Amino acid requirements of South African Mutton Merino lambs
2. Essential amino acid composition of the whole empty body

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The essential amino acid (EAA) composition of the whole empty body of South African Mutton Merino ram lambs fed a standard diet was investigated. The standard diet consisted (%) of 30 lucerne, 8 wheat straw, 56.25 maize meal, 3.5 molasses meal, 1 urea, 0.5 salt and 0.75 ammonium chloride. Twenty lambs were randomly allocated to four pre-assigned average target slaughter weights (30, 35, 40 and 45 kg live weight). The EAA composition of the carcass, blood, head and feet, skin & wool, liver, lungs, kidneys, heart, spleen, testis, digesta-free gastrointestinal tract (GIT) and whole empty body was determined. The composition of the whole empty body remained similar regardless of slaughter weight. The concentration of the following EAAs increased significantly ($p < 0.05$) with increasing live weight (30, 35, 40 and 45 kg): head & feet valine (3.87^a, 5.56^{ab}, 5.68^{ab}, 6.70^b), spleen phenylalanine (4.96^a, 5.00^a, 5.07^{ab}, 5.56^b) and valine (5.31^a, 5.50^{ab}, 5.69^{ab}, 6.03^b) as well as GIT phenylalanine (5.00^a, 6.50^a, 11.10^a, 18.78^b). The amino acid composition of the carcass, skin and wool, and GIT plays a predominant role in regression equations used to predict the whole empty body EAA composition. The whole empty body EAA composition (g AA/100 g crude protein) was as follows: 7.72 arginine; 4.54 histidine; 3.06 isoleucine; 8.53 leucine; 6.46 lysine; 3.56 methionine; 5.22 phenylalanine; 4.65 threonine and 5.18 valine. This composition can serve as an example of the ideal EAA requirements for whole empty body growth between 30 and 45 kg live weight of South African Mutton Merino ram lambs.

Ondersoek is ingestel na die totale leë liggaam essensiële aminosuursamestelling van Suid-Afrikaanse Vleismerino ramlammers wat 'n standaarddieet ontvang het. Die dieet was as volg saamgestel (%): 30 lusern, 8 koringstrooi, 56.26 mieliemeel, 3.5 melassemeel, 1 ureum, 0.5 sout en 0.75 ammoniumchloried. Twintig lammers is ewekansig aan vier voorafbepaalde teiken slagmassas (30, 35, 40 en 45 kg lewende gewig) toegewys. Die essensiële aminosuursamestelling van die karkas, kop en pote, vel en wol, lewer, longe, niere, hart, milt, testis, leë spysverteringskanaal en totale liggaam is bepaal. Die essensiële aminosuursamestelling van die totale leë liggaam is nie deur slagmassa beïnvloed nie. Die konsentrasie van die volgende essensiële aminosure het betekenisvol ($p < 0.05$) met 'n toename in slagmassa (30, 35, 40 en 45 kg) verhoog: kop en pote valien (3.87^a, 5.56^{ab}, 5.68^{ab}, 6.70^b), milt fenielalanien (4.96^a, 5.00^a, 5.07^{ab}, 5.56^b) en valien (5.31^a, 5.50^{ab}, 5.69^{ab}, 6.03^b) asook die leë spysverteringskanaal fenielalanien (5.00^a, 6.50^a, 11.10^a, 18.78^b). Die aminosuursamestelling van die karkas, vel en wol en leë spysverteringskanaal het 'n belangrike bydrae in regressieformules vir die voorspelling van die totale leë liggaam essensiële aminosuursamestelling gelewer. Die totale leë liggaam essensiële aminosuursamestelling (g aminosuur/100 g ruproteïen) was soos volg: 7.72 arginien; 4.54 histidien; 3.06 isoleusien; 8.53 leusien; 6.46 lisien; 3.56 metionien; 5.22 fenielalanien; 6.65 treonien en 5.18 valien. Hierdie aminosuursamestelling kan as 'n aanduiding dien van die ideale aminosuurbehoeftes van Suid-Afrikaanse Vleismerino ramlammers vir totale leë liggaamsgroei vanaf 30 tot 45 kg lewende massa.

