Variability in the Limiting Amino Acid and Fatty Acid Composition of Winter Wheats and Triticales

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The protein contents and amino acid and fatty acid compositions of winter wheat and triticale cultivars, grown at several locations in the high altitude region, were determined. Protein contents varied considerably depending on location. However, in all but one instance the triticales produced grain protein contents higher than those of the wheats. The average lysine content of spring triticales has been reported to be higher than that of wheat. In this study, the lysine content of winter triticales grown at high altitudes, however, did not exceed the lysine content of the control winter wheat. The threonine content of the Colorado grown triticales was higher compared to wheat as has been reported with spring triticales. Total fatty acid profiles showed only minor differences in overall composition as influenced by cultivar, location, and milling. Triticales had higher unsaturated fatty acid levels than wheats but lower levels of short-chain fatty acids. It was concluded that the effects of altitude and location had a more pronounced influence on total protein and amino acid content than on fatty acid composition.

Triticale is a man-made cereal grain developed from hybridization of wheat and rye. Its grain protein content is often higher than that of wheat (Villegas et al., 1968; Qualset et al., 1969; Lorenz, 1972). In studies by Chen and Bushuk (1969) the amino acid composition of triticale was found to be intermediate between that of wheat and rye. Villegas et al. (1968), however, reported that lysine content was higher than observed in bread wheats.

A comparison of the composition of fatty acids in wheat and triticale flours by Lorenz and Maga (1972) showed that these compositions are quite similar qualitatively but different quantitatively. Chung and Tsen (1974), however, pointed out that the amount of lipid components depends largely on the type of triticale grain and on the location at which it was grown, while the lipid composition of endosperm flours also seems to be affected by the efficiency of the milling operation.

Triticale milling fractions have been used for the production of breads (Lorenz, 1972), cakes and cookies (Kissell and Lorenz, 1974), pasta products (Lorenz et al., 1972), and extruded breakfast cereals (Lorenz et al., 1974).

A comparison of the protein nutritive value of wheat and triticale grain for adult humans indicated a higher value for the triticale (Kies and Fox, 1970a,b).

Yields of triticale, however, vary considerably. In a comparison of the 1972–1973 yields of triticale with that of wheat, Lebsock (1974) reports values for triticale ranging from 15% up to 446% of the yield of wheat. Unfortunately, the growing conditions, climates, and fertilizer applications, which resulted in some of these high yields, are not given. Generally, however, average triticale yields appear to be about 75% of the yields of wheat.

In a study by Ruckman et al. (1973), in which several varieties of spring triticale and spring wheat were grown side by side at several California locations, the triticales had a lower yield, but a higher protein and lysine content expressed on an 8% moisture basis. However, expressing protein and lysine on a yield per acre basis, the wheat varieties outperformed the triticales in protein while lysine contents were comparable.

Since location, climate, growing conditions, fertilizer application, irrigation, and other factors seem to affect triticale yields, protein and lysine contents, and also lipid composition considerably, this study of the effects of growing winter triticale in the high altitude region of the U.S. on the limiting amino acid and fatty acid composition was undertaken. Such information is needed by the plant breeder to provide a basis for selection and by the nutritionist to realize that there are differences in nutritional quality of cereals caused by environmental and genetic relationships.

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MATERIALS AND METHODS

Description of Samples. In comparisons among the hard red winter wheat cultivars, Scout and Lancer, and triticale 131, one irrigated and five dryland locations were utilized (experiment 1). The dryland locations were Akron, Julesburg, Burlington, Springfield, and Nunn, Colo. These locations represent a wide range of temperature, wind, and moisture conditions in the high altitude (approximately 4000 ft) section of the Great Plains. Fort Collins is an irrigated high production potential site at an altitude of 4900 ft. Seed development is consistently good at this site.

The two triticales 385 and 386 were compared in experiment 2 with the hard red winter wheat cultivar Centurk at the two dryland locations of Akron and Springfield. Both experiments were conducted in 1973.

