Relationships between live weight, body condition, dimensional and ultrasound scanning measurements and carcass attributes in adult Angora goats

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Abstract

Real-time ultrasound scanning is an accurate non-invasive technique used to improve quality in sheep, cattle and pig meat production but has been overlooked in meat production from heavy goat carcasses. The aims of this study were to: determine subjective and objective carcass attributes of 6 year old Angora castrate goats prior to and following slaughter; and determine the relationships between carcass attributes, bodyweight, body condition score (BCS), body dimension measurements and ultrasound measurements using multiple regression modelling. Key attributes were: on-farm bodyweight (range 35-77 kg), BCS (1, very thin to 4.3, fat), dimensional frame measures (wither height, heart girth, anterior-posterior circumference, body volume (circumference × girth)), carcass weight (range 11.6-33.2 kg), GR tissue depth of carcasses (1-27 mm) and the ultrasound measurements of eye muscle depth (EMD, 17-35 mm) and subcutaneous fat depth (SFD, 1-6 mm). Goats from three genetic backgrounds were grazed on pasture together for 6 years. In the three months preceding slaughter the goats grew from an average live weight of 50.7 kg gaining live weight at an average of 117 g/d to reach an average live weight of 62 kg. There were moderate correlations between all measurements. BCS accounted for 55.1% of the variance in carcass weight, 51.3 % of the variance in EMD, (3.2% more than did GR tissue depth) and 59.9% of the variance in SFD. Live weight accounted for 83.8% of the variance in carcass weight. The best prediction equation for

carcass weight included terms for live weight, SFD, EMD and sire, accounting for 91.5% of variance. Body dimensional measurements were not as useful as BCS in predicting carcass weight, with the best, body volume, accounting for 5% less of the variance than live weight. The best prediction for the EMD included terms for BCS and carcass weight, accounting for 61% of variance. GR tissue depth was primarily associated with SFD, and in combination with carcass weight and BCS explained 71.9% of the variance. In relation to predicting carcass traits, girth accounted for more of the variance in EMD, SFD and GR tissue depth than wither height or body circumference. If breeders aim to alter the EMD and SFD of Angora goats then ultrasound scanning provided better estimates compared with relying on live weight with or without body condition scoring. Both EMD and SFD were also in the best model for predicting carcass weight. BCS was a useful on-farm measurement for estimating carcass attributes but girth was not as useful as body volume in explaining the variance in live weight.
Keywords: meat; eye muscle; fat depth; quality; developing economies

1. Introduction

Meat production is an important component of the financial returns from fibre and wool producing systems of animal production. In Australian wool producing enterprises, sales of surplus young and aged sheep for meat contribute 25 to 40% of total income with a similar proportion of total income arising from meat sales in mohair enterprises in Australia (McGregor, 2010a). The Australian mohair industry imported South African and Texan Angora goat strains in the early 1990s. While the production and quality of mohair from the new genetics has been investigated, there is scant information regarding the production and quality of carcasses when these Angora goats are sold as adults.

The evaluation of carcass attributes is an important component of sheep improvement programs. In centralized breeding schemes in Australia, where real-time ultrasound scanning has been used on-farm to measure eye muscle depth (EMD) and subcutaneous fat depth (SFD) in meat sheep (Hopkins et al., 2007; LambPlan, 2015), improvements have been obtained in growth, carcass weight and a significant medium-term return on investment has been obtained (Holst, 1999). While a centralized breeding scheme for goats has been available in Australia for some years (KidPlan, 2015) few breeders have availed themselves of the service. Real-time ultrasound scanning offers a fast, accurate and safe method of quality control in meat production (Silva and Cadavez, 2012; Scholz et al., 2015) but its use as an *in vivo* pre-slaughter technique to improve goat meat quality has been overlooked in recent reviews (Goetsch et al., 2011; Kannan et al., 2014; Scholz et al., 2015) and what little information that is available is focused on kid carcasses (Monau et al., 2013).

EMD and SFD are measurements of interest in meat production as they form both the muscles and fat covering along the back of animals which provide the high value meat cuts from sheep and cattle carcasses such as: loin and chump chops, racks, saddle, fillet, porterhouse, sirloin, Scotch and T-bone steaks. There has been little measurement and selection within goat breeds for increased eye muscle area and SFD. The lack of application of the measurement of EMD and SFD are probably the result of goat carcasses being traditionally sold with little or no differentiation between cuts, mainly as

slices off the fresh carcass, as whole carcasses, or in western export countries in cubed or six-way cut boxed meat (MLA, 2013) and perhaps the lack of evidence regarding the relevance of the measurements in goats.

The relevance and specific transfer of research findings with sheep to goat carcasses needs to be cautioned by the knowledge that fat distribution within goats differs significantly to that of sheep and so the growth and development of goats cannot be directly equated with that of sheep (Lapido, 1973; Fehr, 1981; Goetsch et al., 2011) and goats have been subject to far less genetic selection for carcass traits than have sheep. From about 20 kg live weight, internal and subcutaneous fat deposits in Angora goats increase at a proportionally greater rate than the empty body, leading to proportionally increased carcass fatness and carcass weight as body weight increases (McGregor, 1992a, 2011) but the changes in other carcass attributes are poorly documented.

On-farm assessments can involve body weight and body dimension measurements, subjective body condition scoring (BCS) and indirect objective measurements using ultrasound scanning. In the abattoir, direct measurements of carcass weight and tissue depth measurements can be made. In meat production, real-time ultrasound scanning (ultrasonography) is an accurate non-invasive indirect *in vivo* measurement technique used to measure the EMD (*M. longissimus thoracis et lumborum*), measured at the USFat C site, 45 mm from the midline at the 12/13th rib) and subcutaneous back fat depth using the same techniques that are used with sheep and pigs (Wood and Fisher, 1990; Stanford et al., 1995; Amin et al., 2000; Hopkins et al., 2007; Teixeira et al., 2008; Monau et al., 2013). This technique provides a visual cross-section image of carcass tissues and enables the direct measurement of tissue depths. BCS was first explained by McClymont and Lambourne (1958) and Jefferies (1961) for use in sheep, and has been applied with goats since at least 1982 (McGregor, 1983, 2010b). BCS in goats has been shown to be related to the commercially important parameters of goat live weight, milk production, carcass production, carcass fatness, reproductive performance and mortality (McGregor, 1990, 1992a, McGregor and Butler, 2008).

