In Vivo and In Vitro Measurements of Composition — AMSA Composition Committee

H. Russell Cross*

Introduction

Measurement of animal and carcass composition is critical to all segments of the meat animal industry. However, compositional endpoints utilized are not consistent within the field of animal science. Animal nutritionists and geneticists report whole body or carcass chemical composition endpoints to discern relative efficiencies when evaluating treatment effects. Physical separable compositional components when utilized as endpoints are directly or indirectly related to the marketable product from a meat animal and provide evidence of treatment differences on an economic level rather than a biological level. Literature definition of physical separable components have varied in the literature. Berg and Butterfield (1968), Butterfield (1965) and Seebeck and Tulloh (1968) defined physically separable fat, lean, and bone as compositional endpoints, whereas Murphey et al. (1960) developed boneless, closely trimmed retail cuts from the round, loin, rib, and chuck as a tool in economically evaluating differences in composition of beef carcasses. Kauffman et al. (1975) and Kauffman et al. (1976) argue for the use of physically separable lean on a lipid-free basis as a valuable composition endpoint.

Scientists throughout the world utilize various methods of defining and measuring composition. This diversity makes the straight forward comparison of results between experiments very difficult. Efforts to standardize methods in Europe were initiated in the 1950's by the European Association of Animal Production (EAAP) which collected information on pig progeny testing and carcass evaluation in European countries (FAO, 1958). Efforts are now being made in Europe to standardize beef carcass evaluation methods and to increase the awareness of techniques used in different countries. A recommended standard EEC method for beef anatomical fabrication, tissue separation, and weight recording has been published (Williams and Bergstrom, 1976). In the U.S. the American Meat Science Association (AMSA, 1967) developed recommended procedures for carcass evaluation. Even with these attempts, carcass composition techniques both across and within animal science disciplines remain quite diverse.

*H. R. Cross, USDA, ARS, Roman L. Hruska U.S. Meat Animal Research Center, P.O. Box 166, Clay Center, NE 68933

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In the spring of 1981, the American Meat Science Association formed a committee to investigate the various techniques used to measure composition and hopefully to develop guidelines for use by animal and meat scientists throughout the world. This document represents the preliminary thoughts of that committee.

General Considerations

What was initially considered to be a routine task by some has proven to be just the opposite. It soon became obvious to the committee that their task would not be quickly and easily accomplished. In fact, many committee members felt that additional research and comparisons would be necessary before the guidelines would be complete. It was decided that the guidelines should be developed based on currently available information with recommendations for future research needs. The committee also concluded that no single compositional definition (endpoint) will satisfy different experimental requirements. The guidelines must remain adaptable to available resources, for if flexibility of experimentation is removed, research requiring compositional information may be impeded. To accomplish their task, the committee divided the preliminary draft of the guidelines into the following outline:

- Introduction
- Recommended Endpoints
- Methods of Reaching Endpoints
  - Direct
  - Indirect
- In Vivo Measurements of Composition
- Conclusions and Recommendations

Recommended Endpoints

Carcass evaluation work is usually conducted with an economic objective in mind. Carcass leanness or saleable meat yield is considered by many to be the most important single economic endpoint. The question becomes a matter of how to define this endpoint. A base-line or standard reference endpoint must be established. This reference is the "ideal endpoint" which would be used if cost, time, labor, and facilities were not a factor. When we estimate composition from measurements, indicator cuts, etc. we are trying to approximate this endpoint. If costs are not a factor, the most comprehensive endpoint is to apply tissue dissection followed by chemical analysis of the resulting tissues. Less detailed techniques such as saleable product, whole body chemical and indicator cuts should be considered as predictors rather than "ideal" or "reference" techniques.

The recommended endpoints are listed in Table 1. As has been mentioned, there is no single endpoint which will satisfy different experimental approaches which together constitute a multidisciplinary meat science. The term "endpoint" is defined as the aspect of composition which is of paramount importance in the context of particular experimental objectives. The aims of the particular project will determine which endpoint we choose. If considerations of energetic efficiency or nutritional inputs are important, then whole body chemical composition should be considered. If profitability in commercial beef operations is the goal, then saleable product may be the endpoint of choice. For growth studies, the physical dissection and chemical analysis endpoint should be considered.

Whole body chemical composition. Whole body analysis has the advantage that maximum information can be obtained regarding chemical constituents in the body. Its disadvantages include: high cost, tediousness, time consumption, inference from small samples, lack of differentiation between various tissues or between edible and more valuable parts, and decrease in product value. With a knowledge of whole body or carcass chemical composition one does not have an estimate of the edible parts of the carcass.

