Sensory characteristics of meat and composition of carcass fat from sheep fed diets containing various levels of broiler litter

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Abstract

The effect of high levels of broiler litter in the diets of sheep on sensory characteristics and composition of fat in mutton was evaluated. Thirty-six South African Mutton Merino wethers weighing *ca*. 41 kg were randomly allocated to four treatment diets containing 0, 28, 56 or 85% broiler litter. All wethers were slaughtered at a target body mass of 55 kg. Dressing percentage was calculated and the composition of fatty acids in the subcutaneous fat was analysed. An analytical sensory panel evaluated sensory characteristics of carcass samples and loin sample characteristics. High sensory scores (7 out of 10) were obtained for all dietary treatments. Compared to the other treatments, a high inclusion level (85%) of broiler litter in the diet reduced (p < 0.05) the flavour and overall acceptability of sensory samples, decreased concentrations of myristic acid (C14:0) and margaric acid (C17:0) in subcutaneous fat and increased linolenic acid (C18:3) concentrations. It was concluded that the inclusion of broiler litter in diets for sheep at levels of up to 56% should not adversely affect the sensory characteristics of the meat, but higher inclusion levels might have a slight adverse affect on subcutaneous fat composition and sensory characteristics.

Keywords: sensory characteristics, broiler litter, sheep, fatty acid composition
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Introduction

As early as the 1950's poultry waste emerged as an alternative source of nitrogen for ruminants (Noland *et al*., 1955). In South Africa, strict legislative control exists over the trade in poultry litter for use as an animal feed. However, because the unregistered product is relatively cheap, South African farmers feed litter produced on-farm or procured as a fertiliser to livestock (Kitching, 1986). During periods of feed shortage, e.g. during droughts or when fires have destroyed large areas of natural grazing, high levels of litter are often fed (Mavimbela *et al*., 1997). In such emergency situations, farmers often have to reduce stock numbers on the farm and consequently, cattle and sheep that have been fed diets containing high levels of poultry litter may be slaughtered and enter the human food chain. Provided that certain precautionary measures are taken (e.g. by ensuring that the poultry did not receive any antibiotics or by enforcing a 15-day withdrawal period from the litter-containing diet before slaughter), the presence of drug residues in the litter that may contaminate meat appears to be minimal (Fontenot, 1991). Taste panels could not detect any sensory effect in the meat of steers consuming diets containing up to 50% broiler litter (Fontenot *et al*., 1971; Smith *et al*., 1979; Ben-Ghedalia *et al*., 1988). The composition of the ruminant diet may influence the flavour (Melton, 1990; Webb *et al*., 1997; Shand *et al*., 1998) or fatty acid composition (Webb *et al*., 1994; Shand *et al*., 1998; Webb *et al*., 1999) of red meat. High-energy grain diets produce a more intense flavour in red meats than low energy diets (Shand *et al*., 1998). In addition, the composition of fatty acids in meat affects the taste of meat (Webb, 1992; Webb *et al*., 1997; Shand *et al*., 1998; Webb *et al*., 1999). Offer & Offer (1994) associated a reduction in the degree of saturation of tissue and milk fat with the feeding of distillery by-products. Similarly, changes in the fatty acid composition of both bovine and ovine tissues were attributed to components in the diet and end-products in the digestive tract originating from the diet (Mills *et al*., 1992; Rule *et al*., 1994; Webb *et al*., 1994; Casey & Webb, 1995; Webb & Casey, 1995). The effect on carcass properties of feeding very high levels of broiler litter typical of an emergency feeding situation has not been investigated. In the present study the sensory characteristics and fatty acid composition of mutton from sheep fed diets containing up to 85% broiler litter were studied.

Materials and Methods

Thirty-six South African Mutton Merino wethers with a mean initial mass of 41 kg (18 months of age) were randomly allocated to one of four dietary treatments, *viz*. diets containing 0, 28, 56 or 85 % broiler litter (Table 1). Sun-dried broiler litter was sifted through a 2.5 cm sieve to remove lumps and foreign material. The wethers were vaccinated against botulinism and de-wormed with a broad-spectrum anti-helmintic five weeks prior to the start of the experiment. Vaccination was repeated one week before the start of the experimental period. The sheep were group-fed for most of the experimental period and had free access to water. On two occasions the sheep were placed in individual feeding pens for two-week periods to measure individual feed intakes and the digestibility of the diets. Feed intake was recorded daily. The sheep were weighed every two weeks. Sheep approaching the target mass were weighed weekly. The sheep were slaughtered on an individual basis upon reaching the target mass of 55 kg. Animals were slaughtered by exsanguination and severance of the spinal cord. Carcasses were electrically stimulated (21 V, 60 Hz, 120 sec.) and chilled overnight (4^{O} C) before cold carcass masses were recorded and samples collected.