The practical question is therefore to what extent does ultrasound measurement provide better estimates of carcass yield, carcass composition and EMD of goats than the easily applied techniques

of on-farm bodyweight measurements, dimensional frame measures, and BCS? However, the costs of both equipment and hire of consultants to conduct ultrasound scanning are likely to result in this technique being applicable only in larger commercial breeding flocks, during genetic selection programs for carcass attributes and where carcass attributes are important in the classification of carcasses at meat works. Thus in developing economies and in remote regions where ultrasound scanning cannot be accessed, low cost subjective evaluation methods such as subjective BCS are the only alternative. Furthermore, previous studies using ultrasound scanning of goat carcasses are limited to young goats with no data on heavy goats. Therefore the aims of this study were to: determine subjective and objective carcass attributes of adult Angora goats prior to and following slaughter; and determine the relationships between carcass attributes, bodyweight, BCS, body dimension measurements and ultrasound measurements.

2. Materials and methods

2.1. Management

Management details for the Angora goats have been provided in earlier reports (McGregor et al. 2012, 2013). In brief, Angora goats born in September 2002 in a progeny testing evaluation at Horsham, Victoria, (36º42'50"S, 142º18'30"E, altitude 180 m) with pedigree breeding records from known sires, were grazed on pasture from birth until 6 years of age. The goats were progeny of various genetic sources including sires of 100% South African origin (n = 2), 100% Texan origin (n = 4), and other interbred admixtures that included sires of South African, Texan and Australian origin (n = 4). These sires were representative of the genotypes available in Australia (Ferguson and McGregor, 2005). Records of dam, birth weight and birth parity were taken for castrated males (wethers). One month after shearing in February 2004 the goats were transported to Attwood, Victoria (37°40’S, 144°53’E, altitude 135 m) and grazed as one flock until November 2008 at near the recommended stocking rate on improved annual temperate pasture (McGregor, 2010b). Goats were moved between

paddocks to match feed requirements. Shelter was available in the form of covered and enclosed building that was always accessible and could accommodate all goats. Fresh rainwater was provided in all paddocks.

During most years in autumn and winter, pastoral conditions were affected by drought and supplementary feeding was undertaken following Australian practice (McGregor, 2005) from mid May to early September to maintain live weight. A mineralised stock block was always available (Ridley AgriProducts Pty. Ltd., Melbourne) with the following content: minimum content Ca 4.9%; P 1%; S 2%; Cu 600 mg/kg; Co 60 mg/kg; I 60 mg/kg; Zn 1000 mg/kg; Fe^{2+} 1100 mg/kg; Se 5 mg/kg; based on NaCl 75 to 85%. Goats were vaccinated against 5 in 1 *Clostridia spp*. and "drenched" with an effective anthelmintic to control gastro-intestinal parasites no more frequently than once per year.

In the six months prior to slaughter, supplementary drought feeding was supplied at a rate of 250 to 310 g/goat/d depending on pastoral conditions between late March and mid-August 2008. Prior to slaughter goats were shorn in September 2008.

2.2. Animal and carcass measurements

In most months during the study all goats were weighed to the nearest 0.2 kg. At each weighing BCS was recorded by an experienced operator by palpating the short ribs and assigning a score as follows: 1 (very lean, sharp prominent backbone and spinal processes, little flesh coverage); 2 (lean); 3 (medium, slight rounding of flesh over spine); 4 (fat); 5 (very fat, cannot detect any backbone or spinal processes) with two intermediate scores assigned between each of these main categories i.e. 2.3, 2.7, 3.0, 3.3 (McGregor, 1983, 1992a, 2005).

Prior to slaughter in November, the goats were weighed, BCS and the EMD (mm) and SFD (mm) of the goats were determined by a very experienced ultrasonic scanning technician (Advanced Livestock Services, Hamilton, Victoria). Goats were measured for wither height, heart girth and body circumference (anterior-posterior, measurement C1 in Couchman and McGregor (1983)), to the nearest cm using a steel tape measure. Body volume was determined as: girth × circumference. Live

weight was also related to a modified Schaeffer's formula as: circumference × girth^2; whereas the usual Schaeffer's formula is related to a linear length along the spine with a square term for girth (Anonymous, undated).

Transport by livestock carrier (300 km) to the meat works Wodonga Food Processing, Wodonga, Victoria commenced two days later. Goats were fasted for 24 hours prior to slaughter with fresh water available during lairage. Standard carcasses were produced (AusMeat, 2001) and hot carcass weight recorded by electronic scales to the nearest 0.2 kg. The standardized carcass weights reported here exclude the weight of: kidneys; kidney fat; omental fat; and tails. Following chilling for 4 h, carcasses were carefully inspected to ensure conformance with the standard carcass as defined above. Tissue depth at the GR site (13th rib) was measured with a GR knife (mm, A.L. Franklin, Sydney).

2.3. Statistical methods

Mean, range and variance (s.d.) were determined for all measurements. Correlations between live weight and other body and carcass measurements were determined (Payne, 2013). Parsimonious general linear models with normal errors were developed in a forward stepwise manner using GenStat 15.2 for Windows (Payne, 2013) to determine the relationships between carcass attributes and body weight, BCS, body dimensional measurements and ultrasound measurements. Multiple regression models were developed so that the additional significance of any attribute was tested. The units for analysis were the individual animal measurements (n = 78). Other data for these animals was also available for analysis from previous studies including sire, date of birth, birth weight and dam age (Ferguson and McGregor, 2005).

