Availability to pigs of amino acids in cereal grains

2. Apparent and true ileal availability

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1. Pigs prepared with re-entrant ileal cannulas were used to determine the ileal availability of amino acids in nine cereal grains including five wheats, sorghum (*Sorghum vulgare* Pers.), maize, barley and *Triticale*.

2. The average true availability of amino acids in these grains was 0·88 but there were consistent differences in availability among amino acids. Generally, lysine and threonine were among the least available amino acids while glutamic acid and arginine were among the most available amino acids in cereal protein.

3. There was as much variation in amino acid availability within a grain species (wheat) as among the other grains.

Cereal grains provide a large proportion of dietary protein for pigs and it is generally recognized as important to formulate these diets using available rather than total amino acid values for both protein concentrates and cereal grains. Values of true amino acid availability determined by faecal analysis have been reported for grains by various workers including Eggum (1973*a*) and Sauer *et al.* (1974). However, the influence of faecal amino acid output of bacterial protein from hind gut fermentation found by Mason *et al.* (1976) suggests that ileal analysis is a more valid measure of amino acid availability than faecal analysis.

The apparent ileal availabilities of amino acids in maize, wheat and barley have been determined by Sauer, Stothers & Phillips (1977). However, with both faecal (Eggum, 1973*a*) and ileal (Taverner, 1979) analysis, apparent availability values were markedly influenced by the protein level in the diet. Apparent availability values increased with increasing protein content especially at lower protein levels, whereas true availability values were not affected by protein level. Therefore, with low protein feedstuffs such as cereal grains, true rather than apparent amino acid concentrations are likely to provide more accurate values for diet formulation and for comparison or calibration with other tests of availability.

The present work was undertaken to determine the true ileal availability to pigs of amino acids in cereal grains and to determine the variation in availability both between different grains and within one grain (wheat).

EXPERIMENTAL PROCEDURES

Animals and design

Five pigs, each with a re-entrant ileal cannula, were used in this study. The live weight of each pig during the period for which each diet was offered is presented in Table 1.

Wheats Nos. 1, 2 and 3 were randomly allocated to each of three pigs, each for one period of collection. Another wheat (No. 4) was originally included in this design, but because of problems encountered during ileal collections with this wheat, collections were eventually completed only after those from all other grains were complete.

Ileal collections from three pigs given sorghum, maize and barley were made according to a 3 × 3 Latin Square design. Digesta samples were also collected from five pigs given *Triticale*, and from four pigs fed on a fifth wheat (No. 5).

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Table 1. *Live weights (kg) of pigs on each diet*

	Pig				
Dietary cereal	A	B	C	D	E
Wheat No.					
1	83	53	48	—	—
2	71	62	59	—	—
3	79	58	53	—	—
4	138	110	110	—	—
5	93	—	72	55	60
Sorghum (*Sorghum vulgare* Pers.)	—	66	70	49	—
Maize	—	70	62	52	—
Barley	—	74	66	46	—
Triticale	132	105	102	80	104

Diets

Each diet contained (g/kg): 972 grain, 20 bone meal, 5 sodium chloride, 2 chromic oxide, 1·3 vitamin and mineral premix. All grains were milled to pass through a 1·58 mm sieve.

The dry diet was mixed with water (1:2·5, w/v) and given to pigs at 08.00 and 20.00 hours as described by Taverner *et al.* (1981).

Sample collection and analysis

Each diet was offered for 12 d and ileal digesta collected for three 12 h periods between feeds from each pig on the third, fifth and twelfth days. For wheat No. 4 only, five ileal collections were completed from three pigs because of blockages in the cannulas.

Taverner *et al.* (1981) described the procedures of sample collection, preparation for analysis, and analysis of nitrogen, chromium and amino acids.

Tryptophan content was determined by the method of Miller (1967) following protein hydrolysis in barium hydroxide. The neutral-detergent fibre (NDF) content of grain was determined both by the original method of Van Soest & Wine (1967) and a modification of this method for cereal grains described by Taverner *et al.* (1981). Acid-detergent fibre was determined by the method of Van Soest (1963). The protein solubility fractions of the grains were determined by a modified Osborne procedure described by Chen & Bushuk (1970) but with the alterations suggested by Orth *et al.* (1976).

Statistical methods

An analysis of variance appropriate to the nested design of the experiment was used to test between wheats for significant differences in availability values for individual amino acids and N. Between sorghum (*Sorghum vulgare* Pers.), maize and barley these differences were tested for significance using analysis of a Latin Square design. In comparing N digestibility with the availability of amino acids within each diet, a 'sub-plot' factor was included in the previously-mentioned Latin Square analysis to form a split-plot analysis of variance. For wheat No. 5 and *Triticale* the differences between pigs were analysed separately for each amino acid as well as by an over-all split-plot analysis including all amino acids. A Dunnett's *t* test (Dunnett, 1964) for comparing various treatments with a control was used to test for significant differences between the availability of each amino acid and the digestibility of N.