Physical carcass dissection. Physical dissection of all of the major tissues is one of the most comprehensive endpoints. If accompanied by chemical analysis of the various tissues it could be considered the "ideal endpoint." Physical dissection

Table 1. Recommended Endpoints

Endpoint	*Required Techniques*	*Applications*	*Advantages*	*Disadvantages*	*Facilities*	*Relative cost 100 = maximum*
Whole body chemical composition (also empty)	1. Dissection 2. Grinding 3. Mixing 4. Proximate analysis	1. Feeding trials and specific energy balance studies 2. Detailed growth studies that include feed intake and development of all tissues 3. Reproductive studies that require the analysis of all body parts and the efficiencies they represent	1. Obtain maximum information regarding chemical constituents of the body	1. Time consuming 2. Costly 3. Product loss 4. Does not differentiate between body tissues 5. Sampling problems	1. Slaughter and dissection rooms 2. Accurate scales 3. Grinders and mixers	100 (bone and lean together) 60 (soft tissue ground separately)
Physical carcass dissection	1. Dissection of fat, lean, and bone 2. Weighing	1. Growth and nutritional studies when it is important to determine the extent to which specific nutrients are retained in the carcass 2. Studies involving the control of growth and distribution of various tissues	1. Accounts for differences in distribution of various gross carcass tissues	1. Time consuming 2. Costly 3. Requires skilled labor 4. Subject to larger errors 5. Does not account for variations in intramuscular fat 6. Product devaluation	1. Slaughter and dissection rooms 2. Accurate scales 3. Skilled labor	75
Fat-constant muscle mass	1. Dissection 2. Grinding 3. Mixing 4. Proximate analysis	1. Growth and nutrition related studies	1. Gives value of all carcass tissues	1. Costly 2. Time consuming 3. Requires skilled labor 4. Product devaluation 5. Sampling problems	1. Slaughter and dissection rooms 2. Accurate scales 3. Skilled labor 4. Grinders and mixers	90
Saleable product	1. Boning 2. Trimming	1. Practical cutting tests at marketplace 2. Relates to industry value	1. Rapid to obtain 2. Less costly 3. Does not devalue carcass 4. Does not assume proportionality is constant for all carcasses	1. Difficult to standardize trim 2. Ignores intramuscular and skeletal fat variation 3. Not indicative of muscle/bone if bone not removed	1. Cutting room 2. Cutting equipment 3. Skilled labor	35

yields a better understanding of the composition and distribution of the various tissues in the carcass. This technique is particularly useful in growth and nutritional studies if it is important to determine the extent to which specific nutrients are retained. The disadvantages of the total dissection technique are that it is costly (labor, facilities, product devaluation), time consuming, and requires skilled labor. Without the care and precision of skilled labor, the error could be considerable. Physical dissection by itself will not account for variations in intramuscular fat.

Fat-free muscle mass. A variation to complete physical dissection would be to separate the soft tissues from the bones, followed by a separation of the muscle and fat tissues, with the fat content of the muscle mass then determined chemically to allow calculation of the fat-free muscle mass. This particular endpoint is likely the closest to the "ideal" endpoint since it accounts for all of the lipid and muscle tissues in their respective locations. This endpoint is also costly, time consuming, and requires skilled labor.

Saleable product. Meat is produced for its edible portion. This must be kept in mind. One could argue that the best indicator of carcass value is the amount of edible product from the carcass. The concept is sound but the problem becomes one of definition. The cutting and trimming methods differ widely throughout the U.S. and even more so throughout the world. The amount of fat remaining on the retail cut is one of the major sources of variation. Bone-in versus boneless retail cuts also present a problem. The following quote from Harrington (1971) clearly identifies the problem: "If one type of animal is generally used in one type of trade, and a second in another it might be quite unfair to compare them by a standard cutting test which reduces cuts as far as possible to a constant level of fatness; conversely, it would be unfair to compare two types by cutting tests appropriate to different trades without suitable qualification. This must be borne in mind when considering the use of cutting tests to demonstrate breed differences in yields of saleable meat; certainly these are needed, provided they are truly comparative, but they can only be evaluated fully if supported by complete separation data to reveal what saleable meat is considered to be."

