3

Meat Composition

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3.1 Preface

Anyone who has an interest in meat should know something about what it consists of, that is, what the pieces are, how much of the whole each piece represents, and how to measure each piece. Furthermore, the interested and educated person really should know from where meat originates and how to measure its composition and what causes it to vary. This is what this chapter is about. When you have finished reading it, I hope you will have a better understanding of where meat comes from, what it consists of, why its consistency varies, and how to assess it. This information should help provide a better understanding of how to use meat as a food, how to make it taste better and safer for
consumption, and how its properties can be best utilized for further processing, storage, and distribution. Specific references are given for further details on specific topics (Allen and others, 1976, Hedrick and others, 1993, Kauffman, 1971, Kauffman and St. Clair, 1978, Kauffman and others, 1986, Kinsman and others, 1994).

3.2 Introduction

3.2.1 Definitions and Measurements

In the broadest sense, meat is the edible postmortem component originating from live animals. For the purposes of this text, these animals include domesticated cattle, hogs, sheep, goats, and poultry, as well as wildlife such as deer, rabbit, and fish. It is reasonable for the definition of meat to include such organs as heart and liver (often defined as variety meats), but the focus of this chapter is on meat defined as those tissues exclusively originating from an animal’s carcass, a proportion amounting to about one-half to three-fourths of the animal’s live weight. This carcass proportion of the live animal weight is classically calculated as dressing percentage and can vary considerably. Some species, such as the turkey, can yield a carcass weighing about 80% of the live weight, whereas a market lamb’s yield is closer to 50%. Animals with small and empty gastrointestinal tracts (such as hogs or poultry rather than ruminants) that are not pregnant, that are more heavily muscled and fatter, that do not have long fleeces or dirty hides, and that have been slaughtered in a manner that leaves the skin and feet intact with the carcasses (hogs) will have higher dressing percentages (see Figure 3.1).

Excluding the skin, the carcass component of live animals basically consists of three parts: muscle, fat, and bone. Of these, muscle is the most important, constitutes the majority of the weight, and often is considered unequivocally synonymous with “meat.” This can be a reasonable assumption, but fat deposits and some bones are often processed, merchandized, and used along with muscle and must be included in the broader definition of meat. Figure 3.2 is included as an example of the relative composition (in specific detail) of market animals and is representative of a live mature beef steer. From this information, one can calculate the proportions of any one part to the various larger component parts. For instance, the longissimus muscle represents (approximately) 51% of the back muscles, 12% of all carcass muscles, 7% of the carcass, and 4% of the live animal. These values can vary depending on species, degree of fatness, and other similar factors affecting dressing percentage. However, it provides a relative guide that reflects the composition of live animals and how it is related to the meat component. Furthermore, Figure 3.2 indicates that “meat” has its origin in many muscles of the carcass. In closer observation, one can deduce that some muscles contribute considerably more to meat than others, and that is because they vary in size and shape, dependent directly on the biological functionality.

Composition is defined as the aggregate of ingredients, their arrangement, and the integrated inter-relationship that forms a unified, harmonious whole. Figure 3.2 is an example of this. For market animals raised to produce meat for human consumption, the greatest emphasis is on the musculature and its relationship to everything else. The proportion of the animal’s musculature is related to several criteria, the three most important being dressing yield, fatness, and muscling (expressed in terms of ratio of muscle to bone). Realistic averages of composition for most meat animals are included in Table 3.1. Muscle varies from 25% (lamb) to 50% (turkey) of the live weight and muscle to bone ratio varies from 1.8 (chicken) to 5.0 (venison).

There are several arithmetic approaches to expressing quantitative composition, but the one most commonly used is the weight of a part expressed as a percentage of a larger part, such as % muscle of a retail cut of meat, or % protein of a muscle. Another less-used technique is to express the part and the whole as logarithmic functions of each other.

Measuring composition can vary from subjective techniques to ones precisely objective. Even when a technique is considered objective, at least some subjectivity inadvertently prevails. Here are some of the more commonly used approaches for determining gross composition (% lean) of meat cuts.
3.2.1.1 Visual Appraisal

Every time consumers purchase cuts of meat, they often select them on the basis of their lean/fat/bone ratios as estimated by visual inspection. This is simply accomplished through visual comparisons. Quantitatively, the method lacks accuracy, but for practical purposes in meat selection, it is effective, especially when compositional variations are large. On a more detailed basis, visual scores can be established with photographs and then the meat cuts scored on proportions of lean. However, scoring is too subjective to reflect quantitative differences and is too difficult to standardize to be consistently applied over time. Perhaps the one greatest value of visual inspection is in the estimation of proportions of intramuscular fat (marbling) when determining gross composition by dissection (in which dissecting marbling is essentially impossible).
Figure 3.2 Approximate proportion of components of meat animals.

The data represents cattle, swine, and sheep. Prototype for this figure was cattle and appropriate carcass proportion of all components for swine and sheep should be 70%.

The data also shows the percentage of live animal, carcass, and non-carcass for fat or skeleton.

Key:
- Live animal
- Carcass
- Fat
- Noncarcass
- Skeleton
- Area of a combination of carcass and non-carcass for fat or skeleton.

The table shows the percentage of major subcomponents, minor first subcomponents, and minor second subcomponents of carcass parts for fat or skeleton.

