Variability in the Lysine Content of Wheat, Rye, and Triticale Proteins[1]

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ABSTRACT

Lysine content of the protein of spring wheat, durum wheat, other wheat species, rye, and triticale was investigated. On an equal-nitrogen basis, spring wheat and durum wheat proteins were about equal in lysine content; triticale and rye proteins were, respectively, about 20 and 30% higher than the spring and durum wheat. Lysine in 16 other wheat species was quite variable. Outstanding in high lysine and protein was the species *Triticum boeoticum*. Statistical analysis indicates that a significant inverse relation exists between lysine in the protein and the protein contents of wheat, rye, and triticale.

Undernutrition and malnutrition are currently widespread in many areas of the world. The most serious nutritional problem is protein-calorie malnutrition among children in developing countries (1,2).

Cereals, the principal source of plant protein, supply 60% of the total world protein supply (3). Further, it is anticipated that more and more of the world's need for protein will have to be supplied by the plant proteins. Unfortunately, cereal proteins are deficient in several amino acids required by man for proper growth. Many nutritional studies have established that lysine is the most limiting essential amino acid in cereal proteins (4,5,6,7).

In 1964, the mutant gene of maize, opaque-2, was reported to be associated with an increase in the lysine content of maize protein (8). This discovery stimulated genetic-biochemical research to find other cereal varieties or mutated seeds that also may contain "high-lysine" genes. In the present study, lysine variability was investigated among species and varieties of wheat, rye, triticale, and wheat amphiploids.

MATERIALS AND METHODS

Wheat

Triticum aestivum. Five varieties of HRS wheat were grown in North Dakota at Fargo and Minot in 1966, and seven varieties at Chapingo, Mexico, in 1965 at two different plantings.

Triticum durum. Five varieties of durum wheat were grown at Edgeley, Fargo, and Minot, North Dakota, in 1966, and twenty-three lines and varieties at Ciudad Obregon, Sonora, Mexico, in 1965-66.

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Triticum Species. Sixty-four samples of diploid, tetraploid, and hexaploid species were supplied by the U.S. Department of Agriculture, World Collection of small grains. They were grown in 1964 at Aberdeen, Idaho. Another group of twenty-six samples of *Triticum* species, including six amphiploids, was grown at Fargo, North Dakota, in 1964.

Rye

A collection of 125 varieties and species of *Secale* was supplied by the International Maize and Wheat Improvement Center in Mexico City, Mexico. These samples were grown in a number of different countries under various ecological conditions.

Triticale

A group of 70 plant and spike selections from 25 varieties or crosses, developed at the University of Manitoba, were grown at Ciudad Obregon, Sonora, Mexico, in 1965-1966.

Sample Preparation

Two types of samples were analyzed, bulked seed and seeds in spikes. With samples supplied in spikes, four kernels from the top, center, and bottom of the spike, or in some cases four kernels from only the bottom and center of the spike, were selected. All samples were stored at 60°F. in 50% r.h. and had moisture content, as determined by the 130° air-oven method (9), between 6 and 9% (as-is). All seeds (four to ten kernels) were finely ground with a Micro-Wiley mill to pass a 60-mesh sieve before analysis for protein and lysine.

Protein Analysis

Nitrogen was determined by the Micro-Kjeldahl procedure (10), and protein was calculated from percent nitrogen by the factor 5.7 for wheat and triticale samples and 6.25 for rye samples. Protein is stated on 14% moisture basis.

Lysine Analysis

Samples (30 mg.) were dispersed in 3-ml. aliquots of 6N hydrochloric acid in hydrolysis tubes fitted with a 28/15 ball joint and glass stopcock. The contents were frozen in dry-ice-alcohol bath and sealed under a vacuum with an oil pump. Subsequently, the samples were heated 22 hr. in an air oven at 110° ± 2°C. The resultant hydrolysates were filtered through 2-ml. fritted disc funnels into 25-ml. filtering flasks, the humin of each sample was washed twice with 1-ml. aliquots of deionized distilled water, and the combined hydrolysates and wash water were evaporated to dryness in the filtering flask over NaOH pellets in a vacuum desiccator evacuated with an oil pump. The dried hydrolysates were each dissolved in 4 ml. pH 2.2 sodium citrate buffer (11) that was 0.2M in Na+ and contained thiodiglycol, BRIJ-35, and caprylic acid. When necessary, the samples were stored a few days at -20°C. before being analyzed. Lysine in the hydrolysate was determined with a Beckman 120B amino acid analyzer; a triplicate-sample method was used (12). A 0.25 μM per ml. solution of L-lysine monohydrochloride (M.A. grade, Mann Research Lab., Inc.) was used as a standard each day. Nitrogen content of this lysine was 15.3% (as-is basis), the theoretical value for lysine

