

Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot

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Abstract

The objective of this study was to determine the effect of time spent in a feedlot on the size of the various fat depots and the distribution of the main tissues (muscle, bone, and fat) of three common South African sheep breeds. Lambs were supplied with a balanced diet (16% protein, 10 MJ ME/kg feed) *ad libitum* and had free access to water. Lambs from each breed were divided into six groups, which were slaughtered at 21-day intervals until a production period of 105 days had been reached. During carcass dressing, visceral and renal fat was removed and expressed as a percentage of carcass weight. The subcutaneous fat (SCF) depth was measured on the *longissimus lumborum* at the 13th rib position using an electronic calliper. The proportion of muscle, bone and fat was determined by dissecting a three-rib cut made on the prime rib between the 9th and 11th ribs. The percentage of visceral and renal fat increased throughout the production period for all breeds. The percentage of renal fat was up to 2.9% higher than the percentage visceral fat in both SAMM production groups. Dorper lambs tended to have high SCF levels (5.6 mm fat after 42 days) due to the early maturing nature of the breed. They reached a maximum fat depth of 20.4 mm fat after 105 days. The SAMM lambs tended to deposit SCF at a slower rate and the late maturing Merino breed was found to be much leaner, and did not reach the high fat levels of the SAMM or Dorper lambs. The percentage of muscle and bone in all carcasses decreased with an increase in the number of days in the feedlot, while the percentage of carcass fat increased during this period. The increase in late maturing adipose tissue in all breeds as they become older is amplified by the restricted movement in the feedlot and high energy diet that the lambs receive.

Keywords: Breeds, carcass composition, late maturing, sheep, subcutaneous fat

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Introduction

An important part of the entire growth process in domestic animals is the deposition of fat, which functions as an energy store, thereby enabling the animal to survive during prolonged periods of underfeeding (Negussie *et al.*, 2003). During periods of starvation, stored glycogen and fat, in the form of triglycerides, are broken down to release glycerol and free fatty acids, which fuel mitochondrial and muscular energy-producing processes (Sherwood, 2000). The partitioning of the various fat depots, along with the sequence of growth, illustrates the importance of each depot in the survival of the animal and the market value of the carcass (Negussie *et al.*, 2003). The order of development of the fat depots is mesenteric, intermuscular, omental, pelvic, renal, and subcutaneous (Texeira *et al.*, 1989). Intramuscular is the final fat depot to develop (Lawrie & Ledward, 1998). It plays a major role in the juiciness and tenderness of cooked meat (Wood *et al.*, 2008), as it contributes to the flavour of the meat and increases salivation in the mouth, enhancing the perception of tenderness and juiciness.

The tissue development of various sheep breeds differs according to the selection pressures applied to correspond with the environment and economically important traits. This results in sheep exhibiting

different growth potentials and maturation rates. It is then expected that early maturing breeds would render a fatter carcass at slaughter, after a constant number of days in feed (Berg & Walters, 1983), which in turn would affect the grading/classification and value of the carcass. It is therefore important to determine the maturation rate of the major carcass tissues of various sheep breeds in order to accurately predict a slaughter weight for ideal grading of the carcass.

The sequence of animal development is characterized by two growth waves. The first wave starts at the head, then spreads down to the trunk, while a secondary wave starts at the extremities of the limbs and moves dorsally. The two growth waves meet at the junction of the loin and the last rib, indicating that this is the last region to develop in an animal's body (Lawrie & Ledward, 1998). In lambs, this region falls between the 9th and 11th ribs. The relative order of tissue maturation is bone followed by muscles and then fat (Rouse *et al.*, 1970). The level of feed intake, age of maturity and slaughter weight are the main production factors that influence the muscle to bone to fat ratios (Murphy *et al.*, 1994; Santos-Silva *et al.*, 2002; Johnson *et al.*, 2005). Age has a significant effect on all tissues, with muscle and bone percentages decreasing with age, and the amount of fat increasing with age (Goliomytis *et al.*, 2006). An increase in slaughter weight decreases the relative amounts of lean and bone in a carcass, while the amount of fat increases (Rouse *et al.*, 1970). Cloete *et al.* (2012) observed differences in fat deposition of mature sheep between wool, dual purpose and mutton breeds. This suggests that different breeds would deposit fat at different levels. It is important to take this into account, as the way fat is partitioned in the carcass affects the classification and quality of the meat.

A trend in South Africa over the last few years has been an increase in the rounding off of lambs in feedlot systems. The effect of this higher quality nutrition on the body or carcass development of the various sheep breeds in South Africa needs to be quantified so that the industry has an idea at what stage the lambs are slaughter ready (Brand *et al.*, 2017). At slaughter, A2-classed lamb carcasses receive the best or highest price per kilogram (Red Meat Producers Organisation, 2017). Because different sheep breeds mature at different rates and partition fat in different depots, to obtain an A2 carcass at slaughter, breeds would have to be slaughtered at different live weights. Hence, it is important to determine the ideal slaughter weight for each breed, which would result in the highest commercial value.

Previous studies have focused on the efficiency of finishing and the slaughter characteristics of sheep under various conditions. The focus of this study was to describe the trends in fat deposition of South African lamb genotypes with an increase in the finishing period. These trends could then be used to inform lamb producers how long they should rear their slaughter lambs to ensure maximum profitability. The objective of this study was thus to determine the effect of the length of time spent in a feedlot on the size of the various fat depots and the distribution of the main tissues (muscle, bone, and fat) in Merino, South African Mutton Merino (SAMM), and Dorper lambs. However, as the feedlot conditions (year, age at entry into feedlot, and production site) differed between the production groups, no comparisons were made between breeds.

