Balancing the duodenal amino acid supply in ruminants with practical feed ingredients

C. Dennison and Anne M. Phillips
Department of Biochemistry, University of Natal, Pietermaritzburg

A least-cost linear programme was used to identify, in qualitative and quantitative terms, the feed ingredients which would be required to balance the duodenal amino acid supply provided by ingredients fermented in the rumen, assuming that the supplemental ingredients by-pass the rumen. These computations revealed that the favoured supplementary ingredients for either milk or meat production are bloodmeal, carcass meal, poultry by-product meal, fishmeal and groundnut oilcake. The amounts required in each case are presented.

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'n Minimumkoste lineêre program is gebruik om die voerbestanddele te identifiseer wat kwalitatief en kwantitatief benodig word om die duodenale rumen aminosuurtoevoer, wat verskaf word deur bestanddele wat in die rumen gefermenteer word, te balanseer as aangeneem word dat die aanvullende bestanddele die rumen verbyvloei. Hierdie rekenaarberekings het getoon dat die mees geskikte aanvullende bestanddele vir melk- of vleisproduksie bloedmeel, karkasmeel, pluimveebyprodukmeel, vismeel en grondboonoliekoek is. Die hoeveelheid wat in elke geval benodig word, word aangetoon.

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C. Dennison* and A.M. Phillips
Department of Biochemistry, University of Natal,
P.O. Box 375, Pietermaritzburg, 3200 Republic of South Africa

*To whom correspondence should be addressed

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Introduction

In a previous communication (Dennison & Phillips, 1983) a method was proposed for the estimation of the amino acids provided by feeds in the duodenum of ruminants, i.e. after fermentation in the rumen. With this information available, a natural sequel is the question of how the amino acids provided may be balanced for optimal production, since microbial protein alone does not meet the protein requirements of the high-yielding cow (Virtanen, Ettala & Mäkinen, 1972). Simple mixing of feeds before feeding (i.e. pre-ruminal mixing) appears to be relatively ineffectual, as differences in the amino acid composition of different feed ingredients are smoothed out as the feed protein is converted to microbial protein during fermentation (Blackburn & Hobson, 1960; Dennison & Phillips, 1983). The alternative is to effect rumen by-pass of amino acids or proteins (Kaufmann, 1979; Beever & Thomson, 1981), a procedure which may be considered as post-ruminal mixing of the feed.

The essential mechanism of rumen by-pass of amino acids or proteins is to render these unavailable to the rumen microbes but available to the enzymes present distal to the duodenum for digestion. The simplest means of effecting this for proteins, is either by rendering the substance insoluble or by selecting insoluble proteins, (Braund, Dolge, Golings & Steele, 1978) since insoluble protein is inaccessible to the cell-bound microbial proteases but accessible to the soluble proteases derived from pancreatic secretions. Whole proteins are more easily protected against microbial attack, either by denaturation (heating) (Ahrar & Schingoethe, 1979) or by chemical treatment (cross-linking) (Bertrand, Tome & Delport-Laval, 1981) than are amino acids, which are relatively small, highly charged and highly soluble molecules. Moreover, as several amino acids are often limiting to a closely similar degree, bypassing of single amino acids has not proved effective (Kaufmann, 1979; Schwab, Satter & Clay, 1976).

In the studies reported here attention has therefore been given to balancing the duodenal amino acid supply provided by fermented forages, with proteins provided by practical feed ingredients. For the purposes of this communication it is assumed that the latter proteins bypass the rumen, since the object of these studies is to identify, in qualitative and quantitative terms, which ingredients should be considered for application of rumen bypass techniques.

It must be stressed that in practice some form of treatment might be necessary to render the supplementary protein undegradable in the rumen. The exact form of treatment which would be most effective is beyond the scope of this communication which is limited to the identification of *the ingredient(s)* to which appropriate treatment(s) might profitably be applied.