TABLE I. EFFECT OF SPIKE DEVELOPMENT CHRONOLOGY AND POSITION OF KERNELS IN SPIKE ON LYSINE CONTENT

Type of Wheat	Variety or Line	Spike Chronology	Kernel Position on Spike	Protein[a] %	Lysine[b] In Protein g./16 g. N	Lysine[b] In Sample %
Hard red spring	Chris	1st	Bottom	13.6	2.27	0.394
			Center	14.9	2.24	0.425
			Top	14.5	2.28	0.423
	Chris	2nd	Bottom	15.1	2.22	0.429
			Center	15.2	2.26	0.438
			Top	15.1	2.20	0.425
	Chris	3rd	Bottom	14.2	2.24	0.406
			Center	14.1	2.25	0.406
			Top	13.6	2.35	0.408
Durum	RD 173-1A		Bottom	15.0	2.67	0.514
			Center	14.5	2.83	0.523
	RD 181-3A		Bottom	14.8	2.42	0.455
			Center	14.8	2.42	0.455
			Bottom	15.5	2.41	0.475
	RD 148-1A		Center	15.6	2.31	0.461

[a]Kjeldahl protein values in this and subsequent tables are reported on 14% moisture basis and represent an average of two determinations.

[b]Lysine content in this and subsequent tables is reported on dry basis and represents a single determination.

monohydrochloride. All values relating to the lysine content of proteins are reported on a dry-weight basis.

RESULTS AND DISCUSSION

Spike Chronology and Kernel Position in Spike

The effect of time of spike formation on the plant (first, second, and third) and position of the kernel in each spike on lysine content were investigated with seven varieties of spring wheat grown in Mexico; only the effect of kernel position in the spike was studied on 23 lines or varieties of durum wheat also grown in Mexico. If variation occurs here, one might increase lysine content by selection over a number of generations. Some typical examples of the results of 153 lysine analyses are given in Table I.

In all cases, only a small variation of lysine content in the protein was observed between kernels from the top, center, and bottom positions of a spike and different spikes from the same plant. Neither the kernel position in the head nor the individual spike used appeared to affect lysine content. The small variation observed was consistent with an inverse relation of lysine to protein content. Thus, improvement of lysine by selection of kernels from spikes does not seem possible.

Triticum aestivum. Results of analyses on five spring wheat varieties grown in two locations in North Dakota and seven spring wheat varieties grown at two plantings in Mexico are given in Tables II and III. The lysine content in the protein varied from 2.15 g. per 16 g. N (Justin, Table III) to 2.77 g. per 16 g. N (Lermo Rojo, Table III). Lawrence et al. (13) reported a variation from 2.26 g. per 16 g. N

TABLE II. LYSINE CONTENT OF HARD RED SPRING WHEAT GROWN AT TWO LOCATIONS IN NORTH DAKOTA[a]

Variety	Fargo			Minot		
	Protein	Lysine		Protein	Lysine	
		In Protein	In Sample		In Protein	In Sample
	%	g./16 g. N	%	%	g./16 g. N	%
Selkirk	15.0	2.39	0.460	16.6	2.27	0.481
Justin	15.8	2.56	0.516	18.8	2.39	0.574
Chris	16.2	2.46	0.507	16.6	2.44	0.517
Manitou	15.6	2.61	0.522	16.8	2.35	0.503
Crim	15.8	2.50	0.506	16.6	2.36	0.500

[a]Lysine in protein vs. protein content, r = −0.4.

