Sensory and objective mutton quality characteristics of SA Merino sheep selected for and against reproductive fitness

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Abstract

The effect of divergent selection for ewe multiple-rearing ability over a 15-year period on mutton quality was examined on the *M. longissimus dorsi* and *M. semimembranosus* of entire rams (R) and ewes (E) derived from two Merino lines. The selection of these two lines was based on maternal ranking values for multiple-rearing ability in a positive (P) and negative (N) line. In the negative line the replacements were based on the progeny of ewes that rear less than one lamb per joining or lambing opportunity (i.e. failed to lamb or lost all progeny born at least once). Progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were selected for the positive line. Ratings of sensory quality characteristics on the *M. semimembranosus* of the different genotype lines were obtained from a trained taste panel and related to data on physical and chemical characteristics. The moisture, total lipids, protein, ash, mineral concentrations and fatty acid composition of the *M. semimembranosus* were obtained. Physical parameters measured on the *M. longissimus dorsi* were: ultimate pH (pH_{48}), drip loss, cooking loss and Warner-Bratzler shear force (WBS). The influence of selection line on the sensory characteristics of the mutton was generally negligible, with the exception of the sensory attribute of first bite, where meat derived from the positive line was rated to be less tender than that of the negative line contemporaries. Chemically, the meat derived from the four different groups differed significantly in moisture and lipid content. The Positive Ram (PR) group had the highest moisture (*ca*. 76%) and the lowest lipid (*ca*. 7%) concentrations, whereas the Negative Ewe (NE) group had the lowest moisture (*ca*. 70%) and the highest lipid (*ca*. 10%) concentration. No significant differences were detected in the proximate chemical composition between the P and N lines. The pH_{48} and WBS values showed significant differences between the four groups. The Negative Ram (NR) group had the highest pH_{48} and the lowest WBS values. Results indicated a line effect on WBS tenderness. Meat derived from the positive line was less tender compared to the meat from the negative line. Differences between the reproductive lines pertaining to the mineral and fatty acid composition were also noted. A general tendency found, was for the Positive Ewes (PE) to have the highest and the NE to have the lowest mineral concentration. Significant differences were detected between the four groups in the individual fatty acids arachidic acid (C20:0), lignoceric acid (C24:0), eicosenoic acid (C20:1*n*-9), linoleic acid (C18:2*n*-6), homo-γ-linolenic acid (C20:3*n*-6), arachidonic acid (C20:4*n*-6), eicosapentaenoic acid (C20:5*n*-3), docosadienoic acid (C22:2*n*-6), docosapentaenoic acid (C22:5*n*-3) and docosahexaenoic acid (C22:6*n*-3) concentrations. The PR group had the highest total PUFA (polyunsaturated fatty acids) content (*ca*. 8%) and the NR the lowest PUFA content (*ca*. 6%). The positive group had significantly higher C18:2*n*-6, C20:3*n*-6, C20:4*n*-6, C20:5*n*-3, C22:5*n*-3 and C22:6*n*-3 concentrations in comparison with the negative line. Significant difference in the total PUFA composition was also detected between lines, with the positive line showing a higher concentration (*ca*. 7%) compared to the negative line (*ca*. 6%).

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Introduction

South African sheep farmers are faced with ever increasing input costs and low product price increases, resulting in the profit margins becoming smaller and smaller. Local farmers need to run their enterprises in the most effective manner in order to survive economically. Given the increasing economic pressures on sheep farmers, it is evident that reproduction should receive the necessary attention. Lamb mortality is regarded as a major constraint on efficient sheep production (Alexander, 1988). It is one of the components of net production rate that is of great importance in small stock farming (Olivier, 1999). The efficiency of reproduction affects all users of animal products such as wool and meat because consumer prices start with production costs (Laas, 1995). The profitability of sheep production in South Africa is

largely influenced by net reproduction rate, defined as total weight of lamb weaned per ewe joined (Olivier, 1999). Against this background Cloete (1999) undertook an investigation on the divergent selection of South African Merino sheep for multiple-rearing ability. The experiment demonstrated that selection of sheep for multiple-rearing ability was a viable method for improving lamb production without serious negative correlated responses on qualitative and quantitative production traits in progeny (Cloete & Olivier, 1998). When retained for breeding purposes, the lower producing negative line had a higher average live weight as well as a higher average wool weight when joined at 5.5 years of age than the positive line contemporaries. Stress placed on the positive line ewes by pregnancy and lactation possibly played a role in this regard (Cloete, 1999). However, despite the apparent importance of reproductiveness on aspects such as live weight and fleece weight, little is known about the consequences of reproductive fitness on the quality of mutton in progeny.

The pre-eminent question in this investigation is to what extent does reproduction fitness influence mutton quality. This investigation reports on the differences in sensory attributes, proximate chemical composition, fatty acid and mineral composition between the two lines of South African Merino sheep. Muscle pH, cooking loss and drip loss and Warner-Bratzler shear force (WBS) were also determined.