Some of the parts listed may be absent due to species, sex, or stage of growth.
3.2.1.2 Linear Measurements

A simple, inexpensive ruler can be used to measure subcutaneous fat thickness, muscle depth and width, and bone length and thickness. From these measurements, areas of each component can be estimated and then expressed as a proportion of the whole. Unfortunately, the areas are not exactly accurate, nor are unexposed bones and seam fat of different dimensions (as well as marbling) included in the estimate.

3.2.1.3 Area Measurements

By tracing the areas of the exposed muscles, bones, and fat on acetate paper and then measuring the exact areas of each component with a compensating polar planimeter, composition can be estimated. Also, such areas can be assessed using photometric, electronic, and computerized imaging techniques. Even though this is more accurate in determining the exposed areas, it has the same limitations as visual appraisal or linear measures because unexposed bone and seam fat as well as marbling cannot be accounted for.

3.2.1.4 Density

The Archimedean principle suggests that cuts of meat displace a volume equal to their own. Because the density of fat is less than that of muscle, such a technique, even though destructive if water displacement is used and expensive if gas displacement is used, would provide an accurate estimate of lean. However, for meat cuts containing bones, the technique would not be satisfactory. The density of bone is nearly twice that of muscle and would bias the estimate of muscle.

3.2.1.5 Anyl-Ray

This is based on x-ray attenuation as an index of tissue fatness. It generates electromagnetic waves of a character sensitive to absorption and reflection or back scatter by the elements in ground meat. The radiation is directed through a sample where size, shape, compaction, and weight must be constant while sample composition varies. When calibrated intensity of radiation is directed through a sample, this energy intensity is directly proportional to sample composition. A carefully mixed and selected ground meat sample is subjected to a minute amount of carefully controlled x-rays. Because lean absorbs more x-rays than fat, there is a difference in energy transmitted. The penetrating rays are collected by a radiation-measuring device, which in turn energizes a calibrated digital percentage fat meter. In the past,
it has been used to determine fat content in ground meat used for processing. The method is fast, requires a sample that can be reutilized for processing after measurement, and has a high degree of accuracy. The instrument correctly evaluates meat at any temperature, provided it can be properly compacted in the container. Further grinding or the addition of warm water may be necessary to achieve proper compaction for frozen samples. However, it is a relatively expensive method for determining the composition, and it cannot be used for small meat cuts or ones containing bone, and it estimates only fat and no other specific chemical components.

### 3.2.1.6 Dissection

This is the one most effective method of determining the gross composition of whole carcasses or individual wholesale or retail cuts. The method can be standardized and is highly repeatable in application. The method requires knowledge of anatomy and the patience and care to separate each component, preventing weight loss through evaporation and drip, and weighing and recording accurately. However, it does not account for variations of marbling, which would have to be assessed visually or subjected to chemical evaluation.

### 3.2.1.7 Proximate Analysis

For animal tissues, the primary chemical components used as a follow-up to or an alternative for physical dissection includes moisture, protein, lipid, and ash. The procedures for chemically analyzing each of these are described in the association of official analytical chemists (AOAC 1999). A major concern in using this method is adequate mixing and sampling of the tissues to be analyzed. Another limitation is in chemically analyzing bone because of the difficulty in grinding and sampling. (This does not apply for the ash determined in muscle.) Also, mixing ground components of soft tissues creates problems of fat collecting on the sides of the mixer. Finally, when moisture is being assessed, large errors occur when muscles are soft and watery or when excessive evaporation of moisture is lost from the surfaces of unprotected samples.

To determine the detailed chemical composition of muscle, fat, or bone, such as specific minerals, myofibrilar proteins, fatty acids, individual vitamins, and bound versus free water, numerous detailed and often extremely difficult, expensive, and sensitive chemical and spectrophotometric procedures are required. These procedures are not identified and described here because of their complexities and the need to maintain brevity.

### 3.3 Description and Composition of Muscle and Its Modifiers

#### 3.3.1 Description

Meat animals contain, as a majority of their carcass weight, many muscles distributed in an unusually designed pattern to move the skeleton, for posture control, and for more specialized functions such as respiration, swallowing, and peristalsis. This musculature is categorized into two major types: striated and nonstriated. The less voluminous nonstriated or smooth muscles have some similar functions as striated muscles but possess different histological structures. Smooth muscles are primarily found in the linings of the gastrointestinal tract and the circulatory system as well as in specialized organs such as the gizzard of birds.

Striated muscles are categorized as either cardiac or skeletal. Cardiac muscles are confined to the heart and have the continuous responsibility of distributing and collecting blood throughout the body. Structurally, they are similar to skeletal muscles, except that they are more highly aerobic in their metabolic properties and therefore require higher concentrations of oxygen for their rhythmic contractions. Skeletal muscles are, as the name implies, associated with the skeleton; they either lie next to a bone or are attached to various bones, either closely or indirectly through their connective tissue fascia that may
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attach directly or indirectly by tendons to distant bones. Depending on function and needs, skeletal muscles contract and relax and have very exacting cross-banding patterns.