Table 2. *Endogenous ileal levels (mg/kg dry matter intake) of amino acids (Taverner* et al. *1981) in pigs*

Indispensable amino acids		Dispensable amino acids	
Arginine	530	Alanine	580
Isoleucine	150	Aspartic acid	820
Leucine	330	Glutamic acid	850
Lysine	320	Serine	630
Methionine	130		
Threonine	600		
Valine	420		

Endogenous amino acid levels

The endogenous values of amino acid output used to calculate the true availability of amino acids at the ileum of pigs given wheat, barley and *Triticale* were those presented in Table 2. They were determined by Taverner *et al.* (1981) using the regression technique with wheat and barley diets. There were no significant differences between values determined by extrapolation from wheat and barley diets containing 140 and 190 mg NDF/g respectively, but at lower levels of dietary fibre (less than approximately 100 mg NDF/g), values of endogenous amino acid output were linearly related to dietary fibre. Using this relationship it was calculated that endogenous values for maize and sorghum were 91·6 and 92·4% respectively, of those used for other grains.

Values for true availability of proline and glycine were not calculated because of the apparent anomalies associated with the determination of their endogenous output (Taverner *et al.* 1981). The high and variable endogenous output of these amino acids appeared to affect the endogenous ileal output of N which, as a consequence, also varied markedly among pigs. The individual values of endogenous ileal N output were obtained from the previous study (Taverner *et al.* 1981); the values (mg N/kg dry matter (DM) intake) were for pigs A–E 2500, 2420, 1930, 1180 and 2810, respectively.

Calculation of digestibility

Ileal availability values were determined by reference to the relative concentrations of Cr in food and in digesta samples.

The term 'digestibility' is used for disappearance of protein (N × 5·7) and DM, and 'availability' for disappearance of amino acids.

RESULTS

Grain composition. The contents of N, energy, fibre, amino acids and the protein solubility fractions in the cereal grains used are presented in Table 3.

Within the wheat samples the amount of lysine in the protein decreased from 35·9 to 27·5 mg/g as the protein content (N × 5·7) increased from 107 to 142 mg/g. Coincident with the decreasing lysine content of the wheat protein there was a decrease in the proportion of albumin and globulins (water- and salt-soluble protein) and an increase in the gliadin (alcohol-soluble) fraction of the wheat. Similarly, the protein of *Triticale* had the highest lysine content as well as the greatest proportion of albumin and globulin proteins. There was also a tendency within the wheats and *Triticale* for the grains with higher levels of NDF to contain in their protein more of the albumin and globulins but less of the alcohol-soluble proteins. Acid- and neutral-detergent fibre levels appeared not to be closely related,

Table 3. *The contents of nitrogen, energy, fibre and amino acids in cereal grains (dry matter basis) fed to pigs*

	Wheat No. 1	2	3	4	5	Sorghum (*Sorghum vulgare* Pers.)	Maize	Barley	*Triticale*
Indispensable amino acids (mg/g)									
Arginine	7·87	7·01	6·41	5·84	5·88	5·26	5·36	6·05	8·00
Histidine	1·81	2·24	1·73	1·90	1·26	ND	ND	ND	3·88
Isoleucine	5·70	5·06	4·18	3·97	4·47	5·27	3·52	4·26	4·49
Leucine	11·17	9·92	7·94	7·91	9·33	17·43	12·20	8·52	9·37
Lysine	4·36	3·99	3·62	3·83	3·78	2·51	2·62	4·61	4·96
Methionine	2·64	2·51	2·06	2·10	1·99	1·66	1·92	2·84	2·41
Phenylalanine	5·34	5·58	3·60	2·62	5·27	8·27	ND	ND	13·47
Threonine	5·32	4·89	3·99	3·29	4·33	5·49	4·52	5·49	4·83
Tryptophan	1·71	1·25	1·54	1·47	2·05	1·08	0·82	1·32	1·60
Valine	5·70	5·08	4·45	4·47	6·55	5·67	4·50	5·78	6·54
Dispensable amino acids (mg/g)									
Alanine	6·57	5·99	5·36	6·02	5·55	12·22	7·80	5·74	6·98
Aspartic acid	7·64	6·99	5·79	6·18	7·11	9·41	6·45	8·22	9·56
Glutamic acid	52·96	45·78	31·22	28·01	37·69	28·37	19·47	32·38	35·11
Glycine	7·02	6·33	5·54	5·41	5·87	4·34	4·08	5·17	7·32
Proline	22·16	21·97	14·52	16·72	14·42	13·01	10·99	15·43	10·04
Serine	6·70	6·19	4·90	4·37	6·26	6·86	5·25	5·75	6·95
Tyrosine	3·83	3·57	2·79	2·44	3·73	4·33	3·44	3·43	4·15
Nitrogen (mg/g)	24·9	23·8	19·2	18·8	22·2	16·7	15·3	21·2	23·6
Gross energy (MJ/kg)	18·27	18·42	18·01	17·95	17·78	18·31	18·68	18·14	17·77
Digestible energy* (MJ/kg)	15·71	15·76	15·36	14·68	15·46	16·82	16·80	15·25	15·26
Acid-detergent fibre (mg/g)	42	38	41	60	40	66	35	72	50
Neutral-detergent fibre† (mg/g): A	129	132	189	193	130	92	79	186	175
B	118	115	158	160	114	83	79	163	128
Protein solubility fractions (g/kg total N)									
Salt–water	282	331	379	433	374	183	204	299	493
Alcohol	330	285	191	155	254	52	203	190	202
Acetic acid	103	97	108	80	75	11	9	47	77
Insoluble residue	257	274	245	276	270	681	579	429	235
Recovery	0·97	0·99	0·92	0·94	0·97	0·93	1·00	0·97	1·01

