collection, temperatures were monitored by the use of a thermocouple attached to a Leeds & Northrup Speedomax potentiometer, and graph recorder device (Model 177974). A copper-constantan thermocouple was used to monitor internal sample temperature in order to maintain a constant 55°C . Entrained volatiles from each ground beef sample were desorbed and analyzed on a Shimadzu QP-1000 GC-MS interfaced with a GC-9A Gas Chromatograph and a SPL-7 Moving Pre-column Injector. Desorption was carried out by placing the Pre-column into the SPL-7 Moving Pre-column Injector at 250°C for 15 min under a He gas flow of 50 ml min^{-1} split 50:1. The volatiles from the pre-column were absorbed on to the 0.25 mm * 30 m SPB-35 column (Supelco, Inc.) which was cryogenically maintained at -50°C by liquid CO_2 using the Shimadzu CRG-9A cryogenic work attachment on the GC oven. After desorption, the trap was removed from the oven's injector and the chromatogram obtained by using a three stage temperature program. The GC temperature program used is shown in Table 4. GC-MS parameters were set according to those shown in Table 5. Actual timing of the

Table 4

Temperature Program for the GC-9A

Temperature	Rate	Time (min)	Reason
-50°C	Hold	15	Desorption
-50°C to 50°C	10°C min ⁻¹	10	Distortion of peak
50°C to 150°C	5°C min ⁻¹	20	Run-Major peaks
150°C to 200°C	10°C min ⁻¹	5	Run-Minor peaks
200°C	Hold	<u>20</u>	Final temp-No peaks
Total time		70	

Table 5

GC-MS Parameters

Item	Setting
Ion source	250°C
Separator	250°C
Injector	250°C
Ion source energy	70 ev
Column	Temperature program
Carrier gas	He 50 ml min ⁻¹ split 50:1
Make up gas	He 25ml min ⁻¹
Gain	3.0 ^a

^a Gain is a unitless measure of signal strength set on a scale from 1.0–5.0.

programed run began 15 minutes before determination of retention times (RT) of individual peaks.

Volatile compounds were identified tentatively by comparison of their mass spectra with mass spectra in the Library Search System LSS-20 on the QP-1000 GC-MS computer hard disk from Shimadzu. Of those compounds that were tentatively identified, most were positively identified by matching retention times and mass spectra to those of standards. Total ion intensity (TII) was used as a measure of peak area.

Statistical Analysis

Steer and carcass characteristics. Weights and fat thicknesses off pasture and at 0-, 56-, and 112-DOF were analyzed along with hot carcass weights by the General Linear Models (GLM) using the Statistical Analysis Systems (SAS) (SAS, 1985). Each dependent variable was analyzed as a function of pasture types (PType), days on feed (DOF) and the PType*DOF interaction as shown in Table 6.

Significantly different means among DOF were separated by Student-Newman-Keuls (SNK) Multiple Range Test. Significantly different means between PTypes did not have to be separated since there were only two.

Chemical analysis. Total lipid concentrations in the ground beef samples were analyzed the same as steer and carcass characteristics with the exception of 6 samples which were lost during storage.

Table 6

Analysis of Variance for Main Effects

Source	Degrees of freedom
Pasture type (PType)	1
Days on feed (DOF)	2
PType*DOF	2
Error	42
Total	47

Sensory analysis. The intensity of each flavor descriptor was analyzed by the GLM as a function of PType, DOF, and PType*DOF interaction as outlined in Table 6.

Significantly different means among DOF were separated by orthogonal polynomials across PTypes in the absence of a significant interaction and for each individual PType in the presence of a significant interaction. Equations were obtained statistically by GLM to explain the significant DOF effect for each dependent variable.

Flavor descriptor intensities were further analyzed by multivariate discriminant analysis using SAS to generate a predicted placement into a PType and DOF group. The predicted placement was then compared to the actual placement to determine the percentage of success (Powers, 1976).

Another method to categorize flavor in sensory analysis is factor analysis which was used to reduce the total number of flavor descriptors and determine which flavor descriptor(s) best described the amount of variation among the meat samples by PType and DOF.

Factor analysis includes both principal component analysis and varimax rotation (orthogonal). Principal component analysis determines to what extent a n-dimensional space can be accommodated in fewer dimensions without loss of important information and attempts to extract initial factors (Galt and MacLeod, 1983; Melton *et al.*, 1987). Varimax rotation attempts to redistribute experimental variance among the extracted factors. By rotating orthogonally, the resultant factors are not intercorrelated and the resultant set of factors or dimensions are more easily interpreted (Melton *et al.*, 1987).

Flavor volatile analysis. The value for percentage of relative abundance (RPA) as measured by the equation:

$$\text{Peak RPA} = \frac{\text{TII Peak}}{\Sigma(\text{TII})} * 100$$

where TII is the total ion intensity of the given peak for each peak was analyzed by GLM as a function of PType, DOF, and PType*DOF interaction. Significantly different means among DOF were separated by orthogonal polynomials across PTypes in the absence of a significant interaction and for each individual PType in the presence of a significant interaction. Equations were obtained from GLM to explain the significant DOF effect for each dependent variable. Significantly different means between PTypes did not have to be separated since there were only two.

Values for peak TII were analyzed by factor analysis using SAS (1985) to reduce the total number of compounds by placing them into factor groups and determine which compounds best described the amount of variation among the meat samples by PType and DOF.

The peak TII values which loaded the highest within each of the factors were further analyzed by stepwise discriminant analysis using SAS to generate a group that described the most amount of variation among the meat samples using average squared canonical correlation (ASCC) as the test of significance along with partial R^2 . The ASSC is close to 1 if all groups are well separated and if all or most directions in the discriminant space show good separation for at least two groups (SAS, 1985). It was this group that was then used in multivariate discriminant analysis using SAS (1985) to generate a predicted placement into a DOF group. The predicted placement was then

compared to the actual placement to determine the percentage of success.

Correlation of subjective with objective analysis. Simple correlation of flavor descriptor intensities with peak TII were run to determine which variables were significantly correlated.

Stepwise regression was also run by SAS using the values obtained from factor analysis for the flavor descriptor intensities along with those factors for the flavor volatiles peak TII to explain the amount of variation within the ground beef samples. Those volatile compounds found to be significant were listed showing $P > F$ values and total R^2 for the model.

CHAPTER 4

RESULTS

Description of Steers

Weights. The mean weights of 48 steers at the time they were removed from different pastures are given in Table 7. Overall, steers that had been grazing on the ryegrass pasture were found to be heavier in weight than steers that had been grazing the fescue–orchardgrass–clover pasture ($P<.05$). After the steers were divided into feeding groups by body type, no differences were found in weight among groups within the pasture types ($P<.05$).

The weights of steers at 0–, 56–, and 112–DOF (days on feed) are summarized in Table 8. At 0– and 56–DOF, steers that had grazed a ryegrass pasture were significantly heavier than steers that had grazed a fescue–orchardgrass–clover pasture. However, from 56– to 112–DOF, steers from the latter pasture gained rapidly such that their weight at 112–DOF was close to the final weight of steers from the ryegrass pasture, and no difference in steer weight existed between pastures at 112–DOF ($P<.05$). Within each pasture type, differences in weight were also noticed among the slaughter groups ($P<.05$). As the time on feed increased, the weight of steers from each pasture type increased significantly.

Table 7

Weights For Steers Directly Off Pastures A and B in 1985

Slaughter group ^b	Pasture Type ^a	
	A	B
	----- kg -----	
Group 1 (n=8)	319 ^c	366 ^c
Group 2 (n=8)	330 ^c	383 ^c
Group 3 (n=8)	335 ^c	376 ^c
Overall mean (n=24)	328 ^x	375 ^y

^a A = Fescue–Orchardgrass–Clover pasture; B = Ryegrass pasture.

^b Group 1 was designated steers slaughtered directly off of pasture (0–DOF);

Group 2 was designated steers slaughtered after 56 days on feed (56–DOF);

Group 3 was designated steers slaughtered after 112 days on feed (112–DOF).

^{cd} Means within columns with unlike superscripts are different ($P < .05$).

^{xy} Means within rows with unlike superscripts are different ($P < .05$).

Table 8

Weights of Steers at Time of Slaughter by Feed Group
Off Pastures A and B in 1985

Slaughter group ^b	Pasture type ^a	
	A	B
	----- kg -----	
0-DOF (n=8)	319 ^{cx}	366 ^{dx}
56-DOF (n=8)	392 ^{cy}	467 ^{dy}
112-DOF (n=8)	498 ^{cz}	513 ^{cz}

^a A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^b 0-DOF steers slaughtered directly off of pasture;
56-DOF steers slaughtered after 56 days on feed;
112-DOF steers slaughtered after 112 days on feed.

^{cd} Means within rows with unlike superscripts are different (P<.05).

^{xyz} Means within columns with unlike superscripts are different (P<.05).

Carcass weights of the 48 steers are summarized in Table 9. the average hot carcass weight of steers from the ryegrass pasture was significantly greater than that of steers from fescue–orchardgrass–clover pasture for slaughter groups 0, and 56–DOF. For 112–DOF, the difference in carcass weights between pasture types was not significant at the $P<.05$ level. The differences in carcass weights between pastures reflect the same differences found in live weights as shown in Table 8. Hot carcass weights for steers also increased from 0– to 56–DOF and from 56– to 112–DOF ($P<.05$).

Fat thickness. Fat thickness at the 12th–13th rib of steers at the time they were removed from different pastures is given in Table 10. Beef produced on ryegrass had a thicker layer of fat than beef produced on fescue–orchardgrass–clover pasture ($P<.05$). Within each pasture type, the fat thickness did not differ among steers assigned to the different slaughter groups ($P<.05$). This lack of difference among slaughter groups within each pasture type shows that a random placement of steers in their respective slaughter groups was achieved.

Fat thickness of steers 0–, 56–, and 112–DOF is summarized in Table 11. At 0– and 56–DOF, steers off the ryegrass pasture had more fat deposited at the 12th–13th rib than steers which came from the fescue–orchardgrass–clover pasture ($P<.05$). No significant difference was noted in fat thickness between pastures at 112–DOF. This lack of difference is probably due to the wider variation among the animals of the fescue–orchardgrass–clover pasture cattle from 56– to 112–DOF. Within pastures, steers that were fed to 112–DOF had a greater fat

Table 9

Carcass Weights of Steers by Feed Group
Off Pastures A and B in 1985

Slaughter group ^b	Pasture type ^a	
	A	B
	----- kg -----	
0-DOF (n=8)	167 ^{cx}	195 ^{dx}
56-DOF (n=8)	223 ^{cy}	271 ^{dy}
112-DOF (n=8)	284 ^{cz}	311 ^{cz}

^a A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^b 0-DOF steers slaughtered directly off of pasture;
56-DOF steers slaughtered after 56 days on feed;
112-DOF steers slaughtered after 112 days on feed.

^{cd} Means within rows with unlike superscripts are different (P<.05).

^{xyz} Means within columns with unlike superscripts are different (P<.05).

Table 10

Fat Thickness^a of Steers Off Pastures A and B in 1985

Slaughter group ^c	Pasture type ^b	
	A	B
	----- mm -----	
Group 1 (n=8)	2.38 ^d	3.63 ^d
Group 2 (n=8)	2.38 ^d	4.38 ^d
Group 3 (n=8)	2.25 ^d	4.00 ^d
Overall mean (n=24)	2.33 ^x	4.00 ^y

^a Fat thickness as measured over the 12th–13th rib 10.2–cm from the mid–line ultrasonically.

^b A = Fescue–Orchardgrass–Clover pasture; B = Ryegrass pasture.

^c Group 1 was designated steers slaughtered directly off of pasture (0–DOF);

Group 2 was designated steers slaughtered after 56 days on feed (56–DOF);

Group 3 was designated steers slaughtered after 112 days on feed (112–DOF).

^{de} Means within columns with unlike superscripts are different ($P < .05$).

^{xy} Means within rows with unlike superscripts are different ($P < .05$).

Table 11

Fat Thickness^a of Steers at Time of Slaughter
by Feed Group
Off Pastures A and B in 1985

Slaughter group ^c	Pasture type ^b	
	A	B
	----- mm -----	
0-DOF (n=8)	2.38 ^{dx}	3.63 ^{ex}
56-DOF (n=8)	5.88 ^{dy}	8.00 ^{ey}
112-DOF (n=8)	9.00 ^{dz}	12.13 ^{dz}

^a Fat thickness as measured over the 12th–13th rib 10.2-cm from the mid-line ultrasonically.

^b A = Fescue–Orchardgrass–Clover pasture; B = Ryegrass pasture.

^c 0-DOF steers slaughtered directly off of pasture;
56-DOF steers slaughtered after 56 days on feed;
112-DOF steers slaughtered after 112 days on feed.

^{de} Means within rows with unlike superscripts are different (P<.05).

^{xyz} Means within columns with unlike superscripts are different (P<.05).

thickness than steers at 56-DOF, and steers at 56-DOF had a greater fat thickness than steers at 0-DOF ($P<.05$).

Lipid Content

Lipid content of raw ground beef patties from of beef produced in this study is shown in Table 12. Differences were found only in the overall mean for each pasture ($P<.05$). Lipid content of ground beef from steers that grazed ryegrass pasture was greater than the lipid content of ground beef from steers that grazed fescue-orchardgrass-clover pasture ($P<.05$). No differences were noted between DOF groups either within PType or across PType.