For each significant variate, the square of that variate and the product of that variate with other significant variates were tested for significance. The best model was developed with terms being added or rejected on the basis of F-tests ($P < 0.05$). Once the final models were determined the marginal significance of each term in the final model was determined and the marginal significance of

rejected terms was also determined. Regression constants (± s.e.), precision as represented by residual standard deviation (RSD), and accuracy as represented by variance accounted for by a model (determined as $100 \times r^2$) are provided. General linear models, that included only prescribed subsets of the parameters in the parsimonious model, were fitted and compared using percentage variance accounted for (Payne, 2013). Predicted responses to significant terms, after adjustment for other terms in the model, are provided in graphs which also show the raw data (GenStat 15.2; Payne, 2013).

3. Results

The mean, s.d. and range for average live weight and for body and carcass attributes are provided in Table 1. There was a wide range in live weights (35-77 kg), carcass weights (11.6-33.2 kg), EMD (17-35 mm), SFD (1-6 mm) and GR tissue depth (1-27 mm). BCS averaged 2.7 and covered the range from 1 (very thin) to 4.3 (fat) (Table 1). Fig. 1 shows the carcasses being chilled after weighing but prior to GR tissue depth measurement.

Average live weight increased from 23 kg at 18 months of age to 62 kg at 75 months of age (Fig. 2). In the three months preceding slaughter the goats grew from an average live weight of 50.7 kg gaining live weight at an average of 117 g/d. There were highly significant correlations between live weight, carcass weight, BCS, EMD, subcutaneous back fat, GR tissue depth, girth, wither height and body circumference ($P < 0.001$, Table 2).

3.1. Carcass weight

The average carcass weight was 24.4 kg (Table 1). BCS alone accounted for 55.1% of the variance in carcass weight ($P < 0.001$, Table 2). Live weight alone accounted for 83.8% of the variance in carcass weight ($P < 0.001$, Table 2, Fig. 3), and adding BCS increased the variance accounted for by 3.4% to 87.2% (Table 3).

The best prediction equation for carcass weight included terms for live weight ($P = 8.3 \times 10^{-22}$), SFD ($P = 0.002$), EMD ($P = 0.009$) and sire ($P = 0.002$) and other terms were not significant (Tables 3, 4). The percentage of variance accounted for was 91.5% and the residual standard deviation recorded was 1.13. In this model, adding SFD and EMD to live weight, increased variance accounted for from 83.8% by 5.3% and adding sire accounted for a further 2.4% of the variation (Table 5). Sire alone accounted for 13.6% of the variance in carcass weight (Table 5). Differences between sires were significant in the final model ($P = 0.002$, Table 3) with a sire range of 2.83 kg in the carcass weight of their progeny at 6 years of age after adjustment for other terms in the best model (Table 3).

BCS and GR tissue depth accounted for similar proportions of the variation in carcass weight (Table 5) but neither was significant in the best prediction model (Table 4). The use of body dimensional measurements were not as useful as BCS, with the best combination, an estimate of body volume accounting for 5% less of the variance than live weight and 8.3% less of the variance than live weight and BCS combined (Table 3). Neither wither height, girth, body circumference, birth weight, date of birth, or age of dam were significant in the final prediction model for carcass weight ($P > 0.2$, Table 4).

3.2. Eye muscle depth

The average EMD was 28 mm (Table 1). EMD was moderately correlated with other measurements (0.44-0.74, Table 2). The on-farm measurements of live weight and BCS separately accounted for 44.5% and 51.3% of the variance in EMD respectively (Table 6), and when used together accounted for 58% of variance in EMD or 94% of that accounted for by the best model (Table 6). BCS accounted for 3.2% more of the variance in EMD than did GR tissue depth (Table 6). The relationship between EMD and BCS is shown in Fig. 4.

Using measurements on the carcass (GR tissue depth and carcass weight) to predict EMD were only marginally better than using on-farm measurements of live weight and BCS accounting for

only a further 1.2% of variance (Table 6). The best prediction equation for the EMD included terms for BCS and carcass weight and other terms including interactions or square functions were not significant (e.g. sire $P > 0.30$). The percentage of variance accounted for was 61% and the residual standard deviation recorded was 2.13. Sire alone accounted for 7.7% of the variance in EMD ($P = 0.10$). Adding sire to regressions which included BCS and live weight or carcass weight did not account for any more variance in EMD (sire $P > 0.3$).

3.3. Subcutaneous fat depth

SFD over the eye muscle averaged 3.1 mm (Table 1) and was moderately correlated with other measurements (0.37-0.77, Table 2). The on-farm measurements of live weight and BCS separately accounted for 38.3% and 59.6% of the variance in SFD respectively (Table 7), and when used together accounted for 61% of variance in SFD or 90% of that accounted for by the best model (Table 7). Fig. 5 shows the relationship between SFD and BCS. Using measurements on the carcass (GR tissue depth, carcass weight) were better predictors of SFD than using on-farm measurements of live weight and BCS and when used together accounted for 67.9% of the variance (Table 7). The best prediction equation for SFD only included terms for GR tissue depth and carcass weight and other terms (interactions or square functions) were not significant (e.g. Sire $P = 0.62$). Sire did account for almost 16% of the variance in SFD (Table 7) but when sire was combined with any other measure, such as live weight, carcass weight or BCS, sire was not a significant determinant ($P > 0.1$).

3.4. GR tissue depth

GR tissue depth averaged 14.6 mm (Table 1) and was moderately correlated with other measurements (0.35-0.80, Table 2). The on-farm measurements of live weight and BCS separately accounted for 39.1% and 59.9% of the variance in GR tissue depth respectively (Table 8), and when

used together accounted for 62% of variance. Fig. 6 shows the relationship between GR tissue depth and BCS. The on-farm measurement of SFD explained 3.9% more variance in GR tissue depth compared with BCS. Adding BCS to SFD accounted for a further 5.7% of the variance in GR tissue depth (Table 8) compared with using SFD alone. GR tissue depth was primarily associated with SFD, and in combination with carcass weight and BCS explained 71.9% of the variance (Tables 2, 7). Sire alone accounted for 26.7% of the variance and adding sire to regressions involving on-farm measurements of live weight and BCS improved variance accounted for from 61.9% to 66.6%, but sire was not significant in the best model. In the final model, sire, other terms, interactions or square functions, were not significant: sire ($P = 0.16$), birth type ($P = 0.28$), birth weight ($P = 0.32$), age of dam ($P = 0.98$) or EMD ($P = 0.84$).