ND, not determined.
* Taverner (1979).
† Neutral-detergent fibre method: (A) Van Soest & Wine (1967) (B) modified method including amylase.

indicating a variable content of hemicellulose, calculated by difference between the two fibre methods. There were differences between values determined by the two NDF methods used, probably due to the differences in the amount of starch removed.

Ileal availability values. Availability values for wheat No. 4 were not included in the statistical analysis of differences between wheats because of the difficulties encountered during ileal collections with this wheat. However, these values and those for wheat No. 5 are included in Tables 4, 5 with the other wheats for comparison. Both apparent and true digestibility of N and availability of amino acids decreased from wheat No. 1 to No. 3. The average apparent availabilities of all amino acids in wheats Nos. 1, 2 and 3 were 0·84, 0·80 and 0·74 respectively. These differences were consistent for all amino acids and apart

Table 4. *Average apparent digestibilities of nitrogen and dry matter, and apparent availabilities of amino acids in wheat samples fed to pigs*

	Wheat No.				Statistical significance of difference	Wheat No.			
						4		5	
	1	2	3	SEM		Mean	SD	Mean	SD
Indispensable amino acids									
Arginine	0·89^{a}	0·81^{b}	0·83^{b}	0·019	*	0·80	0·121	0·81	0·026
Isoleucine	0·88^{a}	0·85^{a}	0·80^{a}	0·032	NS	0·77	0·071	0·86	0·017
Leucine	0·89^{a}	0·86^{ab}	0·81^{b}	0·017	*	0·77	0·119	0·88	0·014
Lysine	0·81^{a}	0·75^{ab}	0·70^{b}	0·027	*	0·62	0·249	0·77	0·035
Methionine	0·87^{a}	0·89^{a}	0·85^{a}	0·014	NS	0·81	0·065	0·86	0·018
Threonine	0·77^{a}	0·76^{a}	0·66^{b}	0·015	**	0·51	0·206	0·75	0·030
Valine	0·84^{a}	0·78^{a}	0·74^{a}	0·036	NS	0·65	0·193	0·83	0·021
Dispensable amino acids									
Alanine	0·81^{a}	0·74^{a}	0·60^{a}	0·039	NS	0·69	0·138	0·79	0·028
Aspartic acid	0·76^{a}	0·72^{a}	0·61^{b}	0·023	*	0·58	0·176	0·73	0·033
Glutamic acid	0·96^{a}	0·94^{a}	0·91^{b}	0·006	**	0·88	0·064	0·94	0·008
Glycine	0·72^{a}	0·64^{ab}	0·58^{b}	0·026	*	0·52	0·100	0·67	0·057
Proline	0·90^{a}	0·91^{a}	0·82^{a}	0·027	NS	0·86	0·088	0·88	0·080
Serine	0·81^{a}	0·78^{a}	0·67^{b}	0·031	*	0·66	0·122	0·83	0·022
Mean	0·84	0·80	0·74	0·020		0·70		0·82	
N	0·83^{a}	0·81^{a}	0·75^{b}	0·011	**	0·71	0·108	0·82	0·029
Dry matter	0·77^{a}	0·75^{a}	0·71^{b}	0·009	**	0·67	0·092	0·78	0·018

NS, not significant.
a, *b*, Within rows, means followed by different superscripts were significantly different ($P < 0·05$).
* $P < 0·05$, ** $P < 0·01$.

from isoleucine, methionine, alanine and proline, amino acid availability values for wheat No. 3 were less ($P < 0·05$) than for wheat No. 1 and in some instances also significantly less than for wheat No. 2. There were similar differences between these wheats in the true availability of amino acids; the average values for the indispensable amino acids were 0·91, 0·89 and 0·85 for wheats Nos. 1, 2 and 3 respectively. Differences in true availability values between wheats were significant ($P < 0·05$) for lysine, threonine, aspartic acid and glutamic acid.

