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MEASUREMENT OF BODY COMPOSITION IN FARM ANIMALS: RESEARCH AND PRACTICAL APPLICATIONS

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Summary

Body composition of animals depends on their genotype, sex, age, nutritional history, health and the climatic environment; their fat content increases until maturity when animals of the same species are generally similar in composition.

In recent years, the meat industries of the world have demanded leaner meat and this has lead to genetic selection for leaner animals at particular live weights. In Australia, condition scoring has been satisfactory for assessing body composition both for breeding and management practices although ultrasonic scanning is now being used in some selection programs. In experimental work accurate, objective methods are required for predicting body composition. The paper discusses specific gravity, ultrasonics, dilution techniques and the more sophisticated equipment used for medical diagnoses (CAT scanning, nuclear magnetic resonance, neutron activation analysis and electrical conductivity).

The meat industries of the world are now moving towards a situation where all participants will demand specification of meat quality. Therefore, it is essential to develop field equipment to do this. New techniques, based on electrical conductivity, the velocity of ultrasound or imaging technology, are likely to be available for this work within the next few years.

I. INTRODUCTION

Body composition in farm animals, as in other species, depends upon genotype, sex, age and nutritional history (Webster 1986). Fat-free composition tends to stabilize at maturity (Moulton 1923), so that fat content is the greatest variable influencing composition. Fat content increases with age until, at maturity, animals of the same species are similar in composition (in fact maturity is sometimes defined as the age/weight at which an animal achieves a given fat content). It follows that, at the same live weight, larger breeds of cattle (e.g. Charolais) are leaner than smaller cattle (e.g. Herefords) because the larger cattle have reached a smaller proportion of their mature size than the smaller breeds. Males are leaner than females and, with the exception of pigs, castrate males are intermediate in fat content. In pigs, barrows are fatter than females at the same live weight. Comparisons (of body composition) between animals can be made at the same live weight (where differences in stage of maturity will be apparent) or at the same stage of maturity (where differences in composition largely disappear).

Nutritional history can influence normal patterns of body compositional changes.. On a given diet, animals on high intakes and growth rates tend to be fatter than similar animals on lower intakes and, therefore, growing more slowly. This results from the deposition (into fat) of energy in excess of the animal's requirements for maintenance and lean growth. Since lean growth requires a supply of dietary protein, at a given intake a higher protein: energy ratio (P:E) produces leaner animals than a lower P:E. Other environmental factors also affect composition. Examples include the climatic environment (which influences energy utilization), and parasite infestation (which can selectively deplete body protein).

In practice, there are several situations in which estimates of body composition in farm animals are useful. In recent years, the various meat processing industries have responded to consumer demand for lean meat by implementing procedures for assessing carcass fatness and for penalizing suppliers of over-fat animals. This trend has resulted in pressure on producers to

a) develop or obtain genetically leaner animals, and

b) manage stock (i.e. through nutritional or other manipulation) to optimize fat content at slaughter.

Pedigree breeders, in turn, have been required to select for leaner animals. In fact, all producers in the animal industries (e.g. meat, milk and wool) also need to estimate body condition (i.e. composition) throughout the year to determine optimal management procedures (e.g. mating) and feeding strategies (e.g. supplementation).

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From the research side, experimental designs often involve changes in body size and composition which must be quantified and interpreted. For example, determination of the efficiency of use of a particular dietary component for, e.g. milk production, would require quantification of intake, production and mobilization (or storage) of body components.

Criteria for adequacy of a given technique for estimation of body composition will depend upon its intended application. Farm-based methods are not required to possess the same level of accuracy and precision as experimental techniques. These differences are accompanied by differences in cost, simplicity and ease of use. Finally, the basis for comparison may vary: nutrition experiments generally require information regarding changes in chemical composition (i.e. water, fat, protein and ash determined by chemical analysis), whilst the meat industry is more interested in lean meat yield (e.g. weight of saleable cuts determined by dissection). Whilst meat yield is positively related to carcass protein and negatively related to carcass fat, these relationships are not absolute. In this contribution, both methods are referred to and identified where necessary.