Subcutaneous fat was sampled (5 g) from the left side of each carcass at a point over the 13th rib and 25 mm from the mid-line (Webb *et al*., 1994), and was stored in a polyethylene bag at -20^{O} C, pending fatty acid analyses. A three-rib sample was cut from the left side at ribs 8, 9 and 10 for dissection and estimation of carcass composition. The ventral extremity of the sample corresponded to a line drawn from the pubic symphysis to the middle of the first rib (Casey *et al*., 1988).

The left loin (*M. longissimus thoracis et lumborum*) was removed form each carcass, vacuum packed and stored at -20^{O} C pending sensory evaluation. Each sample was roasted in an oven at 160^{O} C on a rack in a roasting pan with the fat layer facing upwards until the internal temperature reached 70^{O} C. After roasting, each sample was removed from the oven, weighed and the *M. longissimus thoracis et lumborum* removed from the bone after 10 min. Fat was retained on the meat samples for evaluation, as the aroma and flavour typical of lamb are associated with subcutaneous fat. The eating-quality characteristics of the samples were evaluated by a trained, six-member analytical sensory panel using a 10-point unstructured scale. Panel members were screened and trained according to procedures outlined by AMSA (1978) and Cross *et al*. (1978). The following sensory quality attributes were evaluated: aroma intensity, juiciness, tenderness, flavour, overall acceptability and the presence of foreign odours and flavours. A value of 0 indicated the minimum (negative), and 10 the maximum (positive) presence of a characteristic, except in the case of foreign odour and flavour, where 10 indicated the absence of any taint. The criteria for sensory evaluation, as well as accompanying explanations, were presented to the sensory panel members during each session together with the evaluation form so that there could be no uncertainty regarding the meaning of the values allocated.

Extraction of lipids from subcutaneous fat samples was done according to the procedure described by Ways & Hanahan (1964) as modified by Webb *et al*. (1994). Methyl esters of the fatty acid component were prepared according to the NaOH/methanol method (AOAC, 1975), and separated on a polar phase SP2330 column (2 m x 3 mm, packed with Silar 10c coated on Gas chrom Q) fitted to a Varian 3700 gas chromatograph with a flame ionization detector (Webb *et al*., 1994). The dry matter, organic matter and crude protein concentrations in the diets were determined using standard AOAC (1990) procedures; neutral detergent fibre (NDF) and acid detergent fibre (ADF) concentrations were determined according to the procedure of Robertson & Van Soest (1981).

Differences between the means of dietary treatments were tested by means of multifactor analysis of variance, followed by multiple comparisons between dietary means using the Tukey-method (Steel & Torrie, 1980) which controls the experiment-wise error rate (in contrast with the least significant difference (LSD) method, which only controls the comparison-wise error rate). The GLM procedure of SAS (Statistical Analysis Systems, 1992) was used for these computations.

Results and Discussion

The wethers receiving the 85% litter diet gained very little mass during the first 37 days of the trial, but thereafter gained mass at rates similar to that of sheep in the other treatments. Average daily gains calculated over the entire experimental period did not differ significantly between treatments, although the 85% litter treatment took 155 days to reach the target slaughter mass compared to 106, 112 and 115 days for the 0, 28 and 56% litter treatments respectively (Table 1). Individual mean daily feed intake did not differ between treatments and was 1.63, 1.89, 2.26 and 1.68 kg/day for the 0, 28, 56 and 85% litter treatments respectively (Table 1).