3.5. Body physical measurements

Of the three body physical measurements, body circumference was more highly correlated and accounted for more of the variance in live weight than wither height or girth (Tables 2, 9). The best combination of these physical measurements to predict live weight was body volume, which accounted for almost 80% of the variance (Table 9) and similarly for carcass weight accounting for 79% of the variance (Table 2). In relation to predicting other carcass traits, girth accounted for more of the variance in EMD, SFD and GR tissue depth than wither height or body circumference. However, girth accounted for 10-15 % less of the variance in predicting EMD, SFD and GR tissue depth compared with predictions made with BCS (Tables 6-8).

4. Discussion

4.1. Prediction of carcass weight

As expected live weight was a very good predictor of the carcass weight of these Angora goats. The question of interest to Angora goat farmers is what other measurements are useful in addition to or alternative to the use of live weight in assessing likely carcass production from Angora goats. BCS is known to be positively associated with live weight but it only accounted for 65% of the variance accounted for by live weight (55.1/83.8, Table 5). However, using BCS with live weight increased variance accounted for by 3.4% to 87.2% (Table 5). The use of eye muscle area and SFD instead of BCS, when used without live weight, accounted for 5.6% more variance, but when used with live weight increased variance accounted for by only 1.9% (Table 5). Such a small improvement in the precision of predicting carcass weight would not seem to justify the costs of obtaining these data from ultrasonic scanning when it is possible to use live weight and BCS which have little or no additional cost. Further, there was no benefit in predicting carcass weight by the time consuming process of measuring body metrics if a direct measurements of live weight was available but both body circumference and girth were more correlated with carcass weight than was BCS (Table 2).

Knowledge of the sire explained 13.6% of the total variance in carcass weight, and sire differences explained 2.83 kg in carcass weight in the best final model (Tables 3, 5), representing 11.5% of the mean carcass weight of 24.4 kg (Table 1). However, for sire differences to be useful prior to slaughter they would have needed prior quantification. In the present investigation, knowledge of sire differences were no more useful in predicting carcass weight than BCS when combined with live weight (Table 5), and explained only 1.9-2.4% additional variance when used in combination with live weight and BCS, or in the final model which included live weight, eye muscle area and SFD (Table 5).

The regression coefficients indicate that when used separately, for each 1 kg increase in live weight, carcass weight increased by 463 g, while for each 1 unit increase in BCS carcass weight increased by 4.6 kg (Table 3) but when used together the coefficients were 380 g and 1.53 kg respectively (Table 3). This value is lower than reported for younger and older Australian Angora goats slaughtered following periods of continual live weight gain (McGregor, 1996; 2010b) but higher

than that reported for adult Australian cashmere goats slaughtered after live weight maintenance or loss in mid-summer or autumn (McGregor, 1990).

What the present investigation does is to quantify the regression constants for adult Angora goats from a range of genetic backgrounds. The regression constant for older goats might be expected to be higher than those for younger goats, as during growth and maturation an increasing proportion of the total body mass develops into fat deposits. These fat deposits have a relative growth coefficient greater than 1, meaning that they grow faster than the entire body as a whole. The carcass grows faster than the body as the perirenal fat (+6.8%) and subcutaneous fat deposits (+7.8%), grow faster than the body of an Angora goat as a whole (McGregor, 1992a). Counteracting the relative growth of the carcass is the relative growth of organs not included in the carcass such as skin (+3.6%), horns and the internal deposits of omental fat (+7.4%), but most other organs grow slower than the entire body. In the present study the perirenal fat was not included in the standard carcass and so the removal of the perirenal fat would have reduced the recorded carcass weight, and reduced the regression coefficients.

4.2. Carcass attributes

EMD in these Angora goats was primarily determined by carcass weight, with BCS being the next best attribute to explain variance in EMD (Table 6). The on-farm measurement of BCS was slightly superior in predicting EMD compared with the GR tissue depth made on the carcass in the abattoir, and this may not be surprising as BCS, when carefully undertaken, involves palpation of the tissue covering of the spinal processes. Knowledge of sire did not improve any of the prediction models for EMD suggesting that the effect of sire is primarily on carcass weight (Table 6). None the less, almost 40% of the variance in EMD was unexplained in the best model. Eye muscle area has previously been shown to be positively related to hot carcass yield in Jamunapari goats (Amin et al., 2000). Teixeira et al. (2008) reported that the best correlation for EMD in Spanish Celtiberica adult goats was found for ultrasound measurements taken between the third and fourth lumbar vertebrae.

These estimates accounted for 70% of the variation in muscle depth. Teixeira et al. (2008) also reported that using ultrasound measurement at the lumber site only increased the precision of muscle prediction by 8%, to a total of 90% of variance accounted for, compared with using body weight alone. The lumbar vertebrae sites are the same as those used for BCS on live goats.