Differences between wheats in N digestibility paralleled those in amino acid availability, but there were differences between the digestibility of N and availability of some individual amino acids (Table 6) which appeared to increase as digestibility decreased from wheats No. 1 to No. 3. Lysine and threonine were generally the least available of the indispensable amino acids in these wheats.

For sorghum, maize and barley the average apparent and true availabilities of indispensable amino acids (Tables 7, 8) were 0·85, 0·81 and 0·80 respectively. The availabilities of most amino acids in sorghum were greater ($P < 0·05$) than those in maize or barley; the apparent availabilities of lysine and threonine in barley were greater ($P < 0·05$) than those in maize, but the differences disappeared when values were adjusted for endogenous amino acids.

Tryptophan availability was determined only in maize in which the mean ($\pm$SE) apparent and true availabilities were $0·74 \pm 0·049$ and $0·88 \pm 0·049$ respectively. The average endogenous level of ileal tryptophan was $142 \pm 29·2$ mg/kg DM intake of a protein-free diet (Taverner, 1979).

Table 5. *Average true digestibility of nitrogen and true availabilities of amino acids in wheat samples fed to pigs*

	Wheat No.					Wheat No.			
					Statistical significance	4		5	
	1	2	3	SEM	of difference	Mean	SD	Mean	SD
Indispensable amino acids									
Arginine	0.94^a	0.89^a	0.91^a	0.016	NS	0.87	0.110	0.91	0.027
Isoleucine	0.91^a	0.88^a	0.84^a	0.032	NS	0.81	0.071	0.90	0.017
Leucine	0.92^a	0.90^a	0.86^a	0.017	NS	0.82	0.118	0.92	0.014
Lysine	0.89^a	0.83^{ab}	0.79^b	0.027	*	0.71	0.252	0.86	0.035
Methionine	0.92^a	0.95^a	0.92^a	0.014	NS	0.87	0.065	0.93	0.018
Threonine	0.89^a	0.89^a	0.81^b	0.015	*	0.69	0.206	0.89	0.030
Valine	0.92^a	0.87^a	0.84^a	0.036	NS	0.75	0.192	0.90	0.021
Dispensable amino acids									
Alanine	0.90^a	0.84^a	0.80^a	0.039	NS	0.79	0.138	0.90	0.029
Aspartic acid	0.87^a	0.84^a	0.76^b	0.023	*	0.72	0.176	0.85	0.033
Glutamic acid	0.97^a	0.96^{ab}	0.94^b	0.006	*	0.91	0.064	0.96	0.008
Serine	0.91^a	0.88^a	0.80^a	0.031	NS	0.80	0.122	0.93	0.022
Mean	0.91	0.88	0.84			0.79		0.90	
N	0.92^a	0.91^{ab}	0.87^b	0.012	*	0.83	0.101	0.92	0.043

NS, not significant.
a, *b* Within rows, means followed by different superscripts letters were significantly different ($P < 0.05$).
* $P < 0.05$.

In sorghum, maize and barley the true digestibilities of N were lower than the true availabilities of most amino acids, whereas in the wheats and *Triticale*, the digestibilities of N were relatively greater than most amino acid availabilities (Table 6). Lysine and threonine were again among the least available of the indispensable amino acids in these grains but there was no significant difference between N digestibility and lysine availability in sorghum or barley.

DISCUSSION

The proportion of cereal N passing unabsorbed through the small intestine of the pig varied from 0·08 to 0·17 between grains. More important, this unabsorbed N contained a relatively high content of lysine, of which from 11% to more than 22% of the total in the grain was not absorbed by the pig.

There were certain consistencies in the relative availability of amino acids for all cereal grains (Table 6) the most important of which were the low availabilities of both lysine and threonine. Lysine was generally less available than threonine (except in *Triticale*), whereas glutamic acid, arginine and proline were generally among the most available amino acids in cereal protein. These differences in availability between amino acids are consistent with those found by Eggum (1973*a*), Sauer, Stothers & Phillips (1977) and Sauer *et al.* (1974) for cereals and also those found by Slump *et al.* (1977) for a poorly-digested diet containing 250 g wheat bran/kg. In mixed diets (Just Nielsen, 1968) and in protein concentrates (Eggum, 1973*a*), the differences in availability between amino acids were less than with cereals, and lysine in particular was more available. The most frequent explanation for the large differences in availability between amino acids in grains in the uneven distribution

Table 6. *The relative magnitude of true and apparent ileal availabilities of nitrogen and amino acids in cereal grains fed to pigs*

(Amino acids are listed in order of decreasing availability)