TABLE III. LYSINE CONTENT[a] OF SPRING WHEATS GROWN IN MEXICO[b]

Variety or Line	First Planting			Second Planting		
	Protein	Lysine		Protein	Lysine	
		In Protein	In Sample		In Protein	In Sample
	%	g./16 g. N	%	%	g./16 g. N	%
Chris[c]	14.5	2.55	0.473	14.5	2.25	0.417
Crim[c]	10.6	2.72	0.366	11.9	2.36	0.359
Selkirk[c]	14.3	2.34	0.427	12.4	2.61	0.408
Justin[c]	16.7	2.29	0.482	16.4	2.15	0.449
Lerma Rojo[d]	12.2	2.77	0.425	13.9	2.65	0.465
Narino 59[d]	13.2	2.44	0.410	14.4	2.49	0.456
8156[d]	12.9	2.46	0.407	12.5	2.36	0.391
	Mean Values					
Combined data Tables II and III	14.8	2.45	0.459			

[a]Lysine in protein vs. protein content, r = −0.68.

[b]First planting June 15, 1965; second, June 30, 1965.

[c]Hard varieties with 13.9% average protein and 2.41 g. average lysine per 16 g. N in protein.

[d]Soft varieties with 13.2% average protein and 2.53 g. average lysine per 16 g. N in protein.

to 3.23 g. per 16 g. N for spring wheats, and an inverse relation between lysine content of the protein and protein content of the sample among spring and winter wheats of less than 13.5% protein. Statistical analysis of our data gave a low correlation (r = −0.4) for lysine vs. protein content for the wheats grown in North Dakota with the 15 to 19% protein range and a significant high correlation (r = −0.68) for wheats grown in Mexico with an 11 to 17% protein range. The over-all correlation for spring wheat was −0.49 and significant.

The average values for the spring wheat analyses were 2.45 g. lysine per 16 g. N in the protein, and 0.459% lysine and 14.8% protein in the samples. For spring wheat, Lawrence et al. reported an over-all mean of 2.66 g. lysine per 16 g. N in the protein; for 91 samples of spring and winter wheats with more than 13.5% protein, they reported an average of 2.64 g. lysine per 16 g. N. Their mean value for samples over 13.5% protein, which approximates the protein range of the present study, is a

little higher than that observed here with 24 samples from 8 different varieties.

Soft endosperm portions of the same wheat kernel have been reported by McDermott and Pace (14) to contain less protein but a higher content of basic amino acids than the hard portions of higher protein. In Table III, a comparison of samples of the soft spring wheat varieties Lerma Rojo, Narino 59, and 8156 with the hard spring varieties Chris, Crim, Selkirk, and Justin did not show a consistently lower protein content in the soft wheats nor a significant relation between softness and content of lysine in the protein. The soft wheat samples averaged 13.2% in protein and had a mean of 2.53 g. lysine per 16 g. N in the protein, while the hard wheat samples averaged 13.9% in protein and had a mean lysine content of 2.41 g. per 16 g. N. The average values do, however, follow the pattern of McDermott and Pace's observations.

Triticum durum. The lysine contents of five varities of durum wheat grown in three locations in North Dakota and 23 lines grown in Mexico are given in Tables IV and V. The lysine in the protein varied from 1.84 g. per 16 g. N (Leeds, Table IV) to 3.10 g. per 16 g. N (RD-176-7A, Table V). The sample having the lowest lysine content in the protein was also the highest in protein content (19.9%), whereas the sample having the highest lysine in the protein was the lowest in protein content (9.5%). The relation of lysine content vs. protein was highly significant ($r = -0.77$) for durum wheats grown in North Dakota with 13.8 to 19.9% protein content, but not significant ($r = -0.33$) for durum wheats grown in Mexico with 9.5 to 17.1% protein content. The over-all correlation coefficient for durum is −0.65 and significant.

The over-all means for durum wheats were 2.39 g. lysine per 16 g. N in the protein, and 0.466% lysine and 15.3% protein in the sample. Lawrence et al. (13) reported a mean of 2.71 g. lysine per 16 g. N in the protein for six durum wheat varieties of 13.0% average protein content. Our results indicated lysine in the protein of durum wheat to be lower than that reported by these workers and to be

TABLE IV. LYSINE CONTENT OF DURUM WHEAT GROWN AT THREE LOCATIONS IN NORTH DAKOTA[a]

	Mindum	Wells	Lakota	Stewart 63	Leeds
Edgeley					
Protein, %	16.5	19.2	18.9	18.9	19.9
Lysine					
in protein, g./16 g. N	2.45	2.06	2.09	2.16	1.84
in sample, %	0.517	0.505	0.504	0.544	0.467
Fargo					
Protein, %	13.8	16.0	16.2	15.5	16.0
Lysine					
in protein, g./16 g. N	2.26	2.28	2.24	2.37	2.43
in sample, %	0.399	0.466	0.464	0.472	0.494
Minot					
Protein, %	18.4	17.3	16.1	16.8	18.6
Lysine					
in protein, g./16 g. N	2.06	2.16	2.43	2.24	2.04
in sample, %	0.483	0.478	0.499	0.478	0.483

[a]Lysine in protein vs. protein content, $r = -0.77$.