This paper will concentrate on methods used to estimate body composition in cattle, sheep, goats and pigs. Depending upon the intended application, a given technique may be used primarily for estimating the composition of the whole body, the carcass or both. Methods for indirect estimation of body or carcass composition must be applied via some prediction equation. This is usually obtained by least-squares regression (linear, nonlinear, or multiple) of measured body components against the estimator(s). It is generally agreed that the coefficient of determination (R^2) is not an ideal indicator of the ability of an independent variable to predict the dependent variable, since the range of values used will influence the R^2. Instead, the degree of reduction in the residual standard deviation (RSD) of the dependent variable due to inclusion of the independent variable in the prediction equation is preferred (Kempster et al. 1982). This paper discusses most commonly used techniques for estimation of body composition of farm animals, ranging from simple to very sophisticated methods, with some mention of how these methods can be or have been applied. Several publications contain summaries of progress in this field at certain points in time; some major contributions, not cited in the paper, are included in the reference list.

II. SUBJECTIVE ASSESSMENT

Visual assessment remains the most commonly used method, particularly with regard to sale or management of animals in the rural community. Experienced stockmen and livestock buyers combine knowledge of normal changes in shape during growth with information on seasonal variables to visually assess animals' condition. The value of visual assessment of weight-for-age has been confused by cross-breeding of large European breeds of cattle with smaller British breeds; similar difficulties arise with crossbred sheep. The problem arises because insufficient information is available about growth patterns of the great variety of crossbreds which now exist. This problem can be surmounted by the use of 'condition scores' which are really an index of fatness. Scores are obtained by visual appraisal and palpation of subcutaneous (SC) fat depots along the back. They usually cover a 5 point range from 1 (very poor) to 5 (grossly overfat) and can be related to actual carcass fat contents. As with visual assessments, condition scoring depends upon the experience and training of the assessor.

III. OBJECTIVE MEASURES

Simple objective measurements of body condition include live weight and various linear measures. Live weight is the best single objective measurement for estimating body composition, particularly in growing animals. Due to its low cost and almost universal availability, live weight should be included in any system to predict body composition. In fact, other techniques may be seen as additional to live weight; that is, to distinguish between animals of similar live weight. Linear (surface) measurements require simple equipment (tapes, rulers and calipers) but have not generally been useful in predicting composition. An exception is the measurement of anal skinfold thickness (with calipers) to estimate carcass fatness (Charles 1974).

(a) Specific gravity

The density or, more appropriately, specific gravity of fat (adipose tissue) is less than that of lean tissues (0.912 vs 1.100), which is the basis of this technique. By assuming a two-pool body (i.e. lean and fat, with their respectively densities), body fatness can be estimated from its weights in air and water. This method has the advantages of non-destructiveness and simplicity and was used extensively in the development of the NRC feeding standards in the USA. Garrett (1969) acknowledged that the low precision of the method precluded its use for anything other than estimation of carcass energy contents on a group basis.

(b) Ultrasonic techniques

Simple ultrasound (US) devices are available to measure subcutaneous fat depths, based on reflection of US from tissue-tissue interfaces. Basic models display the echo amplitude against time (i.e. distance); these are referred to as A-mode displays. The ability of these devices to predict body or carcass fatness depends on the contribution of SC fat to total fat, the relationship between the fat depth at the scanned site to total fat and, on dressed carcasses, the degree of fat loss during hide removal. Not incidentally, current methods of objective assessment of carcasses all rely upon fat thickness as a benchmark. US techniques can extended by the use of US imaging devices which enable assessment of muscle depths or areas as well as fat depths. Early models relied upon multiple scans over a specified area (i.e. the Scanogram), whilst more modern equipment uses mutliple transducers to produce a 'real-time' image. Earlier trials of the Scanogram with cattle in Australia indicated that high errors in measurement of muscle area limited the usefulness of the method (Tulloh et al. 1973). Recently, however the Australian Beef Improvement Association has adopted US scanning as a selection tool. Real-time US measurements are also being used in selection of leaner pigs, although this is primarily on the basis of improved estimates of SC fat. As shown in Table 1, loin muscle areas (determined in vivo by real-time US or on the

Table 1. Prediction of carcass composition from pre- and post-slaughter measurements in pigs[1]