Materials and Methods

Ethical clearance for this study was obtained from Stellenbosch University Research Ethics Committee: Animal Care and Use (Ref: 11LV_VAN02). In this study, Merino, SAMM and Dorper lambs were obtained from the research flocks of the Western Cape Department of Agriculture and were housed under feedlot conditions for five finishing periods. In year 1 (y1), 113 Merino lambs, 29 Dorper lambs and 126 SAMM freshly weaned lambs were housed under feedlot conditions at Elsenburg Research farm. In year 2 (y2), data were collected from an additional 105 SAMM freshly weaned lambs housed at the same facility. The weaning ages of the Merino, SAMM y1, SAMM y2, and Dorper lambs were 109, 122, 140 and 127 days old, respectively. Under feedlot conditions, the lambs were supplied a finisher diet (Table 1) *ad libitum* and had free access to water during the trial period. The feedlot production characteristics of the lambs were described by Brand *et al.* (2017).

The lambs in each of the production groups were randomly divided into six slaughter groups at the start of the feedlot trial. The slaughter groups for each breed contained the same number of lambs in each group (19, 21, 18, and 5 lambs for the Merino, SAMM y1, SAMM y2, and Dorper breeds, respectively). The initial (day 0) group was not housed in the feedlot and the lambs were slaughtered at weaning, to set a baseline for the study. Then a group of lambs was slaughtered at five intervals every 21 days. The last group of lambs was slaughtered after approximately 105 days under feedlot conditions. Restrictions in the slaughtering of lambs imposed by the abattoir because of the imminent festive season resulted in the last two groups of Merino lambs being slaughtered after 77 and 98 days in the feedlot rather than after 84 and 105 days respectively.

Each slaughter group was weighed 24 hours prior to slaughter. This weight was used as the final slaughter weight. The lambs were then transported to a nearby abattoir where they stood in lairage for approximately 18 hours. At slaughter, lambs were rendered unconscious by electrical stunning (200 V for 4

seconds) and slaughtered using standard South African techniques as described by Cloete *et al.* (2007). During evisceration, the visceral and renal fat was removed directly after slaughter, weighed, and expressed as a percentage of the slaughter weight. Carcass dressing and classification, according to age and backfat thickness (Government Notice R. 863 of 2006) by an independent trained experienced carcass classifier was completed 20 minutes post mortem and the carcasses were hung in random order in the cooler one hour post mortem. On the following day, the carcasses were transported to a deboning facility and kept in a cooler for another 24 hours prior to sampling. Cold carcass weight was determined 48 hours post mortem, when the core temperature of the carcasses was about 3.7 ± 0.11 °C. At the deboning facility, carcasses were divided into commercial cuts. During this butchery of the carcass, samples taken from the prime rib and loin cuts from the left side of the carcass were taken for further analysis.

Table 1 Ingredient and nutrient composition of trial feed (Brand *et al.*, 2017)

Ingredients	As fed (g/kg)
Lucerne hay	485.06
Maize	394.90
Cottonseed oilcake	57.90
Molasses powder	25.00
Salt	10.00
Urea	5.00
Ammonium sulphate	5.00
Slaked lime	5.00
Ammonium chloride	5.00
Limestone	5.00
Mono calcium phosphate	2.14
<i>Total</i>	<i>1000.00</i>
Nutrients*	As fed
Metabolizable energy (MJ ME/kg feed)	9.41
Crude protein (g/kg)	160.0
Non-degradable protein (g/kg)	34.6
Rumen degradable protein (g/kg)	125.4
Total digestible nutrients (g/kg)	630.0
Crude fibre (g/kg)	160.9
Acid detergent fibre (g/kg)	209.8
Neutral detergent fibre (g/kg)	286.8
Calcium (g/kg)	14.7
Phosphorous (g/kg)	30.0

* Nutrient composition of feed determined by standard laboratory techniques as outlined by AOAC (2002)

The loin cut was taken from the posterior end of the 13th rib of the carcass, following the spine up to the region directly below the rump, between the 3rd and 4th lumbar vertebrae. The *Longissimus lumborum* (LL) muscle excised from this cut was used to measure the subcutaneous fat (SCF) depth at the positions of the 13th rib (Gilmour *et al.*, 1994) and between the 3rd and 4th lumbar vertebra (Cloete *et al.*, 2007). An electronic calliper was placed at both positions, 25 mm from the midline of the spine, to determine fat depth. A three-rib cut was made on the prime rib to include the 9th, 10th and 11th ribs, which extended from the vertebra, following the curvature of the ribs, to the point where the plane of the ribs starts to curve inward. The cut was made cranial to the rib bone of the 9th and 12th ribs. This cut was dissected into muscle, bone and fat and was expressed as a percentage of the whole cut to predict carcass composition (Hankins & Howe, 1946).

As the lambs from the various breeds or production years were not housed together and slaughtered at the same time, comparisons could not be made between the production groups. However, because each

production group was housed under similar conditions, with varying lengths in the feedlot, comparisons were made between the slaughter groups within groups. Differences in fat deposition and carcass composition were tested for each production group by subjecting the data to a one-way analysis of variance using the Proc GLM method of SAS (2006). Linear regressions were developed for carcass composition as well as fat score to describe the changes over time for each of the groups (SAS, 2006). Because the slaughter groups contained different numbers of animals, the results were then expressed as least square means (LSM) with the accompanying standard error (s.e) to compensate for the unbalanced number of measurements.

Results

Lambs used in this experiment had little to no movement for exercise, and received a high energy diet (Table 1). This resulted in increased growth which led to an increase in carcass fat deposition for all production groups with time spent in the feedlot. A similar trend was reported by Crouse *et al.* (1981) with lambs receiving a high-energy diet.

All of the breeds displayed similar trends for the change of carcass weight, abdominal fat and subcutaneous fat depth with time spent in the feedlot (Table 2). However, the rate at which these characteristics increased was dependent on breed. Therefore, these fat deposition characteristics are described for each breed separately.