Sensory Analysis of Beef Flavor

The QDA flavor descriptors for beef produced on different pastures are given in Table 13. Differences were found between pastures only for sour flavor score ($P<.05$). Beef produced on ryegrass pasture had a higher intensity of sourness than that of beef produced on fescue-orchardgrass-clover pasture. No differences were noted in cooked beef fat aroma, milky-oily aroma, cooked beef fat flavor, milky-oily flavor, and off-flavor ($P<.05$).

Mean intensities of different flavor descriptors for beef from steers fed 0 to 112 days on corn are shown in Table 14. Significant differences due to DOF across pastures were found for milky-oily aroma, milky-oily flavor, and off-flavor. DOF*PType interactions were also found for

Table 12

Lipid Content of Ground Beef from Steers
Off Pastures A and B in 1985 by Feed Group

Slaughter group ^b	Pasture type ^a	
	A	B
	(n=22)	(n=20)
	----- mg 100 g ⁻¹ c -----	
0-DOF	19.13 ^{dx}	20.68 ^{dx}
56-DOF	20.91 ^{dx}	22.45 ^{dx}
112-DOF	16.69 ^{dx}	21.66 ^{dx}
Overall mean	18.93 ^d	21.63 ^e

^a A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^b 0-DOF steers slaughtered directly off of pasture;
56-DOF steers slaughtered after 56 days on feed;
112-DOF steers slaughtered after 112 days on feed.

^c Lipid is expressed as mg of lipid 100 g⁻¹ of ground beef

^{de} Means within rows with unlike superscripts are different (P<.05).

^{xy} Means within columns with unlike superscripts are different (P<.05).

Table 13

Flavor of Beef Produced on Different Pastures

Flavor descriptor ^b	Pasture type ^a	
	A	B
	(n=24)	(n=24)
	----- mm -----	
Cooked beef fat aroma	63.5 ^c	64.4 ^c
Milky-oily aroma	69.9 ^c	65.2 ^c
Cooked beef fat flavor	72.2 ^c	75.9 ^c
Milky-oily flavor	67.9 ^c	67.3 ^c
Off-flavor	33.1 ^c	26.8 ^c
Sourness flavor	30.3 ^c	35.2 ^d

^a A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^b As measured from a 150-mm horizontal line.

^{cd} Means within rows with unlike superscripts are different (P<.05).

Table 14

Effect of Days on Feed on the Flavor of Beef
Produced on Different Pastures

Flavor descriptor ^b	Pasture ^c	Days on feed ^a		
		0	56	112
		----- mm. -----		
Cooked beef fat aroma	A ^x	39.6	72.7	78.8
	B ^x	49.2	64.4	81.0
Milky-oily aroma	Across ^y	87.2	64.4	50.0
Cooked beef fat flavor	A ^x	37.0	83.4	97.1
	B ^x	55.4	77.8	96.3
Milky-oily flavor	Across ^y	99.7	60.3	41.4
Off-flavor	Across ^y	22.4	32.5	35.1
Sour flavor	A ^x	29.0	31.6	30.2
	B ^x	29.2	35.0	41.9

^a 0-DOF steers slaughtered directly off of pasture;
56-DOF steers slaughtered after 56 days on feed;
112-DOF steers slaughtered after 112 days on feed.

^b As measured from a 150-mm horizontal line.

^c A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^x n = 8; Significantly affected by DOF and its interaction with pasture.

^y n = 16; Significantly affected by DOF but not the interaction.

cooked beef fat aroma, cooked beef fat flavor, and sour flavor ($P < .05$). Equations showing the significant DOF effects on flavor descriptor intensities either across pasture or for each pasture (those having significant DOF*Pasture interaction) are given in Table 15. Across pastures, milky-oily aroma and flavor of ground beef decreased linearly in intensity as DOF increased from 0 to 112 days ($P < .01$). Off-flavor increased linearly in beef produced on both pastures as DOF increased ($P < .01$). Cooked beef fat aroma and cooked beef fat flavor increased quadratically as DOF increased from 0 to 112 days on beef produced on fescue-orchardgrass-clover pasture ($P < .01$). In contrast, on ryegrass pasture, cooked beef fat aroma and flavor of ground beef increased linearly as DOF increased from 0 to 112 days ($P < .01$). As DOF increased, the sour flavor increased linearly in ground beef produced on ryegrass pasture ($P < .01$). No difference was noted for fescue-orchardgrass-clover pasture ($P < .10$).

Results of discriminant analysis for flavor descriptor intensity are given in Table 16. Results indicated that there were observable and reproducible differences among the ground beef samples for both Ptype and DOF in this model since 93.75% of the samples were classified correctly. Mis-classified samples include one 112-DOF ryegrass pasture as a 56-DOF ryegrass pasture, one 112-DOF ryegrass pasture as an 112-DOF fescue-orchardgrass-clover pasture, and one 112-DOF ryegrass pasture as a 56-DOF fescue-orchardgrass-clover pasture.

The significant factor explaining variance of different flavor descriptor intensities for ground beef from steers off different pastures fed 0 to 112 days on corn is summarized in Table 17. Only one factor

Table 15

Equations Showing Days on Feed Effects For Beef Flavor

Flavor descriptor ^a	Pasture ^b	Equations ^c
Cooked beef fat aroma	A	$y = -0.0043 \text{ DOF}^2 + 0.8316 \text{ DOF} + 39.6190$
	B	$y = 0.2834 \text{ DOF} + 48.9908$
Milky-oily aroma	Across	$y = -0.3335 \text{ DOF} + 85.8480$
Cooked beef fat flavor	A	$y = -0.0050 \text{ DOF}^2 + 1.1202 \text{ DOF} + 37.0000$
	B	$y = 0.3661 \text{ DOF} + 56.0744$
Milky-oily flavor	Across	$y = -0.5226 \text{ DOF} + 96.2692$
Off-flavor	Across	$y = 0.1133 \text{ DOF} + 23.7035$
Sourness flavor	A	Not significantly affected ^d
	B	$y = 0.1129 \text{ DOF} + 29.0391$

^a As measured from a 150-mm horizontal line .

^b A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^c Equations were tested at $P < .01$ level, where y = Intensity of flavor descriptor, and DOF = Days on Feed.

^d ($P < .1$)

Table 16

Grouping by Use of Flavor Descriptor Intensity
on Predicted Classification

Group ^a	n ^b	Classified group ^c					
		1	2	3	4	5	6
1	8	<u>8</u>	0	0	0	0	0
2	8	0	<u>8</u>	0	0	0	0
3	8	0	0	<u>8</u>	0	0	0
4	8	0	0	0	<u>8</u>	0	0
5	8	0	0	0	0	<u>8</u>	0
6	<u>8</u>	0	1	1	0	1	<u>5</u>
Total	48						<u>45</u>
Percentage of success							93.75

^a Group 1 = Fescue–Orchardgrass–Clover pasture, 0–DOF,
 Group 2 = Fescue–Orchardgrass–Clover pasture, 56–DOF,
 Group 3 = Fescue–Orchardgrass–Clover pasture, 112–DOF,
 Group 4 = Ryegrass pasture, 0–DOF,
 Group 5 = Ryegrass pasture, 56–DOF,
 Group 6 = Ryegrass pasture, 112–DOF.

^b n = Number of samples analyzed.

^c Classified groups are the same as the predicted^a groups.

Table 17

**Significant Factors Explaining Variance in Pasture Type
and Days on Feed Effects For Beef Flavor from Factor Analysis**

Factor ^a name	Flavor descriptor	Significant factor loading ^b	% Variance explained
"BEEFY"	Cooked beef fat flavor	0.9753	15.83
	Milky-oily aroma	-0.9633	15.50
	Cooked beef fat aroma	0.9575	15.33
	Milky-oily flavor	-0.9569	15.33
	Off-flavor	0.5280	4.67
	Sour flavor	0.3796	<u>2.33</u>
	Total		68.99

^a Naming of the factor is arbitrarily based on the particular grouping of flavor descriptors trained for within the factor and their relative loadings.

^b Ranking of factor loadings was based on absolute values for each flavor descriptor.

was found in which cooked beef fat flavor loaded the highest based on absolute values and explained 68.99% of the variance therefore, this factor was named "Beefy".

Volatile Flavor Components

Forty volatile compounds were found in the ground beef samples using headspace techniques. These volatile components from beef produced on different pastures along with their respective mean retention times (RT) are presented in Table 19. Beef from steers that grazed on a ryegrass pasture had higher percentages of 2, 3-butanedione, pentanal, octane, (z)-3-octene, (e)-2-octene, toluene and 4-heptenal than beef from steers that grazed fescue-orchardgrass-clover pasture ($P < .05$). In contrast, beef from steers off fescue-orchardgrass-clover had higher percentages of nonane, and unknowns: 1, 3, 6, 7, 8, and 11 than steers from ryegrass pasture ($P < .05$). Composite chromatograms for each DOF group are listed in Appendix A. Mass spectrums for unknown or uncommon volatiles compounds having significant DOF affects are listed in Appendix B.

Mean RPA values of volatiles of beef from steers at 0, 56, and 112 DOF are given in Table 19 either for each pasture because of a significant PType*DOF interaction for that volatile or across pastures. The equations showing the DOF effects and the coefficient of variation, R^2 , for each equation are shown in Table 20. Analysis of variance summaries for peaks 1 through 40 are listed in Appendix C.

Table 18

Volatile Components of Beef Produced on Different Pastures

Peak ^b number	Name ^c	Mean retention time (RT) ^d	Pasture type ^a	
			A (n=24)	B (n=24)
			----- RPA ^e -----	
1	2, 3-Butanedione	4.00	2.71 ^x	3.44 ^y
2	3-Methyl Butanal	6.00	1.38	2.09
3	2, 2-Dimethyl Propane	6.91	1.03	1.48
4	Pentanal	7.37	2.32 ^x	4.36 ^y
5	2, 3-Pentanedione	8.05	1.40	1.75
6	Octane	7.87	4.84 ^x	8.97 ^y
7	(z)-3-Octene	8.38	1.63 ^x	3.53 ^y
8	(e)-2-Octene	8.55	0.87 ^x	1.44 ^y
9	Toluene	8.90	4.80 ^x	8.64 ^y
10	3-Penten-2-one	9.44	0.46	0.82
11	Pentanol	9.38	2.42	2.08
12	Hexanal	10.27	24.25	21.57
13	4-Methyl-3-Penten-2-One	10.30	1.47	1.78
14	Nonane	10.59	1.04 ^x	0.72 ^y
15	Unknown 1	10.85	9.87 ^x	1.13 ^y
16	Ethyl-Benzene	11.32	0.66	0.49
17	m-Xylene	11.47	1.26	1.04
18	Unknown 2	12.30	1.78	1.19

Table 18 (Continued)

Peak ^b number	Name ^c	Mean retention time (RT) ^d	Pasture type ^a	
			A	B
			(n=24)	(n=24)
----- RPA ^e -----				
19	1-Hexanol	11.78	2.07	2.06
20	Unknown 3	12.29	2.35 ^x	1.03 ^y
21	Acetic Acid	12.38	2.65	2.78
22	3-Hydroxy-2-Butanone	13.10	21.84	18.11
23	Propyl-Benzene	13.26	0.60	0.52
24	Heptanal	12.72	9.01	9.59
25	4-Heptenal	13.45	1.02 ^x	1.74 ^y
26	Unknown 4	13.59	0.98	1.01
27	Unknown 5	14.05	1.19	1.25
28	Unknown 6	14.55	1.53 ^x	0.95 ^y
29	Unknown 7	14.71	2.53 ^x	1.81 ^y
30	Acetone	14.61	5.09	4.40
31	1-Ethyl-2-Methyl-Benzene	15.14	0.52	0.75
32	Unknown 8	17.36	0.82 ^x	0.45 ^y
33	Octanal	15.72	2.46	2.06
34	unknown 9	15.35	0.85	0.97
35	Benzyl Aldehyde	16.23	0.91	1.36
36	2-Ethyl-4-Methyl-1-Pentanol	16.13	2.08	1.58
37	γ-Butyro Lactone	17.79	0.55	0.46
38	Nonanal	18.81	1.72	1.49
39	Unknown 10	19.38	1.25	1.23

Table 18 (Continued)

Peak ^b number	Name ^c	Mean retention time (RT) ^d	Pasture type ^a	
			A (n=24)	B (n=24)
----- RPA ^e -----				
40	Unknown 11	19.72	1.64 ^x	0.64 ^y

^a A = Fescue–Orchardgrass–Clover pasture; B = Ryegrass pasture.

^b Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC–Mass Spectrophotometer.

^c Tentative identification. Positive results were obtained from standards.

^d Mean retention times are measured in minutes.

^e Means are expressed as a percentage of relative abundance of the total ion intensity (TII) of the peak divided by the sum of the total ion intensity for all peaks. $\text{Peak RPA} = \frac{\text{TII Peak}}{\Sigma(\text{TII})} * 100$

^{xy} Means within row are different from each other (P<.05).