TABLE V. LYSINE CONTENT OF DURUM WHEATS GROWN IN MEXICO

Line	Protein %	Lysine	
		In Protein g./16 g. N	In Sample %
RD 173-1A	14.8	2.75	0.518
RD 176-2A	14.5	2.72	0.503
RD 176-2B	16.5	2.87	0.604
RD 176-7A	9.5	3.10	0.375
RD 178-4A	13.3	2.49	0.423
RD 181-3A	14.8	2.42	0.455
RD 181-6A	12.4	2.53	0.398
RD 87-2A	17.0	2.46	0.534
RD 87-2B	14.0	2.54	0.453
RD 101-2A	17.1	2.29	0.499
RD 119-4A	15.3	2.41	0.469
RD 138-3A	12.3	2.58	0.406
RD 138-3B	14.3	2.47	0.449
RD 148-1A	15.5	2.35	0.468
RD 182-11A	16.1	2.34	0.479
RD 182-11B	13.5	2.17	0.373
RD 3-2G	11.3	2.35	0.340
(Pi-ThxTc^2) (Z-B) Wells 21584-A	13.1	2.21	0.448
(Pi-ThxTc^2) (Z-B) Wells 21584-B	12.3	2.49	0.398
[(Yt N10-B) BY^2)] Tc^2 18177-6Y	12.7	2.49	0.404
[(Yt N10-B) BY^2)] Tc^2 18177-13Y	13.8	2.47	0.434
(Wt$_E$xTR) Tc^2	13.8	2.63	0.486
(ZxB) Wells	16.5	2.60	0.549
Lysine in protein vs. protein content, r = −0.33			
		Mean Values	
Combined data, Tables IV and V	15.3	2.39	0.466

about the same as the average for spring wheat (2.45 g. per 16 g. N).

Triticum Species. The lysine content of 84 varieties from 16 different wheat species was investigated. The results are given in Tables VI and VII. The protein of five varieties of *T. boeoticum* (Table VI) were on average 20% higher in lysine than the protein of durum or spring wheats. Outstanding examples in this species are the varieties in Table VI which have very high protein contents (average 19.1%) and relatively high amounts of lysine in the protein. The outstanding variety of the species is No. 230133 with 18.5% protein and 3.20 g. lysine per 16 g. N in the protein.

The protein of the varieties of *T. pyramidale, T. carthlicum* (=*T. persicum*), *T. turgidum, T. spelta, T. macha,* and *T. vavilovi* (Table VI) was relatively high in lysine. Average protein content of the first five species was intermediate (10.7 to 12.6%); the last species was low (8.6%).

Lawrence et al. (13) examined several moderately high-protein (15 to 17%) varieties of the species *T. pyramidale* and *T. carthlicum* and also found them to be relatively high in lysine (average 3.0 g. per 16 g. N in protein of both species). In