Carcass weights of the Merino lambs increased with time spent in the feedlot, with the lightest carcass weight being obtained at 0 days in the feedlot (11.8 kg), while the heaviest carcasses were obtained when lambs were reared for 77 and 98 days in the feedlot (21.9 kg and 22.0 kg, respectively). The fat removed from the abdominal cavity also increased with time spent in the feedlot ($P < 0.05$), with the yields of visceral and renal fat being 0.4% of the slaughter weight at 0 days in the feedlot. In lambs slaughtered at the end of the 98-day feeding period, visceral fat was seen to contribute 2.2% to bodyweight and renal fat 2.0%. Subcutaneous fat depth of the LL muscle also showed a general increase with time spent in the feedlot ($P < 0.05$). At the position of the 13th rib, SCF depth was lowest at 0 days in the feedlot (0.7 mm), which increased to 2.0 and 2.9 mm after 21 and 42 days in the feedlot. The fat depths of Merino lambs reared for 63, 77, and 98 days were higher ($P < 0.05$) than those of the earlier production periods (5.0, 5.6 and 5.9 mm, respectively). At the SCF depth measured between the 3rd and 4th lumbar vertebrae (fat depth 2), the lowest fat depth was measured in lambs slaughtered at 0 days (0.6 mm), while the highest levels of fat were recorded in lambs fed for 63 and 98 days (6.3 and 7.6 mm, respectively).

With the SAMM y1 production group, carcass weights of lambs increased from 15.8 kg at 0 days in the feedlot to 19.1 kg after 21 days in feed. Lambs slaughtered after 42 and 63 days in feed delivered carcasses of 22.5 and 24.7 kg, respectively, with the heaviest carcasses being obtained by lambs slaughtered after 84 and 105 days in feed (29.1 and 31.6, respectively). At day 0, the visceral and renal fat depots each weighed 0.5% of bodyweight. The highest level of visceral fat was obtained by lambs slaughtered after 63, 84, and 105 days in the feedlot (1.3, 1.5, and 1.3%, respectively). The percentage renal fat increased with number of days in the feedlot ($P < 0.05$), with the greatest yield of 2.7% being recorded in lambs slaughtered after 105 days. SCF depth was similar for the 0-day and 21-day production groups, at both measurement sites (fat depth 1): 3.5 and 3.9 mm; fat depth 2): 2.2 and 3.2 mm, respectively). The fat depths at both sites then showed a general increase with time spent in the feedlot, with the highest fat depths being observed in the group slaughtered after 105 days (12.3 and 12.0mm for fat depths 1 and 2, respectively).

The lowest carcass weights for the SAMM y2 lambs were again obtained by lambs slaughtered at days 0 and 21 (13.7 and 17.1 kg), while the highest ($P < 0.05$) carcass weights were obtained by lambs slaughtered at days 63, 84, and 105 (24.9, 24.3, and 26.8 kg, respectively). Following this trend, the lowest levels of visceral fat were recorded at days 0 and 21 (0.5%), while higher levels were recorded at days 63, 84 and 105 (1.0, 1.3, and 1.0%, respectively). The percentage of renal fat did not differ significantly between the first three production periods, with higher ($P < 0.05$) levels of renal fat being observed at days 63, 84, and 105 (1.6, 1.5, and 1.8%, respectively). SCF again showed an increase with days in the feedlot at both measurement sites ($P < 0.05$). At fat depth 1, the lowest SCF depth was 1.6 mm at day 0, while the highest depth of 13.8mm was measured at day 105. At fat depth 2, the SCF depths of sheep slaughtered at days 0 and 21 did not differ (1.8 and 1.3 mm) ($P > 0.05$). This was lower than that of SAMM y2 lambs slaughtered at days 42, 63, and 84 (4.1, 4.9, and 9.3 mm, respectively), with the greatest fat depth of 13.0 mm recorded after 105 days in the feedlot.

With the Dorper lambs, the carcass weights of the groups slaughtered at days 0, 21, and 42 did not differ significantly (15.9, 18.2, and 21.0 kg, respectively). The carcass weights at day 63 did not differ from those of day 42 ($P > 0.05$), although the weights of the groups at days 63, 84, and 105 were heavier ($P < 0.05$) than the first two slaughter groups (26.0, 32.1, and 31.5 kg, respectively). A similar trend was observed for the change in yield of visceral fat, with the yields at days 84 (2.4%) and 105 (2.1%) being significantly greater than that at days 0, 21 and 42 (0.6, 1.1, and 1.0%, respectively). The yield of kidney fat

did not differ with days in feed ($P > 0.05$), with an average yield of 0.9%. At fat depth 1, the lowest levels of SCF were recorded at days 0 (1.1 mm) and 21 (4.1 mm) followed by day 42 (6.8 mm), while the greatest levels were recorded at days 63, 84, and 105 (12.3, 15.4, and 18.4 mm, respectively). At fat depth 2, the lowest SCF depth was recorded at day 0 (0.1 mm), followed by days 21 (5.8 mm), and 42 (5.6 mm) which was in turn followed by day 63 (10.9 mm) and 84 (15.7 mm) with the greatest depth of 20.4 mm being achieved at 105 days.

Table 2 Least square means (\pm SE) depicting the effect of number of days in the feedlot on the fat deposition of Merino, South African Mutton Merino (SAMM y1 and y2) and Dorper production groups