It has been well established that goats have a different partitioning of fat between the fat deposits within the body compared with most sheep breeds. As a rule, goats have a lower proportion of their fat deposits as subcutaneous deposits compared with sheep and so subcutaneous fat across the back is generally relatively thin (Lapido, 1973; Fehr, 1981; Goetsch et al., 2011; McGregor, 2011). Excessive SFD is not desired in Western meat markets and butchers remove excess subcutaneous fat, a process which consumes labour and wastes product. It has also been widely asserted that compared with beef and lamb, that goat meat has a lower fat content (McMillin and Brock, 2005), a claim which overlooks mounting evidence that carcasses from relatively well fed and from adult goats with heavier carcasses have significant fat deposits. Research on 238 Texan Angora does culled at 2–6-years of age, of mean live weight 30.7 kg, produced 11.5 kg carcasses that yielded 57% boneless meat (Eggen et al., 1973). For 48 carcasses, the amount of fat trim averaged 11%, but varied from 4 to 23% fat among carcasses, with the average of 10.3% chemical fat content of the boneless meat product. These results imply that the fat content of the relatively small Angora carcasses was about 21%, but for some carcasses the fat content was about 33%. Grain feeding of Angora goats can lead to excessive fat deposits in 14.2 kg carcasses and result in chemical fat content, including perirenal fat, of 30-37% and GR tissue depth of 12 mm (McGregor, 1992b). Increasing the stocking rate of Angora goats slaughtered at 4 years of age reduced GR tissue depth as a direct result of reduced live weight and consequently reduced carcass weight, but once adjustment was made for differences in carcass size the GR tissue depth of the goats was similar to that of similarly grazed Merino sheep (McGregor, 2010b). In that study, BCS explained 72% of the variance in GR tissue depth in the goat carcasses (mean carcass weight 16.0 kg, mean GR tissue depth 7.4 mm) but only 48% of the variance in sheep carcasses (respectively 22.1 kg, 12.5 mm).

In the present study using pasture fed goats, SFD ranged from 1 to 6 mm with the preferred depth of about 3 mm being achieved once BCS was 3 or greater (Fig. 5). Carcass weight was equally useful in accounting for variance in SFD as it was for EMD, and slightly better at accounting for variation in GR tissue depth, but both BCS and GR tissue depth accounted for more variance in SFD, by 8.3% and 15.7% respectively, than they did for eye muscle area (Tables 6-8). GR tissue depth was a better predictor of SFD compared with BCS, which is not surprising as it is a direct measurement on the carcass, but it left unexplained 36% of the variance (Table 7).

BCS alone accounted for almost 60% of the variation in GR tissue depth, or 83% of that accounted for by the best model (Table 8). It is interesting that BCS and SFD were both significant in the best model for explaining GR tissue depth as this indicates that while much of the variance they explain is similar, BCS still provides additional information on GR tissue depth not provided by SFD. It appears practical and reasonably reliable to use BCS with or without live weight as an indirect measure to select goats for GR tissue depth. Increasing BCS from 2 to 3 was associated increasing GR tissue depth from about 10 mm to about 16 mm (Table 8, Fig. 6) and increasing carcass weight by 1 kg was associated with GR tissue depth increasing about 1 mm (Table 8).

4.3. Use of body condition score and body measurements

BCS was a useful on-farm measurement for estimating: carcass weight, when used with live weight (Table 3); EMD, SFD and GR tissue depth when used with either live weight or carcass weight (Tables 6, 7); and GR tissue depth, when used with carcass weight or SFD (Table 8). This finding is similar to that previously reported for grazing Australian Angora goats and adult Australian cashmere goats (McGregor, 1990, 1992a). In these studies BCS and GR tissue depth had similar precision when estimating carcass weight, carcass fat, and SFD.

Body measurements, particularly heart girth, have often been promoted as reliable methods for estimating the live weight of goats in the absence of live weight scales (e.g. Slippers et al., 2000). Mahieu et al. (2011) showed that two body measurements used together, heart girth combined with

paunch girth explained 95% of the variance in live weight of dairy goats. The present results indicate that body volume, a combination of two measurements, was better than heart girth or body circumference in estimating live weight (Tables 2, 9). For these adult Angora goats while girth accounted for 60% of the variance in live weight, and live weight increased 1 kg for each 1 cm increase in the girth of these adult goats, the measurement of body circumference actually accounted for more of the variance (65%) and body volume explained 80% of the variance in live weight (Table 9). This product term was superior to a formula which uses a linear length along the spine with a square term for heart girth (Anonymous, undated; Table 9). None of the body measurements were significant determinants in the best prediction models for carcass weight or other carcass parameters.

5. Conclusion

If breeders aim to alter the EMD and SFD of adult Angora goats then these results indicate that ultrasound scanning will provide better estimates compared with relying on live weight with or without BCS, which could only explain 61-68% of the variance in these attributes. Both EMD and SFD were also in the best model for predicting carcass weight. However, BCS was a very useful on-farm measurement for estimating carcass weight, EMD, SFD and GR tissue depth when used with live weight or carcass weight. BCS is therefore an essential practical skill for farmers, extension agents, meat buyers and researchers in both developing and developed economies. Other body measurements such as girth were not useful in predicting carcass attributes although body volume explained 80% of the variance in live weight and could be a useful metric in developing countries.

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Table 1

Mean, standard deviation and range in average live weight and for body and carcass measurements of Angora wethers slaughtered at six years of age (*n*=78).

Attribute	Mean	SD	Minimum	Maximum
Average live weight (kg)	62.5	7.66	35.3	77.0
Body condition score	2.7	0.63	1.0	4.3
Wither height (cm)	63.7	3.84	55	73.5
Girth (cm)	96.4	5.66	79	107
Body circumference anterior-posterior (cm)	187.3	8.7	162	207
Eye muscle depth (mm)	28	3.4	17	35
Subcutaneous fat depth (mm)	3.1	0.98	1	6
Carcass weight (kg)	24.4	3.87	11.6	33.2
GR tissue depth (mm)	14.6	5.08	1	27
Birth weight (kg)	2.9	0.54	1.6	4.2

Table 2

Correlation coefficients (r, above the diagonal) and percentage variance accounted for ($100r^2$, below the diagonal) for relationships between live weight, carcass weight, body condition score, eye muscle depth, subcutaneous back fat, GR tissue depth, girth, wither height, body circumference and body volume of 6 year old Angora goats (n = 78). All relationships are significant at $P < 0.001$.