TABLE VI. LYSINE CONTENT OF TRITICUM SPECIES

Species and Code No. of Varieties[a]		Protein %	Lysine In Protein g./16 g. N	Lysine In Sample %
T. boeoticum: 227669, 230133[b], 272519, 272520, 277121	Average	19.1	2.89	0.705
	Range	16.7–21.0	2.78–3.19	0.672–0.763
T. monococcum: 10474, 94740, 94743, 119422, 119423	Average	14.7	2.55	0.479
	Range	13.3–16.3	2.36–2.70	0.460–0.498
T. dicoccoides: 190919, 233288, 266841, 272535	Average	16.6	2.61	0.547
	Range	11.0–23.2	2.39–2.96	0.415–0.757
T. timopheevi: 94760, 94761, 190974, 221421, 290518	Average	12.9	2.66	0.437
	Range	11.1–17.7	2.61–2.77	0.378–0.594
T. pyramidale: 113395, 113396, 113397, 113398, 113950	Average	10.7	3.11	0.426
	Range	10.1–11.5	2.99–3.27	0.386–0.481
T. carthlicum: 7692, 78812, 94748, 94750, 94751	Average	12.6	3.10	0.496
	Range	10.9–15.7	2.92–3.64	0.416–0.587
T. turanicum: 113392, 113393, 115815, 173482, 184526	Average	12.5	2.65	0.419
	Range	10.6–14.8	2.44–2.81	0.372–0.460
T. polonicum: 42209, 56261, 56262, 167622, 185309	Average	14.6	2.64	0.489
	Range	13.2–15.7	2.55–2.74	0.460–0.477
T. turgidum: 5988, 7688, 13712, 13713, 277680	Average	12.0	2.84	0.437
	Range	11.0–12.7	2.64–3.06	0.423–0.477
T. dicoccum: 3686, 4013, 12213, 12214, 41024	Average	14.1	2.43	0.438
	Range	13.4–14.6	1.91–2.60	0.357–0.472
T. sphaerococcum: 4529, 4923, 9054, 115818, 182115	Average	14.9	2.46	0.472
	Range	12.8–16.1	2.40–2.54	0.410–0.519
T. spelta: 1772, 168682, 192724, 272574, 272577	Average	11.8	2.90	0.433
	Range	9.9–13.5	2.62–3.21	0.407–0.480
T. macha: 140191, 190923, 272554, 272555	Average	11.2	2.89	0.410
	Range	9.2–14.1	2.52–3.31	0.359–0.459
T. vavilovi: 272598		8.6	3.01	0.329

[a]U.S. Department of Agriculture, World Collection of Small Grains.

[b]3.20 g. lysine per 16 g. N at a protein content of 18.5%.

contrast to our results on *T. sphaerococcum* (Table VI), they found several high-protein (16%) varieties of the species to be relatively high in lysine (average 3.0 g. per 16 g. N in protein); the five varieties of the same species that we examined were no higher than the bread or durum wheats.

The variation of lysine content between species and within a species appeared to be moderately high. The lowest lysine found in the protein of wheat species was 1.91 g. per 16 g. N in the variety No. 12213 (14.7% protein) of the *T. dicoccum* species (Table VI) and the highest 3.64 g. per 16 g. N in variety No. 94750 (11.0%

TABLE VII. LYSINE CONTENT OF TRITICUM SPECIES GROWN IN NORTH DAKOTA

Species	Protein %	Lysine	
		In Protein g./16 g. N	In Sample %
T. boeoticum			
(v. Larionowii)	15.3	2.42	0.472
(v. Pancii)	18.2	2.18	0.507
T. monococcum			
(61-B-2601)	13.8	2.78	0.491
T. dicoccoides			
(v. Aarushnii)	18.6	2.10	0.500
(v. Pseudorufavillosum)	17.5	2.18	0.489
(v. Yaroslove)	12.4	2.56	0.404
T. dicoccum			
(v. Khapli)	16.2	2.40	0.498
T. polonicum	16.1	2.26	0.466
T. turgidum			
(v. Lusitanicum)	11.4	2.51	0.365
T. orientale			
(4B-236)	14.1	2.46	0.440
(4B-237)	14.7	2.34	0.441
T. pyramidale			
(4B-258)	15.4	2.14	0.419
(4B-265)	17.2	2.32	0.509
T. timopheevi			
(v. Wanatahe)	11.6	2.41	0.356
(v. Typicum)	14.3	2.40	0.439
(v. Typicum)	11.7	2.57	0.383
(v. Nigrum)	10.3	2.49	0.329
T. zhukovuskyi	24.2	2.26	0.699
T. zhukovuskyi	19.1	2.62	0.636
T. paleocolchicum	14.3	2.30	0.419

protein) of the *T. carthlicum* species (Table VI). Comparison of the lysine in the same species found in both Tables VI and VII and the lysine content of each variety of a species showed relatively high variation of lysine content within most of the species. For data on each variety of the species listed in Table VI, consult reference 15.

Triticum Amphiploids. Several available hybrids of wheat were analyzed to see if these synthetic wheats might be outstanding in lysine content. As shown in Table VIII, only the last synthetic species from *T. dicoccoides, T. durum*, and *S. cereale* was a little higher in lysine than common and durum wheat.