Keywords: essential amino acids; whole empty body; sheep

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Introduction

It is now well established that the balance of the amino acids required for growth in mammals can be determined from the amino acid composition of body protein (Pellet & Kaba, 1971; ARC, 1981; Whitemore, 1983; Black *et al.*, 1986; Cole & Van Lunen, 1994). Several studies reported on the use of carcass amino acid composition as a criterion to determine the amino acid requirements of cattle (Hogan, 1974; Rohr & Lebzien, 1991; Ainslie *et al.*, 1993) and sheep (Smith, 1980; Lawrie, 1985; Gilka *et al.*, 1989; Chen & Ørskov, 1994; Loëst *et al.*, 1997). Loëst *et al.* (1997) reported that the carcass was responsible for only 57% of the live weight gained during the finishing of South African Mutton Merino ram lambs. The carcass is thus most probably not representative of the ideal protein needs of growing lambs. According to Mäntysaari *et al.* (1989) and Hussein *et al.* (1991) ruminants utilize protein for growth most efficiently when provided with a supply of amino acids that matches tissue requirements. Therefore, the total tissue amino acid composition is an essential ingredient in assessing dietary requirements, and information on the extent of this variation is therefore required (Williams, 1978). The whole empty body, which consists of the carcass plus the rest of the animal (excluding gut fill), compared to the carcass as an example of the EAA balance of absorbed protein thus warrants further investigation. The use of the whole empty body amino acid composition to predict the requirements for growing lambs seems to be limited and only confined to Suffolk × Finn Dorset lambs used by MacRae *et al.* (1993). The proposition that the amino acid composition of the ideal protein is a constant, would, however, only hold if the amino acid composition of the body protein is constant at different live weights. Yet, recent evidence in pigs has suggested that the amino acid composition of the whole body protein might be affected by live weight (Zhang *et al.*, 1986; Moughan & Smith, 1987; Kyriazakis & Emmans, 1992a). It is well documented (Lobley *et al.*, 1980; Attaix *et al.*, 1988; Kyriazakis & Emmans, 1993; MacRae *et al.*, 1993) that tissue weights vary both absolutely and relatively during growth and specific needs exist for a product such as wool (high in sulphur amino acids). Therefore additional work should also focus on the amino acid composition of the whole empty body at progressive stages of growth to determine the amino acid requirements essential for gain. Estimating amino acid composition of the whole empty body is expensive and difficult to finance. It is thus important that the amino acid composition of various tissues and organs be compared with that of the whole empty body to possibly specify one or more that is representative of the whole body. Loëst *et al.* (1997) stressed that the South African Mutton Merino lamb is predominantly used in South African feedlots and thus play a major role in the production of mutton. Since there is no information regarding the EAA requirements of these animals, further research is of utmost importance. The purpose of this study was: (a) to determine the EAA composition (requirements) of the whole empty body of South African Mutton Merino lambs at different live weights, and (b) to predict the EAA composition of the whole empty body from various tissues and organs.

Material and methods

The twenty South African Mutton Merino ram lambs with an initial empty stomach weight of 28 kg described by Loëst *et al.* (1997) were used for the study. The same standard diet as described by Loëst *et al.* (1997) was fed *ad libitum* to provide the nutrient requirements of growing lambs (NRC, 1985). Marais (1988) found no significant ($p > 0.05$) difference in the lambs' total body protein synthesis between a high and low metabolizable energy intake. Therefore it was suitable to formulate only one diet with the metabolizable energy content recommended by the NRC (1985). The experimental design, feeding, slaughter and analyses procedures as described by Loëst *et al.* (1997; 1999) were implemented. On reaching the target weights per slaughter group, the animals were slaughtered and dissected into separate components: half carcass; blood; head and feet; skin and wool; liver; lungs; kidneys; heart; spleen; testis and digesta-free gastrointestinal tract (GIT). The GIT included all the mesenteric, omentum, kidneyknob and channel fat.

Tryptophan was not quantified. However, tryptophan does not appear to be a limiting amino acid in the available literature (Nimrick *et al.*, 1970; Owens *et al.*, 1973; Storm & Ørskov, 1984) and is thus apparently not such an important factor in ruminant nutrition. Regression analysis, one way ANOVA and multiple comparisons (using Tukey's test) were performed on the data using PC SAS 6.04 (SAS Institute Inc., Cary NC). Guidelines were followed from the SAS Procedures Guide (1988) and second edition of SAS System for regression (1991).

Results and Discussion

Physical composition

According to Marais *et al.* (1991) the efficiency of protein deposition in South African Mutton Merino rams decreased from 0.89 to 0.34 with an increase in body weight from 22 to 40 kg. Differences in protein deposition also occurred when different sheep breeds were fed the same diet. The efficiency of protein and fat deposition in ruminants have been found to be more variable (Ørskov & McDonald, 1970; Rattray & Jagusch, 1977) than those of non-ruminant species. Differences in body composition also imply differences in the composition of weight gain (Hofmeyr, 1972). Therefore the physical composition and proportional change in body components with increasing live weight could influence the amino acid requirements of a specific species.

In Table 1 the physical composition of the whole empty body of South African Mutton Merino lambs is shown. No significant ($p > 0.05$) differences in the average weight of the lungs, kidneys, spleen, GIT and blood occurred at different live weights. On the other hand the weight of the carcass, head and feet, skin and wool, liver, heart, and testis increased significantly ($p < 0.05$) with increasing live weight. In contrast to the present study, Colebrook *et al.* (1988) found, with six different breeds, a significant increase in blood and kidney weight as empty body weight increased. Except for heart, the mean weight of the visceral organs in the present study was higher than that of Romney, Timahdit, D'man and Ile de France × D'man lambs investigated by Kabbali *et al.* (1992) and McCutchen *et al.* (1993). Differences in organ weights between the present study and those reported in literature, are probably due to differences in breed, feeding strategies, sex and slaughter weights (Kabbali *et al.*, 1992; McCutchen *et al.*, 1993).