Table 19

Effect of Days on Feed on the Volatile Components of Beef
Produced on Different Pastures

Peak number ^b	Name ^c	Pasture ^c	Days on feed ^a		
			0	56	112
			(n=8)	(n=8)	(n=8)
			-----RPA ^d -----		
1	2, 3-Butanedione	A ^x	2.91	2.71	2.58
		B	2.35	4.84	2.92
2	3-Methyl Butanal	Across ^x	0.87	2.47	2.34
3	2, 2-Dimethyl -Propane	Across ^x	1.35	1.87	0.72
4	Pentanal	Across	2.75	1.99	5.17
5	2, 3-Pentanedione	Across ^x	0.94	1.89	2.10
6	Octane	Across	2.84	5.41	11.14
7	(z)-3-Octene	A	2.60	1.13	0.42
		B	6.58	0.52	0.44
8	(e)-2-Octene	A	1.30	0.48	0.68
		B	2.68	1.08	0.74
9	Toluene	A	9.47	0.47	1.79
		B	19.54	2.49	1.72
10	3-Penten-2-one	Across	0.92	0.93	0.26
11	Pentanol	Across ^x	1.81	2.62	2.65

Table 19 (Continued)

Peak number ^b	Name ^c	Pasture ^c	Days on feed ^a		
			0	56	112
			(n=8)	(n=8)	(n=8)
			-----RPA ^d -----		
12	Hexanal	Across	12.80	30.00	26.63
13	4-Methyl-3-Penten-2-One	Across	1.27	0.92	3.31
14	Nonane	A	0.90	1.48	0.69
		B	0.45	0.87	1.04
15	Unknown 1	A ^y	4.12	1.10	24.39
		B ^y	0.00	0.80	1.25
16	Ethyl-Benzene	Across ^x	0.43	0.52	0.86
17	m-Xylene	Across ^x	1.30	1.07	1.07
18	Unknown 2	Across ^x	1.92	0.89	1.70
19	1-Hexanol	A ^x	2.27	2.21	1.82
		B	1.31	1.59	3.14
20	Unknown 3	A ^y	2.92	0.63	0.00
		B ^x	0.77	0.46	1.94
21	Acetic Acid	Across ^x	2.88	2.91	2.38
22	3-Hydroxy				
	-2-Butanone	Across	21.94	23.71	14.44
23	Propyl-Benzene	Across ^x	0.76	0.63	0.39
24	Heptanal	Across ^x	10.08	8.97	8.58

Table 19 (Continued)

Peak number ^b	Name ^c	Pasture ^c	Days on feed ^a		
			0	56	112
			(n=8)	(n=8)	(n=8)
			-----RPA ^d -----		
25	4-Heptenal	Across ^x	1.26	1.72	1.42
26	Unknown 4	Across	1.22	0.61	1.08
27	Unknown 5	Across	1.55	0.68	1.30
28	Unknown 6	A	1.32	0.62	2.50
		B ^x	1.17	0.80	0.80
29	Unknown 7	Across	1.85	1.74	3.01
30	Acetone	Across	3.55	6.36	2.77
31	1-Ethyl-2-Methyl				
	-Benzene	A ^x	0.35	0.69	0.00
		B ^x	0.54	0.37	2.14
32	Unknown 8	Across ^x	0.52	0.45	0.84
33	Octanal	Across ^x	1.68	1.43	3.66
34	Unknown 9	Across ^x	1.36	0.58	0.77
35	Benzyl Aldehyde	Across ^x	1.52	0.56	0.99
36	2-Ethyl-4-Methyl				
	-1-Pentanol	A	3.20	0.78	2.00
		B ^x	1.33	2.25	1.47
37	γ-Butyro Lactone	Across ^x	0.51	0.54	0.46
38	Nonanal	Across	1.86	0.88	2.03

Table 19 (Continued)

Peak number ^b	Name ^c	Pasture ^c	Days on feed ^a		
			0 (n=8)	56 (n=8)	112 (n=8)
----- RPA ^d -----					
39	Unknown 10	A ^y	1.04	0.00	1.80
		B	2.15	0.37	0.31
40	Unknown 11	Across ^x	1.26	0.87	0.81

^a A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^b Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^c Tentative identification. Positive results were obtained from standards.

^d Means are expressed as a percentage of relative abundance of the total ion intensity (TII) of the peak divided by the sum of the total ion intensity for all peaks. $\text{Peak RPA} = \frac{\text{TII Peak}}{\Sigma(\text{TII})} * 100$

^x These volatiles were either for indicated pasture or across pasture not affected by DOF (P<.05)

^y These volatiles were not present in enough beef samples to be statistically analyzed.

Table 20

Equations Showing Days on Feed Effects For Volatile Components of Beef Flavor

Pk ^a	Name ^b	Pasture ^c	R ²	Equations ^d
1	2, 3-Butanedione	A ^{NS} B ^e	0.5967	$y = -0.0007 \text{ DOF}^2 + 0.0837 \text{ DOF} + 2.35$
2	3-Methyl Butanal	Across ^{NS}		
3	2, 2-Dimethyl -Propane	Across ^{NS}		
4	Pentanal	Across ^e	0.2138	$y = 0.0006 \text{ DOF}^2 - 0.0487 \text{ DOF} + 2.75$
5	2, 3-Pentanedione	Across ^{NS}		
6	Octane	Across ^e	0.4973	$y = 0.0749 \text{ DOF} + 2.26$
7	(z)-3-Octene	A ^e B ^e	0.0616 0.5806	$y = -0.0197 \text{ DOF} + 2.55$ $y = 0.0010 \text{ DOF}^2 - 0.1615 \text{ DOF} + 6.58$
8	(e)-2-Octene	A ^{NS} B ^e	0.4908	$y = -0.0170 \text{ DOF} + 2.46$
9	Toluene	A ^e B ^e	0.1310 0.6440	$y = 0.0016 \text{ DOF}^2 - 0.2529 \text{ DOF} + 9.47$ $y = 0.0026 \text{ DOF}^2 - 0.4499 \text{ DOF} + 19.54$
10	3-Penten-2-one	Across ^e	0.3818	$y = -0.0059 \text{ DOF} + 0.97$
11	Pentanol	Across ^{NS}		
12	Hexanal	Across ^e	0.5725	$y = -0.0033 \text{ DOF}^2 + 0.4906 \text{ DOF} + 12.80$
13	4-Methyl-3 -Penten-2-One	Across ^e	0.5743	$y = 0.0004 \text{ DOF}^2 - 0.0306 \text{ DOF} + 1.27$
14	Nonane	A ^e B ^e	0.2481 0.1231	$y = -0.0002 \text{ DOF}^2 + 0.0224 \text{ DOF} + 0.90$ $y = 0.0006 \text{ DOF} + 0.48$
15	Unknown 1	Across ^x		
16	Ethyl-Benzene	Across ^{NS}		

Table 20 (Continued)

Pk ^a	Name ^b	Pasture ^c	R ²	Equations ^d
17	m-Xylene	Across ^{NS}		
18	Unknown 2	Across ^{NS}		
19	1-Hexanol	A ^{NS}		
		B ^e	0.3814	$y = 0.0163 \text{ DOF} + 1.15$
20	Unknown 3	A ^x		
		B ^{NS}		
21	Acetic Acid	Across ^{NS}		
22	3-Hydroxy			
	-2-Butanone	Across ^e	0.2201	$y = -0.0018 \text{ DOF}^2 + 0.1305 \text{ DOF} + 21.93$
23	Propyl-Benzene	Across ^{NS}		
24	Heptanal	Across ^{NS}		
25	4-Heptenal	Across ^{NS}		
26	Unknown 4	Across ^e	0.2826	$y = 0.0002 \text{ DOF}^2 - 0.0203 \text{ DOF} + 1.22$
27	Unknown 5	Across ^e	0.3996	$y = 0.0002 \text{ DOF}^2 - 0.0288 \text{ DOF} + 1.55$
28	Unknown 6	A ^e	0.3386	$y = 0.0004 \text{ DOF}^2 - 0.0357 \text{ DOF} + 1.32$
		B ^{NS}		
29	Unknown 7	Across ^e	0.1362	$y = 0.0104 \text{ DOF} + 1.62$
30	Acetone	Across ^e	0.2899	$y = -0.0010 \text{ DOF}^2 + 0.1074 \text{ DOF} + 3.55$
31	1-Ethyl-2-Methyl			
	-Benzene	A ^x		
		B	0.7061	$y = 0.0003 \text{ DOF}^2 - 0.0202 \text{ DOF} + 0.54$
32	Unknown 8	Across ^{NS}		
33	Octanal	Across ^e	0.4358	$y = 0.0004 \text{ DOF}^2 - 0.0263 \text{ DOF} + 1.67$
34	Unknown 9	Across ^{NS}		
35	Benzyl Aldehyde	Across ^{NS}		

Table 20 (Continued)

Pk ^a	Name ^b	Pasture ^c	R ²	Equations ^d
36	2-Ethyl-4-Methyl -1-Pentanol	A ^e B ^{NS}	0.2068	$y = 0.0006 \text{ DOF}^2 - 0.0759 \text{ DOF} + 3.20$
37	γ -Butyro Lactone	Across ^{NS}		
38	Nonanal	Across ^e	0.3684	$y = 0.0003 \text{ DOF}^2 - 0.0366 \text{ DOF} + 1.86$
39	Unknown 10	A ^x B ^e	0.6600	$y = -0.0208 \text{ DOF} + 1.98$
40	Unknown 11	Across ^{NS}		

^a Peak numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b Tentative identification. Positive results were obtained from standards.

^c A = Fescue-Orchardgrass-Clover pasture; B = Ryegrass pasture.

^d Equations are tested at P<.01 level, where y = Percentage of Relative Abundance (RPA), and DOF = Days on Feed.

^e Significant at the P<.05 level.

^{NS} Not Significant when tested at the P<.10 level.

^x These volatiles were not present in enough beef samples to be statistically analyzed.

Across pastures, percentages of octane and unknown 7 increased linearly with increasing DOF from 0 to 112 while the percentage of 3-penten-2-one decreased linearly. Also, across pastures, the percentages of the following volatiles: pentanal; octanal; nonanal; 4-methyl-3-penten-2-one; and unknowns 4, 5, and 7 decreased from 0 to 56 days before increasing from 56 to 112 DOF, but the percentages of hexanal and 3-hydroxy-2 butanone increased curvilinearly from 0 to 56 DOF before decreasing from 56 to 112 DOF.

Significant interactions (PType * DOF) were found for 2, 3-butanedione, (z)-3-octene, (e)-2-octene, toluene, nonane, 1-ethyl-2-methyl benzene, 2-ethyl-4-methyl-1 pentanol, 1-hexanol, and unknowns 1, 3, 6, and 10 (Tables 19 and 20).

The percentage of 2, 3-butanedione did not change across DOF in beef from steers off the fescue-orchardgrass-clover pasture, but in beef from steers off ryegrass pasture, the percentage of this compound increased from 0- to 56-DOF before decreasing from 56- to 112-DOF ($P < .05$). In beef from steers off fescue-orchardgrass-clover pasture, the percentages of (z)-3-octene decreased linearly from 0- to 112-DOF, while in beef from steers of ryegrass, the percentage of (z)-3-octene decreased quadratically. The percentage of (e)-2-octene did not change across DOF in beef from steers off the fescue-orchardgrass-clover pasture, but in beef from steers off ryegrass pasture, the percentage of (e)-2-octene decreased linearly from 0- to 112-DOF.

Means in Table 19 indicate that in beef from steers off both pastures the percentage of toluene decreased from 0- to 56-DOF and continued to decrease in beef off ryegrass from 56- to 112-DOF while increasing in beef off fescue type pastures. The equations for toluene as a function of DOF shown in Table 20, however, showed that the minimum level of toluene in beef produced off fescue occurred at 79-DOF and in beef produced off ryegrass, at 86-DOF.

The percentage of nonane in ryegrass produced beef increased linearly with increasing DOF from 0 to 112 days. However, in fescue produced beef, the percentage increased from 0- to 56-DOF before decreasing from 56- to 112-DOF.

In beef produced off fescue-orchardgrass-clover, the percentages of 2, 3-butanedione, 1-hexanol, 1-ethyl-2-methyl benzene, and unknown 10 were either not affected by DOF ($P < .05$), or the volatiles were not present in enough samples to be statistically analyzed. In beef produced off ryegrass the following changes were found in the percentages of these volatiles. The percentage of 2, 3-butanedione increased from 0- to 56-DOF before decreasing from 56- to 112-DOF, and the percentage of 1-hexanol increased linearly from 0- to 112-DOF. The percentage of 1-ethyl-2-methyl benzene decreased from 0- to 56-DOF before increasing to its highest levels at 112-DOF, and the percentage of unknown 10 decreased linearly with increasing DOF from 0 to 112.

The percentages of the volatiles, 2-ethyl-4-methyl-1-pentanol and unknown 6 were not affected by DOF in beef produced off ryegrass pasture, but were affected by DOF in beef off fescue-orchardgrass-clover pasture ($P < .05$). The percentages of both unknown 6 and

2-ethyl-4-methyl-1-pentanol decreased from 0- to 56-DOF before increasing from 56- to 112-DOF for beef produced on fescue-orchardgrass-clover pasture.

When factor analysis using SAS, (1985) was run on the flavor volatiles of ground beef, 11 significant factors were found and are summarized in Table 21. These 11 factors explained 83.75% of the total variation in the ground beef aroma isolated from 35 different ground beef samples in this experiment. Individual benzyl compounds loaded the highest in 4 of the factors. Toluene, ethyl-benzene, 1-ethyl-2-methyl-benzene, and a propyl-benzene all loaded the highest for factors 3, 5, 7, and 8 respectively. Other compounds loading highest in the other factors include: pentanal in factor 1; unknown 7 in factor 2; 4-methyl-3-penten-2-one in factor 4; 3-penten-2-one in factor 6; unknown 8 in factor 9; nonane in factor 10; and unknown 9 in factor 11. Only 2 compounds were found to have loaded highly for more than one factor. Benzyl aldehyde was found in both factors 5 and 11 and 3-hydroxy-2-butanone was found in both factors 7 and 10.

