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The effect of the 1B/1R translocation and endosperm texture on amino acid digestibility in near-isogenic lines of wheat for broilers

F. J. SHORT*, J. WISEMAN† AND K. N. BOORMAN

School of Biological Sciences, *University of Nottingham*, *Sutton Bonington Campus*, *Loughborough*, *Leics*., *LE12 5RD*, *UK*

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SUMMARY

Four near-isogenic lines of wheat were employed to compare the effects of endosperm texture (hard *v*. soft) and the presence or absence of the 1B/1R translocation on amino acid digestion as determined with young broilers. Wheat samples were incorporated into diets at rates of inclusion of 250, 500 and 750 g/kg, with wheat as the only protein source. Diets included a mineral/vitamin mixture (50 g), oil (50 g) and were made up to 1000 g with a 50:50 starch:glucose mixture. Titanium dioxide was included at 5 g/kg as an inert marker. Each of the 12 diets was fed to 6 pairs of growing male (Ross) chickens for 3 days. Samples of ileal digesta were obtained from the birds following slaughter at 21 or 22 days of age and analysed for amino acid and titanium dioxide content. True and apparent digestibility coefficients were determined by regressing the amount of dietary apparently digestible amino acid in the diet against the rate of wheat inclusion and extrapolating the response to 1000 g and 0 g wheat/kg. The ordinate intercept was assumed to represent endogenous losses. Both the presence of the translocation and hard endosperm texture were associated with decreases in the apparent digestibility of amino acids, although the latter characteristic was not as important. As examples, for methionine the translocation was associated with a decrease in the coefficient of digestibility from 0·872 to 0·802 and a change in endosperm texture from soft to hard was associated with a decrease from 0·845 to 0·829.

INTRODUCTION

Wheat is a major constituent of poultry diets often accounting for up to 700 g/kg; a substantial proportion of the UK wheat harvest is fed to poultry. Therefore, it is important that accurate information on the nutritional value of this raw material is available. It has recently become widely accepted that there is variation in nutritional quality of wheats (e.g. Annison 1990; Choct & Annison 1990; Wiseman & Inborr 1990). Wiseman *et al*. (1994) confirmed that there was variation in apparent metabolizable energy (AME) values for wheat fed to young poultry and subsequent studies have established that there is variation in digestibility of amino acids within wheat (Short *et al*. 1999).

* Current address: ADAS-Gleadthorpe, Meden Vale, Mansfield, Notts NG20 9PF, UK.

† To whom all correspondence should be addressed.
Tel.: (0115) 9516054. Fax: (0115) 9516060.
Email: julian.wiseman@nottingham.ac.uk

A problem with previous studies attempting to examine possible differences between cultivars in nutritional value has been that wheat samples have been selected on the basis of named varieties. This means of identification, however, gives no indication as to the genetic relationship between two named cultivars, since these could be distantly or closely related. The emergence of near isogenic lines represents a major development as nutritional implications of specific characteristics may now be investigated against a comparatively uniform genetic background.

Wheats are generally classified as hard or soft depending on their endosperm texture which reflects the protein/starch interaction and is genetically determined (Barlow *et al*. 1974). In soft wheats the starch and protein granules are embedded in a friable matrix which is readily crushed to release the starch and protein easily with little damage. However, in hard wheats a continuous protein matrix physically entraps the starch granules making for difficulty in separating the protein and starch.

A major characteristic present in most feed wheats is the 1B/1R translocation which is found widely in the UK (Foulkes *et al*., 1998) and is reported to be present in over 30% of breeding lines in Germany (Mettin & Bluther, 1984). Modern wheat cultivars contain 21 pairs of chromosomes arranged in three groups of seven. Each chromosome consists of two arms, one being short and the other long. In wheats with the 1B/1R translocation the short arm of chromosome 1B has been replaced with the short arm of the 1R chromosome of rye.

Bernard *et al*. (1977) observed that the 1R rye chromosome contained genes coding for prolamins on the short arm and genes coding for high molecular weight glutenins on the long arm. In wheat, genes coding for gliadin components are located in the homologous chromosome groups 1 and 6. One gene coding for thionine, a high sulphur basic peptide, was found to be located on the long arm of the rye chromosome 1R (Gomez *et al*. 1988).