The proportional weight distribution (%) of the head and feet, and kidneys and blood decreased significantly ($p < 0.05$) while that of the testis increased significantly ($p < 0.05$) at heavier slaughter weights. From Table 1 it is evident that on average, the carcass (56.2%), head and feet (9.2%), skin and wool (9.8%) and blood (5.8%) represent 81% of the total empty body weight. The significant ($p < 0.05$) decrease in weight percentage of head and feet, kidneys, and blood with an increasing live weight, may influence the amino acid composition of the whole empty body at progressive stages

Table 1 Proportional distribution (weight and percentage) of organs/tissues in lamb growth from 30 to 45 kg live weight

Live weight	Whole empty body	Carcass		Head & feet		Skin&Wool		Liver^{3}		Lungs^{2,3}		Kidneys^{3}		Heart^{3}		Spleen^{3}		Testis^{3}		GIT^{4}		Blood	
kg	kg	kg	%^{1}	g	%	g	%	g	%	g	%	g	%	g	%	g	%	g	%	g	%	g	%
30	27.3^{a}	14.6^{a}	53.5	2670^{a}	9.8^{a}	2314^{a}	8.5	707^{a}	2.6	553	2	103	0.408^{a}	157^{a}	0.6	83	0.3	181^{a}	0.7^{b}	4097	15	1820	6.7^{a}
35	30.9^{a}	17.3^{b}	56	3008^{b}	9.7^{ab}	2862^{b}	9.3	780^{b}	2.5	465	1.5	112	0.384^{ab}	174^{ab}	0.6	82	0.3	366^{b}	1.2^{a}	4023	13	1742	5.6^{b}
40	36.0^{b}	20.4^{c}	56.7	3145^{bc}	8.7^{b}	3724^{b}	10.3	913^{b}	2.5	505	1.4	117	0.342^{ab}	215^{c}	0.6	87	0.2	458^{b}	1.3^{a}	4639	12.9	1889	5.2b
45	38.9b	22.6c	58.1	3384c	8.7b	4124c	10.6	948b	2.4	556	1.4	116	0.314b	205cb	0.5	103	0.3	493b	1.3^{a}	5216	13.4	2230	5.7^{b}
0	33.3	18.7	56.2	3052	9.2	3256	9.8	837	2.5	520	1.6	112	0.362	188	0.6	89	0.3	374	1.1	4494	13.5	1920	5.8
SD	±2.2	±1.4	±2.4	±185	±0.6	±496	±1.1	±107	±0.1	±103	±0.4	±9	±0.1	±19	±0.1	±17	±0.1	±85	±0.4	±1134	±1.2	±151	±0.8

[1] The proportional percentage of an organ/tissue relative to that of the whole empty body weight; [2] lungs and trachea; [3] lean organs without fat; [4] GIT = digesta-free gastrointestinal tract, including the mesenteric, omentum, kidneyknob and channel fat; ^{abc} values in columns bearing different superscripts are significantly ($p < 0.05$) different.

of growth. According to Asplund (1994) the amino acid spectrum observed in wool and hair is not typical of that in other body tissues. Wool growth potential, which differs between breeds, may prove to be extremely useful in the clarification of the differences in whole body amino acid requirements of sheep.

Nitrogen

The mean nitrogen (N) concentration of the digesta-free empty body was similar ($p > 0.05$) over the four ascending live weights (33.39 ± 2.21 g/kg). Similar results were obtained by MacRae *et al.* (1993) who indicated that the N content of the empty body weight gain in lambs remained constant (24.2 ± 0.59 g/kg) over the range 25 to 55 kg live weight. Accordingly Marais *et al.* (1991) found a relatively constant protein percentage of 13 to 14.5 in the bodies of Dorper lambs, although the N-deposition rate decreased with increasing live weight. The lower body protein concentration is probably due to the tritium dilution technique used by Marais *et al.* (1991) to estimate body composition of live sheep. The proportional distribution and incremental change of total nitrogen in the different body components are shown in Table 2. Similar to empty body weight, the proportional distribution of N in the carcass, head and feet, liver, lungs, and heart was more or less similar at each slaughter weight. MacRae *et al.* (1993) found no differences in the carcass, wool, skin, GIT, head and feet, and liver N distribution of Suffolk × Finn Dorset wether lambs. In contrast, the wool and skin N deposition increased in the present study, probably owing to the fact that the South African Mutton Merino is a dual-purpose breed, whereas the Suffolk × Finn Dorset lamb is classified as a mutton breed, with a much lower wool production potential. The decreasing GIT nitrogen deposition with an increasing live weight, is probably due to the fact that the ruminant part of the GIT (reticulo-rumen and omasum) developed early when the lamb changed from a milk diet to bulky forage crop feeds (Hammond, 1932).

