Amino acid requirements of South African Mutton Merino lambs 1. Duodenal and carcass essential amino acid profile

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Received 15 November 1998; accepted 23 November 1998

The essential amino acid (EAA) composition of the carcass and duodenal digesta content of South African Mutton Merino ram lambs, fed a standard total mixed diet high in rumen degradable protein (RDP), was investigated. The standard diet consisted (%) of 30 lucerne, 8 wheat straw, 56.25 maize meal, 3.5 molasses, 1 urea, 0.5 salt and 0.75 ammonium chloride. The carcass essential amino acid composition (g AA/100 g crude protein) was as follows: 6.94 arginine; 2.61 histidine; 3.19 isoleucine; 7.19 leucine; 7.03 lysine; 2.08 methionine; 4.15 phenylalanine; 3.79 threonine and 4.28 valine. This composition can serve as an example of the ideal protein requirements for carcass growth of South African Mutton Merino ram lambs fed a standard diet high in RDP. Relatively large differences occurred between the average essential amino acid concentrations of the standard diet and duodenal digesta, with the exception of histidine, leucine and threonine. Duodenal digesta contained significantly lower ($p < 0.05$) concentrations of arginine, histidine, methionine and threonine and significantly higher ($p < 0.05$) concentrations of leucine and phenylalanine when compared to the carcass. Chemical score indicated that the duodenal digesta was first-limiting in histidine and second-limiting in threonine, followed by arginine and methionine for the carcass growth of South African Mutton Merino lambs fed a standard diet. Isoleucine, leucine and phenylalanine appear to be in excess for the carcass growth of lambs.

Ondersoek is ingestel na die karkas- en duodenale essensiële aminosuursamestelling van Suid-Afrikaanse Vleismerino ramlammers, wat 'n standaarddieet hoog in rumen degradeerbare proteïen (RDP), ontvang het. Die dieet was soos volg saamgestel (%): 30 lusern, 8 koringstrooi, 56.25 mieliemeel, 3.5 melasse, 1 ureum, 0.5 sout en 0.75 ammoniumchloried. Die essensiële aminosuursamestelling van die karkas (g aminosuur/100 g ruproteïen) was soos volg: 6.94 arginien; 2.61 histidien; 3.19 isoleusien; 7.19 leusien; 7.03 lisien; 2.08 metionien; 4.15 fenielalanien; 3.79 treonien en 4.28 valien. Hierdie samestelling kan as voorbeeld van die ideale proteïenbehoeftes vir karkasgroei van Suid-Afrikaanse Vleismerino ramlammers dien wat 'n standaarddieet hoog in RDP ontvang het. Met die uitsondering van histidien, leusien en treonien het relatief groot verskille tussen die gemiddelde essensiële aminosuursamestelling van die standaarddieet en duodenale digesta voorgekom. In 'n vergelyking tussen die duodenale-inhoud en karkas het betekenisvolle ($p < 0.05$) laer konsentrasies van arginien, histidien, metionien en treonien en betekenisvolle hoër ($p < 0.05$) konsentrasies van leusien en fenielalanien voorgekom. Volgens die chemiese telling was die duodenale-digesta eerste beperkend in histidien en tweede beperkend in treonien, gevolg deur arginien en metionien vir karkasgroei in Suid-Afrikaanse Vleismerino lammers wat 'n volledige

dieet hoog in RDP ontvang het. Dit het geblyk dat isoleusien, leusien en fenielalanien in oormaat beskikbaar was vir karkasgroei.

Keywords: essential amino acids; carcass; duodenum; sheep

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Introduction

Recently, considerable attention has been devoted to the protein requirements of ruminants, but the possibility of accurately defining the requirements for particular amino acids has received less attention (Buttery & Foulds, 1985). The key components of the NRC (1985) and NRC (1989) protein systems are the estimation of microbial protein synthesis in the rumen and rumen undegraded protein (UDP) which pass to the small intestine.

The advantage of the rumen degradable protein:rumen undegradable protein (RDP:UDP) system, when compared to the crude protein system, is that less protein is required because of more efficient protein utilization (Erasmus, 1992). Unfortunately, the NRC nutrient requirements for dairy cattle (NRC, 1989) and sheep (NRC, 1985) do not take individual amino acid requirements into account, which is necessary for optimal growth and production. However, the latest NRC for beef cattle (NRC, 1996) includes a model to estimate both quantity and production of essential amino acids required by beef cattle and supplied by the diet. Information on the amino acid requirements of lambs are urgently needed to include in future nutrient requirement tables. Furthermore, Merchen & Titgemeyer (1992) concluded that microbial protein alone may not meet the amino acid requirements for maintenance and production (e.g. growth and lactation).