Materials and methods

Since 1986 two lines of South African Merino sheep have been divergently selected for and against multiple-rearing ability from the same base population at the Tygerhoek Experimental Farm. Selection of ewe and ram replacements were based on maternal ranking values for multiple-rearing ability in a positive (P) and negative (N) line (Cloete & Durand, 1994; Cloete & Scholtz, 1998). In the negative line progeny of ewes that rear less than one lamb per joining or lambing opportunity (i.e. failed to lamb or lost all progeny born at least once) were preferred as replacements. Progeny of ewes that reared more than one lamb per joining (i.e. reared twins at least once) were preferably selected as replacements in the positive line. At the end of 1992 both lines were transferred to Elsenburg experimental farm for detailed data collection on lamb mortality, lambing and neonatal behaviour, lamb production, weight and wool traits (Cloete & Scholtz, 1998).

In this investigation 10 mature animals (equal sex ratio) from the positive and 10 from the negative reproduction lines (of the 5th generation) were randomly selected to test for the effect of reproductiveness and sex on the physico-chemical and sensory characteristics of the mutton. The animals from both lines originated from similar environments, although the rams and ewes were kept apart to avoid casual mating. The animals grazed on adjacent wheat stubble fields that were rotated regularly. The sheep were grown to commercial slaughter weight and slaughtered, using standard South African techniques and conditions. The mean live weights for the positive line were 44.7 kg (n = 10) and for the negative line 42.0 kg (n = 10). No electrical stimulation was applied. During the first 48 h post-mortem, the carcasses were chilled at a temperature of 5 °C. Ultimate pH was measured 48 h post-mortem (pH_{48}) with a penetrating glass electrode on a hand-held Crison pH/mV-506 meter. The pH meter was re-calibrated after every fourth reading and the electrode rinsed with distilled water between each measurement. The pH meter contained a temperature probe ensuring automatic adjustment of the pH for temperature. The measurement was taken between the 2nd and 3rd last thoracic vertebrae, 45 mm from the midline. The *M. longissimus dorsi* was removed from the carcass to assess drip loss, cooking loss, shear force and pH_{48}. The legs were removed from the carcasses at a position between the last lumbar and the first sacral vertebrae. The legs were labelled, vacuum packed, frozen and stored at –18 °C until further use. After thawing, the *M. semimembranosus* from both the legs were dissected and used for sensory, proximate, mineral and fatty acid analyses.

The right legs were defrosted at a temperature of 3 – 4 °C for a period of 48 h for the purpose of deboning and the removal of the *M. semimembranosus*. The legs were placed on a flat surface with the lateral side facing upwards. An incision was made on the septa, followed by an incision of the knife at the top end and cutting as close as possible to the pelvic bone. The natural division between muscles then became visible and the *M. semimembranosus* could then be separated from the other muscles by cutting between the muscles. The *M. semimembranosus* cuts were coded, vacuum packed, re-frozen and stored at –18 °C until further analysis. *M. semimembranosus* samples were oven-roasted prior to subsequent sensory analysis. The meat cuts were defrosted for 48 h at a temperature of 3 – 4 °C, wrapped individually in cooking bags and placed fat-side up on the rack of an open roasting pan. The samples were roasted at 160 °C in two conventional electric Defy 835 ovens connected to a computerised electronic temperature control system

(Viljoen *et al*., 2001). A thermocouple was inserted in the centre of each sample and the meat was roasted to an internal temperature of 70 °C (AMSA, 1978). Immediately after cooking all visible subcutaneous fat was removed from each sample. Six 1.5 cm x 1.5 cm cubed samples were taken from the middle of each sample and wrapped immediately in aluminium foil marked with random three digit codes. The samples were placed in preheated glass ramekins in a preheated oven of 100 °C and evaluated within 10 min by the panellists. Descriptive sensory analyses were performed on the meat samples. Panellists were selected and trained in accordance with the American Meat Science Association guidelines for the sensory evaluation of meat (AMSA, 1978). A six-member panel evaluated the meat for the following sensory attributes: aroma intensity, initial impression of juiciness, sustained juiciness, tenderness, residue and overall lamb flavour by means of an eight-point structured line scale. Table 1 depicts the definitions of the attributes used in the sensory analyses. The panellists were seated in individual booths in a temperature and light controlled room, receiving a set of four samples served in a complete randomised order. Crackers and distilled water were used to cleanse the palate between samples (AMSA, 1978).

Table 1: Definition of attributes for sensory analyses of mutton

Attribute	Definition
Lamb aroma 1 = Extremely bland; 8 = Extremely intense	Aroma associated with the animal species
Initial juiciness 1 = Extremely dry; 8 = Extremely juicy	The amount of fluid exuded on the cut surface when pressed between fingers
Sustained juiciness 1 = Extremely dry; 8 = Extremely juicy	Degree/amount of water perceived during mastication
First bite 1 = Extremely tough; 8 = Extremely tender	Force needed to compress the sample of meat between molar teeth on the first bite
Residue 1 = Abundant; 8 = None	The connective tissue remaining after most of the sample has been masticated
Lamb flavour 1 = Extremely bland; 8 = Extremely intense	Flavour associated with the animal species

Proximate chemical analyses were carried out on the raw *M. semimembranosus* from the left leg (the subcutaneous fat layer was included). Total percentages of moisture, protein and ash were determined according to AOAC methods (AOAC, 1997). The protein concentration was determined by the block digestion method and ashing was done at 500 °C for 5 h. The moisture content was determined by drying at 100 °C for 24 h. The lipid content was determined by means of chloroform:methanol extraction (Lee *et al*., 1996).