Skeletal muscles play a major role in locomotion and posture control as well as in protecting vital organs. On average, the meat animal carcass contains about 100 bilaterally symmetrical pairs of individually structured muscles. There are large ones and small ones, depending on function and location. They have different shapes, colors, and concentrations of tendons. Many have a fusiform, multipennate shape, having a large middle portion that tapers at the ends. The attachments contain large quantities of tendinous connective tissue that attaches to bone. The long head of the triceps brachii would be an example of a fusiform-shaped muscle. Other shapes include flat or sheet-like muscles such as the cutaneous trunci, round-shaped muscles such as the quadriceps femoris, and irregular shapes such as the tensor fasciae latae, which has more than two attachments and is somewhat triangular shaped with thick and thin portions. In the more distal portions of the limbs, small muscles are uniquely attached to tendons for the specific purpose of either flexing or extending the feet and legs. In the more proximal locations, the muscles are larger and primarily serve as major sources of power. This is particularly true of the pelvic limb musculature. There are less than ten major pelvic muscles, whereas there are twice as many of smaller size in the thoracic limb. The longissimus thoracis et lumborum is the longest and largest muscle in many species and is located in the back to support the axial skeleton and to extend and erect the vertebral column. The flat muscles, generally located in the abdominal wall, support the abdominal cavity and its contents. Commercially, the flat muscles have less economic importance but they are the only ones found in bacon.

Skeletal muscles have a complex composition because they contain, in addition to muscle fibers, large quantities of supportive connective tissue, a complete vascular supply, and a nerve supply controlling each of the billions of muscle fibers. Also, skeletal muscles serve as storage depots for lipids and contain considerable quantities of extracellular fluids, primarily consisting of water.

Postmortem muscles vary in color, ranging from a dark purplish-red to a pale, light gray. This variation is primarily the result of myoglobin concentration as well as other biological factors such as pH. Myoglobin is a protein physiologically important in the transfer of oxygen and carbon dioxide to and from muscles during their normal metabolic activities. Breast muscles of poultry (pectorales superficialia) are very pale or white in color and contain low quantities of myoglobin, whereas leg muscles of venison are extremely dark purple and contain more than twice as much myoglobin. Striated muscles are multinucleated, distinguishing them from smooth muscles, which are mononucleated. These nuclei are near the sarcolemma cell wall whereas in smooth muscles, the nuclei are more centrally positioned. Skeletal muscles contain mitochondria, but not as many as are found in cardiac muscle. Other organelles such as ribosomes and the Golgi apparatus are also found in muscle fibers. Each fiber is surrounded by an intricate membrane, the sarcolemma, which surrounds the sarcoplasm that bathes the myofibrils, which are the contractile units of the fiber. Lipid particles in the form of neutral droplets and free fatty acids as well as glycogen granules are distributed throughout the sarcoplasm. (In postmortem muscles, glycogen is metabolized to lactic acid.) Enzymes are located in mitochondria and in other portions of the sarcoplasm. The sarcoplasmic reticulum and transverse tubules are responsible for the storage and transportation of calcium for contraction and relaxation.

To permit muscles to function properly as moving forces, they are harnessed to the skeleton through a unique set of connective tissue structures. This connective tissue "harness" circumvents the entire muscle and is called the epimysium; it winds its way through each muscle, dividing fibers into groups called fascicular bundles. The connective tissue at this level is called perimysium. The perimysium subdivides further into endomysium, which lines each fiber. The vascular system, which winds its way through muscles to supply the nutrients and remove toxic wastes, is closely related to individual fibers. In both the extracellular spaces and within fibers, there are fluids high in water content. In addition to the water, there are minerals, some water-soluble proteins, nonprotein nitrogenous materials, and other organic entities. Lipid in the form of neutral triglycerides is stored in the adipose tissue cells, which accumulate around venules and arterioles in the interfascicular spaces. This fat, when visible, is called marbling. Excluding water, the major components in muscle are the contractile proteins, which make up the myofibrils.
3.3.2 Gross Composition

A simpler approach to assessing the composition of muscles is to use proximate analyses to quantitate moisture, protein, lipid, ash, and carbohydrate. Muscle composition varies considerably and the accumulation of lipid is the most influential on this variation. On average, most muscles should contain about 1% ash (primarily represented by the elements potassium, phosphorus, sodium, chlorine, magnesium, calcium, and iron), 1% carbohydrate (primarily glycogen antemortem and lactic acid postmortem), 5% lipid, 21% nitrogenous compounds (predominantly proteins), and the rest (72%) as water. These values are compared to the composition of fat and bone as shown in Table 3.2. Some muscles may contain as much as 15% lipid (fresh weight basis), whereas others may contain <2%. Regardless of the lipid content, the protein/moisture ratio of about 0.3 remains quite constant for mature muscles. If time and expenses are limited, one may quickly, easily, and somewhat accurately assess proximate composition of muscles by making a few assumptions, using moisture analysis for the only determination. If it is assumed that ash and carbohydrate will not vary greatly and that their sum contribution is estimated at 2%, and if it is assumed that the protein/water relationship is 0.3, then if water is determined by homogenizing the sample and drying it, the only unknown left to be estimated is lipid content. This is calculated by difference. For example, if a sample (analyzed for moisture content) contained 70% moisture \( \left( M \right) \), then protein \( \left( P \right) \) content would be equal to \( P/M = 0.3 \), or \( P/70 = 0.3 \). Therefore, \( P = 21 \) or 21% protein. By subtracting the sum \[2\% \text{ (ash and carbohydrate)} + 70\% \left( M \right) + 21\% \left( P \right)\] from 100%, then lipid would be 7% or \[100 - (2 + 70 + 21)\].