The translocation has several reported agronomic advantages. The short arm of the 1R chromosome derived from the segment of the Petkus rye gene carries resistance to powdery mildew, stripe rust, leaf rust and stem rust (Mettin *et al*. 1973). Zeller (1973) found that, in the wheat variety Zorba, the translocation increased disease resistance; it was associated with a high resistance to rust and a moderate resistance to powdery mildew. The wheats produced were adaptable to the environment, but they were susceptible to eyespot.

The translocation is cited by breeders as conferring a 'stay green' effect on the lower canopy during senescence (thus leading to increased canopy persistence and, accordingly, greater photosynthetic efficiency) giving improved specific weight (Foulkes *et al*. 1998). In general it is believed that lines carrying the 1B/1R translocation have a broader adaptability and are environmentally less sensitive.

Whilst 1B/1R translocation has positive agronomic advantages it does have detrimental effects on the quality of hard wheats for bread-making, for example production of sticky dough with high speed mixing, reduced dough strength and intolerance to overmixing (Dhaliwal *et al*. 1987). There are believed to be a number of cultivars in the UK and elsewhere containing the 1B/1R translocation although some of these may not have the whole translocation (W. Angus, personal communication). Considerable research is currently underway in an attempt to fragment the chromosome to remove disadvantageous traits whilst maintaining the positive.

Whilst the agronomic implications of the presence of the 1B/1R translocation have been extensively studied, and influence on bread-making investigated, there would appear to have been no reports on the nutritional implications for animals. The purpose of the current study was to establish if there was an effect of the 1B/1R translocation on amino acid digestibility in 3-week-old broiler chickens. In addition, as endosperm texture is a key variable in wheat cultivars, this characteristic was also examined to investigate whether the expression of any effects of the 1B/1R translocation were influenced by the presence or absence of another feature. By using near-isogenic lines, any effects could be attributed only to the translocation or endosperm texture (and possible interactions) and these would not be masked by background differences.

MATERIALS AND METHODS

Male broiler chickens (Ross) were obtained at one day of age and were held initially in wire cages (four per cage) in an environmentally controlled metabolism room. The room was maintained initially at 34 °C, and the temperature was reduced by 1 °C per day to 22 °C. The birds had free access to feed and water, and lighting was maintained at 23 h on:1 h off. At 7 days of age the birds were split into groups of three and at 14 days they were weighed and placed in the cages in pairs of the same weight (± 10 g). A cage of two birds was a replicate. Birds were fed a standard mash broiler starter diet (containing wheat) until 18 or 19 days old, after which they were fed one of the test diets for 3 days. At 21 or 22 days of age the birds were killed using carbon dioxide asphyxiation. They were then quickly dissected to reveal the lower gastro-intestinal tract between Meckel's diverticulum and the ileo-caecal-colonic junction. After rapid removal of this section, digesta were squeezed, using very gentle digital pressure, into a collection vessel.

Wheats used

Four near-isogenic wheat samples, having the following distinguishing characteristics and having been grown under the same agronomic conditions, were used:

1. Hard endosperm with 1B/1R translocation.
2. Soft endosperm without 1B/1R translocation.
3. Hard endosperm without 1B/1R translocation.
4. Soft endosperm with 1B/1R translocation.

The wheat samples were ground through a mill (Christie and Norris, Cheltenham) fitted with a 3·5 mm screen.

Diets

Twelve experimental diets were formulated using the four wheat samples with three diets per wheat sample. Diets were based on 750, 500 or 250 g wheat/kg, 50 g oil/kg to promote palatability and decrease dust, 50 g complete vitamin and mineral mixture/kg, 5 g titanium dioxide/kg as an inert internal marker and were made up to 1 kg with a 50:50 maize starch:glucose mixture.

Experimental diets were fed to 72 pairs of birds for

Table 1. *Concentration of apparently digestible amino acids (AA) in diets using four isogenic wheat lines (g/kg) at the three inclusion levels (g/kg); 1B/1R is the rye translocation (+ with, − without), endosperm texture is H (hard) or S (soft)*

	Inclusion 250					Inclusion 500				
Wheat	1 +1B/1R H	2 −1B/1R S	3 −1B/1R H	4 +1B/1R S	Mean	1 +1B/1R H	2 −1B/1R S	3 −1B/1R H	4 +1B/1R S	Mean
AA										
ALA	0·67	0·77	0·63	0·67	0·68	1·15	1·48	1·52	1·48	1·41
THR	0·41	0·51	0·38	0·45	0·44	0·74	1·14	1·07	1·10	1·01
LYS	0·63	0·57	0·54	0·60	0·59	1·03	0·94	1·22	1·28	1·12
CYS	0·53	0·63	0·57	0·56	0·57	0·96	1·30	1·27	1·19	1·18
LEU	1·35	1·51	1·29	1·34	1·37	2·37	2·99	2·88	2·88	2·78
HIS	0·51	0·62	0·48	0·49	0·51	0·88	1·21	1·10	1·06	1·06
MET	0·35	0·43	0·37	0·40	0·39	0·62	1·06	0·81	0·82	0·83