For the drip loss determination, *ca*.1.5 cm thick meat samples from the *M. longissimus dorsi* were weighed immediately after being removed from the carcass. The samples were placed in netting and suspended in an inflated plastic bag. After a storage period of 24 h at 4 °C, samples were weighed again and the drip loss was calculated as weight loss expressed as a percentage of the original weight of the sample (Honikel, 1998). For the cooking loss determination, the freshly cut *M. longissimus dorsi* samples (*ca*.1.5 cm thick) were weighed and placed in thin-walled plastic bags in a water-bath at 75 °C. After one hour the samples were removed from the water-bath, cooled in cold water, blotted dry and weighed. Cooking loss was calculated as the difference in sample weight before and after cooking, expressed as a percentage of the initial sample weight (Honikel, 1998). The WBS measurements of the cooked *M. longissimus dorsi* samples were obtained with a Warner-Bratzler shear attachment (Voisey, 1976) fitted to an Instron Universal Testing Machine (Model 4444). Three cylindrical cores were cut from each muscle using a 12.7 mm diameter bore. Samples were randomly removed from the centre of each *M. longissimus dorsi* muscle. Maximum WBS values (N) required to shear a cylindrical core of cooked muscle perpendicular to the grain (at a crosshead speed of 200.0 mm/min) were recorded for each sample and the mean was calculated for each muscle. An increasing value indicated greater WBS and, therefore, tougher meat.

A wet ashing method was used to prepare the meat samples for mineral analysis. The elements calcium (Ca), iron (Fe), selenium (Se), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), zinc (Zn), copper (Cu), and lead (Pb) of the digesta were determined by direct current plasma emission spectrometry (Pinta, 1982).

After the extraction of the lipids, the fatty acid methyl esters (FAME) were prepared according to procedures published by Morrison & Smith (1964). The FAME were analysed with a gas-liquid chromatograph (Varian Model 3300), equipped with flame ionisation detection and two 30 m fused silica megabore DB-225 columns of 0.53 mm internal diameter (J&W Scientific, Folsom, CA). Gas flow rates were hydrogen 25 ml/min and nitrogen (carrier gas) 5-8 ml/min. The temperature programme was linear at 4 ºC/min with initial and final temperatures of 160 ºC and 220 ºC (held for 10 min), respectively. The injector temperature was 240 ºC and the detector temperature 250 ºC. The FAME were identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian, Minnesota).

The experiment consisted of a completely randomised design (2 x 2 factorial) with two reproduction lines (P and N) and two sexes (S and D) as the factors. Data were also pooled to test for the main effects of reproduction line and sex. An experimental unit was a carcass from which samples were taken for measurements. Prior to analysis of variance the sensory scores were transformed to ranks. A factorial analysis of variance was performed on all data using SAS version 8.12 (SAS, 1990). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). In some cases deviations from normality were the cause of one or two outliners, which were excluded before the final analysis. In cases where there was still significant evidence of non-normality, this could be ascribed to kurtosis rather than skewness. Interpretation of the results was thus continued (Glass *et al*., 1972). Student's t-Least Significant Differences (LSD) were calculated at the 5% significance level to compare treatment means.

Results and Discussion

Table 2 Rank means (Means) for the sensory quality characteristics of *M. semimembranosus* as influenced by the main effects of line and sex

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[c]
Aroma[d]	2.92 (6.13)	2.48 (5.83)	2.48 (5.79)	2.13 (5.58)	NS
Initial juiciness[e]	2.90 (6.29)	2.52 (5.88)	2.27 (5.92)	2.31 (6.08)	NS
Sustained juiciness[f]	2.98 (6.38)	2.38 (5.96)	2.35 (6.00)	2.29 (5.96)	NS
First bite[g]	3.02[a] (6.38)	2.33[ab] (5.88)	2.46[ab] (6.04)	2.19[b] (5.92)	0.83
Residue[h]	2.31 (5.63)	2.60 (5.75)	2.63 (5.79)	2.46 (5.75)	NS
Flavour[i]	2.79 (6.29)	2.63 (6.21)	2.44 (6.04)	2.15 (5.92)	NS

[a,b] Rank means in the same row with different superscripts are significantly different ($P \leq 0.05$)
[c] Least significant difference ($P = 0.05$); NS = Not significant ($P > 0.05$)
[d] Aroma: 1 = extremely bland; 8 = extremely intense
[e] Initial juiciness: 1 = extremely dry; 8 = extremely juicy
[f] Sustained juiciness: 1 = extremely dry; 8 = extremely juicy
[g] First bite: 1 = extremely tough; 8 = extremely tender
[h] Residue: 1 = abundant; 8 = none
[i] Flavour: 1 = extremely bland; 8 = extremely intense

Rank means for sensory quality characteristics of the *M. semimembranosus* are presented in Table 2. The means are also provided below the rank means (in brackets) for the interpretation of the results using the rating scale. All sensory quality characteristics, except first bite, were similar ($P > 0.05$) for all the groups. The first bite of the meat from the four groups differed ($P \leq 0.05$), with the PE (Positive line, Ewe) group having the highest (3.0) and the NR (Negative line, Ram) group having the lowest (2.2) rank means. The latter represents the tougher product. The results of this experiment further indicate that, although not significant ($P > 0.05$), the sensory panel also rated the PE group higher in initial juiciness, sustained juiciness and flavour, and slightly higher in the perceived amount of residue compared to the other groups.