Breed	Days in feedlot	Cold carcass weight (Kg)	*Visceral fat (%)	*Renal fat (%)	#Fat depth 1 (mm)	#Fat depth 2 (mm)
<i>Merino</i>						
	0	11.8 ^d \pm 0.67	0.4 ^e \pm 0.12	0.4 ^e \pm 0.09	0.7 ^c \pm 0.50	0.6 ^e \pm 0.47
	21	14.9 ^c \pm 0.61	0.7 ^{de} \pm 0.12	0.8 ^c \pm 0.09	2.0 ^{bc} \pm 0.45	2.2 ^{de} \pm 0.43
	42	18.0 ^b \pm 0.60	1.2 ^{cd} \pm 0.12	1.2 ^{dc} \pm 0.09	2.9 ^b \pm 0.47	3.4 ^{cd} \pm 0.41
	63	20.5 ^{ab} \pm 0.61	1.7 ^{bc} \pm 0.12	1.5 ^{bc} \pm 0.09	5.0 ^a \pm 0.45	6.3 ^{ab} \pm 0.43
	77	21.9 ^a \pm 0.60	1.9 ^{ab} \pm 0.12	1.6 ^{ab} \pm 0.09	5.6 ^a \pm 0.44	4.8 ^{bc} \pm 0.41
	98	22.0 ^a \pm 0.60	2.2 ^a \pm 0.12	2.0 ^a \pm 0.09	5.9 ^a \pm 0.44	7.6 ^a \pm 0.41
<i>SAMM y1</i>						
	0	15.8 ^d \pm 0.67	0.5 ^d \pm 0.08	0.5 ^e \pm 0.11	3.5 ^d \pm 0.66	2.2 ^d \pm 0.45
	21	19.1 ^c \pm 0.67	0.6 ^{cd} \pm 0.08	0.8 ^{de} \pm 0.11	3.9 ^d \pm 0.66	3.2 ^d \pm 0.45
	42	22.5 ^b \pm 0.67	1.0 ^{bc} \pm 0.08	1.2 ^{cd} \pm 0.11	9.3 ^b \pm 0.66	5.4 ^c \pm 0.45
	63	24.7 ^b \pm 0.66	1.3 ^{ab} \pm 0.08	1.7 ^{bc} \pm 0.11	5.9 ^{cd} \pm 0.65	5.9 ^{bc} \pm 0.44
	84	29.1 ^a \pm 0.67	1.5 ^a \pm 0.08	2.0 ^b \pm 0.11	7.8 ^{bc} \pm 0.66	7.5 ^b \pm 0.45
	105	31.6 ^a \pm 0.68	1.3 ^{ab} \pm 0.08	2.7 ^a \pm 0.12	12.3 ^a \pm 0.67	12.0 ^a \pm 0.46
<i>SAMM y2</i>						
	0	13.7 ^d \pm 0.68	0.5 ^c \pm 0.07	0.6 ^c \pm 0.09	1.6 ^e \pm 0.55	1.8 ^{de} \pm 0.55
	21	17.1 ^c \pm 0.80	0.5 ^c \pm 0.08	0.7 ^c \pm 0.11	2.8 ^{de} \pm 0.65	1.3 ^e \pm 0.65
	42	21.4 ^b \pm 0.82	0.9 ^b \pm 0.08	1.1 ^{bc} \pm 0.11	5.2 ^{cd} \pm 0.67	4.1 ^{cd} \pm 0.67
	63	24.9 ^a \pm 0.80	1.0 ^{ab} \pm 0.08	1.6 ^a \pm 0.11	5.6 ^c \pm 0.65	4.9 ^c \pm 0.65
	84	24.3 ^{ab} \pm 0.83	1.3 ^a \pm 0.08	1.5 ^{ab} \pm 0.11	9.8 ^b \pm 0.67	9.3 ^b \pm 0.67
	105	26.8 ^a \pm 0.85	1.1 ^{ab} \pm 0.08	1.8 ^a \pm 0.12	13.8 ^a \pm 0.69	13.0 ^a \pm 0.69
<i>Dorper</i>						
	0	15.9 ^c \pm 1.85	0.6 ^c \pm 0.19	0.5 \pm 0.26	1.1 ^c \pm 1.95	0.1 ^d \pm 1.94
	21	18.2 ^c \pm 1.69	1.1 ^{bc} \pm 0.19	0.5 \pm 0.26	4.1 ^c \pm 1.78	5.8 ^{cd} \pm 1.76
	42	21.0 ^{bc} \pm 1.69	1.0 ^{bc} \pm 0.19	0.6 \pm 0.26	6.8 ^{bc} \pm 1.78	5.6 ^{cd} \pm 1.76
	63	26.0 ^{ab} \pm 1.88	1.8 ^{ab} \pm 0.21	1.0 \pm 0.29	12.3 ^{ab} \pm 1.98	10.9 ^{bc} \pm 1.96
	84	32.1 ^a \pm 1.69	2.4 ^a \pm 0.19	1.3 \pm 0.26	15.4 ^{ab} \pm 1.78	15.7 ^{ab} \pm 1.76
	105	31.5 ^a \pm 1.69	2.1 ^a \pm 0.19	1.2 \pm 0.26	18.4 ^a \pm 1.78	20.4 ^a \pm 1.76

^{a-e} means in a column per breed with different superscript letters differ ($P < 0.05$)

*Calculated as a % of cold carcass weight

#The subcutaneous fat depth between the 3rd and 4th lumbar vertebra was denoted 'Fat depth 1', and the fat depth at the 13th rib was denoted 'Fat depth 2'

Current market trends reveal that lambs with no permanent incisors that are classed with a fat score of 2 or 3 (A2 or A3) achieve the highest value at slaughter (Red Meat Producers Organisation, 2017). Carcass classification was performed at the abattoir by a trained experienced carcass classifier according to national guidelines (Government Notice R. 863 of 2006). The frequency distributions for each fat class in each slaughter group are shown in Table 3. With the Merino lambs, the highest frequency of carcasses with a fat score of 2 was observed after 21 (72.2%) and 42 (89.5%) days. At days 42 and 63, all the Merino lambs

attained a fat class of 2 or 3. After 77 and 98 days in feed it was observed that more than 27% of the lambs slaughtered were classed as over-fat or obese (fat score 5 or 6). The lambs slaughtered in the 0, 21, and 42-day groups from the SAMM y1 production group had the highest frequency of fat class 2 carcasses (71.4, 76.2 and 61.9%, respectively). More than 44% of SAMM y1 lambs slaughtered after 63 days in the feedlot were classed as overfat, and after 105 days, all the lambs were classed as obese. In the SAMM y2 production group, the highest frequencies of A2 carcasses were seen at 21 days (94.1%). In the groups of SAMM y2 lambs slaughtered at 0, 21 and 42 days, more than 50% of the carcasses were classed as A2 or A3. The highest frequencies of obese SAMM y2 carcasses were seen at days 63, 84, and 105 (52.9, 75.0, and 73.3%, respectively). With the Dorper lambs slaughtered at day 0, 40% of the carcasses obtained a fat score of 1, while the remaining 60% were in classes A2 or A3. The carcasses of lambs slaughtered at 21 and 42 days all fell within the A2–A3 fat class range. However, at days 63, 84, and 105, all the carcasses were classed as being obese with a fat score of 6.