It has been suggested by Cole & Van Lunen (1994) that the most important single factor affecting the efficiency of protein utilization for production of meat and other products is the balance of absorbed amino acids. In monogastric animals, examining the pattern of dietary amino acids, the ideal protein provides a simple and effective approach (Fuller & Chamberlain, 1982). While such a concept has probably been best developed in pigs, it is equally applicable to other species (Cole & Van Lunen, 1994).

According to Chen & Ørskov (1994) the concept of an ideal protein has been used to refer to the protein that provides absorbed amino acids in the proportion that gives maximum effieciency of utilization. The amino acid composition of lean meat serves as an example of the amino acid balance of the ideal absorbed protein (ARC, 1981). Williams *et al.* (1954) and Fuller *et al.* (1979) noted a close agreement between amino acid requirements determined by carcass analysis and those determined by conventional nutritional research. This indicates that the carcass analysis procedure is a valid method for the determination of amino acid requirements during growth. Chen & Ørskov (1994) concluded that the amino acid composition required for tissue maintenance is not known, but since the turnover of protein is mainly in tissue, it is possibly similar to that needed for tissue growth. This point was indirectly supported by the work of Storm *et al.* (1983), who observed the same utilization efficiency for microbial protein, regardless of whether the animal was gaining or losing nitrogen.

In monogastric animals the amino acid supply is largely determined by the diet (Zhang *et al.*, 1984), but in ruminants the rumen micro-organisms modify the amino acid patterns of the diet and thus have a considerable effect on the patterns of amino acids absorbed (Tao *et al.*, 1974; Van der Walt & Meyer, 1988; Matras *et al.*, 1991). To estimate the amino acid supply to ruminants, it will therefore be more accurate to determine the amino acid patterns of the duodenal digesta content,

rather than that of the initial diet.

Amino acid composition of bacteria isolated from the rumen has been reported to be constant (Purser & Buechler, 1966; Harrison *et al.*, 1973; Richardson & Hatfield, 1978; Mercer *et al.*, 1980; Matras *et al.*, 1990). However a summary by Clark *et al.* (1992) of the amino acid composition of 441 bacterial samples from animals fed 61 dietary treatments in 35 experiments indicates significant differences in amino acid composition. If the diet has an influence on the amino acid composition of the rumen micro-organisms, research should be focused on the duodenal amino acid composition from a specific diet to detect imbalances in absorbed amino acids. Clark *et al.* (1992) stressed that animals utilized for research should represent the target animal in consuming and producing under specific environmental conditions. Furthermore, composition of dietary ingredients, ruminal degradation, composition of ruminal bacteria, passage of energy and nitrogen fraction of the small intestine, and other related factors, must be measured in research trials rather than estimated from values reported in the literature.

The purpose of this study was to compare the essential amino acid profile of the duodenal digesta contents with that of ideal protein (carcass) to detect imbalances for carcass growth when South African Mutton Merino lambs were fed a standard growth-promoting diet. In the present study the procedures which applied for pigs were followed and the carcass was therefore used as the ideal protein. The results regarding the whole empty body are presented in a next paper.

Material and methods

Twenty South African Mutton Merino ram lambs, described by Loëst *et al.* (1997), were used as experimental animals. An additional three lambs fitted with rumen cannulae were used to determine the degradability of the standard diet. Animals were individually housed throughout the trial.

The same standard diet as described by Loëst *et al.* (1997) was fed to meet the nutrient requirements (crude protein, metabolizable energy, calcium and phosphorus) of growing lambs (NRC, 1985). A diet with a high rumen degradability of protein was formulated to ensure that amino acids reaching the duodenum were predominantly of those originating from microbial protein.

The lambs were randomly allocated to four pre-assigned average target slaughter weights (30, 35, 40 and 45 kg live weight). Before the slaughter process, each animal received one-twelfth of its average daily feed intake (calculated according to the previous seven days) every 2 h during the 48 h prior to slaughter (Hume *et al.*, 1972). This was to eliminate irregular feed intake and thus uneven amounts of digesta in the gastrointestinal tract. The left side of the bisected carcass was stored for amino acid analysis.