	Inclusion 750					Overall means				
Wheat	1 +1B/1R H	2 −1B/1R S	3 −1B/1R H	4 +1B/1R S	Mean	1 +1B/1R H	2 −1B/1R S	3 −1B/1R H	4 +1B/1R S	Mean
AA										
ALA	2·12	2·60	2·25	2·18	2·29	1·32	1·62	1·47	1·44	1·46
THR	1·48	2·09	1·61	1·70	1·72	0·88	1·25	1·02	1·08	1·06
LYS	1·84	1·73	1·85	1·83	1·39	1·17	1·08	1·21	1·24	1·18
CYS	1·74	2·10	1·89	1·79	1·88	1·08	1·34	1·24	1·18	1·21
LEU	4·24	4·94	4·34	4·29	4·45	2·65	3·15	2·84	2·84	2·87
HIS	1·65	2·06	1·69	1·55	1·74	1·01	1·30	1·09	1·03	1·11
MET	1·10	1·32	1·20	1·22	1·21	0·69	0·94	0·80	0·81	0·81

Table 2. *Analysis of variance of digestible amino acid contents for diets based on four isogenic wheat lines for seven amino acids, where translocation (T), endosperm texture (E), and inclusion (I) are the variables. Values are for probabilities (P) and standard errors (S.E.)*

Variable	D.F.		ALA	THR	LYS	CYS	LEU	HIS	MET
T	1	P	0·002	0·003	0·653	0·003	0·001	< 0·001	< 0·001
		S.E.	0·0482	0·0472	0·0469	0·0429	0·0687	0·0378	0·0153
E	1	P	0·009	< 0·001	0·063	0·014	0·001	0·006	< 0·001
		S.E.	0·0482	0·0472	0·0469	0·0429	0·0687	0·0378	0·0153
I	2	P	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001
		S.E.	0·0591	0·0578	0·0574	0·0525	0·0841	0·0463	0·0187
Linear	1	P	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001
Quadratic	1	P	0·123	0·186	0·312	0·532	0·080	0·111	0·102
T*E	1	P	0·855	0·798	0·294	0·423	0·364	0·018	0·055
		S.E.	0·0681	0·0668	0·0663	0·0743	0·0971	0·0535	0·0220

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Table 3. *Linear regression equations* ($y = b+ax$) *relating dietary content of apparently digestible amino acids* (y, *g/kg diet*) *to rate of inclusion of wheat* (x, *g/kg*) *for 7 amino acids* (*AA*). *Characteristics: 1B/1R is the rye translocation* (+ *with*, − *without*), *endosperm texture is H* (*hard*) *or S* (*soft*)

AA	Wheat	Characteristics	b	a*10⁻³	R^2
ALA	1	+1B/1R, H	−0·132±0·198	2·89±0·56	0·964
	2	−1B/1R, S	−0·213±0·171	3·66±0·48	0·983
	3	−1B/1R, H	−0·152±0·063	3·24±0·18	0·996
	4	+1B/1R, S	−0·063±0·041	3·01±0·12	0·998
THR	1	+1B/1R, H	−0·190±0·169	2·14±0·48	0·952
	2	−1B/1R, S	−0·332±0·128	3·16±0·36	0·987
	3	−1B/1R, H	−0·221±0·055	2·48±0·16	0·996
	4	+1B/1R, S	−0·171±0·021	2·51±0·06	0·999
LYS	1	+1B/1R, H	−0·048±0·170	2·43±0·48	0·962
	2	−1B/1R, S	−0·090±0·174	2·33±0·49	0·957
	3	−1B/1R, H	−0·100±0·022	2·61±0·01	0·999
	4	+1B/1R, S	0·009±0·058	2·45±0·17	0·995
CYS	1	+1B/1R, H	−0·139±0·145	2·43±0·41	0·973
	2	−1B/1R, S	−0·131±0·051	2·95±0·14	0·998
	3	−1B/1R, H	−0·079±0·035	2·64±0·01	0·999
	4	+1B/1R, S	−0·055±0·018	2·47±0·05	0·999
LEU	1	+1B/1R, H	−0·132±0·343	5·77±0·97	0·972
	2	−1B/1R, S	−0·276±0·197	6·85±0·56	0·993
	3	−1B/1R, H	−0·209±0·055	6·09±0·16	0·999
	4	+1B/1R, S	−0·119±0·016	5·90±0·15	0·999
HIS	1	+1B/1R, H	−0·127±0·158	2·28±0·45	0·963
	2	−1B/1R, S	−0·147±0·105	2·89±0·30	0·990
	3	−1B/1R, H	−0·119±0·014	2·42±0·04	1·000
	4	+1B/1R, S	−0·031±0·034	2·12±0·10	0·998
MET	1	+1B/1R, H	−0·061±0·088	1·50±0·25	0·973
	2	−1B/1R, S	0·044±0·153	1·78±0·43	0·945
	3	−1B/1R, H	−0·039±0·023	1·67±0·07	0·998
	4	+1B/1R, S	−0·055±0·016	1·64±0·04	0·999