Methods

Using a linear program package (Sperry-Univac Series 1100, FMPS level 9R1) and a matrix of feed ingredient amino acid composition values and prices (Table 1), a least-cost supplement was computed for addition to each of eight fermented forages (and fermented maize), to meet a specified amino acid requirement for either milk or meat production. To ensure maximal use of the fermented ingredient under consideration, this was given an arbitrary but very low price in each case, while each non-fermented supplemental ingredient was given its prevailing market price (as in August 1982).

The amino acid requirements for milk or meat production in ruminants are not accurately known and in the absence of this information, the amino acid requirement was assumed, as a first approximation, to have the same proportional composition as the product; milk or carcass respectively (Boorman, 1980). Only the amino acid composition of the various feed ingredients is taken into account in this work and no attention is given to the energy content. However to make the results realistic, computations have been made to bracket the likely range of protein contents in a mixed feed, *viz.* from 10 % to 20 % and it is assumed that the balance is made up of caloric and non-digestible constituents. The target amino acid composition specified in the least-cost computations therefore, was that of (a) dried milk powder and (b) dried carcass meal, if each were diluted to a protein content of either 10 %, 15 % or 20 % respectively on a dry matter basis.

Results and Discussion

The results of least-cost formulations for milk production are shown in Tables 2 – 4 while those for meat production are shown in Tables 5 – 7.

Tables 2 – 4 reveal that for milk production, bloodmeal, carcass meal, poultry by-product meal and fishmeal are the ingredients favoured to make up deficiencies of lysine, histidine, methionine and isoleucine in the fermented ingredients. At the lowest (10 %) protein level (Table 2), exclusion of bloodmeal and carcass meals (on the basis that there are available in only limited quantities and that they might not be palatable), results in an increase in the amount of fishmeal required with groundnut and brewers grain being selected additionally. Clover (*T. repens*), ryegrass *(L. multiflorum)* and lucerne *(M. sativa)* are different from the other fermented ingredients in that they re-

Table 1 Matrix of data for ingredients selected in least-cost feed formulations[a]