According to Van der Walt & Meyer (1988) the small intestine may be investigated by dividing the gut of slaughtered animals into segments and quantitatively recovering the digesta from each segment. Alternatively, cannulae may be used, which may affect the normal physiological function of the digestive tract (MacRae, 1975). Therefore, the digesta contents of the first 4 m (representing the duodenum) of the small intestine was quantitatively recovered at slaughter. Representative samples were collected and stored at –18°C prior to later analysis. The left half of the carcass was milled, mixed and milled again through a carcass mill while frozen. A representative sample was freeze-dried, mixed with dry ice and milled throught a 1-mm screen. The dry ice was used to prevent the fat from smearing during grinding.

The diet was analysed as described by Loëst *et al.* (1997). The essential amino acid composition of the representative carcass, duodenal digesta content and basal diet samples were determined with a BECKMAN SYSTEM 7300 high performance analyser after 22 h of acid hydrolysis (6 N.HC1) at 110°C (A.O.A.C., 1984).

The *in situ* technique, described by Weakly *et al.* (1983), was used to determine ruminal dry mat-

ter and protein degradation. The dry matter and nitrogen disappearance were measured in duplicate with each of the three lambs as recommended by Mehrez & Ørskov (1977), giving a total of six estimates for the standard diet.

The flow rate of particular matter from the rumen was determined with a chromium (Cr_2O_3) solution according to the process described by Udén *et al.* (1980). The chromium concentration was analysed using an Atomic Absorption Spectrophotometer (VARIAN SPECTR.AA 300/400) and rumen flow rates calculated according to the method of Hartnell & Satter (1979).

The method used to estimate the extent of ruminal dry matter and protein degradation was proposed by Miller (1980; as cited by Stern & Satter, 1984), who mathematically combined results obtained *in situ* with *in vitro* rate of passage measurements. This method was used in preference to more complex methods (Ørskov & McDonald, 1979), since previous studies have shown no clear advantages for either method (Cronjé, 1992).

After the data were tested for differences using ANOVA, multiple comparisons of means (using Tukey's test) were performed with PC SAS 6.04 (Cary, NC. SAS Institute Inc.) as designed in the SAS Procedures Guide (1988) and from the second edition of SAS System for Regression (1991). Mean values in the tables bearing different superscripts indicate significant differences ($p < 0.05$).

Results and Discussion

The essential amino acid composition and effective rumen degradability of the standard diet appear in Table 1. By comparing the essential amino acid concentrations in the standard diet with each other, it is evident that the concentration of methionine is exceptionally low, followed by histidine. According to Nimrick *et al.* (1970) and Richardson & Hatfield (1978) methionine is, in most cases, the most limiting essential amino acid for ruminants.

The effective degradation value for crude protein (80%) in Table 1 confirms that the standard diet used during the present study was highly degradable and, therefore, contained a relatively small fraction (± 20%) of protein that escaped microbial degradation. The degradable fraction of a diet is used as a source of nitrogenous nutrients for the synthesis of rumen microbial protein (Erasmus, 1991). Therefore, the protein fraction of the duodenal digesta in this study can be expected to be predominantly of microbial origin.

An average daily gain of 200 g per lamb was obtained in the present study. According to the NRC (1985), a daily gain of 275 g was expected with a metabolizable energy content of 10.8 MJ/kg which was determined for the standard diet in the present study. This lower gain can possibly be attributed to the high degradable protein content (± 80%) of the standard diet and thus an imbalance in the supply of essential amino acids to the duodenum as well as the amount of amino acids synthesised in the rumen.

Table 2 lists the essential amino acid composition of the standard diet, duodenal digesta and carcass. The essential amino acid profile of the standard diet and duodenal digesta of the present study is remarkably similar. In contrast, relatively large differences between the average essential amino acid concentrations of the standard diet and duodenal digesta occurred, with the exception of histidine, leucine and threonine. Substantially lower concentrations of isoleucine, lysine and methionine, and to a lesser extent arginine, were seen in the standard diet compared to the duodenal digesta, while a remarkably higher concentration of phenylalanine occurred. The large differences between the essential amino acid composition of the standard diet and duodenal digesta were expected to occur, since it has been reported (Merchen & Titgemeyer, 1992; Cole & Van Lunen, 1994) that in diets high in RDP, rumen micro-organisms are the primary source of protein flowing into the duodenum. Through the process of rumen fermentation, rumen microbes, therefore, modify the duodenal amino acid profile compared to that of the standard diet. Furthermore, to complicate

Table 1 Chemical composition and rumen degradability of the standard diet on an air dry basis