Table 3 Percentage distribution of fat classification scores, from 0 (extremely lean) to 6 (obese), for the Merino, South African Mutton Merino (SAMM y1 and y2) and Dorper lamb carcasses at slaughter after varying feedlot finishing periods

Breed	Days in the feedlot	Fat class distribution (%)						
		0	1	2	3	4	5	6
<i>Merino</i>								
	0	30.0	45.0	25.0	.	.	.	.
	21	5.6	22.2	72.2	.	.	.	.
	42	.	.	89.5	10.5	.	.	.
	63	.	.	57.9	42.1	.	.	.
	77	.	.	33.3	22.2	16.7	.	27.8
	98	.	.	5.3	21.1	26.5	21.1	26.3
<i>SAMM y1</i>								
	0	9.5	14.3	71.4	4.8	.	.	.
	21	.	4.8	76.2	19.1	.	.	.
	42	.	.	61.9	38.1	.	.	.
	63	.	.	4.6	18.2	31.8	22.7	22.7
	84	.	.	4.8	9.5	9.5	4.8	71.4
	105	.	.	.	.	.	.	100
<i>SAMM y2</i>								
	0	13.0	34.8	52.2	.	.	.	.
	21	.	.	94.1	5.9	.	.	.
	42	.	.	25.0	25.0	31.2	12.5	6.3
	63	.	.	11.8	23.5	11.8	.	52.9
	84	.	.	.	6.3	18.7	.	75.0
	105	.	.	.	6.7	20.0	.	73.3
<i>Dorper</i>								
	0	.	40.0	40.0	20.0	.	.	.
	21	.	.	40.0	60.0	.	.	.
	42	.	.	60.0	40.0	.	.	.
	63	.	.	.	.	.	.	100
	84	.	.	.	.	.	.	100
	105	.	.	.	.	.	.	100

The three-rib cut was used to determine the relative proportions of bone, lean muscle and fat in the lamb carcasses. Table 4 shows the general trend for the major tissues was for the level of fat to increase, while bone and lean muscle decreased. In Merino lambs, the highest proportion of lean muscle was observed at day 0 (52.8%), with the lowest levels of lean being observed in samples from days 77 (38.3%) and 98 (39.0%). The proportion of bone also decreased with time ($P < 0.05$). The proportion of bone was highest in the three rib cuts from day 0 lambs (30.2%), followed by day 21 lambs (23.9%), while the lowest proportion was seen at the end of the study at 98 days (19.4%). Alternatively, the highest proportions of fat were observed at days 77 and 98, while that at days 0 and 21 were the lowest (41.4, 40.5, 16.4, and 27.6%, respectively) ($P < 0.05$). Linear regressions were developed in order to describe the change in carcass tissues of Merino lambs with time spent in the feedlot for lean ($Y = 51.836 - 0.1465x$; $R^2 = 0.93$), bone ($Y = 27.830 - 0.0993x$; $R^2 = 0.84$), and fat ($Y = 20.028 + 0.2424x$; $R^2 = 0.90$) tissues, where x represents the number of days in the feedlot in each of the equations.

Table 4 Effect of number of days under feedlot conditions on the composition of the main tissues in the lamb carcass, as predicted by the three-rib cut for the Merino, South African Mutton Merino (SAMM y1 and y2) and Dorper production groups

Breed	Days in feedlot	Tissue yield		
		Lean muscle (%)	Bone (%)	Fat (%)
<i>Merino</i>				
	0	52.8 ^a ± 1.38	30.2 ^a ± 1.15	16.4 ^d ± 1.77
	21	48.0 ^{ab} ± 1.26	23.9 ^b ± 1.05	27.6 ^c ± 1.61
	42	45.2 ^b ± 1.22	22.4 ^{bc} ± 1.02	32.3 ^{bc} ± 1.57
	63	43.5 ^{bc} ± 1.26	21.1 ^{bc} ± 1.05	34.9 ^{ab} ± 1.61
	77	38.3 ^c ± 1.22	20.1 ^{bc} ± 1.02	41.4 ^a ± 1.57
	98	39.0 ^c ± 1.22	19.4 ^c ± 1.02	40.5 ^a ± 1.57
<i>SAMM y1</i>				
	0	49.9 ^a ± 1.01	22.9 ^a ± 0.75	26.2 ^d ± 1.39
	21	47.8 ^a ± 1.01	21.4 ^a ± 0.74	30.7 ^d ± 1.38
	42	41.5 ^b ± 1.01	20.1 ^a ± 0.75	38.4 ^c ± 1.39
	63	37.9 ^{bc} ± 0.99	16.6 ^b ± 0.73	45.0 ^b ± 1.36
	84	36.0 ^c ± 1.01	16.4 ^b ± 0.74	47.6 ^{ab} ± 1.38
	105	31.3 ^d ± 1.03	15.1 ^b ± 0.76	53.4 ^a ± 1.41
<i>SAMM y2</i>				
	0	52.4 ^a ± 1.51	26.7 ^a ± 0.84	20.8 ^b ± 1.77
	42	40.6 ^b ± 1.84	17.8 ^b ± 1.02	41.6 ^a ± 2.15
	63	37.5 ^b ± 1.79	17.0 ^b ± 0.99	45.5 ^a ± 2.10
	84	35.5 ^b ± 1.86	17.4 ^b ± 1.03	47.1 ^a ± 2.18
	105	34.5 ^b ± 1.92	16.7 ^b ± 1.06	48.8 ^a ± 2.24
<i>Dorper</i>				
	0	51.3 ^a ± 2.23	23.8 ^a ± 2.28	24.5 ^b ± 2.72
	21	47.6 ^{ab} ± 2.03	19.4 ^{ab} ± 2.07	32.7 ^b ± 2.48
	42	45.9 ^{ab} ± 2.03	23.2 ^a ± 2.07	30.4 ^b ± 2.48
	63	38.2 ^{bc} ± 2.26	14.1 ^c ± 2.31	47.5 ^a ± 2.76
	84	29.4 ^c ± 2.03	13.4 ^c ± 2.07	57.2 ^a ± 2.48
	105	33.4 ^c ± 2.03	15.8 ^{bc} ± 2.07	50.2 ^a ± 2.48