	Live weight	Carcass weight	Body condition score	Eye muscle depth	Subcutaneous back fat	GR tissue depth	Girth	Wither height	Body circumference	Body volume
Live weight	–	0.92	0.66	0.67	0.62	0.63	0.78	0.63	0.81	0.87
Carcass weight	83.8	–	0.74	0.74	0.74	0.76	0.79	0.58	0.77	0.89
Body condition score	43.6	55.1	–	0.72	0.77	0.77	0.60	0.39	0.51	0.64
Eye muscle depth	44.5	55.5	51.3	–	0.74	0.69	0.63	0.44	0.60	0.70
Subcutaneous back fat	38.3	55.5	59.6	54.8	–	0.80	0.67	0.37	0.47	0.67
GR tissue depth	39.1	57.8	59.9	48.1	63.8	–	0.71	0.35	0.50	0.71
Girth	60.1	63.1	36.1	39.5	44.7	50.2	–	0.44	0.54	0.91
Wither height	39.6	33.9	15.4	19.6	13.5	12.3	19.4	–	0.58	0.58
Body circumference	65.4	58.6	25.6	36.1	22.3	25.1	29.7	33.2	–	0.85
Body volume	75.9	79.2	41.2	49.4	44.9	50.0	82.4	33.1	72.2	–

Table 3

Regression constants, correlation coefficient and percentage variance accounted for in relationships between carcass weight (kg) and live weight (kg), subcutaneous back fat depth (SFD, mm), eye muscle depth (EMD, mm), body condition score (BCS), GR tissue depth (mm, at slaughter) and sire. All relationships are significant at $P < 0.001$, $n = 78$.

Dependant variate	Fitted parameters	Estimate	s.e.	RSD	$100r^2$
Carcass weight	Constant	-13.33	2.24	1.79	78.9
	Body volume	0.0021	0.00012		
Carcass weight	Constant	-4.6	1.5	1.56	83.8
	Live weight	0.463	0.0232		
Carcass weight	Constant	-3.6	1.3	1.38	87.2
	Live weight	0.380	0.0274		
	BCS	1.53	0.332		
Carcass weight	Constant	-4.2	1.53	1.13	91.5
	Live weight	0.343	0.0239		
	SFD	0.70	0.221		
	Sire	0.0–2.83	0.55–0.70		
	EMD	0.17	0.064		

Table 4

A list of the statistical significance of rejected and included terms in the final model for predicting the carcass weight of Angora goats. Values in bold have *P*-value < 0.05.

Adjustment to model	*F* value	Degrees of freedom	*P*-value
Terms retained			
Live weight	205.63	1, 65	**8.3×10^{-22}**
Subcutaneous fat depth (SFD)	9.97	1, 65	**0.002**
Sire	3.33	9, 65	**0.002**
Eye muscle depth (EMD)	7.32	1, 65	**0.009**
Terms rejected			
Birth weight	0.95	1, 63	0.33
Date of birth	1.36	16, 48	0.20
Dam age	1.11	8, 56	0.37
Girth	1.25	1, 63	0.27
Wither height	1.11	1, 63	0.30
Body circumference	0.07	1, 63	0.80
Body condition score	0.54	1, 64	0.47
GR tissue depth	1.84	1, 64	0.18
Product of EMD and SFD	0.09	1, 63	0.77
Product of EMD and live weight	0.51	1, 63	0.48
Product of live weight and SFD	0.17	1, 63	0.68
Square of live weight	0.56	1, 63	0.46
Square of SFD	3.67	1, 63	0.060
Square of EMD	0.69	1, 63	0.41

Table 5

Variance in the carcass weight accounted for by live weight, subcutaneous fat depth (SFD), sire, eye muscle depth (EMD), body condition score (BCS) and GR tissue depth.

Terms in model	Residual S.D.	Residual variance	% Variance accounted for by model
None	3.87	14.98	0
Sire	3.62	13.10	13.6
BCS	2.59	6.71	55.1
GR tissue depth	2.53	6.40	57.8
SFD and EMD	2.34	5.48	63.4
Live weight	1.56	2.43	83.8
Live weight and sire	1.39	1.93	87.1
Live weight and BCS	1.38	1.90	87.2
Live weight, BCS and sire	1.28	1.64	89.1
Live weight, SFD and EMD	1.28	1.64	89.1
Full model; live weight, SFD, sire, and EMD	1.13	1.28	91.5

Table 6

Regression constants, correlation coefficient and percentage variance accounted for in relationships between eye muscle depth (EMD, mm) and live weight (kg), body condition score (BCS), carcass weight (kg) and GR tissue depth (GR, mm). All relationships are significant at $P < 0.001$.

Dependant variate	Fitted parameters	Estimate	s.e.	RSD	$100r^2$
EMD	Constant	9.6	2.39	2.54	44.5
	Live weight	0.30	0.038		
EMD	Constant	21.5	0.86	2.47	48.1
	GR	0.47	0.056		
EMD	Constant	17.7	1.20	2.38	51.3
	BCS	3.9	0.43		
EMD	Constant	12.2	1.66	2.27	55.5
	Carcass weight	0.66	0.067		
EMD	Constant	11.4	2.12	2.22	57.7
	BCS	2.6	0.53		
	Live weight	0.16	0.044		
EMD	Constant	14.2	1.76	2.19	58.9
	GR	0.20	0.076		
	Carcass weight	0.46	0.100		
EMD	Constant	12.7	1.56	2.13	61.0
	BCS	2.0	0.58		
	Carcass weight	0.42	0.094		

Table 7

Regression constants, correlation coefficient and percentage variance accounted for in relationships between subcutaneous fat depth (SFD, mm) with live weight (kg), carcass weight (kg) GR tissue depth (mm), body condition score (BCS), girth (cm) and sire. All relationships are significant at $P < 0.001$ unless indicated otherwise.