	Carcass fat (kg)				Carcass protein (kg)			
Predictor(s)	N	Mean	RSD[2]	% RSD	N	Mean	RSD	%RSD
Actual	31	16.2	3.725	23.0	30	11.8	1.264	10.75
Pre-slaughter								
Body wt (kg)			3.455	21.3			0.882	7.50
Fat depth P_2 (US)[3]			2.987	18.4			1.277	10.86
Loin muscle depth (US)			3.600	22.2			1.082	9.20
" " area (US)[4]			3.975	24.5			1.086	9.23
Body wt + P_2			2.790	17.2*			0.822	6.99*
Post-slaughter								
Carcass wt (kg)			3.381	20.9			0.879	7.47
Fat depth P_2 (optical probe)			3.681	16.5			1.203	10.23
" " over rump (at midline)			2.178	13.4			1.248	10.61
" " P_1 (cut loin, calipers)			2.327	14.4			1.258	10.70
Carcass length (mm)			3.734	23.0			1.024	8.71
Loin muscle width A (mm)			3.587	22.1			1.046	8.89
" " depth B "			3.785	23.4			1.129	9.60
" " area (mm^2)			3.654	22.5			1.035	8.80
Carcass wt + P_2			2.397	14.8			0.622	5.29
" " + rump fat + P1			1.754	10.8*			0.677	5.76
" " + P + carcass length			2.298	14.2			0.585	4.97*

[1] Large White cross males and females (91.4 ± 8.3 kg live weight).
[2] RSD, residual standard deviation (standard deviations for actual means).
[3] Subcutaneous fat depth (P2) and loin muscle depth measured at the last rib 65 mm from the mid-line using a Meritronics A-mode US probe.
[4] Loin muscle area measured at the P2 site using a Toshiba real-time US scanner.
* Best combination of predictors

cut loin) did not improve the prediction of carcass protein (Sainz, R.D., Ferlazzo, J. and Harris, J., unpublished observations). This probably reflects the greater contribution of hindleg muscles to variations in carcass protein in pigs as compared to ruminants. In that study, the best predictors of carcass composition were live weight and P2 fat thickness (pre-slaughter), and carcass weight, rump fat and P^2 (post-slaughter).

A recent application of ultrasound technology in estimation of animal and carcass composition departs from traditional measurement of fat and muscle dimensions. Since bone, muscle and fat differ in density, the velocity at which US travels through the body can be used to estimate tissue proportions. The velocity-of-ultrasound (VOS) technique is undergoing extensive development at the Meat Research Institute in Bristol (Wood 1989).

(c) Dilution techniques

Dilution techniques aim to estimate the volume of body water and rely upon the constancy of the fat-free body composition. These methods involve introduction of a tracer into the body water compartment, allowing time for mixing and distribution, then sampling to determine tracer concentration (and therefore dilution). Assumptions include: rapid and free distribution of tracer into all body water compartments; no loss of tracer prior to equilibration; sampled compartment represents all body water pools. Ruminants present special problems because of large variations in water transfer into and out of the digestive tract. This problem has sometimes been addressed by the use of multi-compartment models of water distribution (Shields et al. 1983; Dunshea et al. 1986), which define kinetically similar but not necessarily physiological pools. Protocols involving a single sample being taken several hours after injection of tracer ignore these complications. Tracers which have been used include heavy water (TOH and D_2O), antipyrene and urea. Of these, heavy water would seem to conform to the assumptions above; TOH is easily measured, but D_2O has the advantage of being non-radioactive. Antipyrene and urea are probably not accurate enough to distinguish between animals of the same live weight. the use of allometric equations rather than the usual linear models, and the inclusion of a 'maturity coefficient' may improve predictions (Donnelly and Freer 1974).

A comparison of dilution-based water space and US fat thickness to predict composition of sheep within a narrow live weight range is presented in Table 2 (Sainz, R.D. and Wolff, J.E., unpublished observations. TOH space was determined over four days following injection (Brown

Table 2. comparison of live weight[1], subcutaneous fat depth[2]. and TOH space[3] to predict body composition in sheep

Predictor(s)	N	Body fat (kg) Mean	RSD[4]	%RSD	N	Body protein (kg) Mean	RSD	%RSD
Actual	14	7.16	1.138	15.89	14	5.90	0.475	8.05
Body wt (kg)			1.031	14.40			0.167	2.83
TOH space (kg)			1.154	16.12			0.284	4.81
Fat depth C (US)			0.760	10.61*			0.492	8.34
Wt + TOH space			1.013	14.15			0.167	2.83
Wt + C			0.760	10.61*			0.141	2.39*
Wt + C + TOH space			0.794	11.09			0.147	2.49