Stepwise discriminant analysis was run on the 11 compounds, each of which loaded the highest in a single factor, for classification of samples as to their origin. The results are shown in Table 22. Six of these compounds were useful in classifying the samples into three sources, those from steers fed 0-, 56-, and 112-DOF with an Average Squared Canonical Correlation (ASCC) of .707. Actual classification of the samples into groups are shown in Table 23. Results indicated there were observable and reproducible differences in the levels of toluene, pentanal, unknown 7, 1-ethyl-2-methyl-benzene, 4-methyl-3-penten-

Table 21

Significant Factors Explaining Variance in Pasture Type
and Days on Feed Effects
For Volatile Flavor of Beef from Factor Analysis

Factor no.	Pk ^a	Compound	Significant factor loading ^b	% Variance explained
1	4	Pentanal	0.8541	13.5
	6	Octane	0.8466	
	19	1-Hexanol	0.8233	
	25	4-Heptenal	0.8002	
	12	Hexanal	0.7759	
	2	3-Methyl Butanal	0.6802	
2	29	Unknown 7	0.8662	12.75
	28	Unknown 6	0.8380	
	38	Nonanal	0.8013	
	15	Unknown 1	0.7723	
	33	Octanal	0.7359	
	17	m-Xylene	0.5752	
	37	γ -Butyro Lactone	0.5025	
3	9	Toluene	0.8929	9.5
	7	(z)-3-Octene	0.8755	
	8	(e)-2-Octene	0.8179	
	3	2, 2-Dimethyl Propane	0.6622	
	39	Unknown 10	0.6485	

Table 21 (Continued)

Factor no.	Pk ^a	Compound	Significant factor loading ^b	% Variance explained
4	13	4-Methyl-3-Penten-2-One	0.8881	9.0
	11	Pentanol	0.8104	
	20	Unknown 3	0.7514	
5	16	Ethyl-Benzene	0.7500	7.0
	21	Acetic Acid	0.6640	
	5	2, 3-Pentanedione	0.5493	
	35	Benzyl Aldehyde	0.5204	
6	10	3-Penten-2-one	0.7754	6.5
	40	Unknown 11	0.7111	
	36	2-Ethyl-4-Methyl-1-Pentanol	0.7107	
7	31	1-Ethyl-2-Methyl-Benzene	0.8500	6.0
	1	2, 3-butanedione	-0.5592	
	22	3-Hydroxy-2-Butanone	-0.5419	
8	23	Propyl-Benzene	0.7737	5.5
	18	Unknown 2	0.7510	
	30	Acetone	-0.5686	
9	32	Unknown 8	0.7423	4.75
	27	Unknown 5	-0.5607	

Table 21 (Continued)

Factor no.	Pk ^a	Compound	Significant factor loading ^b	% Variance explained
10	14	Nonane	0.8645	4.75
	22	3-Hydroxy-2-Butanone	-0.6566	
11	34	Unknown 9	0.8495	4.5
	35	Benzyl Aldehyde	0.6030	
Total percentage of variance				83.75

^a Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b Ranking of factor loadings was based on absolute values for each flavor descriptor.

Table 22

**Volatiles in Ground Beef Selected by Stepwise Discriminant Analysis
from Factor Analysis For Inclusion Into the Model to
Predict DOF Classification**

Peak #	Volatile compound ^a	Partial R ²	ASCC ^b
9	Toluene	0.6192**	0.3096
4	Pentanal	0.4622**	0.4832
29	Unknown 7	0.3306**	0.5921
31	1-Ethyl-2-Methyl-Benzene	0.2292*	0.6380
13	4-Methyl-3-Penten-2-One	0.2007*	0.6681
34	Unknown 9	0.1740†	0.7070

^a Tentative identification. Positive results were obtained from standards.

^b ASCC = Average Squared Canonical Correlation with the Prob>ASCC at the .0001 level.

** = P<.01

* = P<.05

† = P<.075

Table 23

Grouping by Use of Flavor Volatile Factor Loadings
on Predicted Classification

Group ^a	n ^b	Classified group ^c		
		0	56	112
0	12	<u>11</u>	1	0
56	11	0	<u>11</u>	0
112	12	0	1	<u>11</u>
Total	35			<u>33</u>
Percentage of success				94.29

^a 0-DOF,
56-DOF,
112-DOF,

^b n = Number of samples analyzed

^c Classified groups are the same as the predicted^a groups

2-one, and unknown 9 that were used in the model since 94.29% of the samples were classified correctly. Mis-classified samples included one 0-DOF as a 56-DOF, and one 112-DOF as a 56-DOF.

Correlation of Subjective with Objective Flavor Analysis

In addition to factor analysis and stepwise discriminate analysis for selection of the most important volatile compounds that explained the difference among ground beef samples or classified them into groups, other statistical methods were used to correlate the chemical with sensory evaluation. Simple correlation coefficients of volatile compounds with the flavor descriptors from the QDA panel are given in Table 24. The following compounds: 2, 3-butanedione, pentanal, octane, hexanal, 1-hexanol, octanal, and γ -butyrolactone were significantly correlated with cooked beef fat aroma and/or flavor, while toluene was negatively correlated ($P < .05$). In general, except for γ -butyrolactone, these compounds correlated also with milky-oily flavor aroma and flavor but in reverse order ($P < .05$). In addition, m-xylene and nonanal were negatively correlated with milky-oily flavor and aroma, and an unknown 7 was negatively correlated with milky-oily aroma and flavor ($P < .05$). The compound (z)-3-octene, was positively correlated with milky-oily flavor ($P < .05$). The following compounds were positively correlated with off-flavor: pentanal, octane, hexanal, unknown 1, and 1-hexanol, and (z)-3-octene and unknown 11.

Table 24

Correlation Coefficients Between Flavor Volatiles and QDA Flavor Descriptors of Ground Beef

Pk ^a	Name ^b	Descriptors					
		Cooked Beef fat aroma	Milky-oily aroma	Cooked Beef fat flavor	Milky-oily flavor	Off- flavor	Sour flavor
1	2, 3-Butanedione	0.36 ^w	-0.33 ^w	0.34 ^w	-0.42 ^x	0.07	0.12
2	3-Methyl Butanal	0.25	-0.17	0.26	-0.29	0.24	0.23
3	2, 2-Dimethyl-Propane	0.11	-0.17	0.13	-0.08	0.01	-0.03
4	Pentanal	0.36 ^w	-0.41 ^x	0.43 ^x	-0.39 ^w	0.32 ^w	0.65 ^z
5	2, 3-Pentanedione	0.11	-0.01	0.09	-0.06	0.24	0.10
6	Octane	0.56 ^y	-0.64 ^z	0.62 ^z	-0.61 ^z	0.43 ^x	0.47 ^x
7	(z)-3-Octene	0.28	0.23	-0.32	0.39 ^w	-0.33 ^w	-0.07
8	(e)-2-Octene	-0.08	-0.01	-0.06	0.11	-0.16	-0.13
9	Toluene	-0.40 ^w	0.32 ^w	-0.44 ^x	0.48 ^x	-0.32	-0.02
10	3-Penten-2-one	-0.06	0.11	-0.11	0.18	-0.23	-0.10
11	Pentanol	-0.13	0.18	-0.13	0.17	-0.17	-0.16
12	Hexanal	0.56 ^y	-0.58 ^y	0.60 ^z	-0.56 ^y	0.48 ^x	0.46 ^x
13	4-Methyl-3-Penten-2-One	0.08	-0.05	0.08	-0.03	-0.14	0.13
14	Nonane	-0.02	-0.01	-0.01	-0.01	0.29	-0.22
15	Unknown 1	0.10	-0.26	0.13	-0.19	0.34 ^w	-0.22
16	Ethyl-Benzene	0.19	-0.16	0.22	-0.17	-0.22	-0.03
17	m-Xylene	0.27	-0.32 ^w	0.22	-0.15	0.09	0.05
18	Unknown 2	-0.28	0.28	-0.23	0.16	-0.14	-0.12
19	1-Hexanol	0.56 ^y	-0.61 ^z	0.57 ^y	-0.55 ^y	0.48 ^x	0.36 ^w
20	Unknown 3	-0.11	0.21	-0.22	0.27	-0.11	0.14
21	Acetic Acid	-0.07	0.06	0.02	0.06	-0.24	-0.12
22	3-Hydroxy-2	-0.06	0.15	-0.10	0.05	-0.20	-0.13
23	Propyl-Benzene	-0.16	0.15	-0.12	0.04	0.04	-0.08
24	Heptanal	-0.03	-0.13	0.05	-0.05	0.17	0.09
25	4-Heptenal	0.21	-0.18	0.22	-0.21	0.31	0.31
26	Unknown 4	0.26	-0.29	0.22	-0.23	0.05	0.18
27	Unknown 5	0.23	-0.23	0.15	-0.15	0.12	0.35 ^w
28	Unknown 6	0.17	-0.28	0.16	-0.14	0.14	-0.13
29	Unknown 7	0.30	-0.45 ^x	0.33 ^w	-0.37 ^w	0.23	-0.12
30	Acetone	0.10	-0.10	0.07	-0.06	-0.21	-0.15

Table 24 (Continued)

Pk ^a	Name ^b	Descriptors					
		Cooked Beef fat aroma	Milky-oily aroma	Cooked Beef fat flavor	Milky-oily flavor	Off- flavor	Sour flavor
31	1-Ethyl-2-Methyl-Benzene	0.06	-0.13	0.12	-0.10	0.17	0.51 ^x
32	Unknown 8	0.20	-0.18	0.16	-0.25	-0.08	-0.11
33	Octanal	0.44 ^x	-0.51 ^y	0.43 ^x	-0.42 ^y	0.21	0.19
34	Unknown 9	-0.02	0.08	-0.09	0.09	0.06	0.28
35	Benzyl Aldehyde	-0.08	0.11	-0.13	0.20	-0.17	0.01
36	2-Ethyl-4-Methyl-1-Pentanol	0.12	-0.12	0.06	-0.02	-0.01	0.12
37	γ -Butyro Lactone	0.35 ^w	-0.31 ^w	0.29	-0.29	0.26	-0.10
38	Nonanal	0.28	-0.36 ^w	0.23	-0.23	0.23	0.03
39	Unknown 10	-0.25	0.17	-0.25	0.29	-0.04	-0.06
40	Unknown 11	-0.21	0.19	-0.20	0.16	-0.32 ^w	-0.13

^a Peak numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b Tentative identification. Positive results were obtained from standards.

^w (P<.05)

^x (P<.01)

^y (P<.001)

^z (P<.0001)

were negatively correlated ($P < .05$). Those compounds positively correlated with sour flavor included, pentanal, octane, hexanal, 1-hexanol, unknown 5, and 1-ethyl-2-methyl-benzene ($P < .05$ or better). No compounds were negatively correlated with sour flavor.

Stepwise regression analysis using SAS was also undertaken using the highest factor loadings generated by factor analysis for the flavor descriptors and the volatile flavor compounds. Results of the model for cooked beef fat flavor ("Beefy") with levels of pentanal, unknown 7, toluene, 4-methyl-3-penten-2-one, ethyl-benzene, 3-penten-2-one, 1-ethyl-2-methyl-benzene, propyl-benzene, unknown 8, nonane, and unknown 9 are given in Table 25. The volatiles, pentanal, unknown 7, toluene, ethyl-benzene, and 1-ethyl-2-methyl-benzene were selected to answer the variation in cooked beef fat flavor ("Beefy"). The model had an R^2 of 0.51.

Table 25

Volatiles in Ground Beef Selected by Stepwise Regression Analysis
from Factor Analysis
of Total Ion Intensity and Flavor Descriptor Intensities

Peak number ^a	Volatile compound ^b	P>F
4	Pentanal	0.0009
29	Unknown 7	0.1264
9	Toluene	0.0076
16	Ethyl-Benzene	0.0751
31	1-Ethyl-2-Methyl-Benzene	0.3002
Equation		
Beef fat flavor = 0.0002*Pentanal + 0.0002*Unknown 7 ("Beefy") - 0.0001*Toluene + 0.0015*Ethyl-Benzene - 0.0004*1-Ethyl-2-Methyl-Benzene - 0.5534 ^c		
Total R ² = 0.51		

^a Peak numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b Tentative identification. Positive results were obtained from standards.

^c Equation measurement unit is Total ion intensity (TII).

CHAPTER 5

DISCUSSION

Steer Weight and Fat Thickness

Results of the analysis of steer weights are found in Tables 7 and 8, pages 41 and 42. The analysis indicates that steers that grazed on ryegrass pasture were heavier than steers that grazed on fescue-orchardgrass-clover pasture. Steers off the ryegrass pasture were heavier until 56-DOF than steers from the fescue-orchardgrass-clover pasture, but not at 112-DOF ($P < .05$). This lack of difference between pastures at 112-DOF is due to some compensatory gain on the part of the fescue-orchardgrass-clover pasture steers during corn feeding. Hot carcass weights given in Table 9, page 44, showed the same significance and trends as live weights at 0-, 56-, and 112-DOF.