Dependant variate	Fitted parameters	Estimate	s.e.	RSD	$100r^2$
SFD	Constant	3.08	0.366	0.90	15.9
	Sire (*P*-value = 0.011)	0–1.63	0.43–0.54		
SFD	Constant	-1.9	0.72	0.77	38.3
	Live weight	0.08	0.011		
SFD	Constant	-0.2	0.32	0.62	59.6
	BCS	1.2	0.11		
SFD	Constant	-1.2	0.58	0.61	61.4
	BCS	0.99	0.146		
	Live weight	0.03	0.012		
SFD	Constant	0.9	0.20	0.59	63.8
	GR tissue depth	0.15	0.013		
SFD	Constant	-0.44	0.447	0.555	67.9
	GR tissue depth	0.11	0.019		
	Carcass weight	0.08	0.025		

Table 8

Regression constants, correlation coefficient and percentage variance accounted for in relationships between GR tissue depth (GR, mm) with live weight (kg), carcass weight (kg), body condition score (BCS) and subcutaneous fat depth (SFD, mm). All relationships are significant at $P < 0.001$.

Dependant variate	Fitted parameters	Estimate	s.e.	RSD	$100r^2$
GR	Constant	13.7	1.77	4.35	26.7
	Sire	0–9.5	2.1–2.6		
GR	Constant	-11.7	3.72	3.96	39.1
	Live weight	0.42	0.059		
GR	Constant	-9.9	2.40	3.30	57.8
	Carcass weight	1.00	0.097		
GR	Constant	-2.5	1.63	3.21	59.9
	BCS	6.2	0.58		
GR	Constant	-8.2	2.99	3.13	61.9
	BCS	5.1	0.75		
	Live weight	0.14	0.062		
GR	Constant	-6.7	3.18	2.93	66.6
	BCS	4.5	0.83		
	Live weight	0.14	0.059		
	Sire	0–5.3	1.4–1.8		
GR	Constant	1.6	1.17	3.10	63.8
	SFD	4.2	0.36		
GR	Constant	-2.12	1.42	2.80	69.5
	SFD	2.6	0.52		
	BCS	3.1	0.80		
GR	Constant	-6.4	2.09	2.69	71.9
	BCS	2.2	0.84		
	Carcass weight	0.35	0.130		
	SFD	2.0	0.54		

Table 9

Regression constants, correlation coefficient and percentage variance accounted for in relationships between live weight (kg) and live body measurements of wither height, heart girth and body circumference (cm) (All relationships are significant at $P < 0.001$, $n = 78$).

Dependant variate	Fitted parameters	Estimate	s.e.	RSD	$100r^2$
Live weight	Constant	-16.6	11.0	5.76	39.6
	Wither height	1.23	0.173		
Live weight	Constant	-36.2	9.12	4.68	60.1
	Girth	1.01	0.094		
Live weight	Constant	-67.5	10.8	4.36	65.4
	Body circumference	0.69	0.057		
Live weight	Constant	17.7	3.06	3.82	73.4
	Body circumference × girth^2	2.5×10^{-5}	1.7×10^{-6}		
Live weight	Constant	-10.6	4.17	3.34	79.9
	Body circumference × girth	0.004	0.0002		

Figure captions

Fig. 1. Carcasses of adult Angora goats being chilled prior to measurement of GR tissue depth.

Fig. 2. The mean live weight of Angora wether goats grazed near Melbourne on annual temperate pastures from 1½ to 6¼ years of age. The vertical bars indicate the standard deviation of the population. Where goats were not weighed on the dates with missing s.d. bars the graph values have been interpolated.

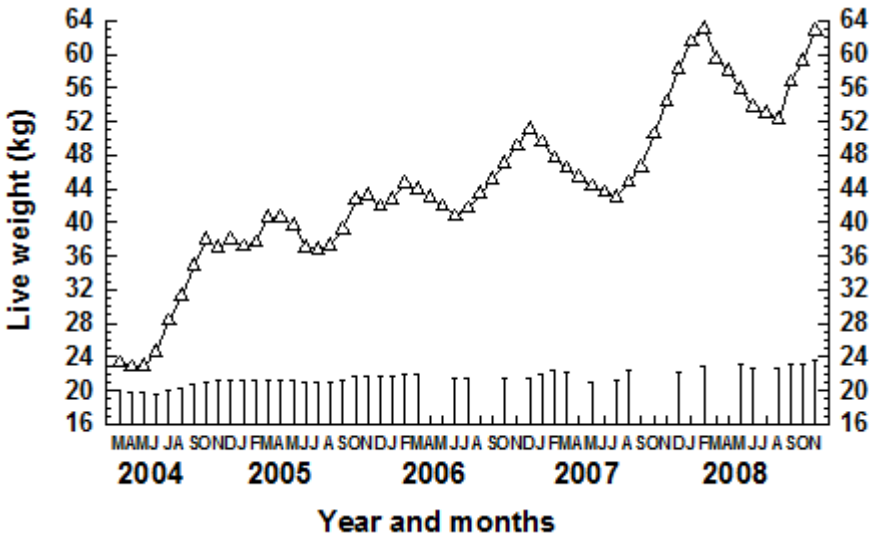

Fig. 3. The relationship between the carcass weight and the live weight of 6 year old Angora wether goats which had been grazing pastures in southern Victoria (n = 78; r = 0.92).