When the data were pooled for main effect of line, differences ($P \leq 0.05$) were only observed in flavour intensity (Table 3). Meat from the positive line was rated more flavoursome (2.7) than the negative line (2.3). The slightly higher flavour intensity of the positive reproduction line could be the result of differences in the fatty acid profile (Table 11, Fisher *et al*., 2000).

Table 3 Rank means (Means) for the sensory quality characteristics of *M.semimembranosus* as influenced by main effects of line and sex

	Line		LSD[c]	Sex		LSD
	Positive	Negative		Ram	Ewe	
Aroma[d]	2.70 (5.98)	2.30 (5.69)	NS	2.30 (5.71)	2.70 (5.96)	NS
Initial juiciness[e]	2.60 (6.08)	2.40 (6.00)	NS	2.42 (5.98)	2.58 (6.10)	NS
Sustained juiciness[f]	2.68 (6.17)	2.32 (5.98)	NS	2.33 (5.96)	2.67 (6.19)	NS
First Bite[g]	2.68 (6.13)	2.32 (5.98)	NS	2.26[b] (5.90)	2.74[a] (6.21)	0.44
Residue[h]	2.46 (5.69)	2.54 (5.77)	NS	2.53 (5.75)	2.47 (5.71)	NS
Flavour[i]	2.71[a] (6.25)	2.29[b] (5.98)	0.40	2.39 (6.06)	2.62 (6.17)	NS

[a,b] Rank means in the same row with different superscripts are significantly different ($P \leq 0.05$)
[c] Least significant difference ($P = 0.05$), NS = Not significant ($P > 0.05$)
[d] Aroma: 1 = extremely bland; 8 = extremely intense
[e] Initial juiciness: 1 = extremely dry; 8 = extremely juicy
[f] Sustained juiciness: 1 = extremely dry; 8 = extremely juicy
[g] First bite: 1 = extremely tough; 8 = extremely tender
[h] Residue: 1 = abundant; 8 = none
[i] Flavour: 1 = extremely bland; 8 = extremely intense

When pooled for ram and ewe effects (Table 3), differences ($P \leq 0.05$) were found in first bite with the ewe group having the highest score (2.74) and the ram group having the lowest taste panel score (2.26). Therefore, meat derived from ewes was more tender than meat from rams. However, Ellis *et al*. (1997), found no palatability differences between sexes in meat quality. Results of the present investigation agree with findings by Jeremiah *et al*. (1998), who in a study comparing cooking properties and palatability attributes between 1660 lambs varying in chronicle age, slaughter weight and gender, found that meat derived from ewe lambs was more tender than roasts from rams. In this latter study these differences became more pronounced when secondary sexual characteristics (particularly as pertaining to the rams) had developed.

The moisture, protein, fat and ash contents of the *M. semimembranosus* samples are presented in Table 4. The meat from the four distinct groups differed ($P \leq 0.05$) in moisture and lipid levels. The level of moisture was highest in the PR group (*ca*. 76%) and lowest in the NE group (*ca*. 70%). The PR group also had the lowest lipid concentration (*ca*. 7%) and the NE group the highest (*ca*. 10%). No significant differences between the four groups were detected regarding the ash or protein levels.

When pooled for sex (Table 5), the ewes had a significant lower moisture (*ca*. 71%) and higher lipid content (*ca*. 10%) than the rams ($P \leq 0.05$). In a study by Ellis *et al.* (1997) carcasses from female lambs, compared to males showed thicker subcutaneous and greater intermuscular fat content. Observed trends by Jeremiah *et al*. (1997) further substantiate the fact that rams produce leaner carcasses than ewes. Tendencies in flavour intensity differences between ewes and rams suggested an association between the higher lipid content of the mutton derived from ewes and the flavour, aroma, initial juiciness and sustained juiciness ratings of their meat. The quantity of fat and its quality affect the nutritive value, appearance, processability, shelf life and palatability of meat. Therefore, fat is an important determinant of meat quality, and the degree of saturation of the fat contributes substantially to the sensory properties of meat (Rhee, 1992; Webb *et al*., 1994).