At 30 kg live weight, 35.76% of the total N was presented as carcass, 19.85% as skin and wool and 15.77% as head and feed, 15.78% as digesta-free gastrointestinal tract (GIT) and 13% as

Table 2 Proportional distribution and incremental change of nitrogen (N) in organs/tissues of lamb growth from 30 to 45 kg live weight

	Incremental change in nitrogen deposition (%)						
Components	% N[1] 30 kg	Incremental[2] change 30-35 kg	% N 35 kg	Incremental change 35-40 kg	% N 40 kg	Incremental change 40-45 kg	% N 45 kg
Carcass	35.76	66.18	39.48	36.13	39.12	39.98	39.19
Head & feet	15.77	14.19	15.58	7.64	14.71	8.39	14.17
Skin & Wool	19.85	37.87	22.06	41.64	24.20	43.95	25.91
Liver	5.18	4.71	5.12	5.92	5.21	2.89	5.01
Lungs	4.24	–4.86	3.13	2.36	3.04	3.08	3.05
Kidneys	0.86	0.76	0.87	0.17	0.79	–1.64	0.58
Heart	0.85	0.89	0.86	0.13	0.78	1.22	0.82
Spleen	0.82	–0.01	0.71	0.30	0.67	0.57	0.66
Testis	0.86	6.68	1.57	6.02	2.06	4.23	2.25
GIT[3]	15.78	–26.40	10.61	–0.32	9.42	–2.68	8.37

[1] As percentage of body nitrogen weight; [2] Incremental nitrogen change = change in components nitrogen weight/total nitrogen weight change (whole body); [3] GIT = digesta-free gastrointestinal tract

organs. As the animals grew from 30 to 45 kg live weight, the highest incremental change in nitrogen deposition resulted from the carcass (± 41%). Therefore, as far as net amino acid requirements are concerned, the major sites of protein deposition seem to be in the carcass as well as the skin and wool. MacRae *et al.* (1993) experienced similar results during their comparative slaughter study with 0.45 of the incremental N deposition in the carcass and 0.25 in the wool of Suffolk × Finn Dorset lambs. The lower wool N deposition experienced by MacRae *et al.* (1993), is probably due to breed differences. The South African Mutton Merino is, as previously mentioned, a dual-purpose breed whereas the Suffolk × Finn Dorset lamb is classified as a mutton breed.

Amino acids

The mean EAA composition of the whole empty body, tissues and organs is presented in Table 3. Similar to N concentration, the amino acid composition of the whole empty body was constant at different live weights. Relatively few publications (Seifter & Gallop, 1966, as cited by Williams, 1978; Smith, 1980) deal with possible changes in the body amino acid composition during growth of animals. This probably results from the knowledge that the composition of muscle protein is genetically determined and not subject to change, even if the conditions during growth (e.g. the quality and quantity of the diet or the health status) are different (Gilka *et al.*, 1989). The results of the present study confirmed that there is no difference ($p > 0.05$) in the ideal protein needs for whole empty body growth at different live weights.

Table 3 Essential amino acid composition (±SD) of whole body, tissues and organs (g AA/ 100 g crude protein)

EAA	Whole body	Blood	Carcass	Head & Feet	Skin & Wool	Liver	Lungs	Kidneys	Heart	Spleen	Testis	GIT
Arg	$7.72b^{c}$	3.16^{e}	6.80^{d}	9.92^{a}	10.59^{a}	8.84^{b}	$8.11b^{c}$	9.08^{ab}	7.84^{bc}	8.822	8.49^{bc}	9.562
SD	±0.58	±0.35	±0.80	±1.35	±1.37	±0.74	±1.61	±1.16	±0.77	±0.66	±1.43	±1.50
His	4.54^{cd}	5.94^{b}	2.56^{ef}	7.62^{a}	5.39^{c}	4.58^{cd}	2.95^{e}	4.80^{cd}	1.75^{f}	4.08^{d}	2.09^{ef}	3.99^{d}
SD	±0.40	±0.46	±0.65	±0.97	±1.09	±0.50	±1.54	±0.64	±0.10	±0.34	±0.38	±0.86
Iso	3.06^{efg}	0.71^{h}	3.13^{efg}	3.17^{efg}	3.48^{defg}	5.37^{a}	2.64^{fg}	4.86^{ab}	3.32^{defg}	3.86^{cde}	2.58^{g}	5.27^{a}
SD	±0.33	±0.19	±0.37	±0.34	±0.48	±0.86	±0.63	±0.56	±0.28	±0.31	±0.59	±2.66
Leu	8.53^{bcdef}	11.57^{a}	7.05^{f}	7.28^{ef}	7.97^{def}	10.25^{ab}	10.06^{abc}	10.72^{ab}	9.25^{abcd}	9.15^{abcde}	8.35^{bcdef}	10.02^{abcd}
SD	±.64	±0.53	±0.82	±0.57	±1.14	±1.90	±1.60	±1.46	±1.89	±0.92	±1.18	±5.46
Lys	6.46^{cd}	9.51^{a}	6.90^{cd}	4.49^{e}	4.53^{e}	6.91^{cd}	6.63^{cd}	6.62^{cd}	7.66^{bc}	6.72^{cd}	7.86^{bc}	5.85^{d}
SD	±0.46	±0.29	±0.86	±1.42	±0.74	±1.21	±0.92	±1.79	±0.48	±0.76	±2.44	±1.54
Met	3.56^{c}	1.86^{d}	2.05^{d}	6.74^{a}	5.50^{b}	3.37^{c}	2.12^{d}	1.72^{d}	2.59^{bc}	2.43^{d}	2.11^{d}	5.0^{b}
SD	±0.22	±0.10	±0.32	±0.88	±0.58	±0.94	±0.76	±0.23	±0.48	±0.61	±0.49	±1.03
Phe	5.22^{bcde}	6.22^{bcd}	4.07^{5}	4.18^{de}	4.58^{cde}	6.17^{bcd}	5.87^{bcde}	5.95^{bcde}	5.01^{bcde}	5.15^{bcde}	6.98^{b}	10.35^{a}
SD	±0.44	±0.21	±0.53	±0.63	±0.61	±0.84	±1.30	±0.65	±0.94	±0.30	±2.71	±3.50
Thr	4.65^{bc}	4.61^{bc}	3.71^{5}	4.64^{bc}	5.56^{a}	5.03^{abc}	3.71^{e}	5.43^{e}	3.30^{e}	4.41^{cd}	3.62^{e}	6.71^{ab}
SD	±0.48	±0.27	±0.35	±0.68	±0.68	±0.56	±0.63	±0.58	±0.37	±0.33	±0.71	±4.14
Val	5.18^{cde}	8.10^{a}	4.20^{efgh}	5.45^{cde}	3.48^{h}	4.89^{cdefg}	4.83^{cdefg}	4.90^{cdef}	4.92^{cdef}	5.63^{cd}	5.36^{cde}	7.07^{b}
SD	±0.41	±0.82	±0.59	±1.40	±0.43	±2.06	±1.01	±0.63	±0.89	±0.33	±1.53	±2.13