In contrast, Preston and Willis (1970) stated that "the supermarket does not advertise longissimus dorsi or biceps femoris, nor is it ever likely to." In response, Berg and Butterfield (1976) proposed muscle mass as the logical target for the meat industry. These authors stated that "muscle is predictive of the edible product no matter what particular consumers desire or what proportions of fat or bone are acceptable in the consumer's product." It provides a reliable standard for comparison from one geographic region to another and over time. Berg and Butterfield (1976) indicated that the use of saleable product as the endpoint has led scientists to erroneous conclusions regarding distribution of primal cuts in the carcass across breeds. This was challenged in a recent text by Kempster et al. (1982). These authors feel that commercial cutting techniques may in fact be the best endpoint in a particular situation if this endpoint is supported by some base-line tissue separation. Their data indicated that the same decisions or rankings would have been made across breeds using either endpoint.

The committee has addressed this particular endpoint (saleable product) in detail and feels that under certain conditions and experimental objectives it can be effectively used. It's relatively easy to obtain, usually does not devalue the carcass and can provide useful information to the industry. It is difficult to standardize and does not provide information about intramuscular and skeletal fat variations.

Methods of Reaching Endpoints

For discussion purposes, one can attempt to obtain information regarding a particular endpoint by using either "direct" or "indirect" approaches. Much of the discussion regarding endpoints (Table 1) have assumed that direct approaches would be preferred. As previously discussed, the direct approach to obtain the endpoints listed in Table 1 are costly and time consuming. Scientists are continually searching for means to predict these endpoints through means which are less costly, easier to complete, and are nondestructive to the carcass. These indirect methods range from simple carcass measurements to the more complex physical dissection of indicator cuts.

Indirect Methods for Measuring Carcass Composition

Prediction Equations. There have been numerous studies to examine the value of different live animal and carcass characteristics for predicting composition. Most of the early research was conducted on a small scale, using data collected as part of feeding and breeding studies. Sample populations were seldom ideal for examining the suitability of predictors for a range of practical applications and, usually, only a single measuring technique was examined, making it difficult or impossible to compare its precision or accuracy to other techniques. MacNeil (1983) presents an indepth evaluation on the selection and use of prediction equations for particular experimental objectives. In addition, Hedrick (1983) has recently reviewed the literature relative to the vast number of prediction equations available for estimation of body composition. Thus, it is not necessary to dwell on this subject in any detail. However, a few general comments are appropriate.

Scientists are often guilty of misusing prediction equations and misinterpreting the relative accuracy between different equations. An understanding of statistical principles is important for the interpretation of carcass evaluation results and for the comparison of various predictors. The correlation coefficient is influenced by the range of values in the sample on which it is based assuming both x and y are both random samples. The dangers of relying on the correlation coefficients can be shown by the example in Table 2. The correlation coefficient is higher in group I than in group II indicating that the prediction equation from group I is perhaps the more accurate. In group II, however, there is less variation in carcass lean percentage and hence a low correlation. There would be no more error in the prediction of carcass lean percentage in group II since the residual standard deviations are equal. The residual standard deviation (RSD) is a better criterion since it takes into account the variation in y.

Instruments destined for measuring a particular trait are often compared with the correlation coefficient. The sample is often drawn from quite variable populations to provide a high

Table 2. Comparison of Predictive Accuracy Between Two Groups of Pigs

Trait	Group I	Group II
Backfat thickness, cm (x), standard deviation	5.10	2.99
Percentage lean, % (y), standard deviation	4.10	2.29
r^2	.75	.21
Residual s.d., %	2.05	2.05

Adapted from Kempster et al. (1982)

correlation. If one instrument is compared to another, it should be conducted using the same sample of carcasses. The correlation of predicted and actual is not useful for the comparison of two pieces of equipment if each piece of equipment is tested on a different sample of carcasses.

Indicator cuts. There is a limit to the level of precision that can be obtained with simple measurements. To go beyond this point, indicator cut dissections will be required. Indicator cuts can be wholesale, primal or retail cuts, or specific anatomical locations. The principle is that a specific cut is dissected and the weights of the tissues used to estimate carcass composition. The precision or accuracy achieved with different cuts or carcass parts may be somewhat dependent on the species. Kempster et al. (1982) present an excellent overview with considerable detail for cattle, sheep, and pigs. There will not be a single cut which would be suitable for all purposes. The relative costs of specific cuts will vary from location to location and to choose a particular cut because scientists elsewhere find it suitable for their purposes may not be a wise decision. One should determine the cost of removal and dissection of different cuts in the study and then choose the one that offers the best compromise between precision and cost.

Hopper (1944) first suggested the beef rib cut as an indicator cut. Hankins and Howe (1946) subsequently developed a prediction equation to predict the whole carcass composition from the 9-10-11 rib section. The rib has been extensively used because of its easy accessibility but it has shortcomings. The amount of bone in the rib is subject to splitting errors. The lean to fat and lean to bone and fat to bone relationships are subject to error because of variations in trimming during the removal of the hide. Larger cuts have been successfully used as predictors such as the trimmed round. Butterfield (1962) suggested the shin as a possible predictor of carcass composition. The shin is a cheap region of the carcass and its removal does not devalue the carcass but its precision as a predictor is not as high as other indicator cuts.