^{a-e} Means in a column per breed with different superscript letters differ ($P < 0.05$)

Dissected three-rib cuts of SAMM y1 lambs showed that the highest proportion of lean muscle was seen at days 0 (49.9%) and 21 (47.8%), while the lowest levels were seen at days 77 (38.3%) and 98 (39%). The proportion of bone in the cuts was higher in samples from days 0, 21 and 42 than in days 63, 84, and 105 ($P < 0.05$). The proportion of fat was lowest at days 0 and 21 (26.2 and 30.7%), while the highest proportion of fat was seen at day 105 (53.4%). Again, equations were developed to describe the change in tissue composition of SAMM y1 lambs for lean ($Y = 50.135 - 0.1792x$; $R^2 = 0.98$), bone ($Y = 22.869 - 0.0784x$; $R^2 = 0.96$), and fat ($Y = 26.419 + 0.2630x$; $R^2 = 0.97$) tissues, where x represents the number of days in the feedlot.

In the SAMM y2 lambs at day 0, the proportions of lean muscle (52.4%) and bone (26.7%) were higher ($P < 0.05$) (52.4%) than at any of the other production intervals, which did not differ from each other ($P > 0.05$), for each respective tissue. Conversely, the proportion of fat was lower ($P < 0.05$) at day 0 (20.8%) than at any of the other slaughter intervals, which did not differ ($P > 0.05$). Appropriate linear regressions ($P < 0.05$) were fitted to the changes in tissue yields of SAMM y2 lambs, to describe the relative change in lean muscle ($Y = 50.201 - 0.1716x$; $R^2 = 0.91$), bone ($Y = 24.421 - 0.0902x$; $R^2 = 0.73$), and fat ($Y = 25.376 + 0.2618x$; $R^2 = 0.85$) tissue, where x represents number of days in the feedlot.

The highest proportion of lean muscle for Dorper lambs was observed at day 0 (51.3%), followed by days 21 (47.6%) and 42 (45.9%), which in turn was greater than that at day 63 (38.2%), with the lowest lean tissue yields being observed at days 84 (29.4%) and 105 (33.4%). The highest yields of bone were observed at days 0, 21, and 42 (23.8, 19.4, and 23.2%, respectively), while the lowest were recorded for lambs slaughtered at days 63, 84, and 105 (14.1, 13.4, and 15.8%, respectively). The proportion of fat did not differ ($P > 0.05$) between days 0, 21, and 42 (24.5, 32.7, and 30.4%, respectively). However, this was lower ($P < 0.05$) than that recorded at days 63, 84, and 105 (47.5, 57.2, and 50.2%, respectively), which in turn did not differ from each other ($P > 0.05$). The relative decrease of lean muscle and bone tissues were described by the equations: proportion lean = $51.802 - 0.2069x$ ($R^2 = 0.88$) and proportion bone = $23.080 - 0.0913x$ ($R^2 = 0.63$); while the relative increase of fat tissue was given by proportion fat = $24.781 + 0.2977x$ ($R^2 = 0.82$).

The fat score of a carcass, determined by the Agricultural Product Standards Act 119 of 1990 (Government Notice R. 863 of 2006), is used as an indicator of the degree of fatness of the carcass. Linear regressions were developed to quantify the degree of fatness for each fat score for each of the production groups (Table 5). The regression for predicting carcass fat of Merino lambs had a moderate coefficient of determination ($R^2 = 0.47$). This may be because in the later slaughter groups, when the highest levels of fat were observed (Table 4), less than 30% of the carcasses were classed as excessively fat (Table 3). This results in a lack of observations at the top end of the scale, which influenced the slope of the regression. Thus, to improve the accuracy of prediction, more observations of excessively fat Merino lambs, slaughtered at a higher live weight, would be needed. The R^2 coefficients of determination for prediction of carcass fat from fat score of SAMM y1, SAMM y2, and Dorper lambs were found to be moderate to high.

Table 5 Linear regressions describing change in proportion of carcass fat (predicted by three-rib cut) with the classification of the carcass at the abattoir for Merino, South African Mutton Merino (SAMM y1 and y2) and Dorper lambs

Production group	Regression equation	R^2
Merino	$Y = 21.559 + 4.386x$	0.47
SAMM y1	$Y = 20.113 + 5.451x$	0.75
SAMM y2	$Y = 18.788 + 5.508x$	0.69
Dorper	$Y = 14.796 + 6.231x$	0.86

Where x is fat score (0-6) (Government Notice R. 863 of 2006)

Currently in the South African red meat industry, lamb carcasses that have been classed as A2 possess the highest commercial value. Because different breeds exhibit different levels of fat deposition at different ages, it is necessary to determine the ideal slaughter weight, which would result in the highest commercial value of the carcass. The slaughter results of A2 lambs of each breed over all the feeding periods were combined to give the average slaughter characteristics of A2 lambs for each breed. Table 6 shows that the ideal slaughter weight for Merino and SAMM lambs would be ~42.7 kg, while Dorper lambs would have to be slaughtered at a lighter weight (~36.0 kg). The dressing percentage of Dorper lambs at this

weight would be about 47.9%, while the dressing percentage of A2 Merino and SAMM lambs would be 42.5% and 45.5%, respectively. The SCF depth of A2 Merino lambs would be expected to be ~3.5 mm and range from 2.7 to 4.3 mm between the ribs and the rump for SAMM lambs. The fat depth for A2 Dorper lambs would then be expected to be 2.6-2.9 mm (Table 6).