Results of the analysis of fat thickness of steers are found in Tables 10 and 11, pages 45 and 46, and generally corresponded to the trends found for the weights. Steers from the ryegrass pasture had more subcutaneous fat measured ultrasonically at the 12th-13th rib than steers from the fescue pasture. Steers on the ryegrass pasture also continued to have more subcutaneous fat at the 12th-13th rib until 112 days on feed was reached where steers from the fescue-orchardgrass-clover pasture had similar fat thickness. This lack of difference between pastures at the 112-DOF level is due to some compensatory gain on the part of the

fescue–orchardgrass–clover pasture steers. The number of days on feed effectively increased the backfat thickness of steers for both pasture types at 56 days and further increased it at 112 days.

Lipid Content in Ground Beef

Analysis of the lipid content of the ground beef samples is given in Table 12, page 48. Although the ground beef was formulated to contain 20% fat, the formulation was based upon the amount of fat in the beef fat and lean determined by the modified Babcock method. This method is only an approximate estimate of fat content and when fat content of ground beef was averaged across DOF for each pasture type, a significant difference was found between pastures. These results could have caused significant differences in absolute amounts of volatiles in cooked meat (Dwivedi, 1975) and is one of the reasons that a relative percentage of volatiles was used to test for differences between pastures and across DOF. Using RPA of each volatile in effect removed differences in amount of volatiles between pastures that might be due to the difference in fat content.

Sensory Analysis

The results of the sensory analysis performed in this study (Quantitative Descriptive Analysis, QDA) are found in Tables 13 and 14, pages 49 and 50, and Table 15, page 52. These results for milky–oily aroma and flavor and beef fat aroma and flavor are in agreement with

Holden (1985), Mann (1983), Melton *et al.* (1982b), and Yeo (1982) who found that the intensities of the undesirable milky-oily aroma and flavor decreased while the intensities of the beef fat aroma and flavor increased over time steers were fed a corn based ration. Although Holden (1985), Mann (1983), Melton *et al.* (1982b), and Yeo (1982) found that the intensity of off-flavor was not significantly affected by DOF, this study showed a linear increase in intensity as DOF increased. Sour flavor was only affected by DOF for the beef produced off ryegrass pasture and increased in intensity linearly as DOF increased. In contrast, Holden (1985) showed as DOF increased a decrease in intensity of sour flavor on beef produced off on both ryegrass and fescue pastures. Melton *et al.* (1982b) reported a slight decrease in the level of sour flavor across time on feed while Yeo (1982) found a slight increase in sour flavor intensity over DOF in beef from steers off fescue pastures. These results disagree with the results of the present study in which no significant change in sour flavor intensity was found in fescue-orchardgrass-clover pasture across DOF. Results, however, do agree with the findings for sour flavor in beef reported by Mann (1983).

Results of discriminant analysis shown in Table 16, page 53, indicates that the observable and reproducible differences among the ground beef samples were enough to correctly classify approximately 94% of the steers from different feeding groups into the correct pasture type and days on feed classification. Mis-classified samples were one 112-DOF steer off ryegrass pasture as a 56-DOF steer off ryegrass pasture, one 112-DOF steer off ryegrass pasture as an 112-DOF steer off fescue-orchardgrass-clover pasture, and one 112-DOF steer off

ryegrass pasture as a 56-DOF steer off fescue-orchardgrass-clover pasture. Panelists did not misplace any pasture-produced samples for grain-produced or *vice versa*.

Factor analysis given in Table 17, page 54, shows that even though the different flavor descriptors were used to describe the flavor of the ground beef samples, all of these were really describing only one factor which was called "Beefy" in the present study. It was this "Beefy" factor that accounted for 69% of the variability in the flavor of the ground beef samples tested by the QDA panel.

Flavor Volatile Analysis

Volatile compounds. Forty volatile compounds were found in the ground beef samples of which 11 compounds have yet to be identified and the analysis of them are listed in Tables 18 through 20 , pages 56 through 65. All identified volatile compounds have been previously identified in beef. Liebich *et al.* (1972) reported the following volatiles in roast beef; 2,3-butanedione, 3-methyl butanal, pentanal, 2, 3-pentanedione, pentanol, hexanal, 4-methyl-3-penten-2-one, 1-hexanol, acetic acid, heptanal, 4-heptenal, 3-hydroxy-2-butanone, octanal, benzyl aldehyde, γ -butyro lactone, nonanal, and 2-ethyl-4-methyl-1-pentanol. Min *et al.* (1977) found a number of alkyl-benzenes in roast beef including; toluene, m-xylene, ethyl-benzene, propyl-benzene and 1-ethyl-2-methyl-benzene. Mottram *et al.* (1982) reported octane, 2- and 3-octene , and nonane among others in cooked beef. Mottram and Edwards (1983) found 2, 2-dimethyl propane in

combination with previously mentioned volatiles. Gault and McLeod (1984) reported 3-penten-2-one and acetone along with many others in cooked beef.

Volatiles as effected by diet. Heptanal, nonanal, and octane were the only volatiles found that were affected significantly by days on feed in a previous study. Larick (1984) reported that the heptanal decreased as time on feed increased and that octane increased as time on feed increased up to 112 days. Larick also stated that nonanal was not significantly affected by DOF. However, these results disagree with the results of the present study. Heptanal was not significantly affected by days on feed for either pasture. Octane RPA increased linearly as DOF increased, while nonanal RPA decreased from 0- to 56-DOF then increased from 56- to 112-DOF. The effect of diet on other volatiles in the present study have not been reported.

Of the 40 volatiles found in the ground beef samples, 11 volatiles were found to be important in describing the days on feed effects on volatile beef flavor using factor analysis (SAS, 1985) and are listed in Table 21, pages 69 through 71. Four benzyl compounds were found, toluene, ethyl-benzene, 1-ethyl-2-methyl-benzene, and propyl-benzene. Other compounds included pentanal, unknown 7, unknown 8, 4-methyl-3-penten-2-one, 3-penten-2-one, nonane, and unknown 9. Each one of these 11 compounds loaded the highest for each of the 11 factor which account for approximately 84% of the variability of the ground beef samples tested by headspace techniques.

Six of these compounds, toluene, pentanal, unknown 7, unknown 9,

1-ethyl-2-methyl-benzene, and 4-methyl-3-penten-2-one, as determined by stepwise discriminant analysis (SAS, 1985) shown in Table 22, page 72, were useful in classifying the samples into three sources, those from steers fed 0-, 56-, and 112-DOF. Discriminant analysis (SAS, 1985) shown in Table 24, page 75, indicated that the observable and reproducible differences in these six volatiles among the ground beef samples were enough to correctly classify approximately 94% of the feeding groups into the days on feed classification.

These DOF effects indicate that, most likely, different biochemical changes that are occurring within the beef animal during the change of diet and are replacing and/or diluting previous precursors of the given volatiles.

Precursors to headspace volatiles. Min *et al.* (1977) has reported that alkyl-benzenes may be formed from the long chained unsaturated hydrocarbons which were derived from thermal oxidative decomposition pathways of fatty acids and from the aromatic compounds by way of a peroxide initiated free radical decomposition. Nonaka *et al.* (1967) also proposed that some alkyl benzenes were formed from the oxidation of 2,4-decadienal, a thermal oxidative product of fat. These long chain 2,4-dienals may form alkyl-benzenes by a 6 membered ring cyclination reaction involving the loss of water.

The presence of hydrocarbons (nonane and others) can be formed from long chained fatty acids by a peroxide initiated free radical decomposition (Selke *et al.*, 1975).

The formation of alkanals (pentanal and others) can be attributed to the thermal decomposition of monohydroperoxides which are proposed to be the initial products of thermally-oxidized, saturated fats (Selke *et al.*, 1975).

The formation of methyl-ketones (4-methyl-3-penten-2-one, and 3-penten-2-one) has been reported by Selke *et al.* (1975). The formation of methyl ketones indicated that they could be the result of β -oxidation of the carbon chain followed by decarboxylation. The short chain ketones originate sequentially from the parent fatty acid in step-wise degradation, losing one carbon atom/degradation step. The three reactions, degradation, β -oxidation, and decarboxylation, were proposed to account for methyl-ketones found from tristearin (Selke *et al.*, 1975).

Correlation Between Sensory Analysis and Flavor Volatile Analysis

Sixteen compounds were found to have simple correlation coefficients with the flavor of beef and are listed in Table 24, pages 75 and 76. One compound, toluene was found to be positively correlated to the sensory panelists' perceptions of milky-oily aroma and flavor in ground beef and, as such, could be an important indicator of grassy flavor in beef.

Seven compounds including; 2, 3-butanedione, octane, 1-hexanol, γ -butyro lactone, and the aldehydes – pentanal, hexanal, and octanal, were found to be positively correlated to cooked beef fat aroma and flavor and may be suitable as indicators of "Beefy" flavor in beef.

Pentanal appears to be the best indicator of beef fat flavor due to it accounting for more of the variation in its factor than any other compound. Larick (1985) did not find 2, 3-butanedione, 1-hexanol, γ -butyrolactone, and the aldehydes – pentanal, hexanal, and octanal, in his study, and did not significantly correlate octane with grassy flavor. Larick (1985) also found that heptanal was positively correlated to the sensory panelists' perceptions of milky-oily aroma and flavor in ground beef. However, this result differs from the present study in that no significant correlation of heptanal with milky-oily flavor was found.

Results of correlating multivariate factor analysis of both flavor volatile total ion intensities and sensory flavor descriptor intensities using stepwise regression analysis (SAS, 1985) is given in Table 25, page 78. Five compounds including; pentanal, unknown 7, toluene, ethyl-benzene, and 1-ethyl-2-methyl-benzene in a model were found to account for 51% of the variation ($R^2 = 0.51$) in beef fat flavor. This indicates that any of these compounds may be suitable as indicators for "Beefy" flavor.

CHAPTER 6

SUMMARY

In summary, this study showed that feeding a corn diet to beef cattle after they had grazed on pasture significantly reduced the undesirable milky-oily aroma and flavor and increased the desirable beef fat flavor and aroma intensities in the ground beef samples. It was also found that although the sensory panel was given six different descriptors to identify the flavor of beef, statistics showed that the panel only identified one factor which was called "Beefy". Differences in the flavor descriptor intensities allowed the panel to correctly classify the samples into their sources of PType and DOF groups.

This study also showed that diet does effect the volatile flavor components of ground beef. Forty volatile compounds were found in ground beef of which 29 were positively identified. Changes in the percentage of relative abundance of 22 volatile compounds of ground beef were found with increasing DOF. In general, 11 volatiles (toluene, ethyl-benzene, propyl-benzene, 1-ethyl-2-methyl-benzene, pentanal, nonane, 4-methyl-3-penten-2-one, 3-penten-2-one, unknown 7, unknown 8, and unknown 9) were found to be important in describing DOF affects for ground beef. Six of these compounds (toluene, pentanal, unknown 7, 1-ethyl-2-methyl-benzene, 4-methyl-3-penten-2-one, and unknown 9) were able to correctly classify approximately 94% of the

feeding groups into the correct days on feed classification.

Sixteen compounds were found to correlate between the flavor of beef (sensory) and beef volatiles (chemical). Of these sixteen compounds, toluene was the only compound found to be positively correlated with milky-oily flavor in ground beef. Seven compounds were found to correlate positively with beef fat flavor with pentanal being the best indicator. Five compounds (pentanal, unknown 7, ethyl-benzene, toluene, and 1-ethyl-2-methyl-benzene) in a model were found to account for 51% of the variation for beef fat flavor and indicates that any of these compounds may be suitable as indicators for "Beefy" flavor.

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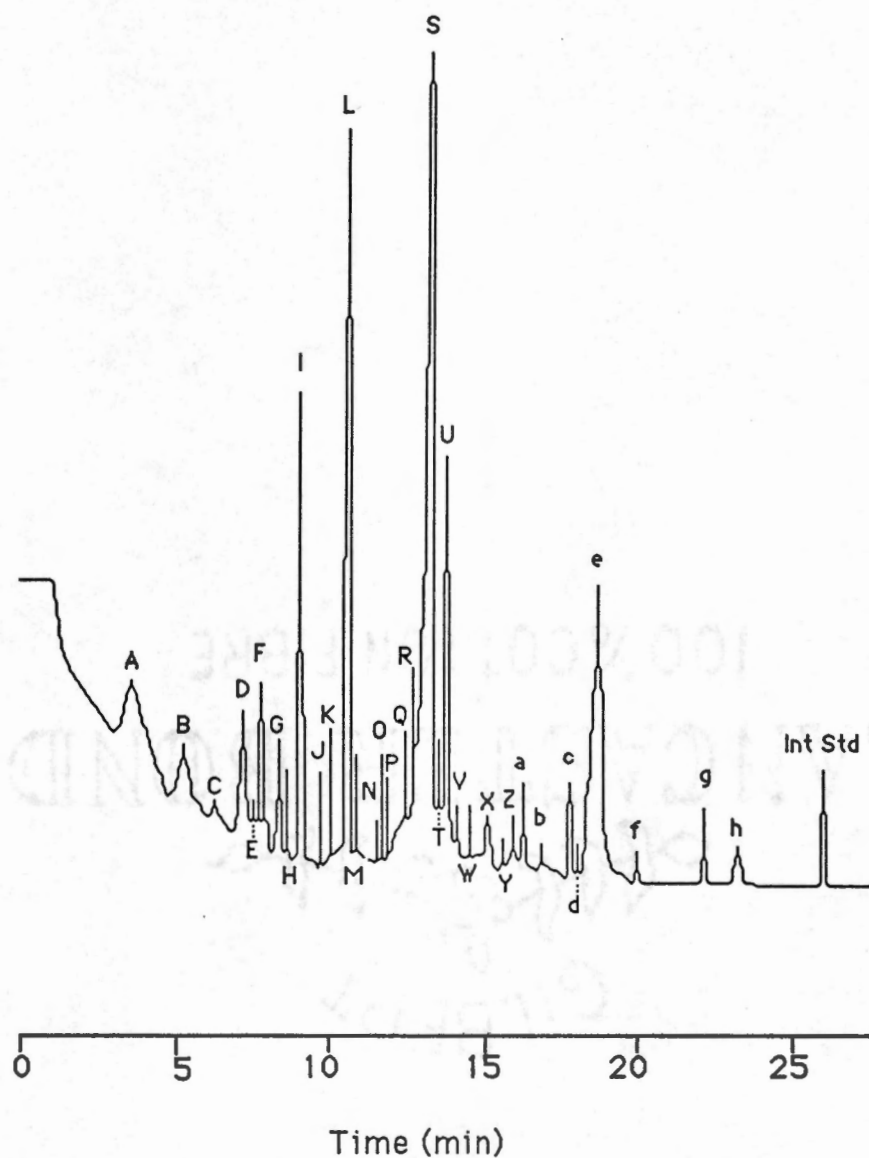
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APPENDICES