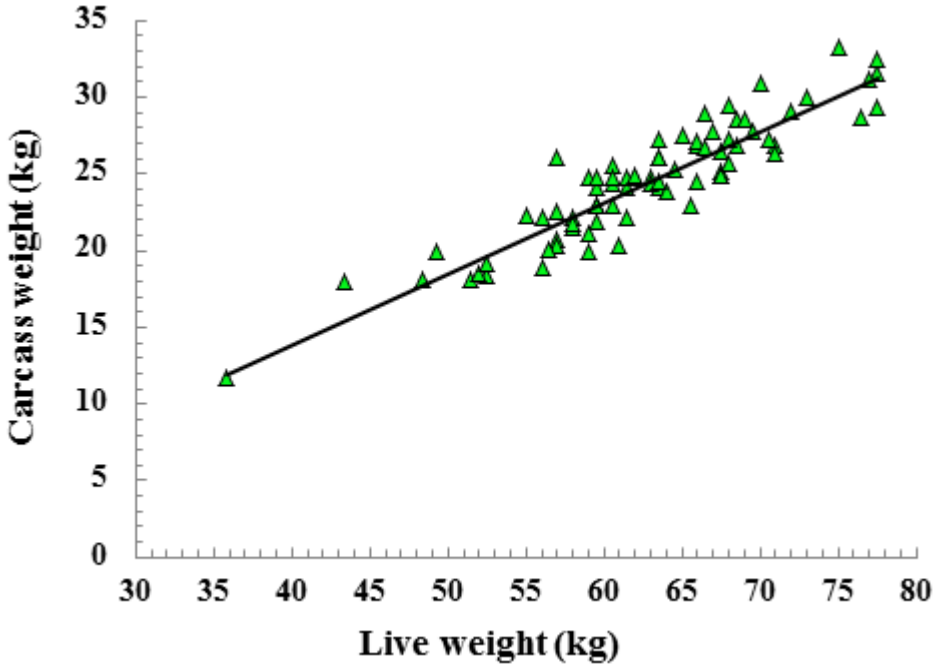

Fig. 4. The relationship between ultrasound scan eye muscle depth and the body condition score of 6 year old Angora wether goats which had been grazing pastures in southern Victoria (note that some points on the graph represent more than one animal; $r = 0.72$).

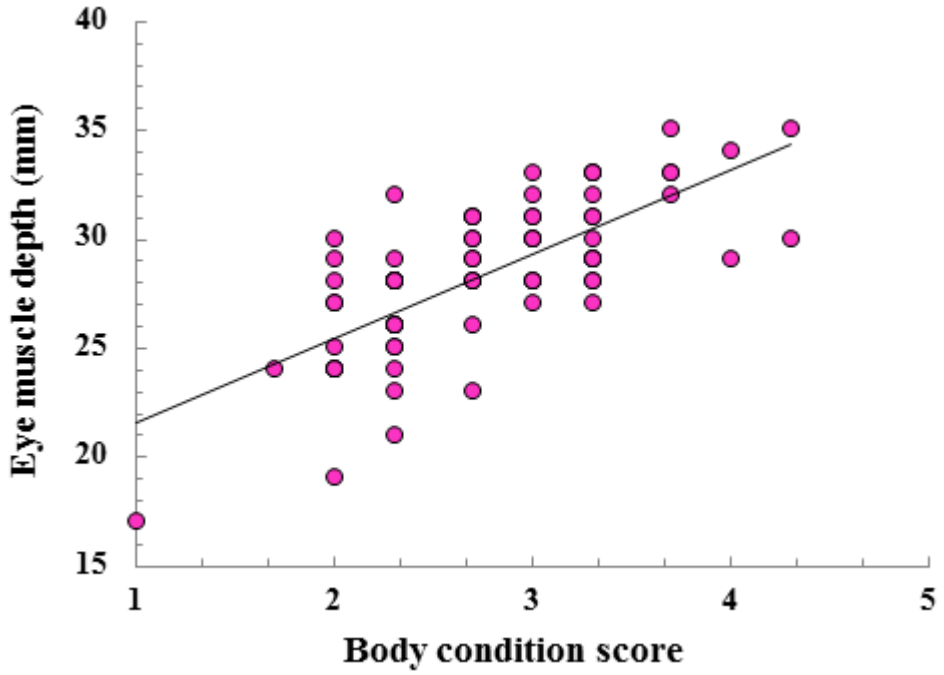

Fig. 5. The relationship between ultrasound scan subcutaneous fat depth and the body condition score of 6 year old Angora wether goats which had been grazing pastures in southern Victoria (note that some points on the graph represent more than one animal; $r = 0.77$).

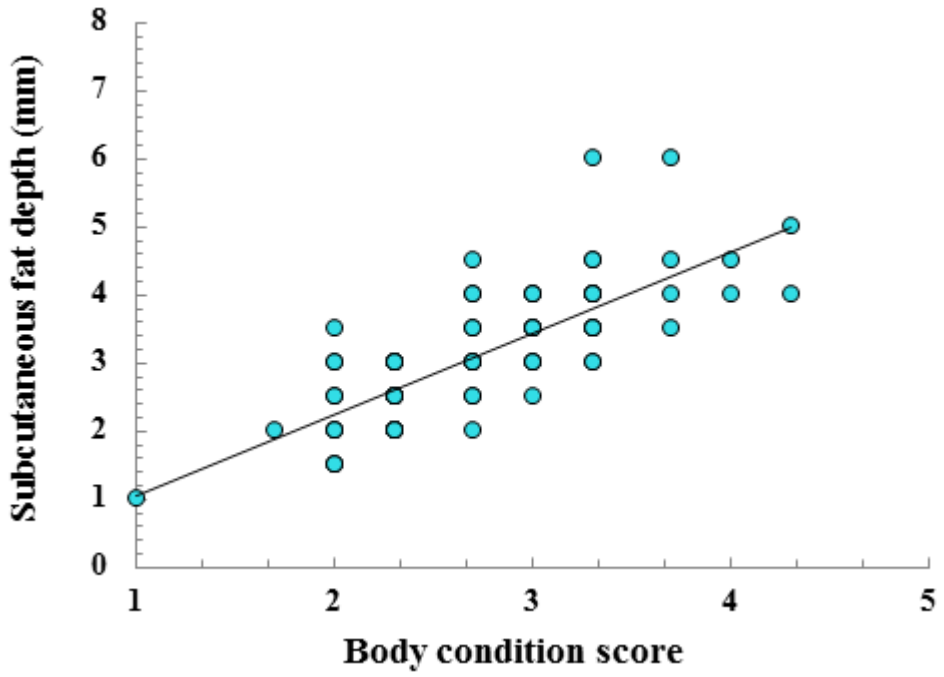

Fig. 6. The relationship between the GR tissue depth determined on the carcass and the body condition score of 6 year old Angora wether goats which had been grazing pastures in southern Victoria (note that some points on the graph represent more than one animal; $r = 0.77$).