Table 4 Means for the proximate chemical analysis of *M. semimembranosus* as influenced by the interaction between the main effects of line and sex (g/100 g meat sample)

	Line	Positive		Negative		
	Sex	Ewe	Ram	Ewe	Ram	LSD[d]
Moisture		71.67[bc]	75.94[a]	70.04[c]	73.91[ab]	3.16
Protein		16.29	17.12	16.68	16.12	NS[e]
Lipid		9.29[ab]	6.66[b]	9.82[a]	6.69[b]	2.94
Ash		1.08	1.02	1.04	1.09	NS

[a,b,c] Means in the same row with different superscripts are significantly different (P ≤ 0.05)
[d] Least significant difference (P = 0.05)
[e] Not significant (P > 0.05)

Table 5 Means for the proximate chemical analysis of *M. semimembranosus* as influenced by main effects of line and sex (g/100 g meat sample)

	Line			Sex		
	Positive	Negative	LSD[c]	Ram	Ewe	LSD
Moisture	74.04	72.46	NS[d]	74.93[a]	70.97[b]	2.223
Protein	16.75	16.32	NS	16.62	16.46	NS
Lipid	7.83	7.86	NS	6.67[b]	9.52[a]	2.07
Ash	1.04	1.07	NS	1.06	1.06	NS

[a,b] Means in the same row with different superscripts are significantly different (P ≤ 0.05)
[c] Least significant difference (P = 0.05)
[d] Not significant (P > 0.05)

The pooled P and N groups did not differ (P > 0.05) in moisture, protein, lipid or ash contents (Table 5). This could possibly be due to the large co-efficient of variation shown by the means. Physical measured traits, pH_{48}, cooking loss, drip loss and WBS resistance of the *M. longissimus dorsi,* are presented in Table 6.

Table 6 Means of pH_{48}, drip loss, cooking loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by the main interaction between the effects of line and sex

	Line	Positive		Negative		
	Sex	Ewe	Ram	Ewe	Ram	LSD[d]
pH_{48}		5.624[b]	5.716[b]	5.588[b]	5.874[a]	0.129
Drip loss (%)		1.480	1.075	1.375	1.292	NS[e]
Cooking loss (%)		29.92	25.74	25.63	31.53	NS
WBS[f] (N)		168.05[a]	106.58[bc]	129.54[b]	95.34[c]	26.39

[a,b,c] Means in the same row with different superscripts are significantly different (P ≤ 0.05)
[d] Least significant difference (P = 0.05)
[e] Not significant (P > 0.05)
[f] Warner-Bratzler shear force value

The pH_{48} and WBS values showed differences (P ≤ 0.05) between the four groups. The NR group had the highest pH_{48} and the lowest WBS value. The significant difference in WBS values was, however, not reflected by findings of the taste panel for the attribute of first bite (Table 2). A possible explanation could be that the latter was conducted on the *M. semimembranosus* and the physical measurements on the *M. longissimus.* The latter muscle is known to be more responsive to temperature, genetics, cooking methods, etc. When ram and ewe groups were pooled (Table 7), differences (P ≤ 0.05) were found for pH_{48}, WBS values and cooking loss. Rams had higher ultimate pH and cooking loss values and a lower WBS value than ewes (P < 0.05). There was a tendency for the higher pH_{48} values to result in lower WBS values, with the pooled ram group having the highest pH_{48} value and the lowest WBS value. Results in Table 7 also indicate a

line effect on meat tenderness. The positive line group had higher ($P \leq 0.05$) WBS values, indicating that meat derived from the positive line is less tender compared to the meat from the negative line.

Table 7 Means of pH_{48}, drip loss, cooking loss and shear force resistance of lamb *M. longissimus dorsi* as influenced by line and sex

	Line			Sex		
	Positive	Negative	LSD[c]	Ram	Ewe	LSD
pH_{48}	5.67	5.73	NS[d]	5.80[a]	5.61[b]	0.09
Drip loss (%)	1.28	1.33	NS	1.18	1.43	NS
Cooking loss (%)	27.83	27.47	NS	30.72	27.77	NS
WBS [e](N)	137.3[a]	112.4[b]	18.66	101.0[b]	148.8[a]	18.66

[a,b] Means in the same row with different superscripts are significantly different ($P \leq 0.05$)
[c] Least significant difference ($P = 0.05$)
[d] Not significant ($P > 0.05$)
[e] Warner Bratzler shear force value

Conflicting reports regarding the relationship between pH and tenderness (WBS and sensory tenderness) are found in the literature. Young *et al*. (1993) showed a curvilinear relationship between pH and WBS values, while Safari *et al.* (2001) found no relationship between pH and WBS or tenderness in four lamb genotypes. No significant correlations were found in this investigation.

Results from this study indicated differences ($P \leq 0.05$) between the four groups involved in the line x sex interaction regarding the Ca, Fe, K, Mg, P and Zn concentrations (Table 8). The major contributors to the mineral concentration of the mutton were K (±122 mg/100 g meat sample) and P (*ca*. 110 mg/100 g meat sample). There was a general tendency for the PE group to have the highest mineral concentration, except for Zn and Cu, whereas the NE group had the lowest concentration in all the minerals, except for Se.