Table 1 Composition of the diet, feed intake and days to slaughter of wethers fed different levels of broiler litter (mean ± SD)

Parameters	Broiler litter (%) in diet			
	0	28	56	85
Diet composition (%)				
Oat hay	40	32.5	16.6	-
Maize meal	31.1	23	12.4	-
Molasses	15	15	15	15
Sunflower meal	11.4	-	-	-
Urea	1	0.5	-	-
Broiler litter	-	28	56	85
Dicalcium phosphate	1	0.5	-	-
Salt	0.5	0.5	-	-
Feed composition and nutritive value				
Dry matter (%)	87	86	86	85
Crude protein (%)	14	13	16	21
Organic matter (%)	93	91	89	86
NDF* (%)	42	37	37	40
ADF** (%)	23	21	22	22
Ether extract (%)	2.4	2.3	2.4	2.4
Organic matter digestibility (%)	72 ± 3.1	67 ± 2.4	66 ± 2.6	60 ± 3.1
Estimated ME (MJ/kg DM)	11.2	10.5	10.3	9.4
Experimental animals				
Number of sheep	9	9	9	9
Initial live mass (kg)	41.02	40.76	40.82	39.98
Feed intake (g/d)	1628 ± 121	1893 ± 264	2258 ± 324	1678 ± 485
Days to slaughter	106	115	112	155

*NDF = Neutral detergent fibre, **ADF = Acid detergent fibre

Carcass mass, carcass composition, dressing percentage and thickness of subcutaneous fat did not differ significantly between treatments (Table 2). The small variation in the degree of fatness between wethers fed different diets was probably due to the fact that all sheep were slaughtered at a target mass of 55 kg. The thickness of subcutaneous fat from sheep fed the 0, 28, 56 and 85% litter diets was 2.22, 2.47, 3.26 and 2.84 mm respectively. The composition of long-chain fatty acids in subcutaneous fat is presented in Table 2. Inclusion of broiler litter in the diets reduced ($p < 0.03$) the proportion of myristic acid (C14:0) in subcutaneous fat from 2.97% (control treatment) to 2.38% (85% litter treatment). Similarly, the proportion of margaric acid (C17:0) in the subcutaneous fat of wethers consuming the 85% broiler litter diet was lower ($p < 0.04$), and linolenic acid (C18:3) higher ($p < 0.0001$) than that of the other treatments. It is well established that the composition of the diet (energy content, nature and kind of cereals used and processing) can change the fatty acid composition of ruminant tissues (Mills *et al*., 1992; Rule *et al*., 1994; Webb *et al*., 1994; Ojowi *et al*, 1997). This has been attributed to a dietary-induced shift in the relative proportions and peak concentrations of volatile fatty acids produced in the rumen (Duncan *et al*., 1974). Although the fat concentration of the diet can also influence the fatty acid composition of subcutaneous fat, the dietary fat concentrations in the present study were low and did not differ between dietary treatments (Table 1).

High sensory scores (7 on a scale of 0 to 10) were recorded for all treatments (Table 3). These scores correspond well with previous sensory scores obtained by the same taste panel for wethers fed normal feedlot diets (Webb *et al*., 1997; 1999). Aroma intensity did not differ significantly between treatments, but tended to decrease with increasing inclusion of litter in the diets. The juiciness score of loin samples from wethers fed the 85% litter diet was lower ($p < 0.05$) than that of wethers fed the other treatments. Ilian *et al*. (1988) recorded the highest juiciness scores in meat from sheep fed a diet containing 40% poultry litter compared to those fed at lower litter inclusion rates. These researchers suggested that the increased juiciness was associated with an increased carcass fat content. In the present study carcass fat content did not differ significantly between treatments (Table 2) and therefore could not have contributed to differences in juiciness.

Table 2 Dressing percentage, carcass mass, carcass composition and subcutaneous fatty acid content of wethers fed diets containing different levels of broiler litter (mean ± SD)

Parameters	Broiler litter (%) in diet			
	0	28	56	85
Carcass characteristics				
Dressing (%)	48 ± 2	49 ± 3	48 ± 6	47 ± 4
Carcass mass (kg)	26 ± 3	27 ± 5	26 ± 7	25 ± 4
Carcass composition (9-10-11 rib)				
% Lean	43 ± 0.80	46 ±0.82	45 ± 0.83	45 ± 1.05
% Fat	33 ± 1.9	30 ± 0.75	32 ± 1.5	32 ± 1.63
% Bone	24 ± 3.2	24 ± 0.39	23 ± 0.65	23 ± 0.71
Subcutaneous fat thickness (mm)	2.22	2.47	3.26	2.84
Fatty acid composition (molar %)[#]				
C14:0	3.0[a]	2.6[ab]	2.3[b]	2.4[b]
C15:0	0.28	0.36	0.27	0.36
C16:0	25.1	25.2	26.2	25.8
C16:1	2.6	2.8	2.7	2.6
C17:0	2.1[ab]	2.4[a]	2.1[ab]	1.9[b]
C18:0	20.0	18.3	18.0	18.5
C18:1	42.4	43.9	44.2	42.2
C18:3	3.3[a]	3.1[a]	3.1[a]	4.7[b]
C20:1	1.2	1.3	1.1	1.6