Specific Gravity. According to Richards (1967), considerable variation has been found in the relative densities of the body tissues. These differences have led to extensive studies in the application of specific gravity as an indicator of carcass composition. The method is based on the principle that a body immersed in water displaces a volume equal to its own. Thus by weighing in air and weighing in water, carcass density can be determined. Fat has a density of about 0.90 and muscle about 1.10. A 0.002 change in density is equal to a 1.0 percent change in carcass fatness.

The advantages to specific gravity are that it is simple and easy to determine on carcasses and carcass parts and it is nondestructive. Although the correlations from the literature between specific gravity and chemical fat are quite high, Kirton and Barton (1958) have shown that the specific gravity method is not sufficiently accurate for individual carcass determinations, particularly at the lower levels of fatness. The standard errors of estimate of fat were over 3.0 percent, for water over 2.5 percent and for protein over 0.6 percent. This is in agreement with the report of Timon and Bichard (1965) in which it was stated that "prediction errors are quite large and emphasize that specific gravity cannot be relied on to reflect real differences in carcass composition between individuals or groups of individuals where these differences are small." However, a number of workers are confident that specific gravity, in combination with other measurements, can provide a reliable estimate of carcass composition (Munson, 1966 and Cordray et al., 1978). Undoubtedly, this technique will segregate carcasses that are quite variable in composition.

The specific gravity technique is also subject to several procedural errors which can have significant effects on the results. The errors are more apt to occur when dealing with large carcasses or carcass parts. Factors which can influence the result include: air pockets, movement, water temperature and precision of the weighing device.

When choosing prediction methods, the following should be considered:

1. If possible, develop prediction equations on a similar population to that in which they are to be applied.
2. Validate the prediction equations on an independent sample of carcasses.
3. Establish a balance between the numbers of animals subjected to complete side dissection (or whatever the base-line reference might be) and the numbers on which only the predicting measurements are taken so that they are cost effective, as well as, statistically valid.
4. When full dissection is impossible, use prediction equations which have proven to be the most reliable and significant for the type of comparisons concerned.

In Vivo (Live) Measurements in Predicting Carcass Composition

Attempts to estimate carcass composition from live animal predictors have met with limited success. Prediction of body composition using live animal measurements is necessary in various circumstances ranging from producers selecting breeding stock to scientists monitoring changes in body composition during growth. The precision achieved with the best equipment has been little better than that obtained by simple fat and muscle measurements.

Time and space do not permit a detailed discussion of the vast amount of research conducted in this area. Table 3 briefly lists most of the approaches that have been investigated over the years. In addition, we have attempted to rate each technique as to its potential as a research tool or as an industry classification tool. This subjective evaluation was based on our evaluation of the literature. Some techniques are more suitable as research tools since speed and market conditions

Table 3. In Vivo Approaches to Measuring Composition

Technique	Value as a predictor of carcass composition[a] Research	Classification
Live weight	5	6
Body dimensions	2	3
Visual assessment	5	6
Ultrasound	7	4
Backfat probes	7	5
Dilution techniques	4	1
K^{40}	6	2
EMME	2	2
X-ray techniques	6	5
NMR imaging	5	4
Physiological predictors	?	?

10 = excellent potential; 5 = slight potential;
1 = poor potential
[a]Subjective classifications based on author's evaluation of literature.

are not considered as would be the case in a grading situation. Simple measurements such as live weight, visual assessment, and back fat probes offer as much potential as some of the more expensive techniques such as EMME and K^{40}. Other approaches such as NMR, x-ray, and physiological predictors have potential, but too little is known and much more work is needed in this area. Eventually, traditional visual appraisal of animals and carcasses will be replaced by more objective methods of evaluation.

Conclusions and Recommendations

We have attempted to identify a select group of composition endpoints that can accurately define composition. The ultimate selection of an endpoint will depend on many factors including experimental objectives, cost, time, etc. The identification of these endpoints only partially fulfills the committee's objectives. There are several questions that remain unanswered:

a. Our understanding of interrelationships between many endpoints is poor, particularly between physical dissection and chemical composition.
b. Standardization of indirect methods to estimate composition has not been accomplished.
c. Further research on instrumental or objective techniques to accurately measure composition in the live animal and carcass is surely needed.

It is obvious that additional research will be required before our final objectives are reached. Perhaps this initial document will stimulate research in this area.

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