Unfermented ingredients[b]														
Gluten	THR	0,0211	VAL	0,028	Carcass meal	THR	0,0235	VAL	0,0351	Imported	THR	0,026	VAL	0,042
	MET	0,0174	ILE	0,0243		MET	0,0098	ILE	0,0143	fishmeal	MET	0,015	ILE	0,030
	LEU	0,0991	TYR	0,0314		LEU	0,0437	TYR	0,0155		LEU	0,05	TYR	0,020
	PHE	0,041	HIS	0,0121		PHE	0,0231	HIS	0,0123		PHE	0,025	HIS	0,0125
	LYS	0,0072	Protein	0,60		LYS	0,0362	Protein	0,50		LYS	0,055	Protein	0,66
	Price	4,31				Price	3,25				Price	5,02		
Groundnut	THR	0,0123	VAL	0,0213	Poultry	THR	0,0293	VAL	0,0414	Bloodmeal	THR	0,0495	VAL	0,0807
oilcake	MET	0,0035	ILE	0,0134	by-product	MET	0,0049	ILE	0,0265		MET	0,0104	ILE	0,0072
	LEU	0,0259	TYR	0,0131	meal	LEU	0,0455	TYR	0,0154		LEU	0,1208	TYR	0,025
	PHE	0,0207	HIS	0,0087	(PBPM)	PHE	0,0266	HIS	0,0069		PHE	0,0693	HIS	0,0549
	LYS	0,0148	Protein	0,40		LYS	0,0188	Protein	0,652		LYS	0,0690	Protein	0,80
	Price	2,000				Price	2,82				Price	3,535		
Fishmeal	THR	0,0281	VAL	0,0338	Full fat	THR	0,0130	VAL	0,0234	Brewers	THR	0,0091	VAL	0,0167
	MET	0,0163	ILE	0,0257	soybean	MET	0,0055	ILE	0,0143	grain	MET	0,0043	ILE	0,0103
	LEU	0,0475	TYR	0,0183	meal	LEU	0,0245	TYR	0,0095		LEU	0,0381	TYR	0,0078
	PHE	0,0245	HIS	0,0162		PHE	0,0156	HIS	0,0079		PHE	0,0134	HIS	0,0059
	LYS	0,045	Protein	0,62		LYS	0,0200	Protein	0,312		LYS	0,0046	Protein	0,27
	Price	4,670				Price	2,2				Price	1,30		
Fermented ingredients[c]														
A. junciformis	THR	0,0023	VAL	0,0041	*E. curvula*	THR	0,0062	VAL	0,0101	*Cynodon sp.*	THR	0,0086	VAL	0,0131
	MET	0,0012	ILE	0,0023		MET	0,0019	ILE	0,0061	(coast cross)	MET	0,0035	ILE	0,0084
	LEU	0,0035	TYR	0,0014		LEU	0,0100	TYR	0,0045		LEU	0,0131	TYR	0,0058
	PHE	0,0020	HIS	0,0006		PHE	0,0064	HIS	0,0015		PHE	0,0075	HIS	0,0019
	LYS	0,0019	Protein	0,0505		LYS	0,0055	Protein	0,1215		LYS	0,0072	Protein	0,1490
D. glomerata	THR	0,0074	VAL	0,0103	*P. clandes-*	THR	0,0096	VAL	0,0101	Maize grain	THR	0,055	VAL	0,0077
(Cocksfoot)	MET	0,0024	ILE	0,0066	*tinum*	MET	0,0033	ILE	0,0088		MET	0,0025	ILE	0,0051
	LEU	0,0115	TYR	0,0068	(kikuyu)	LEU	0,0156	TYR	0,0066		LEU	0,0102	TYR	0,0051
	PHE	0,0079	HIS	0,0015		PHE	0,0089	HIS	0,0025		PHE	0,0053	HIS	0,0017
	LYS	0,0050	Protein	0,155		LYS	0,0085	Protein	0,20		LYS	0,0054	Protein	0,0940
T. repens	THR	0,0093	VAL	0,0155	*L. multi-*	THR	0,0080	VAL	0,0124	*M. sativa*	THR	0,0064	VAL	0,0096
(clover)	MET	0,0025	ILE	0,0110	*florum*	MET	0,0022	ILE	0,0088	(Lucerne)	MET	0,0018	ILE	0,0069
	LEU	0,0163	THR	0,0097	(Ryegrass)	LEU	0,01322	THR	0,0069		LEU	0,0097	TYR	0,0049
	PHE	0,0105	HIS	0,0040		PHE	0,0086	HIS	0,0029		PHE	0,0063	HIS	0,0021
	LYS	0,0123	Protein	0,231		LYS	0,0095	Protein	0,2095		LYS	0,0082	Protein	0,1332

[a] Amino acids and protein are expressed as g/g of feed ingredient and prices are in Rand/10 kg.

[b] Available, but unselected ingredients were: yellow maize, sorghum, wheatbran, wheatpollard, sunflower oil, molasses, ricebran, maizegerm, cotton seed oilcake, bonemeal, soyabean meal, sunflower oilcake meal, sunflower seed husk, sucrose, hominychop, hydrolysed feathermeal. Amino acid composition data are from the data matrix maintained by the Dept.of Poultry Science, University of Natal. These data are from various sources, including Dennison & Gous (1980), the references quoted therein, and in-house analyses.

[c] Amino acid composition data from Dennison & Phillips (1983), except for clover, ryegrass and lucerne which were analysed according to Dennison & Phillips (1983).