3 days from 18 or 19 to 21 or 22 days of age, with each pair of birds being allocated one of the 12 diets, giving six pairs (replicates) on each diet. To spread the workload, the trial was carried out in two halves with one half (three replicates) being given experimental diets at 18 and the second half at 19 days of age.

Chemical analyses

Samples of ileal digesta obtained from the birds were deep frozen (−20 °C) immediately after removal and later freeze-dried before being ground using a pestle and mortar. The samples were then analysed for amino acid and titanium concentrations.

Amino acid analyses

Amino acid concentrations in wheats and ileal digesta were determined using samples (0·2 g) which had been hydrolysed in 6 M HCl for 18 h at 110 °C under nitrogen. All samples were oxidized using performic acid to allow measurement of cystine and methionine. Samples were then dried on a rotary evaporator and dissolved in 0·2 M sodium buffer (2 ml) and the pH adjusted to 2 with 10 M NaOH. Aliquots of these samples were assayed on a cation exchange column (Pharmacia Biochrom), with nor-leucine as the internal standard. The amino acids were eluted using sodium citrate buffers and the eluted amino acids were detected by a ninhydrin colour reaction at 570 nm for all amino acids except proline which was detected at 440 nm.

Titanium analyses

Titanium was analysed using a modified version of the AOAC method (Short *et al*. 1996). Samples (0·1 g) were ashed at 580 °C for 13 h before dissolving in 7·4 M H_2SO_4. The solutions were diluted with water and H_2O_2 (30% v/v). The absorbance was measured at 410 nm on a spectrophotometer.

Calculations

The titanium dioxide and amino acid concentrations were used to calculate the apparent amino acid digestibility content using the following equation:

$$1-(aa_{dig} * marker_{feed})/(aa_{feed} * marker_{dig})$$

where aa_{dig} = amino acid concentration in digesta; $marker_{feed}$ = titanium concentration in the diet;

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aa_{feed} = amino acid concentration in the diet; $marker_{feed}$ = titanium concentration in the digesta. From the digestibility and the amino acid content of the diet the concentration of the ileal apparently digestible amino acid/kg diet was calculated. This was then regressed on rate of inclusion of wheat (using treatment means). Analysis of variance was conducted with rate of inclusion as a variate. This allowed evaluation of the linearity of the regression equations derived. Extrapolation of the linear equations derived to 1000 g wheat/kg diet gave the content of apparently digestible amino acid in a wheat which, when divided by the total amount, gave the coefficient of apparent digestibility for that amino acid. Extrapolation to zero wheat intake (the intercept) gave an estimate of the endogenous losses which could be used to calculate true ileal digestibility.

RESULTS

Table 1 displays the apparently digestible contents for seven chosen amino acids (cystine, methionine, threonine, alanine, leucine, histidine and lysine) in the diets. The statistical analysis of data for digestible amino acid content is shown in Table 2 for translocation, endosperm texture, inclusion rate and the interaction between translocation and endosperm texture. Other interactions were examined but were generally not significant. The apparently digestible amino acid content of the diets increased with the rate of wheat inclusion and the analysis of variance confirmed highly significant linear responses, with no significant curvature.