Table 6 Least square means (\pm standard error) for carcass characteristics of A2 graded carcasses from Merino, South African Mutton Merino (SAMM y1 and y2) and Dorper lambs

Trait	Merino	SAMM	Dorper
Slaughter weight (kg)	42.7 \pm 0.81	42.7 \pm 0.81	36.0 \pm 1.51
Carcass weight (kg)	18.2 \pm 0.41	18.0 \pm 0.33	17.2 \pm 0.82
Dressing percentage (%)	42.5 \pm 0.28	45.5 \pm 0.21	47.9 \pm 0.86
Fat depth 1 (mm)	3.4 \pm 0.19	2.7 \pm 0.17	2.9 \pm 0.59
Fat depth 2 (mm)	3.5 \pm 0.28	4.3 \pm 0.36	2.6 \pm 0.66

Discussion

Total body fat and its deposition in the various fat depots affects the classification of a carcass and plays a major role in deciding the optimal age or weight to slaughter an animal (Mtenga *et al.*, 1994). As the slaughter weight of an animal increases, it is accompanied by changes in the carcass composition, with a decrease in the proportion of muscles and an increase in the proportion of fat, including kidney and channel fat (Santos-Silva *et al.*, 2002). Increasing the energy content of the diet results in an increase in the level of fat deposition, including in the visceral and renal fat depots (Ebrahimi *et al.*, 2007). In this investigation, the percentage of carcass fat in all depots increased throughout the production periods for all breeds, which was enhanced by the restricted movement along with the high energy diet. Visceral and kidney fat in lamb carcasses increased as the slaughter weight and age of lambs increased, which was also observed by Santos-Silva *et al.* (2002) and by Barone *et al.* (2007). In Merino and Dorper carcasses renal fat deposition (Table 2) occurred at a slower rate than visceral fat, which can be explained by a study by Teixeira *et al.* (1989), who concluded that the renal fat depot developed at a later stage than the visceral fat depot. However, fat deposition in the SAMM production groups differed somewhat, in that the percentage of renal fat in the carcasses was higher than that of visceral fat, indicating that the renal fat depot may develop earlier in SAMM lambs.

According to Lawrie and Ledward (1998), the high SCF depth observed in the Dorper lambs can be explained by the early maturing characteristics that can be associated with the breed, which tends to deposit fat readily (Cloete *et al.*, 2007). This effect is amplified by intensive feeding regimes (Claasen, 2008). Fourie *et al.* (2009) found that Dorper lambs had a SCF depth of 1.32–1.57 mm after 35 days in a feedlot. Cloete *et al.* (2007) found that the SCF depth of Dorper lambs slaughtered at 43 kg was ~2.16 mm, while crossbred lambs from SAMM and Merino sires had a significantly thinner fat depth. The SAMM breed tends to deposit SCF at a relatively slower rate (Neser *et al.*, 2000; Cloete *et al.* 2004) than the early maturing Dorper breed. The Merino is a leaner and later maturing breed, and so would deposit fat at a slower rate than other meat sheep breeds. As these three breeds have been bred for different purposes, it is expected that each breed would exhibit a different pattern of development and fat deposition, depending on the selection pressures to which it had been exposed. Abdominal fat is generally removed during slaughter, and has little influence on the value of the carcass. However, it serves as an energy store for sheep during nutritional stress (Negussie *et al.*, 2003). The relative proportions of the major carcass tissues are of greater significance in determining the quality and value of the carcass, and so it is necessary to predict the carcass composition of the growing lambs.

Although the most accurate method of predicting carcass composition still consists of grounding and analysing a whole (or half) carcass, this method is seldom used as it is time consuming, expensive and difficult. Nor is it economically viable, because half of the carcass cannot be marketed (Paulino *et al.*, 2005). Hankins & Howe (1946) found significant correlations when predicting the total fat ($r = 0.91$), total bone ($r = 0.53$), and total muscle ($r = 0.83$) of a beef carcass using the three-rib cut. This method was thus applied in this study to determine the carcass composition of lambs and predict the proportion of lean muscle, bone and fat. For each of the production groups, the proportions of lean muscle and bone decreased, while fat increased as the lambs were slaughtered at heavier live weights (Table 3). The age of the animal, or length

of the finishing period, thus influenced the yields of muscle, bone, and fat the carcasses for Merino, SAMM and Dorper lambs. The main production effects that have been found to result in differences in the proportions of muscle, bone and fat are the level of nutrition, age of maturity and slaughter weight (Murphy *et al.*, 1994; Johnson *et al.*, 2005). As was seen in this study, the lambs consumed an energy-dense diet as they grew to maturity in the prolonged feeding periods, promoting higher levels of fat deposition as they increased in live weight. The relative order of tissue development of an animal is bone, followed by muscle and then fat (Butterfield, 1988). Fat is a late maturing tissue. Therefore, there is increased fat deposition in older animals (Goliomytis *et al.*, 2006), which explains the higher proportion of fat in the carcasses slaughtered at the end of the production period. During the growth of an animal, when feed is not limiting, fat deposition shows a disproportional increase as the live weight of the animal increases (Murphy *et al.*, 1994). This relative increase in fat deposition in older lambs is negatively correlated with the change in the proportion of bone and muscle tissues. As the proportion of fat increases, the proportion of bone is seen to decrease drastically, while, the proportion of muscle decreases at a slower rate (Table 4). A higher muscle to bone ratio can be associated with a better body/carcass conformation (Santos-Silva *et al.*, 2002). As the sheep grow, it is expected that the body conformation would change, with increased musculature giving a more rounded carcass shape, particularly at the rump region (Butterfield, 1988). The relative muscle to bone proportion ratio for all breeds remained at ~2:1 for each slaughter age group, indicating a favourable proportion of muscle. This indicates that the absolute lean muscle contribution increased with carcass weight, with the higher proportions of fat also accounting for greater conformation of lambs reared for longer periods. Useful regressions were developed in this study, which can be used to predict the proportions of the major carcass tissues for the various breeds with reasonable to high accuracy. The linear regressions describing the change of the proportion of carcass tissues for each of the breeds were found to be significant with high coefficients of determination (R^2). This indicates that over the entire production period, the sheep from each breed were still in the phase of linear growth and had not reached their mature mass on the sigmoidal growth curve. If the lambs had been reared for additional periods nearing maturity, nonlinear models would then have been more appropriate to predict carcass composition of the lambs. Goliomytis *et al.* (2006) showed similar trends with varying rates, for the change in tissue composition of Karagouniko sheep, when dissecting the tissues from the carcass cuts. Burger *et al.* (2013) also dissected the major tissues of the major carcass cuts, and observed that the percentage lean meat in Dorper and SAMM lambs was about 51.3%, with fat percentages of 13.9% (Dorper) and 12.5% (SAMM) at 35 days post weaning. These proportions differ from those seen in the corresponding SAMM and Dorper lambs slaughtered at 21 and 42 days, as these lambs were reared in the feedlot on a concentrate diet owing to higher levels of fat, and relatively less lean meat. The lambs used by Burger *et al.* (2013), however, were reared on pasture, resulting in lower levels of fat and relatively higher proportion of lean.