Table 2 Least-cost feed formulations to balance the DAAS[b] (for milk production) to protein of milk dry matter at the 10 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)											
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Brewers grain	Gluten	Price	% Protein	Protein efficiency	Amino acids at lower limit
A. junciformis	100									1,0	5,1	47,1	
	83,6	2,6		7,4		6,4				63,1	15,4	64,9	LYS, MET, ILE
	85,1	Excl.		1,8	8,7	4,4				68,8	13,8	72,5	LYS, HIS, ILE
	81,6	Excl.	Excl.	Excl.	2,8	7,9	7,7			69,0	14,2	70,4	LYS, HIS, ILE
E. curvula	100									10,0	12,2	50,4	
	94,2	2,2			3,6					33,8	15,4	64,9	LYS, MET
	88,8	Excl.	8,3				2,8	0,1		41,5	16,1	62,1	LYS, MET, HIS
	91,7	Excl.	Excl.		6,7		1,6			43,7	15,9	62,9	LYS, HIS
Cynodon sp.	100									10,0	14,9	53,3	
	98,2	1,8								16,1	16,1	62,5	LYS
	90,7	Excl.	1,8				7,5			30,0	17,4	57,5	LYS, HIS
	91,3	Excl.	Excl.		1,5		7,2			30,4	17,4	57,5	LYS, HIS
D. glomerata	100									10,0	15,5	40,4	
	94,8	5,2								27,7	18,8	53,2	LYS
	89,8	Excl.	9,5			0,7				43,2	19,1	52,4	LYS, HIS
	92,1	Excl.	Excl.		6,3	1,5				46,5	19,2	52,1	LYS, HIS
P. clandestinum	100									10,0	20,0	50,0	
	99,8	0,2								10,7	20,1	49,8	HIS
	98,4	Excl.					1,6			13,1	20,3	49,3	HIS
Maize	100									10,0	9,4	76,2	
	92,4	3,8		3,8						33,3	14,2	70,4	LYS, ILE
	91,5	Excl.	6,9			1,6				39,4	13,1	76,3	LYS, HIS
	93,2	Excl.	Excl.		4,6	2,2				41,7	13,0		LYS, HIS
T. repens	100									10,0	23,2	57,9	
	99,3								0,7	12,8	23,3	42,9	MET
L. multiflorum	100									10,0	21,0	56,3	
	97,4								2,6	21,1	22,0	45,5	MET
M. sativa	100									10,0	13,3	65,8	
	94,8				0,4				4,8	31,9	15,7	63,7	LYS, MET

[a] Protein efficiency = $\frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100$.

[b] DAAS: Duodenal Amino Acid Supply.

Table 3 Least-cost feed formulations to balance the DAAS (for milk production) to protein of milk dry matter at the 15 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)											
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Brewers grain	Gluten	Price	Protein	Protein efficiency[a]	Amino acids at lower limit
A. junciformis	100									1,0	5,1	47,1	
	73,1	1,3		10,0	3,0	12,8				111,3	21,5	69,8	LYS, HIS, ILE, MET
	73,0	Excl.		6,9	12,5	7,5				116,9	21,0	71,4	LYS, HIS, ILE
	62,6	Excl.	Excl.	Excl.		18,2	4,3	14,9		119,8	20,9	71,8	LYS, HIS, ILE
E. curvula	100									10,0	12,2	50,4	
	84,9	1,8			7,4	6,0				79,3	20,3	73,9	LYS, MET, ILE
	81,0	Excl.	8,0		8,9	2,1				86,1	20,7	72,5	LYS, HIS, ILE
	83,0	Excl.	Excl.		14,3	2,8				88,8	20,7	72,5	LYS, HIS
Cynodon sp.	100									10,0	14,9	53,3	
	90,7	6,2				3,1				46,5	20,5	73,2	LYS, ILE
	79,9	Excl.	17,6				2,4			70,2	21,5	69,1	LYS, HIS
	86,0	Excl.	Excl.		13,9	0,1				74,0	21,5	69,8	LYS, HIS
D. glomerata	100									10,0	15,5	40,4	
	86,1	3,8				10,2				73,0	23,1	64,9	LYS, ILE
	78,5	Excl.	16,2		1,9	3,4				86,3	23,7	63,3	LYS, HIS, ILE
	82,5	Excl.	Excl.		12,7	4,8				91,9	23,9	62,8	LYS, HIS
P. clandestinum	100									10,0	20,0	50,4	
	92,8	5,6			1,2	0,4				36,6	24,0	62,5	LYS, MET, ILE
	85,7	Excl.	14,0			0,2				55,4	24,3	61,7	LYS, HIS
	89,4	Excl.	Excl.		9,2	1,4				58,9	24,5	61,2	LYS, HIS