^{abcd} Means in rows bearing different superscripts are significantly ($p < 0.05$) different

However, in dealing with sheep breeds with different potentials in wool/meat production, a variance in the whole empty body EAA composition can occur owing to a difference in the proportional contribution of wool and carcass to the EAA composition of the whole empty body. According to the results of the present study, the major sites of protein deposition were in the carcass as well as skin and wool.

It has already been recognised in poultry that the proportion of total protein represented by feather protein will change as protein weight changes. This factor will have an effect on the amino acid concentration of total protein (Nitsan *et al.*, 1981; Fisher & Scougall, 1982). In the present study the proportion of total protein represented by skin and wool also changed and could have had an effect on the amino acid concentration of total protein. However, no variance was detected in the present study with South African Mutton Merino lambs over the weight range 30 to 45 kg live weight.

The concentration of isoleucine, phenylalanine and valine in Table 3, which differed non- significantly ($p > 0.05$) between the carcass and skin and wool, are expected to be independent of protein weight (live weight). This is supported by the consistent leucine, phenylalanine and threonine concentrations, which differed little between hair and the remaining tissues, as reported for pigs at different live weights (Kyriazakis & Emmans, 1993).

According to Smith (1980), the fact that the proportion of connective tissue in muscle may vary with increasing age, cannot be ignored. This factor, however, seems to have no influence on the EAA concentration of the lamb's whole empty body over the weight range implemented in the present study. The reason might be due to the relatively short duration of the experiment (73 days) and thus lack of sufficient ageing of the lambs.

Of the nine EAAs measured in tissues and organs, only the following concentrations (g AA/100 g crude protein) increased significantly ($p < 0.05$) over increasing live weight (30, 35, 40 and 45 kg): head and feet valine (3.87^{a}, 5.56^{ab}, 5.68^{ab}, 6.70^{b}), spleen phenylalanine (4.96^{a}, 5.00^{a}, 5.07^{ab}, 5.56^{b}) and valine (5.31^{a}, 5.50^{ab}, 5.69^{ab}, 6.03^{b}) as well as GIT phenylalanine (5.00^{a}, 6.50^{a}, 11.10^{a}, 18.78^{b}). The EAA composition of the other tissues/organs remained similar ($p > 0.05$) or showed no clear trend with increasing live weight. Similar to the results from the present study, MacRae *et al.* (1993) experienced that the EAA composition of the carcass, wool, skin and liver remained similar regardless of slaughter weight, during the comparative slaughter study (25 to 55 kg live weight) with growing lambs fed alternatively a high and low roughage diet. In contrast to the present study, MacRae *et al.* (1993) found no difference in the GIT EAA concentration. These authors stated that the non-significant ($p > 0.05$) differences in organ/tissue EAA concentrations at different live weights found in their studies, are possibly related to the fact that the animals were restricted to only double the maintenance level of intake. The lambs would probably still have had considerable potential for increasing their rates of amino acid gain, if the diet had been offered *ad libitum* as in the present study.