3.3.3 Molecular Composition

There are a host of chemical compounds in muscle. They include free fatty acids, glycerol, triglycerides, phospholipids, nonprotein nitrogenous components such as DNA, RNA, ammonia, amine groups, and vitamins. There are glycogen granules and ATP. Myoglobin is present. Several minerals are present in minute quantities. Most important from a quantitative perspective are the various proteins of each fiber. These proteins are classified into four groups, the largest of which is myofibrillar. Myofibrillar proteins represent about 60% of the total proteins, whereas sarcoplasmic proteins represent 29%, stroma proteins 6%, and granular proteins 5%. Figure 3.3 is included to provide a detailed overview of the complexity of muscle composition. It is not intended to be precisely accurate nor to be memorized, but to serve as a reference to identify the various components of muscle and their quantitative contributions to its mass. It is assumed that these values represent mature, postrigor muscles of various species. Of all information presented in this chapter, Figures 3.2 and 3.3 should receive special attention because they are a detailed summary of the most important features of meat composition. (It required more time and effort to construct these figures than everything else combined in this chapter!) It should be understood that the methods of analysis used to determine most of the components of Figure 3.3 greatly affect the quantities reported.

### Table 3.2

<table>
<thead>
<tr>
<th></th>
<th>Muscle</th>
<th>Fat</th>
<th>Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>72</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Nitrogenous compounds (%) (primarily proteins)</td>
<td>21</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Lipid (%)</td>
<td>5</td>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1</td>
<td>&lt;b</td>
<td>45</td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>1</td>
<td>&lt;b</td>
<td>&lt;b</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Proximate analysis expressed on a fresh basis for mature, postmortem tissues representing various anatomical locations.

\(<b\) <0.5%.
The myofibrillar proteins are responsible for the contractile mechanisms and thus shorten or lengthen the muscle for movement and support functions. Sarcomplasmic proteins are primarily represented by enzymes and myoglobin. Stroma proteins originate from the connective tissue structure found as a part of muscle, the most important quantitatively being collagen. Collagen is resistant to most enzymatic reactions except collagenase. When heated in water, collagen is converted into gelatin, which is readily hydrolyzed by several enzymes. About one-third of collagen’s amino acid residues consist of glycine, whereas another one-fifth is proline and hydroxyproline. It is the only protein known which contains hydroxyproline, with the possible exception of reticulin. Hydroxyproline analysis is often used as a measure for determining the total connective tissue in muscles. Another stroma protein of less concentration is elastin. It is even more resistant to degradation: to degrade, it must be subjected to high temperatures in the presence of strong bases or acids. Elastin contains about one-third of its amino acid residues as

* = Thiamine is about eight times higher in pork muscle.

Data are for mature, post rigor muscles representing various species. Each number following a part is its approximate percentage of larger parts by weight.

For example: Myosin represents about 5% of fresh muscle, 23% of nitrogenous compounds in muscle, 26% of all proteins and 43% of myofibrillar proteins.
glycine and over one-tenth as proline. Reticulin is the other major stroma protein. Its amino acid composition is similar to that of collagen, and it is often considered a form of collagen that contains lipids and carbohydrates.

There are nine known major myofibrillar proteins, as illustrated in Figure 3.3. Quantitatively, the one most important protein is myosin. In referring to Figure 3.3, myosin represents 43% of the myofibrillar proteins, 26% of all muscle proteins, 23% of all nitrogenous compounds, and 5% of the fresh muscle mass. Myosin is the thick strand of protein that appears in the sarcomere structure. Actin represents about 22% of myofibrillar proteins and is the thin filament within this same contractile formation. The other seven proteins represent smaller compositional fractions, but play equally important roles in contraction. Titin represents 10% and has by far the largest molecular weight and is considered more structural than metabolic in function. Troponin and tropomyosin each contribute about 5% and can be found attached to the actin molecule and are primarily responsible for initiating contraction after calcium has been released by the sarcoplasmic reticulum. All the other proteins combined represent <20% of the weight.

All the above mentioned proteins are composed of the 22 amino acids shown in Figure 3.3. Each amino acid is different according to the molecular characteristics of its side chain. The 10 essential and 12 nonessential amino acids and their mole contributions to muscle mass are included in Figure 3.3.

In addition to the proteins, there are other important nitrogenous constituents in muscle. First are the vitamins, which are divided into two classes based on their solubility in either aqueous or nonaqueous solutions. The lipid-soluble vitamins are minimal because of the small quantities of fat normally deposited in most muscles. However, water-soluble vitamins, primarily the B vitamins, are present in substantive enough quantities to serve as appropriate sources to meet daily dietary requirements for humans. They include thiamin, riboflavin, niacin, pyridoxine, pantothenic acid, biotin, folic acid, and B12. Ascorbic acid (vitamin C) and calcium are essentially absent in muscles, and because of this, muscles are not considered a perfect food from a nutritional perspective. The nitrogenous, nonprotein extractives include creatine, nucleotides, ammonia, methylamines, free amino acids, and other derivatives of proteins. Two of the components in highest concentrations are carnosine and anserine. Other extractives include volatile organic carbonyls, such as acetyl aldehyde, acetone, carbon dioxide, and formaldehyde, all of which have been found in muscles. Various sulfur compounds include hydrogen sulfide, methylmercaptans, and methyl sulfides.