Table 8 Means for mineral composition of *M. semimembranosus* as influenced by the interactions between the main effects of line and sex (mg/100 g meat sample)

Line	Positive		Negative		
Sex	Ewe	Ram	Ewe	Ram	LSD[c]
Ca	6.498[a]	5.792[a]	3.347[b]	4.622[ab]	2.420
Fe	1.828[a]	1.747[a]	1.108[b]	1.335[ab]	0.575
Se	0.087	0.054	0.067	0.054	NS
K	134.5[a]	128.1[ab]	99.63[b]	126.9[ab]	28.73
Mg	19.15[a]	18.13[ab]	14.93[b]	16.57[ab]	3.998
Na	17.56	17.76	13.36	17.29	NS
P	124.1[a]	117.1[a]	92.02[b]	107.7[ab]	24.49
Zn	2.717[a]	2.966[a]	2.077[b]	2.403[ab]	0.583
Cu	0.003	0.012	tr[e]	0.028	NS
Pb	0.007	0.001	tr	0.003	NS

[a,b] Means in the same row with different superscripts are significantly different ($P \leq 0.05$)
[c] Least significant difference ($P = 0.05$)
[d] NS = Not significant ($P > 0.05$)
[e] trace = < 0.001 mg/100 g meat sample

When pooled together across sexes for positive and negative reproduction groups (Table 9), positive line animals had higher concentrations of Ca, Fe, P and Zn than their negative line contemporaries. Rams and ewes did not differ with regard to mineral concentrations.

Table 9 Means for mineral composition of *M. semimembranosus* as influenced by the main effects of line and sex (mg/100 g meat sample)

	Line			Sex		
	Positive	Negative	LSD[d]	Ram	Ewe	LSD[c]
Ca	6.106[a]	4.144[b]	1.678	5.207	5.148	NS[d]
Fe	1.783[a]	1.250[b]	0.399	1.541	1.519	NS
Se	0.069	0.058	NS	0.054	0.078	NS
K	130.9	116.7	NS	127.5	119.5	NS
Mg	18.58	15.95	NS	17.35	17.34	NS
Na	17.67	15.82	NS	17.53	15.76	NS
P	120.2[a]	101.8[b]	16.97	112.4	110.3	NS
Zn	2.855[a]	2.281[b]	0.404	2.685	2.443	NS
Cu	0.007	0.017	NS	0.021	0.001	NS
Pb	0.004	tr[e]	NS	0.002	0.002	NS

[a,b] Means in the same row with different superscripts are significantly different ($P \leq 0.05$)
[c] Least significant difference ($P = 0.05$)
[d] Not significant ($P > 0.05$)
[e] trace = < 0.001 mg/100 g meat sample

Marked variations in the mineral composition of meat due to the effects of age, feeding regimen (diet), breed, season and geographical differences have been noted. The mineral content of retail cuts within any single carcass also varies significantly (Ono *et al,.* 1984; Lin *et al.,* 1989). The latter is caused by variation in muscle fibre type and physical activity between muscles (Kotula & Lusby, 1982). The sheep in the present study were selected from a single geographical location, feeding regimen (diet) and the same age group. It is well known that meat is an excellent food source of Fe and Zn, especially considering the higher bio-availability of these two minerals compared to that from plants (Lin *et al*., 1989). Approximately 40% of the Fe in meat is heme iron, and this form of Fe is more available to man than non-heme iron (Simonsen *et al.,* 1988). Meat, therefore, contributes significantly to the minerals required in the human diet. The concentration of Fe, Zn and Cu in meat is higher than that provided by the other food sources (non animal) in the rest of the diet as a whole (Williams, 1987). The results from this investigation indicated significant differences in the mineral composition between lines. The meat from the positive line could contribute higher concentrations of minerals to the human diet than the negative line could.

The fatty acid composition of the *M. semimembranosus* from the four sheep groups is presented in Table 10. Oleic acid (C18:1*n*-9) occurred at the highest proportion of all fatty acids, contributing to approximately 39% of the total fatty acid content, followed by palmitic acid (C16:0) (±27%) and stearic acid (C18:0) (±23%). These results agree with those of Webb *et al*. (1997) who found that C16:0, C18:0 and C18:1*n*-9 constituted the highest proportion of the fatty acids in the meat of South African Mutton Merino wethers. No significant differences existed between the four groups in the concentration of the major saturated fatty acids (SFA), i.e. C16:0 and C18:0 (Table 10). However, there were significant differences ($P \leq 0.05$) between groups in arachidic acid (C20:0) and lignoceric acid (C24:0) concentrations. Total SFA concentrations did not differ significantly between the four groups. Eicosenoic acid (C20:1*n*-9) was the only mono-unsaturated fatty acid (MUFA) that differed ($P \leq 0.05$) between the four groups, with the ewes having a higher proportion than the rams. Total MUFA did not differ ($P > 0.05$) between groups. As far as the polyunsaturated fatty acids (PUFA) are concerned, differences ($P \leq 0.05$) were detected between the groups in linoleic acid (C18:2*n*-6), homo-γ-linolenic acid (C20:3*n*-6), arachidonic acid (C20:4*n*-6), eicosapentaenoic acid (C20:5*n*-3), docosadienoic acid (C22:2*n*-6), docosapentaenoic acid (C22:5*n*-3) and docosahexaenoic acid (C22:6*n*-3) concentrations. These differences in individual PUFA resulted in a significant difference ($P \leq 0.05$) in total PUFA between the four groups. The PR group had the highest total PUFA concentration (±8%) and the NR the lowest (±6%).