Collagen, the main protein component of muscle connective tissue, tendons and skin, is poor in all the EAAs except for arginine (Seifter & Gallop, 1966, as cited by Williams, 1978). This statement explains the high ($p < 0.05$) arginine concentration in the head and feet, and skin and wool (Table 3). This factor, however, seems to have no influence on the EAA composition of the whole empty body at the weight range implemented in the present study. The nine EAAs exhibited significant differences ($p < 0.05$) either in the carcass or at least in one of the organs when compared to that of the mean EAA composition of the whole empty body (Table 3). The carcass contained, in general, a lower ($p < 0.05$) concentration of most EAAs when compared to the organs/tissues. These findings are in agreement with the work of Ainslie *et al.* (1993) and Loëst *et al.* (1997), who accordingly reported that the amino acid values were higher when determined on selected muscle tissue than on the whole carcass. According to Williams (1978) and Farid (1991), the abovementioned findings occurred as a result of the presence of connective tissue (poor in all EAAs except arginine) in some body components.

Prediction of amino acid composition

Stepwise regression was performed on the data for possible combinations of organs and tissues that may predict the EAA composition of the whole empty body accurately (Table 4). From Table 4 it is clear that the prediction equations formulated from the data of the present study, have relatively high coefficients of determination (r^2). All the tissues/organs included in the EAA composition regression equations have a significant ($p < 0.05$) contribution to the coefficients of determination (r^2) when compared to that of the whole empty body. The highest correlation between a single organ/tissue and the whole empty body occurred between the GIT and whole empty body threonine ($r^2 = 0.85$). The carcass, skin and wool and GIT play a major role in predicting the whole empty body EAA composition.

Table 4 Regression equations for predicting the whole body essential amino acid composition (g AA/100 g crude protein) and the coefficients of determination (r^2) between dependent and independent variates

Independent variable (X)	Dependent variable (Y)	r^2	Regression equation $Y = b_0 \times b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$	Y-estimate
Arginine				
Carcass (X_1)	Whole body	0.63	$Y = 3.64 + 0.60X_1$	0.73
Skin & Wool (X_2)		0.76	$Y = 2.21 + 0.57X_1 + 0.16X_2$	0.77
GIT (X_3)		0.88	$Y = 0.47 + 0.59X_1 + 0.19X_2 + 0.13X_3$	0.70
Head & feet (X_4)		0.92	$Y = 0.28 + 0.53X_1 + 0.18X_2 + 0.11X_3 + 0.09X_4$	0.61
Histidine				
GIT (X_1)	Whole body	0.45	$Y = 3.53 + 0.26X_1$	0.28
Carcass (X_2)		0.61	$Y = 2.81 + 0.26X_1 + 0.27X_2$	0.36
Skin & Wool (X_3)		0.84	$Y = 1.73 + 0.19X_1 + 0.35X_2 + 0.22X_3$	0.33
Head & Feet (X_4)		0.91	$Y = 1.06 + 0.16X_1 + 0.36X_2 + 0.16X_3 + 0.14X_4$	0.31
Blood (X_5)		0.93	$Y = 0.26 + 0.16X_1 + 0.36X_2 + 0.17X_3 + 0.13X_4 + 0.13X_5$	0.46
Spleen (X_6)		0.96	$Y = -0.41 + 0.15X_1 + 0.36X_2 + 0.16X_3 + 0.11X_4 + 0.17X_5 + 0.18X_6$	0.48
Heart (X_7)		0.97	$Y = -1.96 + 0.15X_1 + 0.36X_2 + 0.17X_3 + 0.10X_4 + 0.25X_5 + 0.20X_6 + 0.60X_7$	0.80
Isoleucine				
GIT (X_1)	Whole body	0.58	$Y = 2.59 + 0.09X_1$	0.11
Carcass (X_2)		0.82	$Y = 1.27 + 0.08X_1 + 0.43X_2$	0.29
Skin & Wool (X_2)		0.91	$Y = 0.50 + 0.08X_1 + 0.46X_2 + 0.19X_3$	0.28
Head & Feet (X_4)		0.94	$Y = 0.07 + 0.08X_1 + 0.43X_2 + 0.19X_3 + 0.18X_4$	0.30
Lungs (X_5)		0.95	$Y = -0.08 + 0.08X_1 + 0.42X_2 + 0.20X_3 + 0.18X_4 + 0.06X_5$	0.29
Testis (X_6)		0.96	$Y = -0.27 + 0.07X_1 + 0.44X_2 + 0.18X_3 + 0.19X_4 + 0.06X_5 + 0.06X_6$	0.30
Leucine				
GIT (X_1)	Whole body	0.56	$Y = 7.73 + 0.08X_1$	0.20

Table 4 Regression equations for predicting the whole body essential amino acid composition (g AA/100 g crude protein) and the coefficients of determination (r^2) between dependent and independent variates (Continued)