[ab]Means in the same row with different superscripts are significantly different ($p < 0.05$)
[#]Expressed as a proportion of identifiable fatty acids (unidentified peaks < 3%)

The tenderness of *M. longissimus thoracis et lumborum* samples from sheep fed the 85% litter diet was lower ($p < 0.05$) than that of sheep fed the 28 or 56% litter diets, but did not differ from that of the control samples. Ilian *et al*. (1988) reported that meat was more tender when up to 40% poultry litter was included in the diet of sheep than when no litter was included. In the present study, inclusion of 85% litter in the diet decreased ($p < 0.05$) the flavour of the sensory samples compared to samples from wethers fed the other diets (Table 3). Webb *et al*. (1997) found that a higher proportion of carcass fat and a thicker subcutaneous fat depth were associated with lower flavour scores in loin samples. They calculated that 31% of the variability in the flavour of the samples was due to the proportion of fat in the carcass. However, this difference in flavour could be related to the lower proportions of C14:0 and C17:0 and the higher proportion of C18:3 fatty acids in the carcass fat of the 85% litter treatment compared to the other treatments (Table 2). Another factor that is related to lower flavour scores is a high level of arsenic in the diet (Westing *et al*., 1985). Although the concentration of arsenic can be high in broiler litter (Westing *et al*., 1985), arsenic concentrations were not measured in the diets used in the present study, and require further study.

The carcasses of wethers fed the broiler litter diets tended to have lower fat firmness scores ($p < 0.065$) than those fed the the control diet (Table 3). A decline in fat firmness scores was observed when wethers consumed diets with high maize contents, that are associated with a high propionic acid concentration in ruminal fluid, compared to diets with a lower maize content (Webb *et al*., 1997). Likewise, processing of cereals, which is associated with an increased proportion of propionic acid in ruminal fluid, was found to decrease the firmness of subcutaneous fat in sheep (Ørskov *et al*., 1974; Webb *et al*., 1999). Fontenot & Jurubesco (1980) and Rossi *et al*. (1996) reported that the inclusion of litter in diets altered rumen fermentation towards increased propionic acid production. Poultry litter is a combination of fine manure powder and coarse bedding material; consequently, the effect of dietary litter inclusion on volatile fatty acid composition in the rumen will vary according to the ratio of these components.

Table 3 Sensory and loin sample characteristics of wethers fed different levels of broiler litter in the diet (mean ± SD)

Parameter	Broiler litter (%) in diet			
	0	28	56	85
Sensory characteristics[*]				
Aroma intensity	7.61 ± 0.46	7.58 ± 0.38	7.52 ± 0.57	7.41 ± 0.52
Juiciness	7.78 ± 0.50[a]	7.66 ± 0.56[a]	7.58 ± 0.65[a]	7.24 ± 0.60[b]
Tenderness	7.48 ± 0.67[ab]	7.61 ± 0.71[a]	7.70 ± 0.78[a]	7.27 ± 0.93[b]
Flavour	7.71 ± 0.43[a]	7.64 ± 0.45[a]	7.58 ± 0.45[ab]	7.45 ± 0.52[b]
Overall acceptability	7.65 ± 0.44[a]	7.61 ± 0.53[a]	7.55 ± 0.59[a]	7.23 ± 0.57[b]
Fat firmness (%)				
Firm	89[a]	67[b]	67[b]	78[c]
Soft	11	33	33	22
Fat:Muscle ratio (%)				
Little	56[a]	22[b]	22[b]	22[b]
Medium	44	67	78	56
Abundant	0	11	0	22
Taint (%)				
Typical	100	100	100	93.7
Atypical	0	0	0	6.3

[a,b,c]Means in the same row with different superscripts are significantly different ($p < 0.05$).
[*]A score of 0 indicates the minimum (negative) and 10 the maximum (positive) presence of a characteristic.

The taint of all meat samples from the 0, 28 and 56 % broiler litter treatments was classified as "typical", while 6.3% of the samples from the 85% litter diet were classified as "atypical" (Table 3). The taint of these samples was described as "sour". According to Melton (1990) and Shand *et al*. (1998), the composition of the ruminant diet may influence the flavour of red meat. Webb *et al*. (1994), Casey & Webb (1995) and Shand *et al*. (1998) observed that the composition of the diet also affected subcutaneous fatty acid composition. The "atypical" taint observed in this study may be due to the composition of the litter. However, the magnitude and cause of differences in flavour need to be confirmed in further studies.