The elemental components include carbon, hydrogen, and oxygen in great abundance either because of their molecular weight or number of molecules and are listed in Figure 3.3. In addition, nitrogen is abundant because it is a component of all proteins. Some minute quantities of sulfur are present in the form of the amino acids cystine, cysteine, and methionine. Inorganic minerals include calcium, magnesium, sodium, potassium, chlorine, phosphorus, and iron, but their contributions to mass are minimal. In assessing the various elements in the various components of muscles, in most instances—whether proteins, lipids, carbohydrates, vitamins, or nucleic acids—the elements carbon, hydrogen, and oxygen are always present. The unique compositional difference among proteins, nucleic acids, and vitamins is that in proteins, nitrogen molecules are in the side chains; in the other two groups, nitrogen molecules are incorporated into the ring structures. The protein myoglobin is somewhat of an exception in structure in that it contains a heme group as well as a globular protein fraction and contains iron as its central ion in the heme ring. The iron element in myoglobin is paralleled by the cobalt element in vitamin B-12.

### 3.3.4 Modifiers of Muscle Composition

General fatness of the animal influences the composition of muscles. Individual muscle fibers remain constant in their composition, but fresh muscle may vary from 1% to 15% in lipid content. This variation is due to such factors as genetics, stage of growth, sex, and the amount of physical exercise. As animals mature and muscles stop growing, intramuscular fat may accumulate around the vascular system, thus decreasing the relative mass of other components. The nature of the connective tissue matrix also affects the accumulation of fat. Loosely arranged muscles such as the latissimus dorsi, having parallel connective tissue strands, contain more fat than tightly compacted muscles such as the peroneus longus. The latter’s connective tissue strands are thicker and more tightly structured, thus physically preventing excess fat accumulation.
Nutrition affects muscle composition simply by controlling the total lipid accumulation, depending on the total caloric intake and expenditure. In submaintenance diets, fat is mobilized (rather than deposited) from muscles. Quality of nutrition can also affect the mineral and vitamin content of muscles, but not to the extent that fat deposition is affected.

Stage of growth affects the protein/moisture relationship of muscles. In very young animals, this ratio is low (~0.1), whereas at maturity, the relationship is about 0.3. As already indicated, this remains reasonably constant throughout the animal's life and serves as a reliable guide in estimating the composition.

In addition to the structural differences in connective tissue, anatomical location of muscles affects composition because some muscles contain higher concentrations of tendon and epimysial sheaths of connective tissue. Because of this, there is a difference in the quantity of stroma proteins as compared to myofibrillar, sarcoplasmic, and granular proteins. For example, lower limb muscles have higher concentrations of connective tissue proteins than do supportive back muscles. Even though the molecular nature of stroma proteins changes during growth, the absolute quantities do not change. Some muscles such as the gluteus medius and longissimus have proportionately more white fibers requiring less oxygen. Therefore, their energy needs for muscle contraction are more anaerobic than that of muscles containing more red fibers. Consequently myoglobin concentration is lower and this may be true for fat content as well. An exception to this is the trapezius. It contains over 60% red fibers but also contains high amounts of lipid. The semitendinosus contains two clearly defined portions, one having predominantly red fibers and the other predominantly white fibers. As a result, molecular composition within this muscle varies considerably. However, in this example, the white fiber portion contains considerably more lipid than the red fiber portion, suggesting that muscle location and function affect composition more than fiber type per se. Perhaps fiber type affects composition primarily by its effect on postmortem tissue characteristics. The postmortem musculature originating from short-term stressed animals (especially those genetically susceptible to stress) become soft and watery and are much more susceptible to exudation during processing. Therefore, composition is readily affected if processing is considered. Dark, firm, and dry (DFD) muscles that contain high concentrations of red fibers (often the result of long-term ante-mortem stress) are less susceptible to such abnormal postmortem shrinkage.

Disease influences composition. Portions of muscles may be eroded away by muscular dystrophy and replaced with fat. Certain inorganic elements are lost from the tissues during stressful conditions related to disease. Certain central nervous system diseases also affect the general composition of muscle, primarily affecting the fat component. Injury to muscles affects composition. When major nerves are severed (accidentally or experimentally) the muscle atrophies and fat accumulates in the vacated spaces.

Exercise stimulates fiber hypertrophy and mobilization of lipids within muscles. However, there is little evidence suggesting changes in other chemical components.

Genetics affects fatty accumulation in muscles because of its relation to rate of maturity. Certain species of animals, such as the domestic duck, deposit very little fat in muscles. The rabbit has similar tendencies, whereas certain breeds of pigs, cattle, and sheep deposit large quantities of intramuscular fat. Within species, some breeds have greater tendencies to deposit intramuscular fat. Duroc swine appear to contain more intramuscular fat for a given degree of body fatness and age. Hereford and Charolais cattle do not deposit as much intramuscular fat at a given physiological state of maturity as do Angus cattle.

Fat in muscles is related to the total fatness of the body. When carcasses from obese animals are examined, there is generally more intramuscular fat than from those possessing leaner carcasses as compared to total body fat per se (e.g., Japanese Wygwe cattle producing highly marbled Kobe beef), whereas other animals deposit large quantities of subcutaneous fat but deposit very little intramuscular fat.