Secale Species. Rye belongs to the genus *Secale*, which is closely related to *Triticum*. This cereal can be crossed with wheat to form hybrids of potential use in agriculture. Also, rye protein is reported to have better nutritional quality than

TABLE VIII. LYSINE CONTENT OF WHEAT AMPHIPLOIDS GROWN IN NORTH DAKOTA

Species	Protein %	Lysine	
		In Protein g./16 g. N	In Sample %
T. timopheevi X Aegilops squarrosa[2]	16.9	2.15	0.465
T. timopheevi X T. durum[2]	20.1	2.39	0.613
T. timopheevi X T. polonicum[2]	16.8	2.13	0.457
T. timopheevi X T. pyramidale[2]	17.1	2.41	0.525
T. dicoccoides X S. cereale[2] X T. durum "Stewart" X S. cereale[2]	16.6	2.64	0.559

wheat protein (6). To obtain more information on the lysine content of rye, a number of varieties were analyzed. Analyses were made on 125 rye varieties; because of the large number of tests, the results on only 20 of the samples, typical of the total, are presented in Table IX.

The lysine content varied from 2.55 to 4.26 g. per 16 g. N in the protein with a mean of 3.39 g. per 16 g. N. The protein content varied from 6.2 to 17.7% with a mean of 12.4%. Lysine content in the protein was significantly correlated with protein content of rye ($r = -0.69$). Whereas the lysine content was higher than found in spring and durum wheats, the protein content was lower. There are, however, a number of varieties having high lysine and relatively high protein content. These are Explorer, USDA PI 168178, Rye Gator, Detenicke, and *Secale*

TABLE IX. LYSINE CONTENT OF RYE SPECIES AND VARIETIES

Variety and/or Species	Protein %	Lysine	
		In Protein g./16 g. N	In Sample %
Antelope	11.4	3.33	0.443
Carsten	9.2	3.65	0.392
Secale dalmaticum CPI 22755	16.5	3.23	0.621
Explorer[a]	14.1	3.30	0.542
USDA PI 168178[a]	14.6	3.22	0.549
USDA PI 227870	10.5	3.71	0.453
Rye Gator[a]	17.3	3.21	0.649
Prolific Spring	14.9	3.25	0.563
Balbo	11.2	3.63	0.474
Detenicke[a]	16.0	3.37	0.628
Secale cereale 5-SC-18	12.8	3.22	0.482
Rye Korean I	15.3	3.05	0.544
Dominant	11.0	3.80	0.489
Volyanko	11.9	2.91	0.400
Afganistan Winter Rye	10.4	3.35	0.405
Canadian Spring Rye	9.2	3.71	0.397
Secale montanum[a] 23-282	16.9	3.10	0.611
Secale segetale 23709	17.2	3.02	0.604
Abruzzi A	9.9	2.55	0.292
Maia barroso (5053)	10.6	4.26	0.524

[a]Ryes with relatively high lysine and protein.

Montanum 23-282 (Table IX) as well as a number of others not shown in Table IX (see ref. 15 for complete list). Thus, a number of ryes appear to be outstanding because of high protein that is relatively rich in lysine.

Triticale. This synthetic cereal species is a cross of *Triticum* with *Secale.* Hexaploid triticale is reported to be a potential cereal crop that may give high yields of high-protein grain (16). Although this triticale has relatively poor baking quality, it may have potential in other food or feed uses.

Since rye protein was higher in lysine than durum, the lysine content of hexaploid and octaploid hybrids of these 2 grass species, *Secale* and *Triticum*, would be of interest. Analyses on 25 varieties or crosses are given in Table X. In 15 of these, two to eight plant or spike selections were analyzed, but only the average results on each variety or cross are given here (see ref. 15 for complete data). The lysine content of the protein varied from 2.32 (selection of 6A 250 X 6A 190) to 3.42 g. per 16 g. N (selection of 6A 250 X 6A 191) with a mean of 2.96 g. per 16 g. N. The protein varied from 10.1 to 19.3% with a mean of 15.0%. Triticale protein, in general, was found to be higher in lysine than common or durum wheats but not quite as high as rye protein. This agrees with the results of Fox and DeFontaine (17) who analyzed one triticale and its rye and wheat parents. Lysine content in the protein was significantly correlated with protein content of triticale ($r = -0.50$).