Item	Content
Chemical composition	
Rumen degradable protein (%)	11.81
Undegradable protein (%)	2.91
Essential amino acid composition	
Arginine (%)	0.73
Histidine (%)	0.29
Isoleucine (%)	0.42
Leucine (%)	1.22
Lysine (%)	0.77
Methionine (%)	0.19
Phenylalanine (%)	0.95
Threonine (%)	0.47
Valine (%)	0.68
Effective rumen degradability	
Dry matter (%)	80.08
Crude protein (%)	80.22
Kd (dry matter)[1)]	0.0469
Kd (crude protein)[1)]	0.0438
Kr[2)]	0.0195

[1)] Kd = Rate constant for disappearance of dry matter and protein from the rumen incubated polyester bag; [2)] Kr = Rate constant for passage of undegraded dry matter or protein from the rumen

matters even more, the amino acid profile of the UDP fraction of feeds is often different from those of the original feeds (Hvelplund *et al.*, 1987; Susmel *et al.*, 1989; Erasmus *et al.*, 1994).

The average essential amino acid profile of digesta in the literature (Table 2) is relatively similar to that of the present study. The mean values in the literature, however, seem to contain higher concentrations of individual amino acids such as histidine, threonine and valine, and a lower arginine concentration than that of the present study. These differences are most likely due to the effect of different diets (Laughren & Young, 1979) reported in the literature. According to Chalupa (1975), the animal is normally supplied with a mixture of microbial and rumen bypass protein, which is dependant on the solubility and degradability of the diet (Mercer *et al.*, 1980; Merchen & Titgemeyer, 1992). Several authors (Stern & Hoover, 1979; Clark *et al.*, 1992; Oldham, 1993) also mentioned that the energy and nitrogen content of diets are major determinants of the amount of microbial protein synthesized in the rumen. In the present study, dietary protein was readily degraded in the rumen which probably could have been the reason why the amino acid patterns entering the small intestine were highly representative of rumen microbial protein.

According to Wolfrom & Asplund (1979), tissue amino acid patterns more closely represent the patterns animals required than did the plasma amino acid patterns. Tagari & Bergman (1978) also mentioned that plasma free amino acid levels are frequently difficult to interpret because of the

Table 2 Essential amino acid content of standard diet, duodenal digesta content and carcass (g AA/100 g crude protein)

EAA	Standard diet[1)]	Average duodenal digesta[2)]	Duodenal digesta[3)]	Carcass[4)]
Arg	4.96	4.07	6.26[b]	6.94[a]
SD			±1.03	±0.49
His	1.97	2.78	2.10[b]	2.61[a]
SD			±0.23	±0.58
Iso	2.85	5.48	3.44[a]	3.19[a]
SD			±0.71	±0.23
Leu	8.29	8.39	8.04[a]	7.19[b]
SD			±0.82	±0.40
Lys	5.23	7.55	7.03[a]	7.03[a]
SD			±0.99	±0.46
Met	1.29	2.07	1.91[b]	2.08[a]
SD			±0.26	±0.23
Phe	6.45	4.93	4.98[a]	4.15[b]
SD			±0.53	±0.37
Thr	3.19	4.89	3.11[b]	3.79[a]
SD			±0.34	±0.26
Val	4.62	5.19	4.25[a]	4.28[a]
SD			±0.52	±0.40

[1)] Standard diet used in the present study; [2)] Compiled from data of Mercer *et al.* (1980), Sklan & Halevy (1985) and Hussein *et al.*(1991); [3)] Mean values determined from the 20 South African Mutton Merino lambs used in the present study; [4)] Mean carcass values; [a,b)] Values in rows bearing different superscripts are significantly different ($p<0.05$).

multiplicity of factors that can be involved. In order to identify the limiting amino acids for growth, a comparison of the essential amino acid composition of the lamb carcass and duodenal digesta is thus quite informative.

From Table 2 it is apparent that significantly lower ($p < 0.05$) concentrations of arginine, histidine, methionine and threonine occurred in the duodenal digesta content when compared to that of the carcass. From this comparison a first- and second-limiting amino acid can hardly be identified, and thus for a better evaluation, the chemical score and resulting essential amino acid index (Table 3) was calculated. This method has been used by several authors (Chandler, 1989; Schingoethe, 1991; Erasmus, 1992) as a classical approach to determine limiting amino acids in individual feed ingredients. The chemical score presents the proportion of a specific essential amino acid relative to that in carcass protein, while the essential amino acid index represents the proportion of nine essential amino acids (tryptophan excluded) relative to that of carcass protein. For this calculation, all scores greater than 100 were assigned values of 100, as the protein score is given credit for only 100% supply of a particular essential amino acid (Chandler, 1989).