There were significant differences among the wheat samples in digestible amino acid contents associated with translocation and endosperm texture but not, generally, their interaction. The 1B/1R translocation was associated with significant decreases in the amounts of apparently digestible amino acids with the exception of lysine. The effect of endosperm texture was also significant in all cases except lysine for which the *P* value was 0·063. Decreases in digestible amino acid content can result from either decreases in total amino acid content or amino acid digestibility or

Table 4. *Apparently digestible amino acid (AA) concentrations in wheat estimated by regression (see Table 3), total AA contents by chemical analysis and calculation of apparent (A) and true (T) digestibility coefficients for seven amino acids in the four isogenic wheat lines*

AA	Wheat	Characteristic	Apparently digestible AA (g/kg wheat)	Total (g/kg)	Coefficient A	Coefficient T	Coefficient S.E.
ALA	1	+1B/1R, H	2·76	4·15	0·665	0·728	(±0·046)
	2	−1B/1R, S	3·45	4·54	0·759	0·853	(±0·053)
	3	−1B/1R, H	3·09	4·27	0·723	0·794	(±0·049)
	4	+1B/1R, S	2·95	4·35	0·677	0·706	(±0·045)
THR	1	+1B/1R, H	1·95	3·28	0·595	0·710	(±0·043)
	2	−1B/1R, S	2·83	3·80	0·744	0·919	(±0·054)
	3	−1B/1R, H	2·26	3·35	0·674	0·806	(±0·048)
	4	+1B/1R, S	2·34	3·95	0·592	0·679	(±0·045)
LYS	1	+1B/1R, H	2·38	3·49	0·683	0·710	(±0·046)
	2	−1B/1R, S	2·24	3·60	0·622	0·672	(±0·043)
	3	−1B/1R, H	2·50	3·49	0·719	0·777	(±0·049)
	4	+1B/1R, S	2·46	3·58	0·687	0·682	(±0·045)
CYS	1	+1B/1R, H	2·29	2·91	0·787	0·883	(±0·055)
	2	−1B/1R, S	2·82	3·26	0·865	0·945	(±0·059)
	3	−1B/1R, H	2·56	3·09	0·829	0·880	(±0·056)
	4	+1B/1R, S	2·42	3·03	0·797	0·833	(±0·053)
LEU	1	+1B/1R, H	5·64	7·21	0·782	0·819	(±0·053)
	2	−1B/1R, S	6·57	7·88	0·834	0·904	(±0·057)
	3	−1B/1R, H	5·88	7·25	0·811	0·869	(±0·055)
	4	+1B/1R, S	5·78	7·45	0·776	0·808	(±0·051)
HIS	1	+1B/1R, H	2·15	2·96	0·727	0·813	(±0·051)
	2	−1B/1R, S	2·74	3·28	0·836	0·926	(±0·058)
	3	−1B/1R, H	2·30	3·02	0·762	0·841	(±0·052)
	4	+1B/1R, S	2·09	2·96	0·706	0·727	(±0·047)
MET	1	+1B/1R, H	1·44	1·78	0·808	0·877	(±0·055)
	2	−1B/1R, S	1·82	2·04	0·894	0·851	(±0·058)
	3	−1B/1R, H	1·63	1·92	0·849	0·890	(±0·048)
	4	+1B/1R, S	1·59	1·99	0·796	0·852	(±0·045)

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Table 5. *The influence of the 1B/1R translocation and endosperm texture in wheat near isogenic cultivars on apparent digestibility coefficients of amino acids. Data presented are main effects*

AA	+1B1R	−1B/1R	Hard	Soft
ALA	0·671 (±0·0301)	0·741 (±0·0294)	0·694 (±0·0320)	0·718 (±0·0343)
THR	0·593 (±0·0297)	0·709 (±0·0337)	0·634 (±0·0306)	0·668 (±0·0345)
LYS	0·685 (±0·0303)	0·671 (±0·0293)	0·701 (±0·0317)	0·655 (±0·0542)
CYS	0·792 (±0·0362)	0·847 (±0·0377)	0·808 (±0·0368)	0·831 (±0·0386)
LEU	0·779 (±0·0349)	0·823 (±0·0364)	0·797 (±0·0360)	0·805 (±0·0307)
HIS	0·717 (±0·0327)	0·799 (±0·0352)	0·745 (±0·0346)	0·771 (±0·0374)
MET	0·802 (±0·0365)	0·872 (±0·0475)	0·829 (±0·0466)	0·845 (±0·0539)

both. This is explored further in the discussion. The regression equations from which digestible amino acid contents were derived are shown in Table 3 and the derivations in Table 4. The calculated apparent and true digestible coefficients are also shown in these Tables. The coefficients were then expressed as main effects (influence of the 1B/1R translocation and endosperm texture) which are displayed in Table 5.