True ileal availability								Apparent ileal availability							
Wheat No.								Wheat No.							
1	2	3	5	Sorghum	Maize	Barley	*Triticale*	1	2	3	5	Sorghum	Maize	Barley	*Triticale*
Glu	Glu	Glu*	Glu*	Val*	Met*	Glu*	Glu*	Glu*	Glu*	Glu*	Glu*	Leu*	Leu*	Glu*	Glu*
Arg	Met	Met	Ser	Arg*	Arg*	Met*	Arg*	Pro*	Pro*	Met*	Leu*	Glu*	Met*	Met*	Arg*
N	N	Arg	Met	Met*	Leu*	Ser	Ser	Arg*	Met*	Arg*	Pro*	Ile*	Glu*	Ile*	Leu*
Met	Leu	N	Leu	Leu*	Ala*	Val	N	Leu	Leu	Pro*	Ile*	Ala*	Ile*	Leu*	Met*
Val	Arg	Leu	N	Ala*	Glu*	Thr	Met	Ile	Ile	Leu*	Met*	Val*	Ala*	Pro	Val
Leu	Thr	Ile	Arg	Ser*	Ser	Ile	Val	Met	N	Ile	Val	Met*	Arg*	Val	Ile
Ile	Ile	Val	Val*	Glu*	Ile	Leu	Leu*	Val	Arg	N	Ser	Arg*	Ser	Arg	N
Ser	Ser	Thr*	Ala*	Asp	Asp	Arg	Ala*	N	Val	Val	N	Ser*	Val	Lys	Pro
Ala	Val	Ser*	Ile*	Thr	Val	N	Lys*	Lys	Ser	Lys	Arg	Asp	Pro	Ser	Ser
Lys	Ala*	Ala*	Thr*	Ile	N	Lys	Asp*	Ser	Thr	Ala*	Ala*	Thr	N	N	Lys
Thr	Asp*	Lys*	Lys*	N	Thr	Ala	Ile*	Ala	Lys*	Ser*	Lys*	N	Asp	Thr	Ala*
Asp	Lys*	Asp*	Asp*	Lys	Lys*	Asp	Thr*	Thr	Ala*	Thr*	Thr*	Lys	Thr	Ala	Asp*
								Asp*	Asp*	Asp*	Asp*	Pro	Lys*	Asp	Thr*
								Gly*	Gly*	Gly*	Gly*	Gly*	Gly*	Gly*	Gly*

Arg, arginine; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Thr, threonine; Val, valine; Ala, alanine; Asp, aspartic acid; Glu, glutamic acid; Gly, glycine; Pro, proline; Ser, serine.

* Values were significantly different ($P < 0.05$) from the digestibility of N.

Table 7. *Average apparent digestabilities of nitrogen and dry matter, and apparent availabilities of amino acids in sorghum* (Sorghum vulgare *Pers.*), *maize, barley and* Triticale *fed to pigs*

	Sorghum	Maize	Barley	SEM	Statistical significance of difference	*Triticale* Mean	*Triticale* SD
Indispensable amino acids							
Arginine	0.84^{a}	0.84^{a}	0.77^{b}	0.010	***	0.85	0.038
Isoleucine	0.89^{a}	0.85^{b}	0.83^{c}	0.007	***	0.83	0.021
Leucine	0.91^{a}	0.89^{b}	0.82^{c}	0.006	***	0.85	0.017
Lysine	0.76^{a}	0.71^{b}	0.77^{a}	0.013	*	0.81	0.028
Methionine	0.86^{a}	0.88^{a}	0.88^{a}	0.008	NS	0.85	0.031
Threonine	0.81^{a}	0.74^{b}	0.76^{c}	0.011	***	0.74	0.034
Valine	0.87^{a}	0.78^{b}	0.80^{b}	0.008	***	0.83	0.025
Dispensable amino acids							
Alanine	0.88^{a}	0.85^{b}	0.73^{c}	0.009	***	0.80	0.022
Aspartic acid	0.84^{a}	0.76^{b}	0.72^{c}	0.010	***	0.78	0.037
Glutamic acid	0.90^{a}	0.87^{b}	0.90^{a}	0.005	**	0.92	0.010
Glycine	0.60^{a}	0.54^{b}	0.53^{b}	0.020	*	0.67	0.049
Proline	0.76^{a}	0.76^{a}	0.80^{a}	0.015	NS	0.82	0.063
Serine	0.85^{a}	0.79^{b}	0.76^{b}	0.010	***	0.82	0.025
Mean	0.83	0.79	0.78			0.81	
N	0.79^{a}	0.76^{b}	0.76^{b}	0.007	**	0.82	0.013
Dry matter	0.83^{a}	0.80^{a}	0.71^{b}	0.005	***	0.71	0.020