Table 3 continued

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)										
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Brewers grain	Gluten	Price	Protein	Protein efficiency[a]	Amino acids at lower limit
Maize	100									10,0	9,4	76,2	
	79,9	3,6		9,7		7,1				83,4	21,3	70,4	LYS, MET, ILE
	82,3	Excl.		1,8	10,4	5,5				89,6	19,0	78,9	LYS, HIS, ILE
	77,9	Excl.	Excl.	Excl.	3,9	9,6	8,6			91,2	19,5	51,3	LYS, HIS, ILE
T. repens	100									10,0	23,2	57,9	
	91,1				1,7				7,2	48,1	26,4	56,8	LYS, MET
L. multiflorum	100									10,0	21,0	56,3	
	88,2				8,7				3,2	62,8	25,7	58,4	LYS, MET
M. sativa	100									10,0	13,3	65,8	
	85,7				11,8				2,5	74,4	20,2	74,3	LYS, MET

[a] Protein efficiency = $\frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100.$

Table 4 Least-cost feed formulations to balance the DAAS (for milk production) to protein of milk dry matter at the 20 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)										
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Gluten	Price	Protein	Protein[a] efficiency	Amino acids at lower limit
A. junciformis	100								1,0	5,1	47,1	
	60,9	1,0		14,6	9,3	14,3			160,2	28.5	70,2	LYS, MET, HIS, ILE
	60,8	Excl.		12,2	16,8	10,2			164,5	28,2	70,9	LYS, HIS, ILE
		Excl.	Excl.	Excl.		unfeasable						
E. curvula	100								10,0	12,2	50,4	
	71,4	1,0		5,5	12,0	10,1			132,9	27,2	73,5	LYS, MET, HIS, ILE
	71,3	Excl.		3,1	19,5	6,0			137,3	26,8	74,6	LYS, HIS, ILE
	72,2	Excl.	Excl.	Excl.	17,3	10,5			140,7	26,4	75,8	HIS, ILE
Cynodon sp.	100								10,0	14,9	53,3	
	79,9	3,0		1,7		15,4			100,7	25,6	78,1	LYS, HIS, ILE
	73,7	Excl.	9,4		14,2	2,7			118,0	26,3	76,0	LYS, HIS, ILE
	76,0	Excl.	Excl.		20,5	3,4			120,7	26,3	76,0	LYS, HIS
D. glomerata	100								10,0	15,5	40,4	
	73,6	2,2		4,6	2,7	16,9			125,7	29,0	69,0	LYS, MET, HIS, ILE
	72,6	Excl.	1,4		18,5	7,5			136,0	28,4	70,4	LYS,. HIS, ILE
	72,9	Excl.	Excl.		19,5	7,6			136,5	28,4	70,4	LYS, HIS
P. clandestinum	100								10,0	20,0	50,4	
	82,1	2,2		1,1	1,3	13,3			91,9	28,5	70,2	LYS, MET, HIS, ILE
	77,1	Excl.	7,3		11,6	4,0			105,5	28,9	69,2	LYS, HIS, ILE
	79,1	Excl.	Excl.		16,4	4,6			107,3	29,0	69,0	LYS, HIS
Maize	100								10,0	9,4	76,2	
	68,7	1,6		11,7	3,1	14,9			134,9	27,1	73,8	LYS, MET, HIS, ILE
	68,6	Excl.		8,0	15,0	8,5			141,8	26,5	75,5	LYS, HIS, ILE
	62,3	Excl.	Excl.	Excl.		22,7	14,9		150,2	26,8	74,6	HIS, ILE
T. repens	100								10,0	23,2	57,9	
	80,8				14,0			5,2	95,7	30,4	65,8	LYS, MET
L. multiflorum	100								10,0	21,0	56,3	
	78,8				20,1			1,1	106,4	29,6	67,6	LYS, MET
M. sativa	100								10,0	13,3	65,8	
	74,0			2,9	15,4	5,3		2,5	124,4	26,2	76,3	LYS, MET, HIS ILE
	75,3	Excl.	Excl.	Excl.	14,3	10,5			126,7	25,8	77,5	HIS, ILE

[a] Protein efficiency = $\frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100.$

quire mainly gluten as a supplement, only lucerne requiring fishmeal in addition.