Table 10 Means proportions of the fatty acid content of *M. semimembranosus* as influenced by the interaction between the main effects of line and sex (% by weight of total fatty acids)

	Line	Positive		Negative		
	Sex	Ewe	Ram	Ewe	Ram	LSD[d]
C14:0		2.988	2.342	2.383	2.412	NS[e]
C16:0		26.33	27.65	27.02	27.65	NS
C18:0		23.27	21.63	24.28	22.84	NS
C20:0		0.317[a]	0.202[b]	0.263[ab]	0.303[a]	0.068
C22:0		0.063	0.044	0.047	0.056	NS
C24:0		0.038[ab]	0.050[a]	0.040[ab]	0.026[b]	0.021
C16:1*n*-7		1.423	1.590	1.197	1.542	NS
C18:1*n*-9		38.56	38.52	38.22	39.18	NS
C20:1*n*-9		0.200[a]	0.106[b]	0.247[a]	0.098[b]	0.065
C24:1*n*-9		0.023	0.020	0.017	0.016	NS
C18:2*n*-6		3.735[ab]	4.356[a]	3.570[ab]	3.406[b]	0.817
C18:3*n*-6		0.093	0.053	0.070	0.074	NS
C18:3*n*-3		1.310	1.260	1.277	1.140	NS
C20:2*n*-6		0.055	0.022	0.033	0.040	NS
C20:3*n*-6		0.098[b]	0.138[a]	0.087[b]	0.076[b]	0.030
C20:4*n*-6		0.605[ab]	0.848[a]	0.470[b]	0.472[b]	0.266
C20:3*n*-3		0.025	0.010	0.013	0.014	NS
C20:5*n*-3		0.298[ab]	0.450[a]	0.220[b]	0.270[b]	0.176
C22:2*n*-6		0.080[ab]	0.074[b]	0.220[a]	0.036[b]	0.141
C22:4*n*-6		0.028	0.038	0.025	0.026	NS
C22:5*n*-3		0.398[ab]	0.500[a]	0.210[c]	0.284[bc]	0.167
C22:6*n*-3		0.120[a]	0.118[a]	0.060[b]	0.072[b]	0.046
SFA[f]		52.97	51.89	54.04	53.25	NS
MUFA[g]		40.21	40.23	39.69	40.83	NS
PUFA[h]		6.835[ab]	7.924[a]	6.293[ab]	5.914[b]	1.699
PUFA:SFA[i]		0.130[ab]	0.154[a]	0.120[ab]	0.112[b]	0.036
DFA[j]		70.31	69.78	70.27	69.59	NS
(C18:0+C18:1):C16:0		2.370	2.202	2.313	2.266	NS

[a,b,c]Means in the same row with different superscripts differ significantly ($P \leq 0.05$)
[d] Least significant difference ($P = 0.05$)
[e] Not significant ($P > 0.05$)
[f] Saturated fatty acids
[g] Mono-unsaturated fatty acids
[h] Polyunsaturated fatty acids
[i] Ratio of polyunsaturated to saturated fatty acids
[j] Desirable fatty acids

When pooled across selection lines, no concentration differences ($P > 0.05$) occurred between sexes for total SFA, total MUFA or total PUFA (Table 11). Except for C20:1*n*-9, no differences ($P > 0.05$) were detected in the individual fatty acid composition. The absence of significant differences in SFA, MUFA and PUFA concentrations between males and females suggests that the fatty acid profile was independent of sex (at a slaughter weight of *ca*. 43 kg). These results agree with the findings of Horcoda *et al*. (1998), but differ from those of Solomon *et al*. (1990), who found that the ram lambs had lipids richer in PUFA and poorer in SFA than ewes. The latter could be due to an age effect as the sheep used in the present investigation were older.

When pooled across sexes (Table 11), the positive line animals had a higher PUFA concentration (*ca*. 7%) than their N group contemporaries (*ca*. 6%). The total SFA and MUFA composition did not differ ($P > 0.05$) between the lines. The higher ($P \leq 0.05$) proportions of the C18:2*n*-6, C20:3*n*-6, C20:4*n*-6, C20:5*n*-3, C22:5*n*-3 and C22:6*n*-3 PUFAs in the P group resulted in this group having a higher ($P \leq 0.05$) total PUFA concentration than the N group.