NS, not significant.
a, b, c, Within rows, means followed by different superscripts letters were significantly different ($P < 0.05$).
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 8. *Average true digestibility of nitrogen and true availabilities of amino acids in sorghum,* (Sorghum vulgare *Pers.*), *maize, barley and* Triticale *fed to pigs*

	Sorghum	Maize	Barley	SEM	Statistical significance of difference	*Triticale* Mean	*Triticale* SD
Indispensable amino acids							
Arginine	0.94^{a}	0.93^{a}	0.86^{b}	0.010	***	0.92	0.038
Isoleucine	0.91^{a}	0.89^{b}	0.87^{c}	0.007	***	0.87	0.021
Leucine	0.93^{a}	0.92^{a}	0.86^{b}	0.006	***	0.89	0.017
Lysine	0.88^{a}	0.83^{b}	0.84^{b}	0.013	*	0.88	0.028
Methionine	0.93^{a}	0.94^{a}	0.92^{a}	0.007	NS	0.90	0.031
Threonine	0.91^{a}	0.86^{b}	0.87^{b}	0.011	**	0.87	0.034
Valine	0.94^{a}	0.87^{b}	0.88^{b}	0.008	***	0.90	0.025
Dispensable amino acids							
Alanine	0.93^{a}	0.92^{a}	0.84^{b}	0.009	***	0.88	0.022
Aspartic acid	0.92^{a}	0.87^{b}	0.83^{c}	0.010	***	0.87	0.036
Glutamic acid	0.92^{a}	0.91^{a}	0.92^{a}	0.005	NS	0.95	0.010
Serine	0.93^{a}	0.90^{a}	0.88^{b}	0.010	*	0.91	0.025
Mean	0.92	0.89	0.87			0.89	
N	0.89^{a}	0.86^{b}	0.84^{c}	0.007	**	0.91	0.027

NS, not significant.
a, b, c, Within rows, means followed by different superscripts were significantly different ($P < 0.05$).
* $P < 0.05$ ** $P < 0.01$, *** $P < 0.001$.

of amino acids within the grain, with the less-available amino acids such as lysine occurring predominantly in the less-digestible grain fractions (aleurone cells), and the more available amino acids such as glutamic acid occurring in the highly-digestible endosperm fractions (Munck, 1972; Eggum, 1973*a*; Sauer *et al.* 1974). However, this explanation fails to account for the relative differences in availability of certain amino acids such as arginine, which is one of the most available amino acids yet also occurs in high concentration in aleurone cells. Similarly, the low availability of threonine, whose concentration varies little between the different fractions of the grain (Stevens *et al.* 1963), cannot be accounted for by this hypothesis. It may be that other factors such as the presence of enzyme-resistant bonds or particularly slow absorption may also reduce the availability of certain amino acids in cereal grains. However, the relative importance of these factors is largely unknown.

There was a difference between grains in the true digestibility of N relative to most amino acids. The digestibility of N in wheat and *Triticale* was greater than the average of the amino acids, but in barley, maize and particularly sorghum, N was less digestible than most amino acids. This effect may be related to the particularly low solubility of proteins in barley, maize and sorghum in which 43, 58 and 68% of the N was insoluble.

Just Nielsen (1968) and Slump *et al.* (1977) also found that most amino acids in mixed feeds were better digested than was the total N. Slump *et al.* (1977) suggested that this difference may be due to catabolism of amino acids by microbial activity in the hind gut, but the results of the present experiment support the suggestion of Just Nielsen (1968) that lower N compounds such as amides are absorbed to a lesser extent than proteins.

Wheat. Generally it appeared that protein digestibility and amino acid availability decreased as the protein content of the grain decreased. A similar relationship was reported for barley by Eggum (1973*b*); Eppendorfer (1977) also found the true digestibility of protein in oats and rye appeared to decrease linearly with decreasing protein content. This effect may be explained by the changing proportions of protein fractions of differing protein content, composition and digestibility. Generally, as the protein content of the grain decreased the proportion of gliadin also decreased and the proportion of albumin and globulin increased. Gliadin occurs most abundantly in wheat flour in which Sauer, Stothers & Parker (1977) found an average of 90% of amino acids to be apparently absorbed at the ileum, whereas albumin and globulins occur most abundantly in the remainder of the grain (wheat offal) in which only 72% of amino acids were apparently absorbed at the ileum. In both fractions, lysine was relatively less available than average 0·84 and 0·66 respectively. Therefore, as the proportion of gliadin in the grain protein decreases, the ratio, offal: flour fractions in the grain probably increases, and the over-all protein digestibility and amino acid availability of the grain decreases.