DISCUSSION

Although not the principal objective of the current study, the negative intercept derived for all linear regressions with the exception of two (Table 3) is a further indication (e.g. Short *et al.* 1999) that the methodology adopted is an acceptable means of estimating endogenous losses and, accordingly, may be employed to derive true in addition to apparent digestibility.

Wheat used in animal feed is generally that which has not attained the standards required for bread making. However it has been observed recently that there is considerable variation in nutritional value of wheats used for inclusion in animal (particularly poultry) diets. The main objective of the current study was to evaluate the effects of the 1B/1R translocation and endosperm texture in four wheat samples. The wheat samples used were near-isogenic thus, apart from endosperm texture and translocation, they were as genetically similar to each other as is possible using conventional plant breeding techniques. Thus although the lines were not completely pure it is likely that any differences between the wheats in terms of nutritional value could be attributed substantially to endosperm texture and/or translocation. The experimental design allowed the testing of these two characteristics as the main effects and the possibility of interactions between them.

The analyses of variance (Table 2) revealed that, for all amino acids investigated apart from lysine, the influence of the 1B/1R translocation was a significant reduction in digestible amino acid content. A similar observation was obtained for endosperm texture. The interaction between translocation and endosperm in most cases was not significant, with the exception of histidine ($P = 0{\cdot}018$) for which there is no apparent explanation.

Rye provides significant concentrations of anti-nutrititive factors in poultry diets. The problems with rye have been attributed to soluble non-starch-polysaccharides (NSP) which have a negative effect on the physico-chemical conditions in the gut (Campbell & Bedford 1992). The predominant component of NSP in rye and wheat is the arabinoxylan fraction which is present in similar amounts in both cereals but a higher proportion of this fraction from rye is soluble (Bedford & Classen 1992). It has been suggested by many studies (e.g. Choct & Annison 1992) that components of the arabinoxylan complex become soluble when consumed by the chicken resulting in an increased digesta viscosity and decreased digestion of nutrients. The 1B/1R translocation involves the replacement of some wheat chromosomes with those of rye and it is likely that the genetic material passed into the wheat results in greater concentrations in wheat of those arabinoxylans normally present in rye.

In the majority of cases (Table 5) the amino acids in hard wheat were less digestible than in the softer wheat. This may result from the interaction between the starch and the protein within the structure of the wheat grain.

The nutritional value of a raw material depends upon the total content of each specific nutrient and its digestibility. Whilst the major objective of the current study was an assessment of digestibility, inspection of the data for total amino acid content (Table 4) revealed that both the translocation and endosperm texture were having an effect on total amino acid concentration. Thus the absence of the 1B/1R translocation was associated, for six out of the seven amino acids studied, with an increase of the order of 3·5% in total amino acid content (individual data ranged from 6·9 to −1·1%). Similarly soft endosperm texture improved the content of all seven amino acids collectively by an average of 7·1% (range 16·9 to 2·9%). Thus the translocation altered available amino acid content of the wheat primarily by reducing its digestibility whereas the hard endosperm texture reduced digestible amino acid content because it lowered the total concentration of amino acids.

The major observations emerging from the current study are that the presence of the 1B/1R translocation and, separately, hard endosperm texture appeared to decrease nutritional value (defined in terms of amino acid digestibility) of wheat for young poultry. The exception to this overall trend was for lysine which, as it is more likely to be a nutritionally limiting essential amino acid in poultry diets, is a matter for further study. There was a general lack of an interaction between the translocation and endosperm texture. There is the suggestion that both the translocation and hard endosperm lower total amino acid content of wheat (Table 4). It was for this reason that comparisons of digestibility were based on coefficients (Table 5) rather than absolute quantities as differences in the latter could be attributable to both total content and digestibility. The major objective of the programme was an assessment of the degree of digestibility and, thus, the former approach was employed.

The wheats investigated in the current programme were developed by plant breeders and the techniques employed may not have inserted all of the genetic material desired into the plant and/or may have inserted other material. The description 'near isogenic' indicates that the principal differences between lines were the translocation / endosperm texture, although the backgrounds in which these characteristics were present cannot be described as identical. Further studies with increasingly pure backgrounds are therefore necessary to confirm the observations of the current study and establish why they were obtained.

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