As the protein level to be met is increased to 15 % or 20 % (Tables 3 and 4), so the proportion of fishmeal required also increases, while the amount of blood and carcass meals required remains relatively static or declines slightly. In general as this protein level is increased, the efficiency of protein utilization also increases, reflecting the better balance of fishmeal, in relation to milk, compared to that of microbial protein. Because it requires the least amount of supplementation, clover

Table 5 Least-cost feed formulations to balance the DAAS (for meat production) to protein of meat dry matter at the 10 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)										
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Gluten	Price	Protein	Protein [a] efficiency	Amino acids at lower limit
A. junciformis	100								1,0	5,1	46,7	
	88,2	6,6		5,3		0,01			39,0	13,1	76,3	LYS, MET, ILE
	83,0	Excl.	14,5				2,5		53,0	12,4	80,6	LYS, HIS
	87,8	Excl.	Excl.		12,0	0,25			58,1	12,0	83,3	LYS, HIS
E. curvula	100								10,0	12,2	49,9	
	97,3	2,7							19,2	14,0	71,4	LYS
	87,3	Excl.	2,4				10,2		37,0	15,9	62,9	LYS, HIS
	88,2	Excl.	Excl.		2,0		9,8		37,8	15,9	62,9	LYS, HIS
Cynodon sp.	100								10,0	14,9	52,7	
	98,9	1,1							13,9	15,6	64,1	HIS
	91,2	Excl.					8,8		26,8	17,1	58,5	HIS
	91,2	Excl.	Excl.				8,8		26,8	17,1	58,5	HIS
D. glomerata	100								10,0	15,5	39,9	
	96,6	3,4							21,8	17,7	56,5	LYS
	88,7	Excl.	5,1				6,3		37,9	18,8	53,2	LYS, HIS
	90,5	Excl.	Excl.		4,2		5,3		39,3	18,8	53,2	LYS, HIS
P. clandestinum	100								10,0	20,0	49,8	
Maize	100								10,0	9,4	75,2	
	97,2	2,8							19,7	11,4	87,7	LYS
	90,8	Excl.	4,4				4,8		32,9	12,6	79,4	LYS, HIS
	92,4	Excl.	Excl.		3,6		4,0		34,0	12,5	80,0	LYS, HIS
T. repens	100								10,0	23,2	69,9	
L. multiflorum	100								10,0	21,0	55,7	
M. sativa	100								10,0	13,3	65,0	
	98,5	0,6						1,0	16,0	14,2	70,4	MET, HIS
	94,9	Excl.	1,8				3,3		21,9	14,9	67,1	MET, HIS
	95,0	Excl.	Excl.		0,9		4,2		22,0	14,9	67,1	MET, HIS

[a] Protein efficiency $= \frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100.$

Table 6 Least-cost feed formulations to balance the DAAS (for meat production) to protein of meat dry matter at the 15 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g)											
		Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Gluten	Brewers grain	Price	Protein	Protein efficiency[a]	Amino acids at lower limit
A. junciformis	100									1,0	5,1	46,7	
	80,2	7,2		6,9		5,7				74,2	18,1	82,9	LYS, MET, ILE
	75,2	Excl.	19,4		5,1	0,3				89,0	16,8	89,3	LYS, HIS, ILE
	77,1	Excl.	Excl.		15,3	4,0	1,8		1,7	98,2	17,2	87,2	LYS, HIS, LEU, PHE
E. curvula	100									10,0	12,2	49,9	
	90,3	6,6			3,0					46,6	18,2	82,4	LYS, MET
	77,1	Excl.	15,3				7,6			72,6	20,1	74,6	LYS, HIS
	82,4	Excl.	Excl.		12,5		5,1			76,7	19,8	75,8	LYS, HIS
Cynodon sp.	100									10,0	14,9	52,7	
	94,0	6,0								30,6	18,8	79,8	LYS
	78,7	Excl.	9,7				11,6			62,7	21,2	70,8	LYS, HIS
	82,1	Excl.	Excl.		7,7		10,2			64,7	21,1	71,9	LYS, HIS
D. glomerata	100									10,0	15,5	39,9	
	90,8	9,2								41,7	21,4	70,1	LYS
	78,2	Excl.	17,6				4,1			73,3	22,6	66,4	LYS, HIS
	84,6	Excl.	Excl.		14,5		0,9			78,1	22,5	66,7	LYS, HIS
P. clandestinum	100									10,0	20,0	49,8	
	96,0	4,0								23,6	22,4	67,0	LYS
	84,5	Excl.	6,7				8,8			47,8	23,8	63,0	LYS, HIS
	87,0	Excl.	Excl.		5,2		7,8			48,7	23,8	63,0	LYS, HIS