[1] 14-month old Romney wethers (40.5 + 3.6 kg live weight)
[2] Subcutaneous fat depth measured at the C site using a Toshiba real-time ultrasound scanner.
[3] TOH space determined from the zero-time intercept of TOH specific radioactivity during four days following injection of tracer.
[4] RSD, residual standard deviation (standard deviations for actual means).
* Best combination of predictors.

and Taylor 1986). When combined with live weight, TOH space did not improve the prediction of body components, but inclusion of SC fat thickness reduced RSD for body fat from 14.4 to 10.6%, and for body protein from 2.83 to 2.39%. Nevertheless, dilution techniques have been and are widely used to predict body composition in growing sheep (Searle 1970; Searle et al. 1972), cattle (Rule et al. 1986), and pigs (Houseman and Mcdonald 1976; Ferrell and Cornelius 1984); in lactating sheep (Foot et al. 1979; Cowan et al. 1979), cattle (Trigg and Topps 1981; Brown et al. 1989), pigs (Shields and Mahan 1983) and goats (Brown and Taylor 1986). These contributions are included as examples only to which interested readers are referred. Clearly, dilution techniques have the potential to improve experimental estimates of body composition but have limited applicability under field conditions.

(d) Techniques requiring sophisticated instrumentation

Several techniques have been developed which, with the aid of sophisticated instrumentation, enable accurate determination of body components (both chemical and anatomical). These are generally very expensive and their application is strictly limited to research purposes. An early technique required whole-body counting of ^{40}K (a naturally-occurring isotope of potassium, distributed in cellular fluids therefore related to lean mass). This approach has generally been abandoned in favour of less demanding methods. As technology improves and becomes less expensive, these methods, often developed for medical purposes, should find wider application. These methods include:

(i) CAT Scanning (X-Ray) An X-ray tube rotates around the (stationary) subject; images are captured by a computer which combines them to produce a cross-sectional image of the animal. Serial cross-sections enable a picture of the whole body to be built up and an estimate of body components to be made using image analysis and integration techniques. Instrumentation is expensive and the animal must be anaesthetized or dead.

(ii) Nuclear magnetic resonance Within a strong magnetic field, pulsed radio waves cause protons to resonate with measurable relaxation times. Protons in muscle, fat and bone resonate with distinctive relaxation times. As with CAT scans, cross-sectional images are produced, with similar analytical requirements. This technology remains beyond the reach of most agricultural research facilities; a notable exception is the Institut fur Tierzucht und Tiervehalten in Mariensee, Germany (see Kallweit et al. 1989).

(iii) Neutron activation analysis Irradiation with neutrons induces transient radioactivity in stable elements. Activation followed by whole-body counting enables estimation of major body elements (e.g. C, N, O, H), from which body fat, water, protein and minerals can be calculated. This technique has found use in medicine and basic research and has been shown to give accurate estimates of sheep and pig carcass composition (Preston et al. 1984).

(iv) Electrical conductivity Due to higher water and electrolyte contents, lean tissues conduct electricity better than adipose tissue. Two approaches can be used to measure whole-body composition: direct injection of current, and non-contact measurement. This latter method is referred to as TOtal Body Electrical Conductivity (TOBEC), and depends on the disruption to the electromagnetic field of a coil through which a current is passed. Results of several studies have shown excellent predictions of fat and lean in animals and packaged meat (Boileau 1988). Prototype TOBEC instruments are being tested by the CSIRO's Cannon Hill Meat Laboratory. This technique is more rapid and less expensive than the preceding three, and is the most likely to find early application in the livestock and meat industries.

IV. CONCLUSIONS

Estimates of body composition based on live weight, sex, age and an indicator of fatness (condition score and/or fat thickness) are effective and continue to be used in the livestock and meat industries. New technologies have been pursued and continue to be developed. This has been driven by the need for improved estimates of composition by researchers on one hand, and of the push by meat industries around the world towards objective quality assessment on the other. This latter point cannot be over-emphasized. The meat industries in Australia, America and Europe are progressing rapidly toward a transparent market; that is, one in which information on desirable specifications is available to all participants. Such a system must of necessity be based on objective assessment of quality. Sophisticated equipment designed for medical diagnoses has provided a starting point but generally is unsuitable for use with farm animals or under harsh field conditions. Therefore, development of specialized equipment for the livestock and meat industries is essential. New techniques based on electrical conductivity, velocity of ultrasound, or imaging technology are likely to be available for field use within the next few years.

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