Independent variable (X)	Dependent variable (Y)	r^2	Regression equation $Y = b_0 \times b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$	Y-estimate
Carcass (X_2)		0.85	$Y= 4.53 + 0.07X_1 + 0.47X_2$	0.58
Skin & Wool (X_3)		0.98	$Y= 2.78 + 0.08X_1 + 0.44X_2 + 0.23X_3$	0.28
Testis (X_4)		0.98	$Y= 2.38 + 0.09X_1 + 0.44X_2 + 0.24X_3 + 0.03X_4$	0.36
Lysine				
Carcass (X_1)	Whole body	0.54	$Y= 3.58 + 0.42X_1$	0.62
Skin & Wool (X_2)		0.71	$Y= 2.76 + 0.39X_1 + 0.22X_2$	0.58
Head & Feet (X_3)		0.83	$Y= 2.21 + 0.38X_1 + 0.25X_2 + 0.11X_3$	0.48
GIT (X_4)		0.90	$Y= 1.70 + 0.38X_1 + 0.26X_2 + 0.12X_3 + 0.07X_4$	0.42
Blood (X_5)		0.93	$Y= -0.95 + 0.37X_1 + 0.25X_2 + 0.13X_3 + 0.08X_4 + 0.28X_5$	1.04
Liver (X_6)		0.95	$Y=-1.1 + 0.36X_1 + 0.24X_2 + 0.13X_3 + 0.08X_4 + 0.27X_5 + 0.05X_6$	0.91
Kidneys (X_7)		0.96	$Y= -1.07 + 0.36X_1 + 0.21X2 + 0.14X_3 + 0.08X_4 + 0.26X_5 + 0.04X_6 +0.03X_7$	0.83
Methionine				
GIT (X_1)	Whole body	0.44	$Y= 3.22 + 0.07X_1$	0.10
Carcass (X_2)		0.68	$Y= 2.35 + 0.06X_6 + 0.44X_2$	0.26
Head & Feet (X_3)		0.77	$Y= 1.81 + 0.06X_1 + 0.41X_2 + 0.09X_3$	0.30
Skin & Wool (X_4)		0.84	$Y= 0.83 + 0.07X_1 + 0.52X_2 + 0.09X_3 + 0.13X_4$	0.48
Phenylalanine				
GIT (X_1)	Whole body	0.69	$Y= 4.48 + 0.07X_1$	0.14
Carcass (X_2)		0.89	$Y= 2.57 + 0.07X_1 + 0.48X_2$	0.36
Skin & Wool (X_3)		0.94	$Y= 1.65 + 0.07X_1 + 0.44X_2 + 0.22X_3$	0.35
Head & Feet (X_4)		0.98	$Y= 1.31 + 0.08X_1 + 0.33X_2 + 0.23X_3 + 0.18X_4$	0.24
Blood (X_5)		0.99	$Y= -0.07 + 0.07X_1 + 0.34X_2 + 0.24X_3 + 0.17X_4 + 0.22X_5$	0.49
Liver (X_6)		0.99	$Y=-0.47 + 0.08X_1 + 0.32X_2 + 0.26X_3 + 0.14X_4 + 0.24X_5 + 0.06X_6$	0.38
Heart (X_7)		0.99	$Y= -0.65 + 0.07X_1 + 0.39X_2 + 0.25X_3 + 0.13X_4 + 0.21X_5 + 0.05X_6 + 0.04X_7$	0.29
Threonine				
GIT (X_1)	Whole body	0.85	$Y= 3.97 + 0.10X_1$	0.08
Carcass (X_2)		0.95	$Y= 2.03 + 0.10X_1 + 0.53X_2$	0.34
Skin & Wool (X_3)		0.97	$Y= 1.50 + 0.09X_1 + 0.50X_2 + 0.12X_3$	0.32
Head & Feet		0.98	$Y= 1.17 + 0.09X_1 + 0.45X_2 + 0.13X_3 + 0.11X_4$	0.26
Testis (X_5)		0.99	$Y= 0.74 + 0.09X_1 + 0.48X_2 + 0.13X_3 + 0.12X_4 + 0.06X_5$	0.29
Lungs (X_6)		0.99	$Y= 0.55 + 0.09X_1 +0.46X_2 + 0.15X_3 + 0.12X_4 + 0.06X_5 + 0.05X_6$	0.30
Blood (X_7)		0.99	$Y= 0.11 + 0.09X_1 + 0.47X_2 + 0.16X_3 + 0.12X_4 + 0.05X_5 + 0.06X_6 + 0.08X_7$	0.38
Kidneys (X_8)		0.99	$Y= 0.09 + 0.09X_1 + 0.48X_2 + 0.17X_3 + 0.11X_4 + 0.05X_5 + 0.08X_6 + 0.11X_7 -0.04X_8$	0.34
Valine				
GIT (X_1)	Whole body	0.67	$Y= 4.10 + 0.15X_1$	0.19

Table 4 Regression equations for predicting the whole body essential amino acid composition (g AA/100 g crude protein) and the coefficients of determination (r^2) between dependent and independent variates (Continued)