Table 6 continued

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g): Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Gluten	Brewers grain	Price	Protein	Protein[a] efficiency	Amino acids at lower limit
Maize	100									10,0	9,4	75,2	
	89,0	8,0		3,0						45,6	16,7	89,8	LYS, ILE
	80,2	Excl.	17,0				2,8			68,9	17,2	87,2	LYS HIS
	86,2	Excl.	Excl.		13,7	0,2				73,3	16,7	89,8	LYS, HIS
T. repens	100									10,0	23,2	69,9	
	98,0							2,0		18,5	23,8	62,8	MET
L. multiflorum	100									10,0	21,0	55,7	
	94,9	0,5			3,2			1,3		32,1	23,1	64,9	LYS, MET, HIS
	92,1	Excl.	6,3		1.6					37,0	23,4	64,1	MET, HIS
	92,3	Excl.	Excl.		4,7		3,1			37,2	23,5	63,8	MET, HIS
M. sativa	100									10,0	13,3	65,0	
	92,0	1,4			5,1			1,5		44,6	17,4	86,2	LYS, MET, HIS
	82,7	Excl.	12,8				4,5			58,8	19,2	78,1	MET, HIS
	82,9	Excl.	Excl.		6,3		10,7			59,3	19,3	77,7	MET, HIS

[a] Protein efficiency = $\frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100.$

Table 7 Least-cost feed formulations to balance the DAAS (for meat production) to protein of meat dry matter at the 20 % level

Fermented ingredients (g/100 g)		Unfermented ingredients (g/100 g): Blood	Carcass	PBPM	Fish	Imported fish	Groundnut	Gluten	Soy fat	Brewers grain	Price	Protein	Protein efficiency[a]	Amino acids at lower limit
A. junciformis	100										1,0	5,1	46,7	
	75,5	5,2		3,5		15,9					108,7	20,7	96,6	LYS, MET, ILE
	66,4	Excl.	20,2	0,2	12,7		0,6				127,2	21,7	92,2	LYS, HIS, ILE, LEU
	61,9	Excl.	Excl.		17,3	5,5	0,9		10,7	3,8	139,0	22,2	90,1	LYS, LEU, HIS, PHE, VAL
E. curvula	100										10,0	12,2	49,9	
	82,2	7,8			10,0						82,4	22,4	89,3	LYS, MET
	64,5	Excl.	26,1				9,4				110,2	24,7	81,0	LYS, HIS
	73,7	Excl.	Excl.		21,3		5,0				117,1	24,2	82,6	LYS, HIS
Cynodon sp.	100										10,0	14,9	52,7	
	88,3	11,7									50,0	22,5	88,9	LYS
	65,8	Excl.	21,5				12,7				101,9	25,6	78,1	LYS, HIS
	73,3	Excl.	Excl.		17,1		9,6				106,5	25,4	78,7	LYS, HIS
D. glomerata	100										10,0	15,5	39,9	
	83,6	10,9			3,2	2,3					73,2	25,2	79,4	LYS, MET, ILE
	65,4	Excl.	28,1				6,5				110,8	26,8	74,6	LYS, HIS
	75,5	Excl.	Excl.		23,2		1,3				118,4	26,6	75,2	LYS, HIS
P. clandestinum	100										10,0	20,0	49,8	
	90,2	9,7			0,1						43,7	25,9	77,2	LYS, MET
	70,7	Excl.	18,9				10,4				89,4	27,8	71,9	LYS, HIS
	77,7	Excl.	Excl.		14,9		7,4				92,1	27,7	72,2	LYS, HIS
Maize	100										10,0	9,4	75,2	
	80,3	8,8		5,5		5,4					81,6	21,7	92,2	LYS, MET, ILE
	67,0	Excl.	27,6				5,4				107,1	22,2	90,1	LYS, HIS
	76,3	Excl.	Excl.	1,5	22,2		0,01				115,6	21,9	91,3	LYS, HIS
	73,7	Excl.	Excl.	Excl.	19,8	0,6			5,9		115,8	21,4	93,5	LYS, HIS, VAL
T. repens	100										10,0	23,2	69,9	
	89,4				7,0			3,6			57,1	27,1	73,8	LYS, MET
L. multifloroum	100										10,0	21,0	55,7	
	86,8	1,0			12,2						69,1	26,5	75,5	LYS, MET
	78,9	Excl.	18,0		3,1						80,7	27,4	73,0	MET, HIS
	80,3	Excl.	Excl.		12,8		6,9				81,5	27,5	72,7	LYS, HIS
M. sativa	100										10,0	13,3	65,0	
	84	2,0			13,6			0,4			80,5	21,4	93,5	LYS, MET, LEU
	70,8	Excl.	27,0				2,1				99,3	23,8	84,0	MET, HIS
	72,5	Excl.	Excl.		14,7		12,1			0,6	101,1	23,8	84,0	LYS, HIS, LEU