TABLE X. LYSINE CONTENT OF TRITICALES[a]

Variety or Cross	Average Protein %	Average Lysine In Protein g./16 g. N	Average Lysine In Sample %
1593A X 1620	14.7	3.08	0.577
1593B	15.1	3.08	0.594
1593C	16.4	3.06	0.641
1593D	14.3	3.26	0.589
1594A	16.2	2.98	0.615
1594A X 1601	15.8	3.11	0.627
1594A X 1613	16.6	3.35	0.711
1594A X 1628A	14.5	3.02	0.559
1605	14.6	2.89	0.539
1609B X 1636	16.6	2.92	0.618
1636A	13.9	3.25	0.578
1636A X 1614	15.0	3.08	0.590
1636C	14.3	3.02	0.556
1636C X 1642	14.5	3.04	0.563
1637C	16.0	2.92	0.597
1641A	12.8	3.12	0.507
1641B	13.1	3.04	0.509
1641D	13.8	3.21	0.565
6A 250 X 6A 190[b]	16.1	2.73	0.557
6A 250 X 6A 191[c]	13.3	2.94	0.496
My 64 X Triticale	17.0	2.75	0.595
Triticale S-112	13.8	2.72	0.479
Triticale 6913	18.5	2.71	0.639
Triticale 100C-132-1	14.7	2.84	0.563
6A 250 (6A66.12 X 6A20)	15.0	2.82	0.540

[a]Average lysine and protein content of selections from each variety or cross.

[b]One selection contained the low of 2.32 g. lysine per 16 g. N in the protein.

[c]One selection contained the high of 3.42 g. lysine per 16 g. N in the protein.

Comparison of Wheat, Rye, and Triticale at Equal Protein Contents

The lysine contents of these cereals are difficult to compare because the lysine varies with the protein content. For this reason, the regression equation for lysine in protein vs. protein content was used first to estimate the over-all lysine content at 13.5 and 17.2% protein, and second, the variability of lysine content for each cereal. The results are given in Tables XI and XII.

A protein content of 13.5 and 17.2% (20% d.b.) was chosen because 13.5% protein is considered fairly high protein for wheat and 17.2% the maximum recommended in protein-enriched foods by USDA (18). As shown in Table XI, the proteins of spring and durum wheats at equal protein contents are estimated to be almost equal in lysine content, whereas triticale and rye are, respectively, about 20 and 30% higher than the spring and durum wheat. If a N-to-protein conversion factor of 5.73, which is the average reported by Jones (19) and Tkachuk (20), is used, rye protein is about 35% higher.

The lysine content in the protein for varieties of each cereal was recalculated to give the estimated amount that should have been observed if the grain had been at a 15% protein level. This was done by adding or subtracting from the observed value the product of the regression equation slope for each cereal times the difference in protein from a 15% level. The standard deviation for each cereal was determined from the recalculated values. As seen in Table XII, spring wheat was found, from the calculations, to be the least variable, rye and triticale the most, and durum wheat intermediate between the other cereals. The influence of climatic conditions cannot be ascertained on the spring and durum wheats and ryes because they were not grown in one location. On the other hand, the variation in the triticales appears to be due to varietal difference, since they were all grown in one location. For this reason one might suspect that much of the variation in the spring durum wheats and ryes also is due to varietal differences.

TABLE XI. ESTIMATED LYSINE CONTENT OF WHEAT, RYE, AND TRITICALE AT 13.5 AND 17.2% PROTEIN

Cereal	Lysine per 16 g. N in Protein	
	13.5% Protein g.	17.2% Protein g.
Spring wheat	2.49	2.36
Durum wheat	2.51	2.26
Rye	3.30 (3.39)[a]	3.01 (3.11)[a]
Triticale	3.06	2.81

[a]Estimated value when a N-to-protein factor of 5.73 is used.

TABLE XII. VARIABILITY OF THE ESTIMATED LYSINE CONTENT AT 15% PROTEIN LEVEL IN WHEAT, RYE, AND TRITICALE

Cereal	Standard Deviation as Lysine per 16 g. N in Protein g.
Spring wheat	0.13
Durum wheat	0.17
Rye	0.24
Triticale	0.21

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