Muscles grow at different rates and mature at different physiological times. This in itself affects composition. These differences are small, but if a muscle matures earlier and also has the structural potential for accumulating fat, then it will have a higher fat content at a given age than another muscle that matures at a later stage. This variation is also responsible for differences in protein/moisture ratios among muscles.

Control of various body processes by the endocrine system affects fat deposition in muscles. Thus by the presence or absence of testosterone, fat deposition is regulated in muscles. Bulls, rams, and boars possess muscles containing less intramuscular fat than male castrates (steers, wethers, and barrows). When cattle are fed diethylstilbestrol (a synthetically produced hormone that is currently banned from
use), it changes the composition of muscles simply by slowing down the animal’s physiological time clock. The supplementation of certain hormones will increase fat mobilization in muscles; however, most of these changes are small.

3.4 Description and Composition of Fat and Its Modifiers

3.4.1 Description

Fat is often associated with such words as obese, plump, oily, wasty, greasy, big, and thick. Also it has been defined as the excess “white stuff” that is trimmed from a piece of meat, or the grease that lubricates a skillet, or some of the juices that flow out of hamburgers during cooking, or the foodstuff that is responsible for making foods “rich” because of its high caloric content. Fat has probably received more attention from consumers, and has been referred to more often, than any other single biological substance.

Epithelial, nervous, muscular, and connective are the four basic tissues involved in the processes of postnatal growth. Connective tissue’s primary function is structural support: it is responsible for the physical shape of such biological substances as bone, cartilage, muscle, and fat. Adipose tissue is a type of connective tissue that surrounds synthesized lipids, which serve as heat–cold insulators and as reserve supplies of body energy. Therefore, fat is defined as a collection of adipose cells suspended in a matrix of connective tissue distended with cytoplasmic lipids, water, and other constituents.

Often the words fat and lipid are used interchangeably. Generally this is appropriate, but specifically it is an incorrect concept. Adipose or fatty tissue contains lipids, but lipids per se do not contain connective tissue, water, enzymes, and other constituents present in fat. However, because lipids are the major components of fat, it is important to describe these lipids in greater detail. Lipids include that group of nonpolar compounds soluble in organic solvents but insoluble in water. Pure lipids are colorless, odorless, and flavorless and can be classified as follows.

3.4.1.1 Simple Lipids

Simple lipids are esters of fatty acids with certain alcohols such as glycerol. If lipids are solid at room temperature, they are called fats; if liquid, oils. Waxes are simple lipids that are esters of fatty acids with long-chain aliphatic alcohols or with cyclic alcohols. Examples of waxes include esters of cholesterol as well as the vitamins A and D.

3.4.1.2 Compound or Conjugate Lipids

Compound or conjugate lipids are esters of fatty acids that, on hydrolysis, yield such substances as phosphoric acid, amino acids, choline, carbohydrates, and sulfuric acid, in addition to fatty acids and an alcohol. Examples include phospholipids, glycolipids, sulfolipids, and lipoproteins [such as low-density lipoprotein (LDL) found in blood].

3.4.1.3 Derived Lipids

Derived lipids are formed in the hydrolysis of simple or compound lipids. Examples include saturated and unsaturated fatty acids, aliphatic alcohols, sterols, alcohols containing the β-ionone ring, aliphatic hydrocarbons, carotenoids, squalene, and the vitamins D, E, and K. Fat is found in nearly every anatomical location imaginable, but the great majority of it occurs subcutaneously, inter- and intramuscularly, in the mesentery, on the walls of the thoracic, abdominal and pelvic cavities, and in bone marrow (intraskelital). Fat is deposited in the udders of females and in the scrotal sacs of male castrates. Fat is deposited in brain, liver, and kidney, and the quantity may be excessive under abnormal conditions (diseases).

Lipids are found in some form in all body cells because phospholipids contribute to the structure of every cell wall. Blood and lymph contain lipids, the quantity varying greatly with time after an animal consumes a fatty meal. All dietary fats are transported to body tissues via one of these routes. Although
adipose tissue is ubiquitous, it is not evenly and universally distributed in obesity, but is deposited in certain preferential sites while other sites are spared. For example, feet, eyelids, nose, ears, and genitalia seldom accumulate excess fat.

### 3.4.2 Gross and Molecular Composition

Quantitatively, Table 3.3 represents an example of variations in proportionality of fat in different anatomical locations and it is expressed on both a dissectable and an extractable basis. For this example, as the animal matures, the total fat increases when compared to other body tissues, but for the most part the proportionate distribution remains reasonably constant. On an extractable basis, the internal cavity fats (cavity wall and mesentary) represent about one-tenth, intermuscular about one-fifth, intramuscular and intraskeletal about one-fourth, and subcutaneous over one-half of the total lipids deposited, regardless of stage of growth. Even though intramuscular and intraskeletal lipids are not included in the dissectable allocation, the total representation of extractable lipids (as a percentage of empty body weight) are lower than for the dissectable fat values because water is not included when extractable portions are expressed. One must remember that fat contains significant quantities of water. Table 3.2 includes the gross composition of fat and how it compares to that of muscle and bone.

Adipose cells vary in size depending on such factors as age, species, and state of nutrition. The increase in numbers of adipose cells does not necessarily dictate the quantitative amount of fat deposited. For mature pigs, about 45% of the total adipose cells are in intramuscular fat but this fat component represents <15% of the volume of extractable lipid. This is verification that cell hypertrophy contributes more to volume than does cell hyperplasia.