Chemical scores would suggest that duodenal digesta is first-limiting in histidine and second-limiting in threonine followed by arginine and methionine. More than adequate ratios were present for isoleucine, leucine and phenylalanine in the duodenal digesta. It is interesting to note that the

Table 3 Chemical score, essential amino acid index and essential amino acids expressed as a percentage of lysine

	Chemical score[1)]		EAA: Lysine[2)]		
EAA	Standard diet	Duodenal digesta	Standard diet	Duodenal digesta	Carcass
Arg	71	91	95	89	99
His	75	80	38	30	37
Iso	89	108	54	49	45
Leu	115	112	159	114	102
Lys	74	100	100	100	100
Met	62	92	25	27	30
Phe	155	119	123	71	59
Thr	84	82	61	44	54
Val	108	99	88	60	61
EAA (Index)3)	84	94			

[1)] Chemical score presents the proportion of a specific essential amino acid relative to that of carcass protein; [2)] EAA : lysine expresses each essential amino acid as a percentage of lysine (lysine = 100%); [3)] EAA (Index) presents the proportion of all the essential amino acids studied relative to that of carcass protein.

theoretical calculations by Oldham (1987) also indicated that histidine might be the first-limiting amino acid for milk protein synthesis when the major part of the amino acid supply to the animal consisted of a typical mix of rumen bacteria and protozoa. These results were supported in a more recent study by Fraser *et al.* (1991).

A summary of the results in the literature (Nimrick *et al.*, 1970; Owens *et al.*, 1973; Storm & Ørskov, 1984) revealed that methionine is the first and lysine the second-limiting amino acid for growing lambs. The results of Storm & Ørskov (1984) and Chen & Ørskov (1994) indicated that histidine is the third-limiting amino acid in growing lambs. Other amino acids suggested to be third-limiting were threonine (Nimrick *et al.*, 1970), valine (Owens *et al.*, 1973) and arginine (Storm & Ørskov, 1984). According to Smith (1980), requirements for methionine and other sulphur amino acid deposition in different animals and species vary widely owing to differences in product (e.g. meat, wool and milk) composition. Smith (1980) added that the sulphur amino acid requirements for sheep are high owing to wool production. However, methionine was found not to be first-limiting, but fourth-limiting in the present study. This was most likely due to the fact that the present study focused on growth requirements by assay of the carcass. The amino acid profile for wool was not considered.

Although Nimrick *et al.* (1970), Owens *et al.* (1973) and Storm & Ørskov (1984) found lysine to be second-limiting, this was not the case in the present study. In fact, the lysine content of the duodenal digesta and carcass were remarkably similar (Table 2). The finding was supported by Smith (1980), who mentioned that lysine requirements for sheep are low, thus making it difficult to envisage a specific lysine deficiency normally occurring in this animal. MacRae *et al.* (1993) also reported that the lamb carcass exhibits smaller requirements for lysine when compared to the whole body.

During the present study the carcass was responsible for 57% of the live weight gain (30 to 45 kg) and was therefore most probably not totally representative of the ideal protein needs of growing

lambs. Therefore, it seems important to compare the results of the present study to those of the whole body of South African Mutton Merino lambs.

Based on the chemical score and resulting essential amino acid index, duodenal digesta protein exhibits superior biological value over the standard diet. This result supports the view of Laughren & Young (1979), who stated that ruminants are capable of modifying the form of a poor quality dietary protein to a higher biological value.

Although ruminants are normally less susceptible to the effects of imbalances by virtue of extensive microbial metabolism of amino acids, in some instances ruminal degradation serves to initiate detrimental effects through the generation of reactive metabolites from specific amino acids (D'Mello, 1994). In an effort to prevent the harmful effects of imbalances, the ARC (1981) proposed a specific pattern for the ideal amino acid composition of dietary protein for pigs. Included in this recommendation is the assumption that an amino acid imbalance should be avoided if overall efficiency of protein utilization is to be maximised (D'Mello, 1994). Moughan (1991) calculated that, on average, ingested dietary protein was utilized by the growing pig with an efficiency of only 0.30. According to D'Mello (1994), the low efficiency was attributed, in part, to a dietary amino acid imbalance. Based on the chemical score of the present study (Table 3), it is evident that the duodenal digesta has provided an imbalanced ratio of essential amino acids for absorption.