The overall acceptability (Table 3) of loin samples tended to decrease with increasing levels of litter inclusion in the diets, with overall acceptability of the 85% litter treatment being lower ($p < 0.05$) than acceptability of the other treatments. A higher proportion of carcass fat and an increased thickness of subcutaneous fat were found to be associated with a decline in overall acceptability of loin samples (Webb *et al*., 1997). In the present study the thickness of the subcutaneous fat tended to increase with increasing level of litter inclusion and an increase in the number of days to slaughter, but these differences were not statistically significant ($p > 0.05$). The lower overall acceptability score recorded for the 85% litter treatment appears to be due mainly to the "atypical taint" ($p < 0.05$) and slight reduction in fat firmness scores ($p < 0.065$).

Conclusions

It was concluded that the inclusion of broiler litter at levels of 85% might induce slight detrimental effects on the sensory quality of meat. This seems to be mainly due to changes in fatty acid composition of carcass fat and an atypical flavour. However, in the event of an emergency feeding situation, mutton producers could include up to 56% broiler litter in the diet without affecting the eating quality of the mutton. In addition, the utilisation of broiler litter as an animal feed should be done in accordance with all other requirements for the feeding of the product, such as the prevention of the accumulation of drug residues in meat.

References

AMSA, 1978. Guidelines for cookery and sensory evaluation of meat. American Meat Science Association in cooperation with National Livestock and Meat Board, Chicago.

AOAC, 1975. Association of official analytical chemists. Official methods of analysis. AOAC, Washington, D.C.

AOAC, 1990. Association of official analytical chemists. Official methods of analysis. 15th Ed., AOAC, Washington, D.C.

Ben-Ghedalia, D., Miron, J., Est, Y. & Yosef, E., 1988. SO_2 treatment for converting straw into a concentrate-like feed: A growth study with lambs. Anim. Feed Sci. Technol. 19, 219-229.

Casey, N.H., Van Niekerk, W.A. & Spreeth, E.B., 1988. Fatty acid composition of subcutaneous and kidney fat of sheep grazed on eight different pastures. Meat Sci. 23, 55-63.

Casey, N.H. & Webb, E.C., 1995. Influence of dietary energy levels and form of the diet on the composition of fatty acids in the subcutaneous adipose tissue of wethers. Small Rum. Res. 18, 125-132.

Cross, H.R., Moen, R. & Stanfield, S., 1978. Training and testing of judges for sensory analysis of meat quality. Food Technol. 32, 48.

Duncan, W.R.H., Ørskov, E.R., Fraser, C. & Garton, G.A., 1974. Effect of processing of dietary barley and of supplementary cobalt and cyanocobalamin on the fatty acid composition of lamb triglycerides, with special reference to branched-chain components. Br. J. Nutr. 32, 71-75.

Fontenot, J.P., 1991. Recycling animal wastes by feeding to enhance environmental quality. Prof. Anim. Scientist. 7, 1-8.

Fontenot, J.P. & Jurubescu, V., 1980. Processing of animal waste by feeding to ruminants. In: Digestive Physiology and Metabolism in Ruminants. Eds. Ruckebusch, Y. & Thivend, P., M.T.P. Press Limited. pp. 641-662.

Fontenot, J.P., Webb, K.E., Harmon, B.W., Tucker, R.E. & Moore, W.E.C., 1971. Studies of processing, nutritional value and palatability of broiler litter for ruminants. Livestock Waste Management and Pollution Abatement. Proc. Int. Symp. Livestock Wastes. Columbus, Ohio. p. 301.

Ilian, M.A., Razzaque, M.A. & Salman, A.J., 1988. Unconventional feeds for sheep: Effects on performance and meat quality and composition. Biol. Wastes 24, 115-125.

Kitching, J.P., 1986. The uses and dangers of poultry litter feeding in cattle. S. Afr. Vet. Assoc. Biennial Congr. August, 1986.

Mavimbela, D.T., Van Ryssen, J.B.J. & Last, R., 1997. The effect of high broiler litter diets as survival ration on the health of sheep. J. S. Afr. Vet. Assoc. 68, 121-124.