According to Hall *et al.* (2015), A2 lamb carcasses consist of about 66.2% meat, 13.2% fat, and 20.2% bone, while mutton carcasses (C2) consist of about 62.7% meat, 17.0% fat and 20.3% bone when dissecting the tissues of one half of the carcass. These values differ from those of the current study because different cuts were dissected and only fat score 2 lamb carcasses were used, so one would not expect to see large differences in the composition of the carcass tissues, particularly fat. As is expected with older animals, the proportion of meat decreased, and the proportion of fat tissue increased in mutton carcass (Berg & Walters, 1983). This is important to consider, as these yields affect the classification at slaughter, as well as the value of the carcass deemed by the processor or consumer. The rates at which the proportions of these tissues change over time for the various sheep breeds must thus be considered to ensure maximum profitability. The prediction equations mentioned earlier are then useful to predict the yields of the major carcass tissue for Merino, SAMM and Dorper lambs with time spent in the feedlot.

Carcass classification systems were developed to inform processors and consumers about the quality of the carcass and thus to distinguish its market value. Currently, lamb carcasses classed A2 obtain higher market values at slaughter (Red Meat Producers Organisation, 2017). The fat scores applied to lamb carcass classification range from 0, indicating an extremely lean carcass, to 6 which is regarded as excessively fat. The highest frequencies of A2 carcasses for Merino and Dorper lambs were achieved after feeding for 42 days and 21 days for both the SAMM production groups. Lambs began to be classed as over-fat (fat scores of 4 or higher) when Merino lambs were reared for 77 days, SAMM y2 after 42 days, and SAMM y2 and Dorper lambs after 63 days. The carcass fat scores were combined with the data from the three-rib cuts to develop prediction regressions to give an indication of the degree of fatness that can be associated with the fat score for the various breeds (Table 5), though the model derived for Merino lambs is regarded as less accurate, owing to the lower coefficient of determination ($R^2 = 0.47$). To improve the accuracy of this model, more data from excessively fat Merino lambs, classed A6, should be included to expand the upper limits of the fatness scale. Because Merino sheep are bred primarily for wool, they are regarded as a late maturing breed in terms of meat production and fat deposition. Therefore, Merino lambs

would have to be reared for extended periods to achieve high degrees of fatness, unlike Dorper lambs, which are known to be early maturing and deposit high levels of fat at an earlier age (Cloete *et al.*, 2000). Strydom *et al.* (2009) developed similar linear regressions for the increased SCF percentage with carcass fat score with high accuracy ($R^2 = 0.87$) for Dorper lamb carcasses. The high accuracy associated with these regressions is due to the SCF percentage being used in this instance, as the SCF cover is judged visually during fat classification, whereas in this study the fat class was used to predict the overall proportion of carcass fat (predicted by three-rib cut).

To present lamb producers with an indication of the ideal slaughter weight of lambs that would give a high value A2 carcass, the data from lamb carcasses that were classed A2 in this study were combined to provide the guidelines for the three sheep breeds. As expected, the ideal slaughter weight of Dorper lambs is lower than that of the SAMM or Merino lambs, owing to the inherent nature of the Dorper to deposit fat at an earlier age (Cloete *et al.*, 2000). The carcass weights of these A2 lambs are then expected to be ~17.2 kg, which resembles the carcass weights of A2 Dorper lambs reported by Strydom *et al.* (2009). At these carcass weights it is also expected that Merino and SAMM lambs would present abdominal fat levels of 2% of slaughter weight, with Dorper lambs obtaining slightly less abdominal fat. From the equations, it is predicted that A2 Merino and SAMM lamb carcass would consist of about 30% fat, while Dorper carcasses would consist of about 27% fat. This contradicts the findings of Hall *et al.* (2015), who reported that A2 carcasses consisted of 13.2% fat tissue, although different methods were used to determine tissue composition. It is proposed that producers should use these slaughter traits as a guideline for finishing lambs to obtain optimum market prices and prevent penalties at the abattoir because of excessive fat deposition. Meat consumers and processors could also use this information to predict the tissue composition and degree of fatness of the fat classes of various breeds.

Conclusion

In this study, a change in carcass tissue composition, particularly fat, was observed for Merino, SAMM and Dorper lambs. Because the selection pressures under which the breeds were developed determine meat production and fat deposition potential, it is important to know that the rate at which the proportions of carcass tissues develop would change. Because carcass fat is the main constituent in carcass classification and value, fat deposition trends for the different breeds in the fat depots should be known. These guidelines would then inform producers how to rear their slaughter lambs, avoiding overfeeding.

The trends shown in this study would aid sheep producers in determining an optimum finishing period for a breed to gain maximum profitability. At the same time, these trends would give processors and lamb consumers an indication of the degree of fatness and proportions of various tissues for carcasses within a fat class, which determines the value of the lamb carcass.

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Authors' contributions

Conception and design: TSB; data collection and analysis: EJvdW; drafting of paper: DAvdM; critical revision and final approval of version to be published: LCH.

Conflicts of interest

The authors certify that they have no affiliations with any organisation or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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