Independent variable (X)	Dependent variable (Y)	r^2	Regression equation $Y = b_0 \times b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$	Y-estimate
Carcass (X_2)		0.82	$Y= 2.88 + 0.13X_1 + 0.34X_2$	0.36
Head & Feet (X_3)		0.90	$Y= 2.41 + 0.09X_1 + 0.39X_2 + 0.09X_3$	0.31
Blood (X_4)		0.95	$Y= 1.39 + 0.08X_1 + 0.39X_2 + 0.10X_3 + 0.13X_4$	0.36
Liver (X_5)		0.97	$Y= 1.24 + 0.08X_1 + 0.38X_2 + 0.09X_3 + 0.14X_4 + 0.03X_5$	0.27
Skin & Wool (X_6)		0.98	$Y= 1.01 + 0.07X_1 + 0.39X_2 + 0.09X_3 + 0.14X_4 + 0.03X_5 + 0.08X_6$	0.26
Spleen (X_7)		0.99	$Y=1.60 + 0.08X_1 + 0.39X_2 + 0.10X_3 + 0.14X_4 + 0.04X_5 + 0.09X_6 - 0.14X_7$	0.28
Testis (X_8)		0.99	$Y= 1.40 + 0.09X_1 + 0.40X_2 + 0.11X_3 + 0.16X_4 + 0.04X_5 + 0.11X_6 - 0.19X_7 + 0.02X_8$	0.27

Table 5 compares the EAA composition of lamb whole empty body, determined in the present study with carcasses, and whole bodies reported in the literature. The carcasses in the present study contained significantly ($p < 0.05$) lower arginine, histidine, methionine, threonine and valine concentrations when compared to the whole empty body. The hypothesis that the change in the proportion of whole body protein as skin and wool protein could affect the concentrations of arginine, histidine, leucine, lysine, methionine and threonine may explain the wide variation in the concentration of these amino acids between the carcass and whole body (Kyriazakis & Emmans, 1993). Except for lysine, which was quite similar ($p > 0.05$) between the carcass and whole empty body in the present study, the other five EAAs (arginine, histidine, leucine, methionine and threonine), reported by Kyriazakis & Emmans (1993), support this hypothesis. Therefore the carcass EAA composition does not seem representative of the South African Mutton Merino lambs' needs for whole empty body growth.

Table 5 Amino acid profile of carcass and whole empty body (g AA/100 g crude protein)

Literature	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val
MacRae *et al.* (1993)[1]	7.3	2.6	3.8	7.5	7.0	1.8	3.9	5.0	4.9
Williams (1978)[2]	7.0	2.5	2.8	6.9	6.4	1.7	3.6	4.0	3.9
Rohr & Lebzien (1991)[3]	6.9	2.8	3.4	7.5	6.9	2.2	4.0	4.2	4.9
Ainslie *et al.* (1993)[4]	5.9	2.1	2.3	5.7	5.8	2.0	3.0	3.5	3.3
Carcass[5]	6.8^a	2.6^a	3.1^a	7.1^a	6.9^a	2.1^a	4.1^a	3.7^a	4.2^a
Whole body[5]	7.7^b	4.5^b	3.1^a	8.5^a	6.5^a	3.6^b	5.2^a	4.7^b	5.2^b
Kyriazakis & Emmans (1993)[6]	6.7	2.8	3.5	7.4	7.1	1.8	3.8	3.8	4.7

[a,b] Means in rows bearing different superscripts are significantly ($p < 0.05$) different; [1] Values determined from Suffolk × Finn Dorset carcasses; [2] Values determined on whole Friesian empty body; [3] Values determined on whole cattle empty body; [4] Average whole empty body of Holstein steers; [5] Present study; [6] Whole body composition of the growing pig.

The high histidine and methionine concentrations in the whole empty body, as encountered in the present study, compared to the whole empty bodies of cattle or pigs, are probably due to the significantly ($p < 0.05$) higher concentration in the head and feet and skin and wool (Table 3) when compared to that of the carcass. Substantial differences also occurred between the EAA composition of various whole cattle empty bodies. From Table 5 it is clear that the relatively large differences between most of the EAAs, reported in the literature, do not support the view of Smith (1980), who stated that the amino acid composition of the bodies of animal species are remarkably similar. However, Smith (1980) added that variations do occur. For an accurate estimation, it appears to be necessary to establish the amino acid composition for specific species (Loëst *et al.*, 1997).

Conclusions

From the results of the present study, it can be concluded that the EAA composition of the whole empty body remained similar regardless of slaughter weight. As the animals grew from 30 to 45 kg live weight, the highest incremental change in nitrogen deposition resulted from carcass (± 48%) and skin and wool (± 41%). Therefore as far as net amino acid requirements are concerned, the major sites of protein deposition seem to be in the carcass as well as the skin and wool.

The carcass, skin and wool and GIT play a major role in predicting the whole empty body EAA composition. The high whole empty body histidine and methionine concentrations in the present study, in comparison with the whole cattle or pig empty bodies in the literature, are probably due to the significantly ($p < 0.05$) higher concentrations in the head and feet and skin and wool, when compared to the carcass. Therefore the results from the present study do not support the view in the literature that the amino acid composition of the bodies of animal species is remarkably similar. The difference in wool and meat production potential between sheep breeds necessitates the establishing of the amino acid composition for specific species and breeds. The average EAA composition of the whole empty body determined in the present study could serve as an ideal example of the EAA requirements of South African Mutton Merino lambs needed for whole empty body growth at tissue level.

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