Melton, S.L., 1990. Effects of feeds on flavour of red meat: A review. J. Anim. Sci. 68, 4421-4435.

Mills, E.W., Comerford, J.W., Hollender, R., Harpster, H.W., House, B. & Henning, W.R., 1992. Meat composition and palatability of Holstein and beef steers as influenced by forage type and protein source. J. Anim. Sci. 70, 2446-2451.

Noland, P.R., Ford, B.F. & Ray, M.L., 1955. The use of ground chicken litter as a source of nitrogen for gestating-lactating ewes and fattening steers. J. Anim. Sci. 14, 860-865.

Offer, J. & Offer, N.W., 1994. Distillery by-products for cattle. Feed Mix. 2, 14-17.

Ojowi, M., McKinnon, J.J., Mustafa, A. & Christensen, D.A., 1997. Evaluation of wheat-based wet distillers grains for feedlot cattle. Can. J. Anim. Sci. 17, 447-454.

Ørskov, E.R., Fraser, C. & Gordon, J.G., 1974. Effect of processing of cereals on rumen fermentation, digestibility, rumination time, and firmness of subcutaneous fat in lambs. Br. J. Nutr. 32, 59-69.

Robertson, J.B. & Van Soest, P.J., 1981. The detergent system of analysis and its application to human foods. In: The Analysis of Dietary Fibre in Food. Eds. James, W.P.T. &. Theander, O., Marcel Dekker, New York. pp. 123-158.

Rossi, J.E., Goetsch, A.L., Patil, A.R., Kouakou, B., Park, K.K., Wang, Z.S., Galloway, D.L. & Johnson, Z.B., 1996. Effects of forage level in broiler litter-based diets on feed intake, digestibility and particulate passage rate in Holstein steers at different live masses. Anim. Feed Sci. Technol. 62, 163-177.

Rule, D.C., Busboon, J.R. & Kercher, C.J., 1994. Effect of dietary canola on fatty acid composition of bovine adipose tissue, muscle, kidney and liver. J. Anim. Sci. 72, 2735-2744.

Shand, P.J., McKinnon, J.J. & Christensen, D.A., 1998. Eating quality of beef from animals fed wet brewers' grains and wheat-based wet distillers' grains. Can. J. Anim. Sci. 78, 143-146.

Smith, L.W., Calvert, C.C. & Cross, H.R., 1979. Dehydrated poultry excreta vs cottonseed meal as nitrogen supplements for Holstein steers. J. Anim. Sci. 48, 633-640.

Statistical Analysis Systems, 1992. SAS user's guide: statistics. S.A.S. Institute Inc., Cary, N.C.
Steele, R.G.D. & Torrie, J.H., 1980. Principles and procedures of statistics: a biometrical approach. McGraw-Hill, New York. pp. 633.
Ways, P. & Hanahan, D.J., 1964. Characterization and quantification of red cell lipids in normal man. J. Lipid Res. 5, 318-328.
Webb. E.C., 1992. The influence of dietary energy levels on subcutaneous fatty acid profiles and meat quality of sheep. MSc (Agric.) thesis. University of Pretoria.
Webb. E.C., 1994. Synthesis of long-chain fatty acids in ruminants and their effects on meat quality. PhD thesis, University of Pretoria.
Webb, E.C., Casey, N.H. & Van Niekerk, W.A., 1994. Fatty acids in the subcutaneous adipose tissue of intensively fed South African Mutton Merino and Dorper wethers. Meat Sci. 38, 23-131.
Webb, E.C. & Casey, N.H., 1995. Genetic differences in fatty acid composition of subcutaneous adipose tissue in Dorper and SA Mutton Merino wethers at different live masses. Small Rum. Res. 18, 81-88.
Webb, E.C., Bosman, M.J.C. & Casey, N.H., 1997. Influence of dietary presentation on the composition of fatty acids and sensory characteristics of meat from wethers. S. Afr. J. Food Sci. Nutr. 9, 69-76.
Webb, E.C., Casey, N.H. & Bosman, M.J.C., 1999. Dietary influences on lutein pigments and carcass fat quality in wethers of different maturity types. S. Afr. J. Anim. Sci. 29, 1-10.
Westing, T.W., Fontenot, J.P. & McClure, W.H., 1985. Characterization of mineral element profiles in animal waste and tissues from cattle fed animal waste. 1. Heifers fed broiler litter. J. Anim. Sci. 61, 670-681.