The greater decrease in lysine availability relative to N digestibility probably reflects the greater proportion of total grain lysine compared to total N that occurs in offal rather than flour. But the low availability of lysine in the whole grain cannot be entirely attributed to its major occurrence in the relatively-poorly-digested fractions of the grain. Sauer, Stothers & Parker (1977) also found that lysine was the least available of the indispensable amino acids in wheat-flour protein. Factors such as the occurrence of enzyme resistant peptides may also contribute to the low availability of lysine and also of threonine in grain protein. Kakade (1974) suggested that the ratio, lysine plus arginine: proline in the grain might be a measure of the possible effect of such peptides on protein digestibility. Kakade's (1974) hypothesis was that protein with a higher value for lysine plus arginine: proline may be more digestible because it might contain fewer of the trypsin resistant lysylprolyl and arginylprolyl linkages. However, there was no evidence from the present experiment to support this hypothesis; the protein digestibilities of the wheats decreased from wheats Nos. 1 to 5, 2, 3 and 4 but, in the same order, the values for lysine plus arginine: proline were 0·6, 0·7, 0·5, 0·7, 0·6.

In other studies Sarwar & Bowland (1975) and Dittman *et al.* (1976) found that variation in lysine availability or protein digestibility among wheat samples was not related to the protein content of the grain. Similarly, Ivan & Farrell (1976) found very different apparent ileal availability values for lysine in wheats of approximately equal protein content but which differed in grain hardness. Therefore, although variation in grain protein content is usually accompanied by differences in the distribution of amino acids within the grain and often, as it appears in the present experiment, these differences seem related to variations in amino acid availability between grains, other factors that may be associated with grain composition or with differences in grain processing or grain hardness or both may also have an important influence on amino acid availability.

Maize. The amino acids in maize have generally been found to be more available than in other grains (Eggum, 1973*a*). For example, Eggum (1973*b*) found that the true faecal digestibility of lysine in rats given high-protein maize varieties was approximately 0·93; in a lower-protein maize variety containing 91 g protein/kg, Eggum (1973*a*) found the true faecal digestibility of lysine was 0·85 in rats and 0·89 in pigs. These values were considerably higher than those found by Eggum (1973*a*) for sorghum and barley. However, in the present experiment the average availability of amino acids in maize was not greater than that of all the other grains, and lysine was poorly available (0·83) relative to most other grains, including sorghum. The average apparent ileal availability of amino acids (0·79) was lower than that found by Sauer, Stothers & Phillips (1977) 0·86. The lower protein content of the maize used in this experiment 87 mg/g compared with that used by Sauer, Stothers & Phillips (1977) 114 mg/g may have contributed to this difference, first because of the dependence of apparent availability values on dietary protein concentration, especially at low protein levels. Secondly, it may be with maize, as Eggum & Christensen (1975) found with barley, that the true digestibility of protein is positively related to the protein concentration in the grain.

Although maize protein is particularly low in tryptophan (Table 3) which has been found to limit the growth rate of pigs given some maize-based diets, there are few estimates of tryptophan availability in maize or other grains. This is because of the destruction of tryptophan during the usual acid-hydrolysis of proteins for amino acid analysis. However, Copelin *et al.* (1978) recently determined tryptophan availability in sorghum using a growth assay technique with pigs. They found a tryptophan availability of 0·93. Similarly, Sarwar & Bowland (1976) reported that tryptophan was a highly-available amino acid in wheat. Eggum & Jacobsen (1976) also found that faecal availability of tryptophan was at least as high as N digestibility values in barley, oats and wheat. However, they reported in maize that the true faecal availability of tryptophan was only 0·83 and lower than all other amino acids (average 0·88). Rivera *et al.* (1976) also found the tryptophan in maize was less available to pigs than that in sorghum.

In the present experiment the true ileal availability of tryptophan in maize was 0·88 which was less than the average, and with lysine, threonine and valine, was one of the least available of the indispensable amino acids of maize.

Sorghum. The average ileal availability of amino acids in sorghum was among the highest of all the grains studied. The least available amino acid was lysine (0·88, which is similar to values for *Triticale* and the most digestible of the five wheats). Bragg *et al.* (1969) reported a similar value (0·89) for the true ileal availability of lysine in sorghum for chickens. However, there are several other reports in which lysine availability was considerably less than 0·88. Eggum (1973*a*) found the true faecal availability of lysine in sorghum was 0·72 while Copelin *et al.* (1978) estimated lysine availability at 0·63 using a growth assay with young pigs. The estimate of threonine availability for sorghum in the present experiment (0·91) was greater than that determined by Eggum (1973*a*) (0·83) or Copelin *et al.* (1978)

(0·89), although the differences between experiments were less for threonine than for lysine.