Abomasal infusion studies by Schwab *et al.* (1976), revealed that the supplementation of more than one limiting amino acid will likely give greater response than supplementation of a single rumen-protected amino acid. Past studies (Nimrick *et al.*, 1970; Owens *et al.*, 1973; Storm & Ørskov, 1984) have focused on limiting amino acids and ignored essential amino acids which may have occurred in excess, causing a depression in growth, food intake and/or nutrient utilization. Since amino acid imbalances and toxicities are known to occur (Harper, 1964, cited by Wolfrom & Asplund, 1979), further research should focus on correcting this problem in the duodenum in order to possibly enhance the efficiency of utilization of absorbed amino acids for maintenance and growth.

To provide a direct comparison of the essential amino acid composition regardless of protein quantity, the values for duodenal digesta, standard diet and carcass are expressed as a percentage of lysine (Table 3). If the requirements for one essential amino acid such as lysine with no known function other than for the synthesis of tissue protein are known, then the requirements for the other essential amino acids may be estimated from the essential amino acid (EAA) to lysine ratio in the bodies of ruminants (Williams & Hewitt, 1979). According to Baker & Han (1994), the logic involved in expressing amino acid requirements as ideal ratios to lysine is that a multitude of dietary factors (e.g. protein level, energy level and feed intake) environmental factors (e.g. disease and heat stress) and genetic factors (e.g. sex and capacity for lean vs. fat growth) may affect amino acid requirements, but the ideal ratio of essential amino acids to lysine should remain largely unaffected by these variables. Hence, one can place emphasis on establishing accurate lysine requirements under a variation of circumstances, after which the remaining essential amino acid requirements can be calculated. Lysine is selected as the reference amino acid for three primary reasons:

(1) its analysis in feedstuffs is relatively simple and straight-forward (Baker & Han, 1994);
(2) unlike several other amino acids, absorbed lysine is used only for protein accretion (Williams & Hewitt, 1979; Baker & Han, 1994);
(3) together with methionine, lysine seems to be limiting in most ruminant diets (Owens *et al.*, 1973; Cole & Van Lunen, 1994).

According to the EAA to lysine ratios (Table 3), it is interesting that leucine and phenylalanine concentrations in particular, are exceptionally high in the diet when compared to those of the car-

cass. In the case of duodenal digesta, the ratio of arginine, histidine and threonine to lysine tends to exhibit lower concentrations when compared to that of the carcass. However, these differences are small and it can thus be concluded that the essential amino acid patterns of the duodenal digesta are a closer approximation of those of the carcass. It is thus evident that during the present study, the micro-organisms in the rumen of the lambs were capable of modifying the basal diet protein to a more favourable protein with more appropriate essential amino acid patterns.

Conclusions

According to the results, the average essential amino acid profile of the duodenal digesta was disproportionate to that of the standard diet. These large differences between the essential amino acid content of the standard diet and duodenal digesta were not surprising, as it has been known for some time that rumen micro-organisms are capable of modifying the amino acid profile of the diet.

Results from the present study pointed out that histidine, threonine, arginine and methionine would appear to be limiting for the carcass growth of lambs fed a high degradable (± 80%) standard diet. A summary of results in the literature (Nimrick *et al.*, 1970, Owens *et al.*, 1973; Storm & Ørskov, 1984) also demonstrated that these amino acids have previously been reported to be limiting for growing lambs. The two most limiting amino acids in the literature, however, were different to those found in the present study. These differences were most likely due to different diets and species used during the trials, as well as different methods applied to assess requirements. The present study focused on determining growth requirements by assay of the carcass which was responsible for 57% of the live weight gain. The whole body compared to the carcass as an example of the essential amino acid balance of absorbed protein thus warrants further investigation.

Past research (Nimrick *et al.*, 1970, Owens *et al.*, 1973; Storm & Ørskov, 1984) has focused on limiting amino acids and ignored essential amino acids which have occurred in excess, thus causing an imbalance which may stunt growth or depress feed intake and nutrient utilization. According to the results of the present study, isoleucine, leucine and phenylalanine would appear to be in excess for the carcass growth of lambs. The effects of imbalances (under and over supply) of essential amino acids on the performance of ruminant animals thus requires further investigation.

Acknowledgements

The assistance of Prof. J.P. Hayes, Mr. A.C. Adams and Miss. J.A. van Wyk of the Department of Poultry Science, University of Stellenbosch, South Africa, with the amino acid analysis, is gratefully acknowledged.

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