Lipids dominate in their contribution to adipose volume and weight. However, other constituents are also present. In immature tissues, there is a significant quantity of water. Also, because adipose tissue is structurally supported by a connective tissue matrix, the extracellular protein collagen is present. Other substances include enzymes responsible for lipogenesis and lipolysis, traces of certain minerals and minute quantities of glycerol, glucose, and glycogen as well as nervous tissue.

### Table 3.3

<table>
<thead>
<tr>
<th>Stage of Growth (Days of Age)</th>
<th>21–43</th>
<th>64–106</th>
<th>149–213</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dissectable Fat Basis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total fat as % of empty body</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td><strong>Distribution by Location</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity wall (%)</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Mesentary (%)</td>
<td>8</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Intermuscular (%)</td>
<td>29</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Subcutaneous (%)</td>
<td>58</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Sum</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Extractable Lipid Basis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total lipid as % of empty body</td>
<td>7</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td><strong>Distribution by Location</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity wall (%)</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Mesentery (%)</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Intermuscular (%)</td>
<td>18</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Subcutaneous (%)</td>
<td>51</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>Intramuscular (%)</td>
<td>20</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Intraskeletal (%)</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Sum</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Adipose tissue lipids are primarily present as mono-, di-, or triglycerides. Each is composed of a molecule of glycerol bonded to one, two, or three fatty acids. These acids are either synthesized in the adipose cell or are synthesized in the liver and subsequently transported to the adipose cell via the circulatory system. Fatty acids in adipose tissue usually contain 16 or more carbon atoms, but there are a few that are shorter. The carbon chain may be completely saturated with hydrogen atoms, or there may be some double bonds, and these are called unsaturated fatty acids. The dietary origin of the fat dictates the variation expected and the iodine and saponification values reflect such variations. Oleic, palmitic, and stearic acids represent over 80% of the composition of meat animal lipids. However, the primary difference in physical properties of lard as compared to beef tallow is the higher quantity of linoleic acid that is more unsaturated and occurring in higher proportions in lard, giving it a softer structure at room temperature. Also, this higher degree of unsaturation results in a fat more susceptible to oxidative rancidity.

### 3.4.3 Modifiers of Fat Composition

The discussions that follow will parallel some of those already covered in the muscle section and thus will be limited to unique differences pertaining exclusively to fat. When compared with mature animals, young ones contain adipose tissue having considerably more water. Also, the phospholipid component is proportionally higher in young animals as compared with their triglyceride content.

For ruminants, most dietary fats are digested in the rumen where ingested unsaturated fatty acids are hydrogenated and then absorbed into the circulatory system. However, for monogastric animals, ingested unsaturated fatty acids are not hydrogenated and are absorbed and deposited in adipose tissue in their original structures. Therefore, this explains why pork fat is softer than beef tallow. The release of some hormones will stimulate mobilization of fatty acids. If this persists, the triglyceride fraction will be significantly reduced.

Anatomical location of fat is important when determining its composition. The number of intramuscular adipose cells represents nearly half the total adipose cell population of the body, yet the amount of extractable lipid is <10%. These cells are smaller and contain more water than do cells located subcutaneously. Also, within subcutaneous tissue, that portion located at the base of the pelvic limb contains less extractable lipid than the cells located over the back. Furthermore, the three distinct layers of subcutaneous fat over the back of pigs vary in fatty acid composition. The outer layer contains greater proportions of unsaturated fatty acids as compared with the other layers. Mesentary adipose tissue contains more saturated fatty acids than subcutaneous tissue; udder fatty tissues contain more fluid, nonlipid material, and less extractable lipids than other adipose tissues. Finally, certain organs such as the bovine kidney contains 30% oleic acid and 33% stearic acid as compared with bovine subcutaneous fat, which contains 40% oleic acid and <20% stearic acid.

Genetic variables influence the quantity of fat and its composition. Some examples include (a) more hydrogenated fatty acids in ruminants than monogastric species, (b) double-muscled cattle do not deposit fat as quickly as normal cattle, (c) some breeds of sheep accumulate greater quantities of fat over the rump, and (d) pigs contain more subcutaneous and less intermuscular fat than sheep or cattle. Females have the capacity to lactate, which is a unique process of fat accumulation in milk. Intact males of most species contain less fat than castrate males or females of similar chronological ages. Heifers contain more fat than steers at a given age whereas gilts contain less fat than barrows at a similar age. This observation may simply reflect variations in stages of compositional, physiological, and sexual maturity.

Atypical conditions such as obesity and steatosis (excessive fat deposition in muscles) increases the quantity of lipids deposited. Conversely, exercise and various environmental stresses reduce lipid deposition.

### 3.5 Description and Composition of Bone and Its Modifiers

#### 3.5.1 Description

Bone is a complex tissue and subject to continual metabolic activity. A most obvious difference, when compared to muscle and fat, is its dense, hard, mineralized, cellular type tissue. The three cellular
components of bone are of one cell type and may change in morphological characteristics directly according to specific functional needs of the tissue. The cells involved include osteocytes which are responsible for maintenance; osteoplasts, which are involved in formation of new bone; and osteoclasts, which are responsible for mobilization and reabsorption of bone material. Histologically bone is characterized by its branching lacunae, which are cavity-like membranous materials, and by canaliculi, which are fine-structured canals. Bone contains a dense matrix of collagenous fibrous bundles in a ground substance encased with calcium and phosphorus. Bone is capable of structural alterations to accommodate stresses due to mechanical changes and biological demands incurred by pressure and by vascular, nerve, endocrine, and nutritional influences. Most of the rigid material in the skeletons of meat animals is either compact or cancellous bone. This indicates that there are different degrees of mineral density in the bone including available porous spaces which provide for the accumulation and maintenance of the marrow.