APPENDIX A

COMPOSITE CHROMATOGRAPHS
OF 0, 56, AND 112 DAYS ON FEED GROUPS
ACROSS PASTURE TYPES

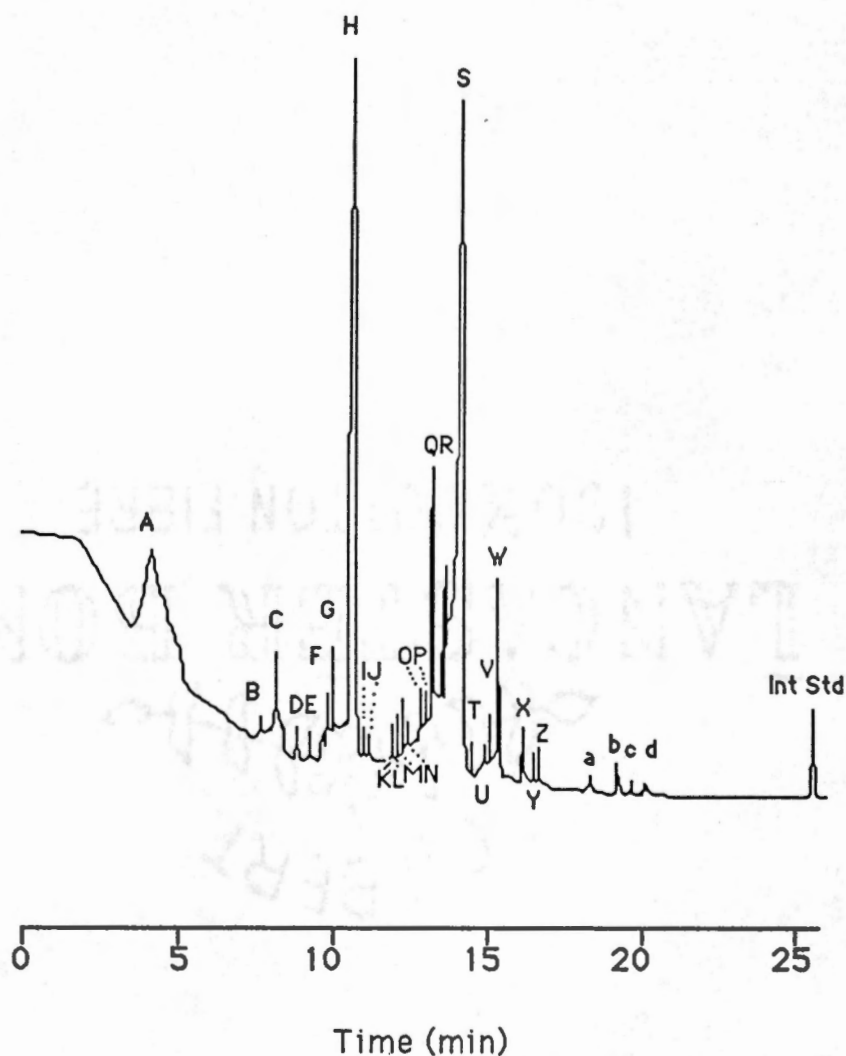


A = 2, 3-Butanedione
 B = 3-Methyl-Butanal
 C = 2,2-Dimethyl Propane
 D = Pentanal
 E = 2, 3-Pentanedione
 F = Octane
 G = (z)-3-Octene
 H = (e)-2-Octene
 I = Toluene
 J = 3-Penten-2-one
 K = Nonane
 L = Hexanal

M = Pentanol
 N = Ethyl-Benzene
 O = m-Xylene
 P = Unknown 2
 Q = 1-Hexanol
 R = Acetic Acid
 S = 3-Hydroxy-2-Butanone
 T = Propyl-Benzene
 U = Heptanal
 V = 4-Heptenal
 W = Unknown 4
 X = Unknown 5

Y = 1-Ethyl-2-Methyl-Benzene
 Z = Unknown 6
 a = Unknown 7
 b = Unknown 9
 c = Octanal
 d = Benzyl Aldehyde
 e = 2-Ethyl-4-Methyl-1-Pentanol
 f = γ -Butyrolactone
 g = Nonanal
 h = Unknown 11
 Int Std = Methyl Caprate

Figure A-1. Composite 0-DOF Chromatogram

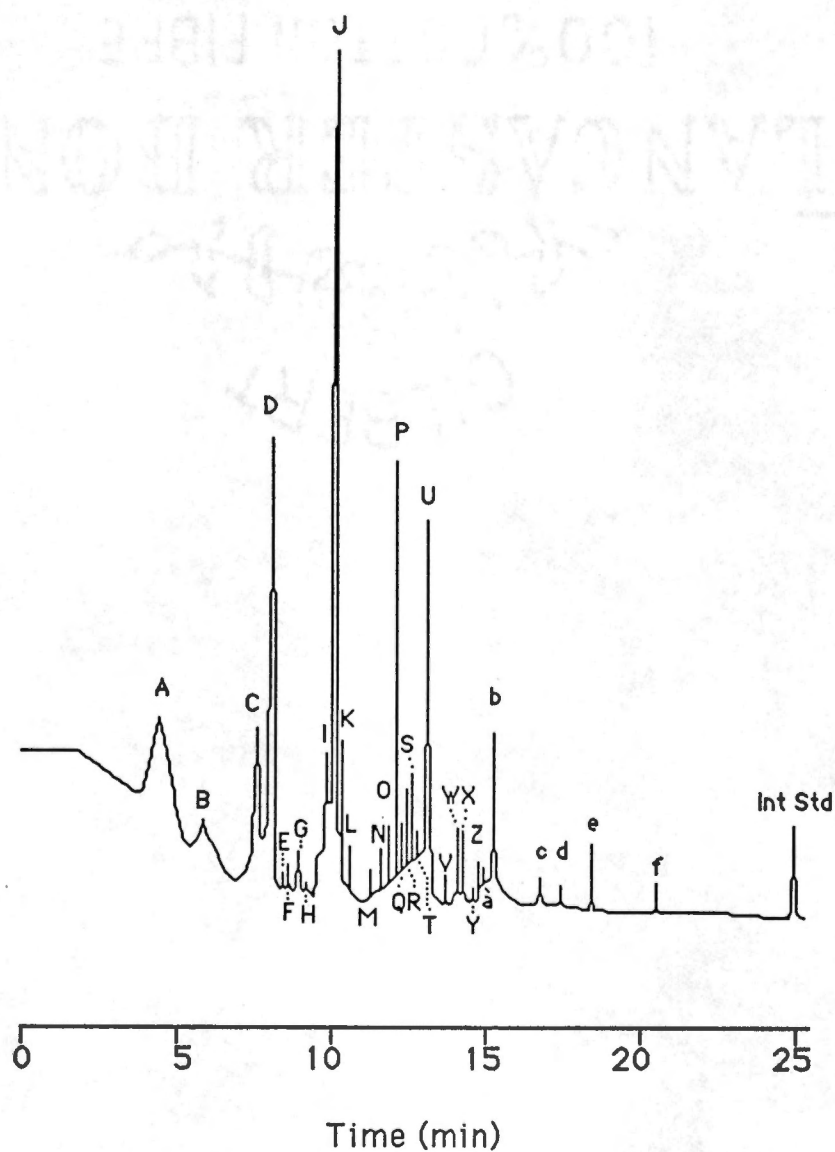


A = 2, 3-Butanedione
 B = Pentanal
 C = Octane
 D = (e)-2-Octene
 E = (z)-3-Octene
 F = Toluene
 G = Pentanol
 H = Hexanal
 I = Nonane
 J = Unknown 1
 K = Ethyl-Benzene
 L = m-Xylene

M = 1-Hexanol
 N = Unknown 3
 O = Alkyl-Benzene
 P = Unknown 2
 Q = Heptanal
 R = Acetic Acid
 S = 3-Hydroxy-2-Butanone
 T = 1-Ethyl-2-Methyl-Benzene
 U = Unknown 6
 V = Unknown 7
 W = Acetone
 X = Octanal

Y = Unknown 9
 Z = Benzyl Aldehyde
 a = γ -Butyrolactone
 b = Nonanal
 c = Unknown 10
 d = Unknown 11
 Int Std = Methyl Caprate

Figure A-2. Composite 56-DOF Chromatogram



A = 2, 3-Butanedione	M = Ethyl-Benzene	Y = Unknown 6
B = 3-Methyl-Butanal	N = m-Xylene	Z = Unknown 7
C = Pentanal	O = 1-Hexanol	a = Unknown 9
D = Octane	P = Heptanal	b = Octanal
E = (z)-3-Octene	Q = Unknown 2	c = Unknown 8
F = (e)-2-Octene	R = Unknown 4	d = 2-Ethyl-4-Methyl-1-Pentanol
G = Toluene	S = Unknown 3	e = Nonanal
H = 3-Penten-2-one	T = Acetic Acid	f = Unknown 11
I = Pentanol	U = 3-Hydroxy-2-Butanone	Int Std = Methyl Caprate
J = Hexanal	V = Alkyl-Benzene	
K = 4-Methyl-3-Penten-2-one	W = 4-Heptenal	
L = Unknown 1	X = Acetone	

Figure A-3. Composite 112-DOF Chromatogram

APPENDIX B

MASS SPECTRUMS
OF UNKNOWN OR UNCOMMON VOLATILE COMPOUNDS
SIGNIFICANTLY AFFECTED BY DOF
IN GROUND BEEF

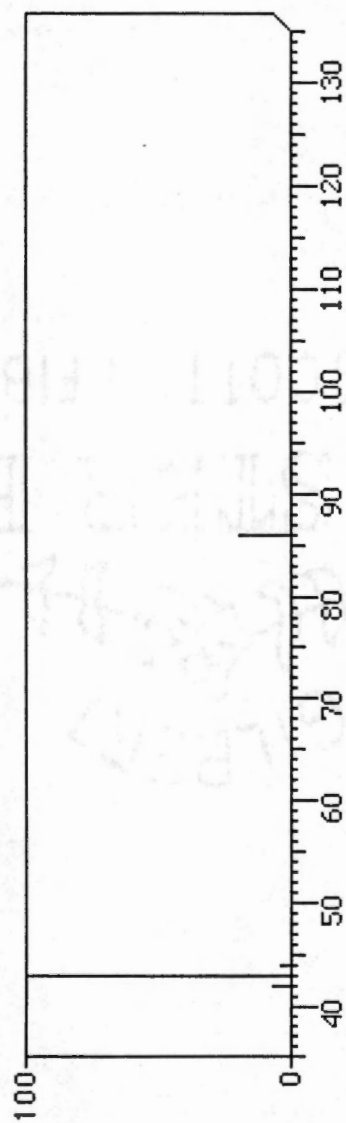
Volatile Compound Name: 2, 3-Butanedione

Peak Number: 1

Molecular Weight: 86

Molecular Formula: $C_4H_6O_2$

Mass Spectrum:



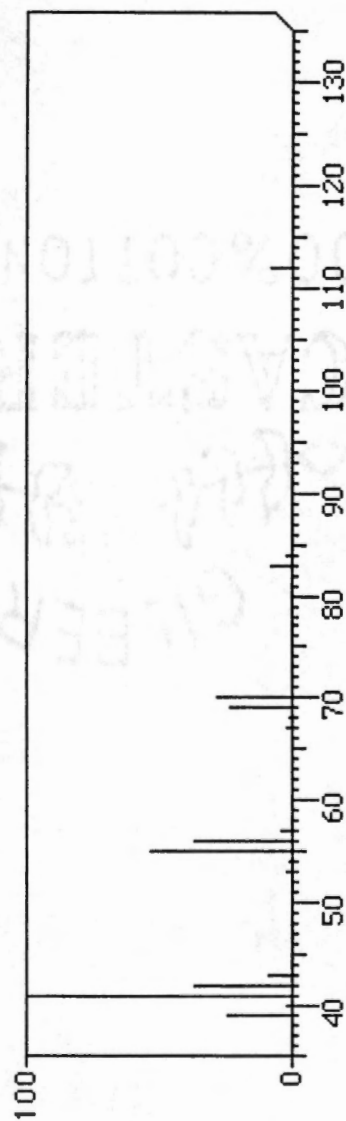
Volatile Compound Name: (z)-3-Octene

Peak Number 7

Molecular Weight: 112

Molecular Formula: C_8H_{16}

Mass Spectrum:



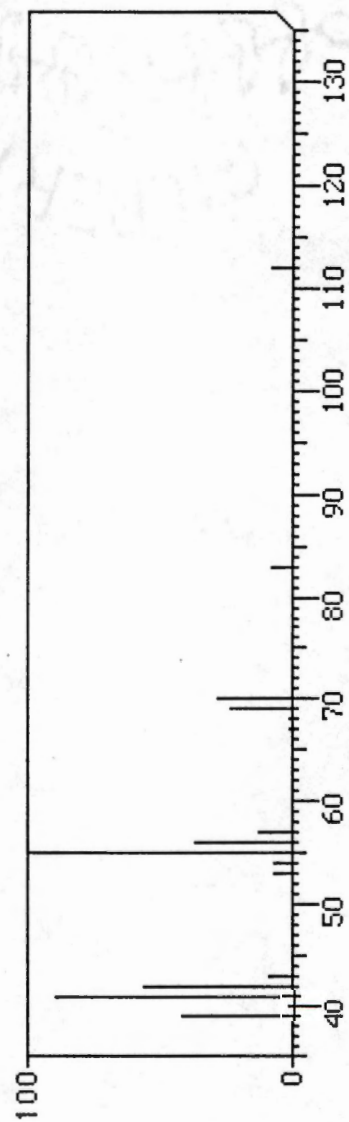
Volatile Compound Name: (e)-3-Octene

Peak Number 8

Molecular Weight: 112

Molecular Formula: C_8H_{16}

Mass Spectrum:



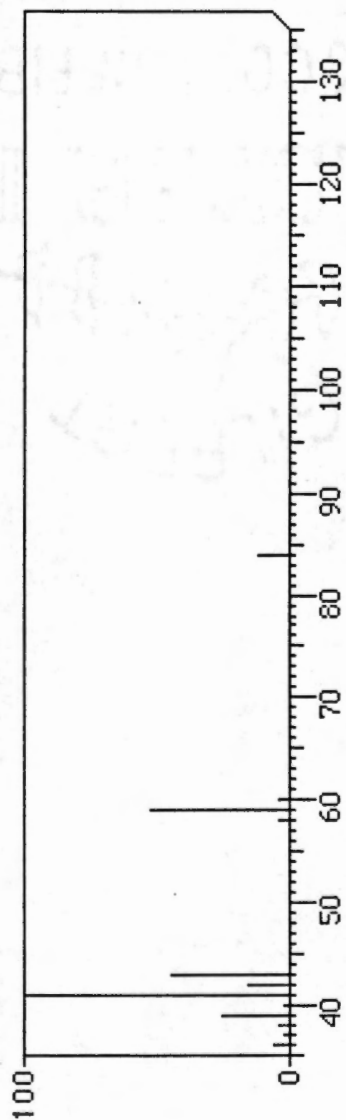
Volatile Compound Name: 3-Penten-2-One

Peak Number 10

Molecular Weight: 84

Molecular Formula: C_5H_8O

Mass Spectrum:



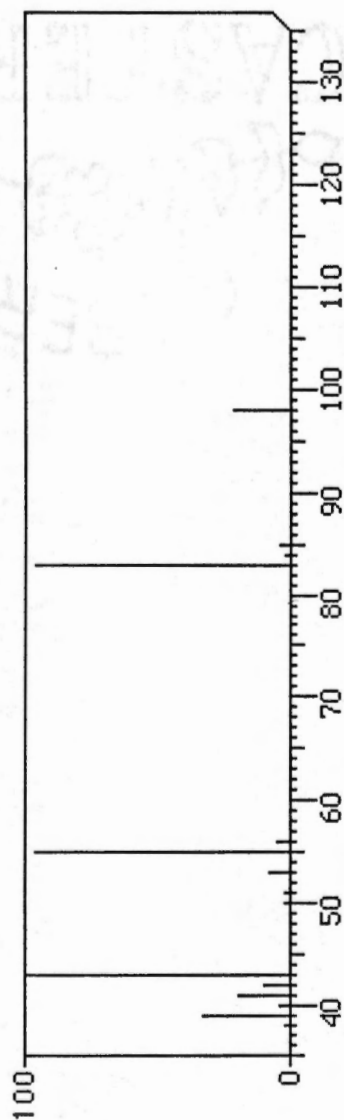
Volatile Compound Name: 4-Methyl-3-Penten-2-One

Peak Number 13

Molecular Weight: 98

Molecular Formula: $C_6H_{10}O$

Mass Spectrum:



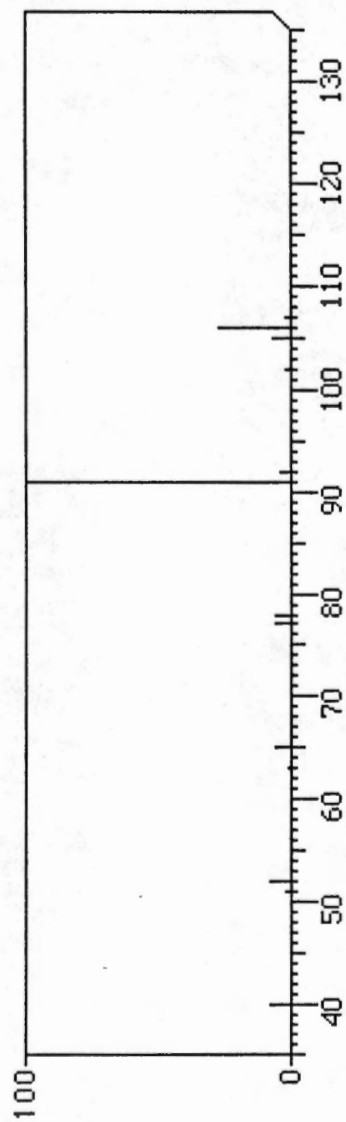
Volatile Compound Name: Ethyl-Benzene

Peak Number 16

Molecular Weight: 106

Molecular Formula: C_8H_{10}

Mass Spectrum:



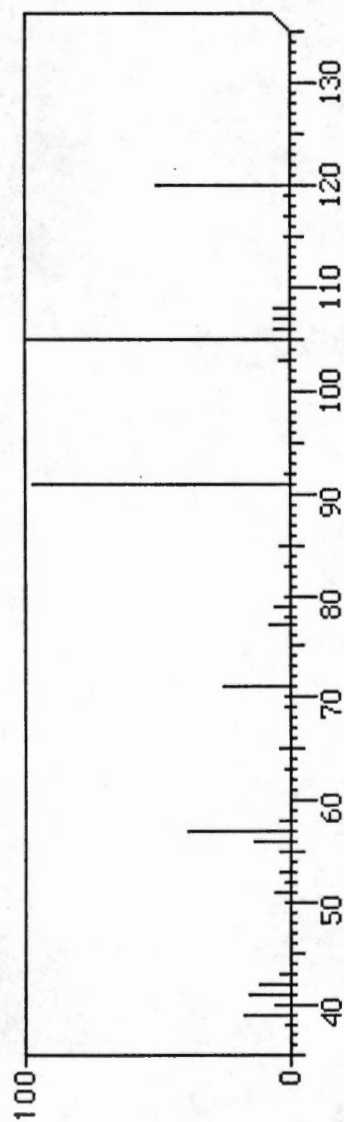
Volatile Compound Name: Propyl-Benzene

Peak Number 23

Molecular Weight: 120

Molecular Formula: C_9H_{12}

Mass Spectrum:



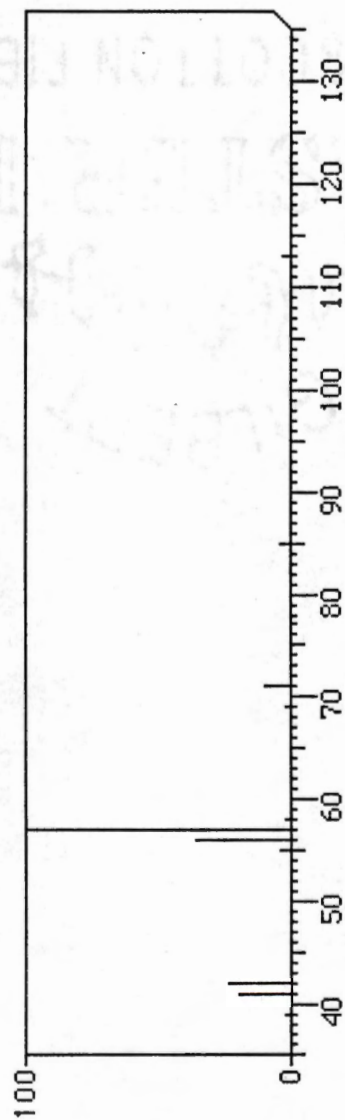
Volatile Compound Name: Unknown 4

Peak Number 26

Molecular Weight: 113

Molecular Formula:

Mass Spectrum:



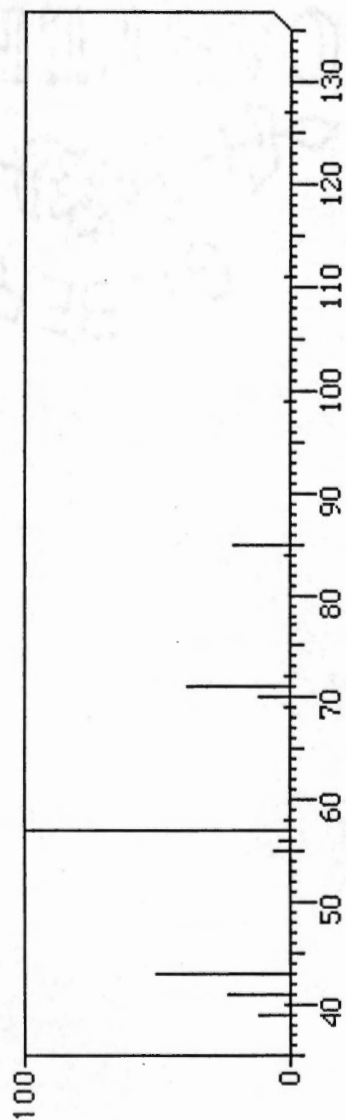
Volatile Compound Name: Unknown 5

Peak Number 27

Molecular Weight: 127

Molecular Formula:

Mass Spectrum:



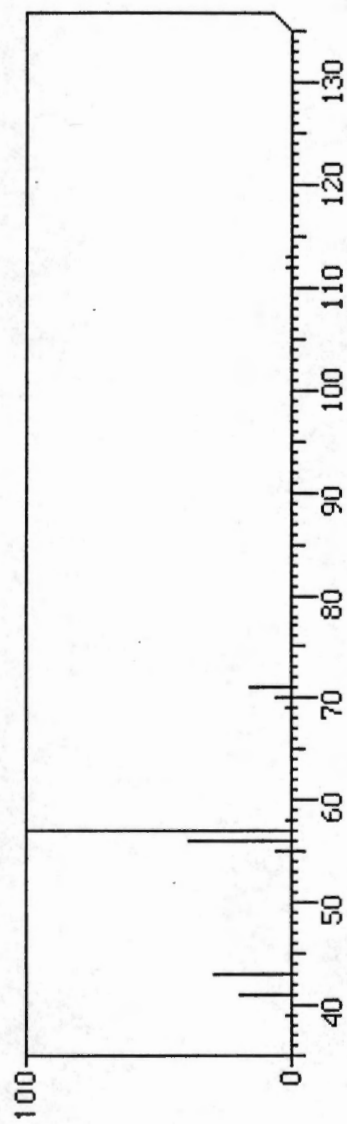
Volatile Compound Name: Unknown 6

Peak Number 28

Molecular Weight: 113

Molecular Formula:

Mass Spectrum:



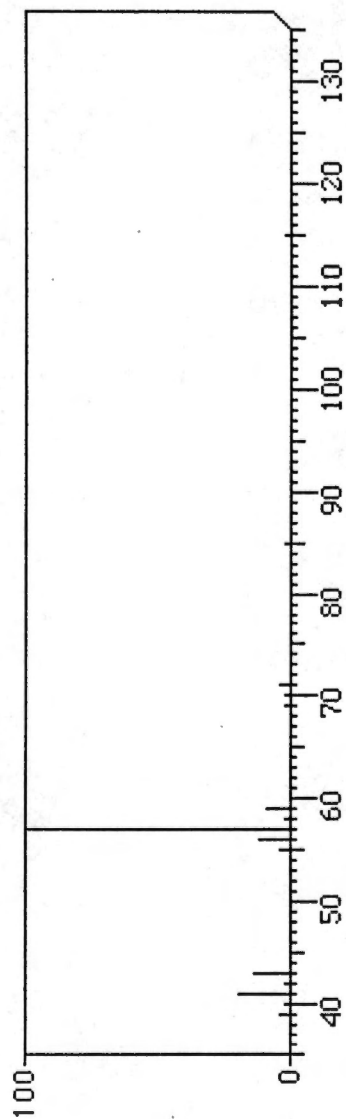
Volatile Compound Name: Unknown 7

Peak Number 29

Molecular Weight: 115

Molecular Formula:

Mass Spectrum:



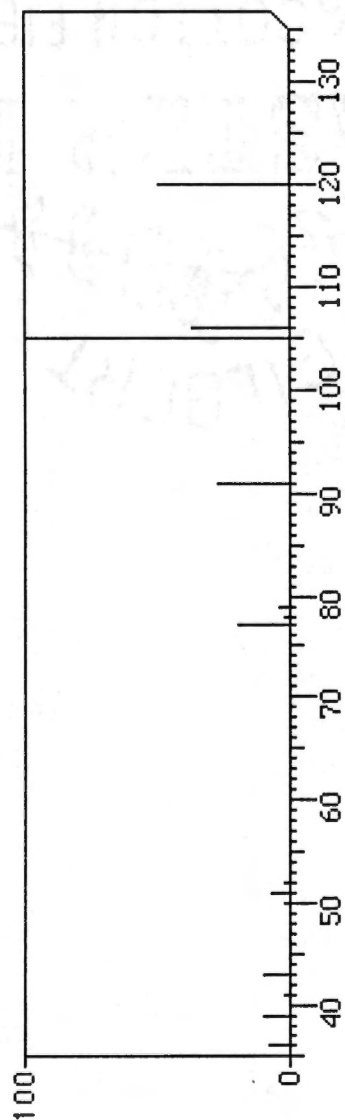
Volatile Compound Name: 1-Ethyl-2-Methyl-Benzene

Peak Number 31

Molecular Weight: 120

Molecular Formula: C_9H_{12}

Mass Spectrum:



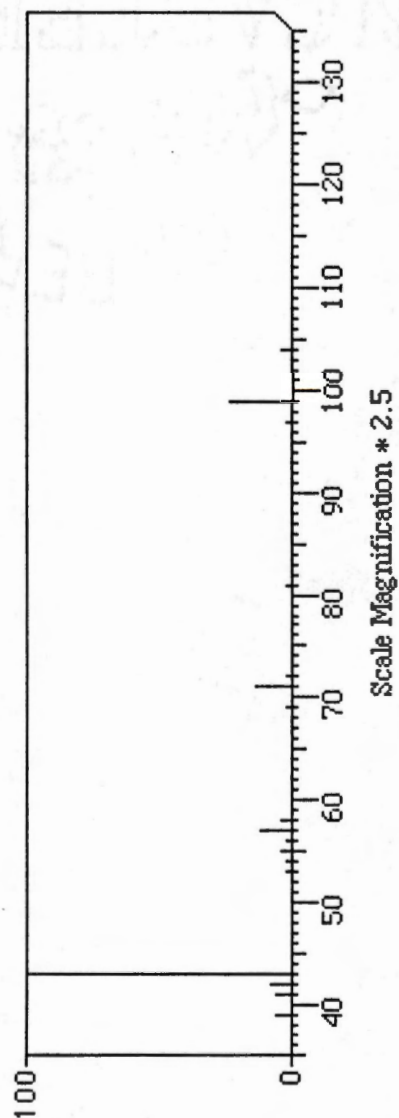
Volatile Compound Name: Unknown 8

Peak Number 32

Molecular Weight: 114

Molecular Formula:

Mass Spectrum:



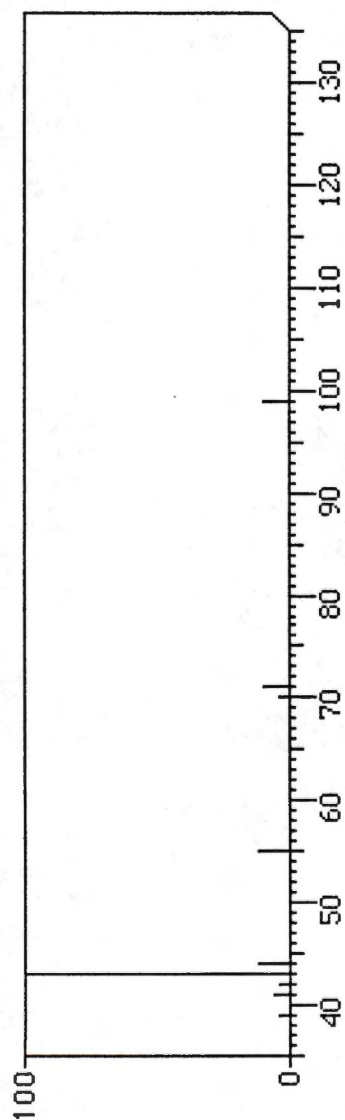
Volatile Compound Name: Unknown 9

Peak Number 34

Molecular Weight: 99

Molecular Formula:

Mass Spectrum:



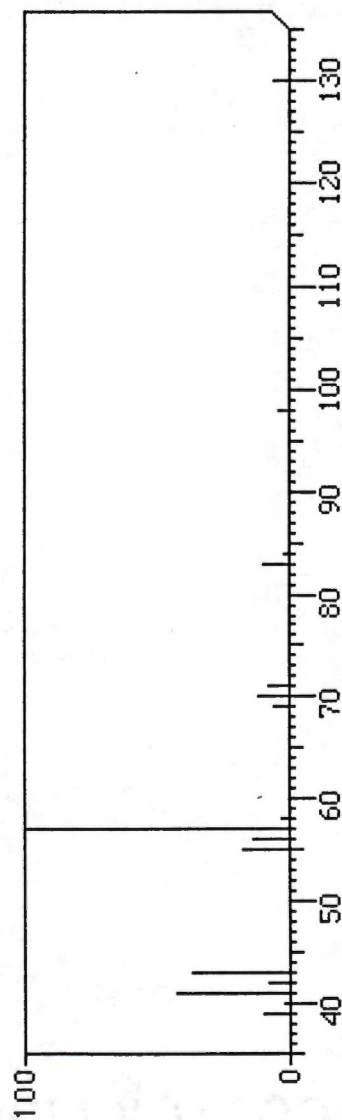
Volatile Compound Name: 2-Ethyl-4-Methyl-1-Pentanol

Peak Number 36

Molecular Weight: 130

Molecular Formula: $C_8H_{18}O$

Mass Spectrum:



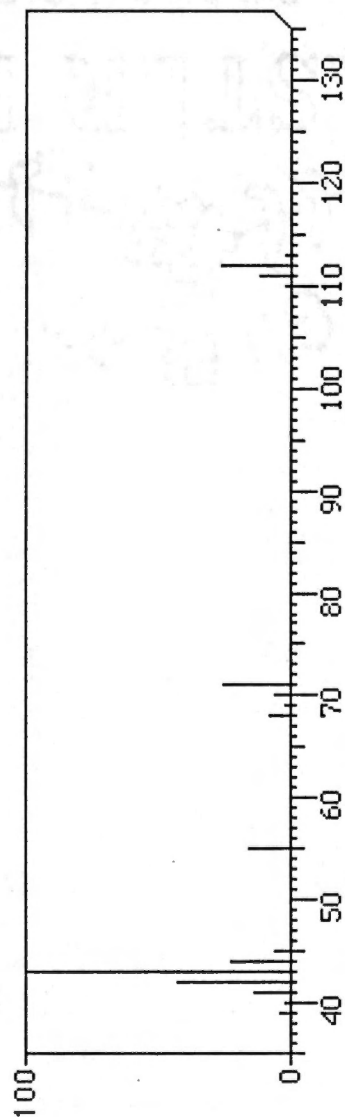
Volatile Compound Name: Unknown 10

Peak Number 39

Molecular Weight: 113

Molecular Formula:

Mass Spectrum:



APPENDIX C

ANALYSIS OF VARIANCE SUMMARIES
OF THE PERCENTAGE OF RELATIVE ABUNDANCE
FOR PEAKS 1 THROUGH 40

APK ^a											
		1	2	3	4	5	6	7	8	9	10
	DF	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
PType ^b	1	4.01*	1.41	0.65	30.87**	0.53	139.50**	21.65**	1.86**	110.06**	0.46
DOF ^c	2	7.05*	4.90	2.02	53.42**	5.13	369.40**	97.05**	8.76**	1217.14**	1.49**
PType*DOF	2	9.06**	4.79	3.04	2.38	2.17	21.27	26.47**	1.70**	157.05**	0.19
PType = A											
Linear	1	0.26						11.82**	0.77	169.50**	
Quad	1	0.01						0.24	0.54	62.75**	
PType = B											
Linear	1	0.33						91.97**	8.05**	914.81**	
Quad	1	15.51*						19.48*	1.08	227.14**	
Error	24	7	7	24	12	27	18	17	24	8	
MS	1.28	3.08	1.30	7.43	1.10	9.06	2.60	0.24	12.04	0.16	

^a Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b A = Fescue-Orchardgrass-Clover Pasture; B = Ryegrass Pasture.

^c 0-DOF samples slaughtered directly off of pasture;
56-DOF samples slaughtered after 56 days on feed;
112-DOF samples slaughtered after 112 days on feed.

* = P<1.0

** = P<0.05

		APK ^a									
		11	12	13	14	15	16	17	18	19	20
	DF	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
PType	1	0.80	63.01	0.25	0.56*	130.68** ^x	0.14	0.42	1.98	0.0002	4.63** ^y
DOF	2	4.28	1927.08*	11.27*	1.20**	164.38** ^x	0.48	0.46	4.52	3.88**	4.66** ^y
PType*DOF	2	3.21	100.18	0.24	0.80*	156.39** ^x	0.68	0.52	2.03	7.97**	1.54* ^y
PType = A											
Linear	1				.14	x				0.53	y
Quad	1				1.17**	x				0.10	y
PType = B											
Linear	1				0.65*	x				10.03**	1.60
Quad	1				0.05	x				1.19	0.68
Error	21	29	45.05	6	17	2	13	28	17	25	7
MS	0.88	0.88	0.88	1.37	0.16	0.03	0.21	0.19	1.17	0.58	0.61

^a Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b A = Fescue-Orchardgrass-Clover Pasture; B = Ryegrass Pasture.

^c 0-DOF samples slaughtered directly off of pasture;

56-DOF samples slaughtered after 56 days on feed;

112-DOF samples slaughtered after 112 days on feed.

* = P<1.0

** = P<.05

^x Peak 15 lacked sufficient degrees of freedom to allow any further analysis on Ptypes.

^y Peak 20 lacked sufficient degrees of freedom to analyze Ptype A, but did have a higher amounts in 0-DOF samples than in 56 or 112-DOF samples.

APK ^a													
	21	22	23	24	25	26	27	28	29	30			
DF	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
PType	1	0.12	117.76	0.01	2.48	1.99*	0.003	0.02	2.49**	4.31*	2.62		
DOF	2	1.89	544.78**	0.24	12.96	0.34	1.30*	2.73**	3.95**	10.95**	57.78*		
PType*DOF	2	7.42	152.77	0.01	13.48	0.19	0.16	0.49	4.84**	1.48	4.43		
PType = A													
Linear	1								3.40*				
Quad	1								4.89*				
PType = B													
Linear	1								0.39				
Quad	1								0.10				
Error	25	28	5	24	10	16	15	24	27	16			
MS	2.59	58.02	0.09	14.10	0.54	0.19	0.23	0.55	1.39	8.74			

^a Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b A = Fescue-Orchardgrass-Clover Pasture; B = Ryegrass Pasture.

^c 0-DOF samples slaughtered directly off of pasture;
56-DOF samples slaughtered after 56 days on feed;
112-DOF samples slaughtered after 112 days on feed.

* = P<1.0

** = P<.05

		APK ^a											
		31	32	33	34	35	36	37	38	39	40		
DF	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
PType	1	0.19	0.49**	1.33	0.10	0.91	1.72	0.04	0.45	0.001	5.79**		
DOF	2	2.38** ^x	1.29**	33.65**	2.92	2.01	3.48	0.02	8.94**	4.23** ^y	1.19		
PType*DOF	2	0.19** ^x	0.27	0.79	0.75	0.53	11.36*	0.11	0.34	2.61** ^y	2.59		
PType = A													
Linear	1	y					3.61			z			
Quad	1	y					9.51*			z			
PType = B													
Linear	1	1.22**					0.03			5.26**			
Quad	1	1.11**					1.69			1.14			
Error	9	0.06	8	27	22	12	22	14	29	7	19		
MS			0.07	1.47	0.64	0.66	2.13	0.04	0.49	0.27	0.53		

^a Numbers were assigned on a basis of retention time from the chromatograms obtained from the GC-Mass Spectrophotometer.

^b A = Fescue-Orchardgrass-Clover Pasture; B = Ryegrass Pasture.

^c 0-DOF samples slaughtered directly off of pasture;
56-DOF samples slaughtered after 56 days on feed;
112-DOF samples slaughtered after 112 days on feed.

* = P<1.0

** = P<0.05

^x Lack of observations made this peak significant.

^y Peak 31 lacked sufficient degrees of freedom to analyze Ptype A due to not being detected in 112-DOF for Ptype A.

^z Peak 39 lacked sufficient degrees of freedom to analyze Ptype A due to not being detected in 112-DOF for Ptype A.

VITA

James Craig Bolton was born September 17, 1957 in Chicago, Illinois, the son of Mr. James H. Jr. and Mrs. MaryEllen Penny Bolton. He received his high school diploma from Greeneville High School in Greeneville, Tennessee in May, 1975. In October, 1975 he served a tour with the United States Army, Military Intelligence Branch which ended in October, 1978. In August 1980, the author enrolled in Tusculum College, and transferred to Carson-Newman College in August 1982, in the Departments of Chemistry and Biological Sciences. He graduated Cum Laude and received his Bachelor of Arts degrees in May 1984. In the fall of 1984 he accepted a research assistantship in the Department of Food Technology and Science at the University of Tennessee, and began study toward a Master's Degree. This degree was awarded in June 1987.

The author is a member of the Alpha Chi Honor Society, Blue Key Honor Fraternity, Beta Beta Beta-Honor Society of Biology, Institute of Food Technologists, American Meat Science Association, and American Society of Animal Science.