The wide variation between these estimates of lysine availability in sorghum is due either to real differences between the sorghum varieties studied or to differences between assay methods. Stephenson *et al.* (1971) found large differences in amino acid availability between different sorghum hybrids. In later work (Nelson *et al.* 1975) this appeared to be related to the tannin content of the grain. However, the decreased availability found by Stephenson *et al.* (1971) involved a general reduction in amino acid availability; as lysine availability decreased from 0·82 to 0·58, the average value of all other amino acids also decreased from 0·84 to 0·60. Therefore, the very low lysine availabilities determined by Eggum (1973*a*) and Copelin *et al.* (1978), which appeared not to be associated with a generally low availability of other amino acids, were probably not caused by a high tannin content of these sorghum grains. Nor could the differences in lysine availability be related to differences in the protein content of the grains; the grains studied by Eggum (1973*a*), Copelin *et al.* (1978) and in the present experiment contained 20·6, 18·4 and 16·7 mg N/g grain.

The low solubility of sorghum protein in the present experiment (Table 3) was similar to that reported by Skoch *et al.* (1970) who found only 28–40% of soluble protein in a range of different sorghum grains. Jumbunathan & Mertz (1973) found that a very different procedure was required to extract most of the protein from sorghum; the additional soluble protein was in the glutelin fraction.

Barley. The grain studied in the present experiment was of similar protein and amino acid content to that studied by Sauer, Stothers & Phillips (1977); there were also close similarities between the experiments in the respective estimates of apparent ileal availability of amino acids (0·76, 0·78) and N (0·71, 0·75). These ileal availability values also compare well with those determined by Zebrowska (1973) who found an average ileal availability of 0·76 for amino acids in barley.

There are numerous estimates of faecal digestibility of N and availability of amino acids in barley. Eggum (1973*a*, *b*) reviewed many studies and found that the variation in protein digestibility was related both to the protein content of the grain and to its tannin content (Eggum & Christensen, 1975). The true availability of individual amino acids also varied considerably between reports in a way that was also probably related to these factors.

Triticale. *Triticale* is a cereal species produced by combining the genomes of wheat and rye. Chen & Bushuk (1970) found that many of the chemical properties of *Triticale* were intermediate to those of the parent grains. Thus, compared with wheat, *Triticale* contained more albumin and globulin proteins but less gluten and insoluble proteins. These differences were also found in the present experiment, as can be seen in the higher lysine and lower glutamic acid and proline contents of *Triticale* protein compared to wheat proteins (Table 3).

McNab & Shannon (1974, 1975) determined amino acid availability in *Triticale*, rye and wheat by faecal analysis with colostomized hens. They found that N and amino acids in both *Triticale* and wheat were equally well digested and to an extent considerably greater than that in rye. Although the ileal values determined in the present experiment were greater than the faecal values of McNab & Shannon (1975), the results were similar in the comparison of amino acid availability between *Triticale* and wheat and also in the relative availabilities of amino acids in *Triticale*.

Sauer *et al.* (1974) determined faecal availability for pigs of amino acids in *Triticale*, wheat and barley. They found that the true digestibility of N in *Triticale* was approximately 0·91, which was similar to that found at the ileum in the present experiment. However, the true faecal availabilities of lysine, (0·85 in 10 kg pigs and 0·78 in 30 kg pigs), were less than the proportion estimated to be truly absorbed by the pig (80 kg live weight) in the present experiment (0·89). Sauer *et al.* (1974) found that faecal availability values of amino acids in *Triticale* were generally greater than those in wheat, although these values for wheat were lower than those determined in other wheats by Eggum (1973*a*), Sarwar & Bowland (1975) Sauer, Stothers & Parker (1977) and Sauer, Stothers & Phillips (1977).

For the nine grains studied, an average of approximately 0·88 of the amino acids considered were truly absorbed by the pig. However, within each grain there were differences between amino acids in availability that often exceeded 0·10. There appeared to be some consistencies in the relative differences between amino acids such that glutamic acid, methionine and arginine were usually among the most available and lysine, threonine and aspartic acid were among the least available amino acids.

The practical implication of this result is that if corrections for availability are to be applied to total amino acid values in cereal protein, correction with an average availability value for amino acids, estimated perhaps as the true digestibility of N, will over-estimate the availability of threonine and particularly lysine. Availability values of these amino acids are probably more important than all others in cereal protein and thus corrections specific for lysine and threonine should be considered.

There was found to be as much variation within one grain species as between grains. Therefore, the practical application of the specific availability values determined in this study appears to be limited unless they can be related to the spectrum of values probably associated with each grain species. For example, although the amino acids in sorghum were more available than those in maize in this experiment, Eggum (1973*a*) found the reverse, suggesting perhaps a wide range in availability values within each grain. Clearly, the factors that most influence, or are most associated with availability of amino acids, and particularly lysine, in cereal grains need to be identified so that values can be estimated that are at least relative to an average value expected for a grain. It appeared from the present study, and in some others, that the variations in amino acid availability within a species of grain may be related to its protein content. But this has not been confirmed in all studies and there are other factors such as tannins in barley (Eggum & Christensen, 1975).

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