Table 11 Means proportions of the fatty acid content of *M. semimembranosus* as affected by the main effects of line and sex (% by weight of total fatty acids)

	Line			Sex		
	Positive	Negative	LSD[d]	Ram	Ewe	LSD
C14:0	2.629	2.401	NS[e]	2.377	2.729	NS
C16:0	27.06	27.41	NS	27.65	26.63	NS
C18:0	23.38	22.36	NS	22.23	23.61	NS
C20:0	0.245	0.286	NS	0.247	0.290	NS
C22:0	0.052	0.053	NS	0.050	0.055	NS
C24:0	0.043	0.031	NS	0.035	0.039	NS
C16:1*n*-7	1.516	1.413	NS	1.566	1.326	NS
C18:1*n*-9	38.54	38.82	NS	38.85	38.42	NS
C20:1*n*-9	0.148	0.154	NS	0.102[b]	0.220[a]	0.046
C24:1*n*-9	0.021	0.016	NS	0.018	0.020	NS
C18:2*n*-6	4.080[a]	3.468[b]	0.566	3.881	3.664	NS
C18:3*n*-6	0.073	0.073	NS	0.064	0.083	NS
C18:3*n*-3	1.282	1.191	NS	1.200	1.296	NS
C20:2*n*-6	0.037	0.038	NS	0.031	0.046	NS
C20:3*n*-6	0.120[a]	0.080[b]	0.021	0.107	0.093	NS
C20:4*n*-6	0.740[a]	0.471[b]	0.184	0.660	0.547	NS
C20:3*n*-3	0.017	0.014	NS	0.012	0.020	NS
C20:5*n*-3	0.382[a]	0.251[b]	0.122	0.360	0.264	NS
C22:2*n*-6	0.077	0.105	NS	0.055	0.140	NS
C22:4*n*6	0.033	0.026	NS	0.031	0.027	NS
C22:5*n*3	0.454[a]	0.256[b]	0.115	0.392	0.317	NS
C22:6*n*3	0.119[a]	0.068[b]	0.032	0.095	0.094	NS
SFA[f]	52.37	53.55	NS	52.57	53.42	NS
MUFA[g]	40.22	40.40	NS	40.53	39.98	NS
PUFA[h]	7.440[a]	6.056[b]	1.177	6.919	6.603	NS
PUFA:SFA[i]	0.143[a]	0.115[b]	0.025	0.133	0.126	NS
DFA[j]	70.13	69.84	NS	69.68	70.29	NS
(C18:0+C18:1):C16:0	2.277	2.284	NS	2.234	2.346	NS

[a,b] Means in the same row with different superscripts differ ($P \leq 0.05$)
[d] Least significant difference ($P = 0.05$)
[e] NS = Not significant ($P > 0.05$)
[f] Saturated fatty acids
[g] Mono-unsaturated fatty acids
[h] Polyunsaturated fatty acids
[i] Ratio of polyunsaturated to saturated fatty acids
[j] Desirable fatty acids

Desirable fatty acids (DFA), according to the health classification of Rhee (1992), are the sum of all unsaturated fatty acids and stearic acid. Oleic acid (C18:1n-9), Palmitic acid (C16:0) and stearic acid (C18:0) represented the majority of the fatty acids measured in the *M. semimembranosus* in this investigation. It is well known that C16:0 increases blood cholesterol levels, whereas C18:0 has no effect and C18:1*n*-9 decreases blood cholesterol content. Therefore, the ratio of (C18:0 + C18:1):C16:0 indicates the possible health effects of the lipids (Grundy, 1997; Banskalievaa *et al*., 2000). Within the four reproduction fitness groups (Table 10), as well as in the pooled groups for sexes and lines (Table 11), no significant differences were detected in DFA or (C18:0+C18:1):C16.

The PUFA:SFA ratio is an important guideline illustrating the total impact of SFA on blood cholesterol. Values of 0.45 or above for the PUFA:SFA ratio in dietary fats have been recommended in the United Kingdom (Warris, 2000). The PUFA:SFA ratio is lower in ruminant than non-ruminant meat because of the bio-hydrogenation of dietary unsaturated fatty acids by ruminal micro-organisms (Banskalievaa *et al.*, 2000). Particularly the concentration of linoleic acid (C18:2*n*-6), the major plant fatty acid, is therefore much lower in ruminant than in non-ruminant tissue. These factors lead to ruminant meat having a PUFA:SFA ratio below the value of 0.45 required in the human diet (Warris, 2000). Previous reports found PUFA:SFA

ratio of lipids from bovine or lamb meat to be between 0.11 and 0.15 (Geay *et al.,*2001). The PUFA:SFA ratio of the four groups in this investigation differed ($P \leq 0.05$), but were all markedly below the recommended value of 0.45. The P group had a higher PUFA:SFA ratio of 0.143, compared to the N production group that had a PUFA:SFA ratio of 0.115.

Conclusions

The objective of this investigation was to determine if meat quality differed between two lines of South African Merino sheep that were divergently selected for and against multiple-rearing ability. Differences detected in meat quality between the two lines were of a slight magnitude, although more important differences were found in the WBS values and mineral and fatty acid composition of the meat. However, the latter did not affect the sensory quality of the meat. This investigation provides important scientific insight into the effect of reproduction rate on general mutton quality. Results indicated that the selection of sheep for an increased multiple-rearing ability did not result in negative correlated responses on general mutton quality and therefore appears to be feasible. The only exception was with regard to tenderness, where the mutton derived from the positive line animals was generally tougher, according to WBS measurements, than the negative line contemporaries. This point needs further elucidation, as this is a quality attribute that plays an important role in a consumer's decision on whether to purchase or not to purchase a specific meat type.

Analytical results of the fatty acid and mineral content of mutton derived from sheep raised under typical South African conditions are reported on a fresh meat basis and will serve as valuable information to use in national food composition tables.

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