[a] Protein efficiency = $\frac{\text{\% target protein}}{\text{\% protein in formulated feed mix}} \times 100.$

appears to be the best ingredient for milk protein production.

A similar pattern is revealed by Tables 5 – 7 for meat production. Again, bloodmeal, carcass meals and fish-meal are the favoured supplementary ingredients but with the exclusion of blood and carcass meals, relatively less fish-meal and more groundnut is selected, than is required for milk production. Clover also appears to be the best ingredient for meat production.

While it is really incidental to the primary purpose of this paper, it might be of some interest to look ahead to the possibility of getting the selected ingredients to by-pass the rumen, which is of course essential. Bloodmeal, carcass meal, poultry by-product meal and fish-meal are all heated during processing. Depending on its extent, this heating should tend to denature the protein in these ingredients, rendering it insoluble and more likely to by-pass the rumen. The absence of fibre in these ingredients also means that they may be more easily comminuted and would thus tend to readily pass out of the rumen. Together, these considerations suggest that these ingredients might be more easily induced to by-pass the rumen than some other ingredients would. In certain cases very little further processing might be necessary. For example, Miller (1973) found that Peruvian fish-meal escapes degradation in the rumen to the extent of 70 %, although this might not be true of all fish-meals. Heat processing of feeds unfortunately introduces the problem of lower availability of lysine (Anderson & Quicke, 1980) which is especially significant in the present context as lysine is frequently at the lower limit in the least-cost mixed feeds reported in Tables 2 – 7.

With the candidate ingredients identified, the questions of the methodology and efficiency of rumen by-pass of these ingredients and the availability of their lysine remains to be addressed experimentally. Especially necessary are techniques for the rapid assessment of the extent of rumen by-pass by supplementary proteins so that individual batches of feed ingredients may be evaluated and modifying treatments may be monitored. Some adaptation of the *in vitro* technique of Dennison & Phillips (1983) might prove useful in this regard.

In practical terms the major barrier might be the availability of the supplementary ingredients as they are all in limited supply and are in great demand in the poultry industry. However, because feeds for monogastric animals can be balanced by the addition of individual amino acids, while ruminant feeds require whole proteins to by-pass the rumen, it may be argued that an increased proportion of the practical ingredients might advantageously be directed to ruminant feeds. This is especially true as relatively small amounts of these ingredients improve the utilization efficiency of relatively large amounts of forage protein.

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