Another method of classifying bone is on the basis of bone formation. Some bones develop within mesenchymal tissue such as the skull, which is known as membrane bone. Other bones depend on prior cartilaginous scaffolding, such as the vertebrae, and this is called cartilage bone. This cartilage-type bone contains collagen and polysaccharides.

There are more than 200 individual bones in meat animals, and they are either on the axial skeleton or the appendicular skeletons (limbs). Figure 3.2 includes the major bones and their proportionate masses in the live animal. They all include bone marrow, which produces the majority of the red blood cells. They store minerals and mobilize them as needed for other body tissues. They repair themselves after an injury and are designed to provide the greatest support with a minimum amount of weight; this is why most bones have hollow structures.

3.5.2 Gross and Molecular Composition of Bone and Its Modifiers

Bone basically contains mineral deposited in an organic matrix. The matrix includes not only calcium, phosphorus, and carbonate, but also citrate, water, and small amounts of sodium, magnesium, potassium, fluorine, and chlorine. The crystals of bone mineral have a chemical composition similar to that of fluorapatite. Fibers of collagen run throughout the matrix. The remaining space in the bone “mortar” is filled with a semiliquid substance that exchanges materials to and from the bone mineral via the circulating blood.

More than 99% of the body calcium is in bones. Collagen is about 93% of the total organic portion of bone. There are small amounts of insoluble sclera proteins and ground substance that are composed of mucopolysaccharides and mucoproteins. In fat-free analyzed bone, the mineral content accounts for about two-thirds of the mass, whereas in fresh bone it is about two-fifths. As included in Table 3.2, water represents about one-fourth the mass, protein about one-tenth, and the remaining one-fifth portion (which is the most variable) is lipid. As indicated, type of bone, age of the animal, and species are three factors that most affect bone composition.

Bone ash is composed mostly of calcium and phosphorus and much lesser quantities of magnesium, sodium, potassium, chlorine, and fluorine. When comparing bone to fat and muscle as shown in Table 3.2, the average composition is considerably different. If bone is compared to the Achilles tendon (almost entirely connective tissue), the tendon consists of two-thirds water and one-third organic solids with very little inorganic material. This compositional profile is quite similar to muscle. For the ligamentum nuchae, which is slightly more similar to bone, water content is about 57% and organic solids make up most of the remainder, but the elastin content is considerably higher than that for tendon.

The factors modifying the composition of bone are quite similar to that of muscle and fat and will not be repeated here. As illustrated in Table 3.4, age, species, and type of bone are three major modifiers of bone composition. Other unique factors modifying bone composition are (a) absence of vitamins D and A from the diet, (b) abnormalities in endocrine secretions (both low and high quantities), (c) lack of mineral supplementation in the diet (especially calcium and phosphorus), and (d) wasting-type diseases that mobilize mineral content from the bone, creating brittle and friable structures that have been significantly altered in composition.
3.6 The Composition–Quality Paradox of Meat

When evaluating meat, both composition and quality are important. Leanness (as contrasted to fatness) is virtuous, but by itself, it fails to meet ultimate expectations of consumers. The nutrient density of muscle is higher in lean meat and nutritive value is a part of quality. Therefore, from this perspective, composition affects quality. However, quality is more than just nutrient density. Wholesomeness, appearance, water-holding capacity, and palatability are quality virtues too! Marbling contributes to juiciness and flavor, however, more marbling reduces nutrient density. Furthermore, the exterior fat covering of fresh meat cuts is related to marbling. The association is not strong, but fatter cuts usually exhibit muscles containing more marbling. The paradox is that meat animals are fed to heavier weights, for longer times, and to ultimately less favorable “feed-to-meat” ratios so that muscles will contain more marbling to ultimately satisfy the consumer demands. This negative relationship between marbling and leanness is difficult to compromise and is one of the reasons why beef and lamb cuts may be too fat.

In pork and turkey, trim and heavily muscled carcasses appear to be more susceptible to the pale, soft, and exudative (PSE) condition. Meat cuts from such carcasses possess lean, heavily muscled cuts containing minimum quantities of fat. Nevertheless, the muscles often shrink excessively during processing. Fresh cuts of pork (loin and ham) and turkey (breast) that are exceptionally lean may be pale in color, soft in texture, and watery, all of which detract from appearance and ultimately their acceptance by consumers.

Therefore, quality of all meat products must be considered along with composition when assessing the overall value. The conflict between composition and quality continues to challenge scientists to discover new genetic combinations, different feeding and management programs, and more satisfactory postmortem processing technologies to ensure an ideal meat product that meets consumer demands.

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providing financial assistance, support, and encouragement. Finally, the reader is encouraged to carefully reexamine Figures 3.2 and 3.3. They summarize this chapter and serve as foundations for those that follow!

REFERENCES