Five pounds of grain was milled from each location for each cultivar. The individual samples were obtained by compositing equal amounts from each of four reps at each location. The triticales were tempered to 14% moisture and the wheats to 15% for 18 hr and milled on a Brabender Quadrumat Sr. mill.

Proximate Analyses. Moisture and ash were determined by AOAC (1960) procedures and whole grain and flour protein contents by the standard Udy Protein Analyzer method (AACC, 1962).

Amino Acid Analysis. (*a*) *Hydrolysis of Samples.* The amino acid composition of the grains and of the flours was determined by gas–liquid chromatography (GLC). One gram of each of the grains and the flours was placed in hydrolysis tubes. Twenty-five milliliters of 6 *N* HCl was added and the tubes were flushed with nitrogen and closed. The samples were heated in a boiling water bath for 12 hr, transferred to 25-ml volumetric flasks, and brought to volume with 0.1 *N* HCl.

(*b*) *Isolation of Amino Acids.* Columns (2 × 7 cm) of Amberlite CG-200-H (80–100 mesh) resin were prepared. The Amberlite resin was soaked overnight in 1 *N* HCl to convert it to the hydrogen form. The 25 ml of hydrolysates was passed through the columns at a rate of 1–2 ml/min. Five (5–10 ml) portions of distilled water were used to wash the resin after the hydrolysates had passed through. The effluents and washings were discarded. The amino acids

Table I. Wheats; 1973 Yields, Test Weights, and Milling Data

Cultivar	Colo. location	Yield, bushel/acre	Test wt, lb/bushel	Grain moisture, %	Flour[a] extraction, %	Bran,[a] %	Shorts,[a] %
Centurk	Akron	40.4	59.9	11.8	63.2	27.6	8.0
	Springfield	40.4	50.4	11.1	64.2	28.1	6.6
Scout	Akron	38.2	61.1	11.1	68.0	24.8	5.9
	Burlington	44.7	61.0	10.6	66.0	26.7	6.3
	Springfield	39.0	53.1	10.7	65.4	27.7	5.2
	Fort Collins[b]	110.6	59.9	10.8	66.3	25.3	7.0
	Julesburg	39.8	57.7	10.2	66.3	26.7	6.0
	Nunn	39.2	58.3	11.1	68.8	25.7	4.4
Lancer	Akron	46.0	61.2	10.9	69.4	24.2	5.4
	Burlington	39.6	60.0	10.4	66.5	26.2	6.2
	Springfield	30.0	54.9	11.0	65.2	26.7	7.0
	Fort Collins[b]	106.6	59.5	10.8	73.0	22.0	3.9
	Julesburg	37.9	55.5	9.9	63.8	28.1	7.1
	Nunn	42.1	59.6	10.9	68.1	25.9	5.3

[a] Quadrumat Senior Mill. Wheats tempered to 15% H_2O. [b] Irrigated.

Table II. Triticales; 1973 Yields, Test Weights, and Milling Data

Cultivar	Colo. location	Yield, bushel/acre	Test wt, lb/bushel	Grain moisture, %	Flour[a] extraction, %	Bran,[a] %	Shorts,[a] %
TR 385	Akron	27.6	45.4	10.3	55.7	33.8	9.2
	Springfield	26.8	40.1	10.2	52.3	36.3	10.2
TR 386	Akron	29.4	45.4	10.2	55.0	34.0	9.3
	Springfield	27.3	40.8	10.2	52.3	35.9	10.6
TR 131	Akron	32.0	44.1	10.4	45.6	42.3	10.5
	Burlington	28.0	42.8	9.7	47.4	42.0	8.9
	Springfield	28.1	41.0	10.6	46.2	40.7	11.2
	Fort Collins[b]	89.4	47.1	10.3	50.3	37.4	11.2
	Julesburg	32.9	44.8	9.2	44.7	42.7	10.8
	Nunn	32.4	41.6	9.6	45.0	42.5	10.5

[a] Quadrumat Senior Mill. Triticales tempered to 14% H_2O. [b] Irrigated.

were eluted from the resin with 2–5 ml portions of 3 *N* NH_4OH at a flow rate of 1–2 ml/min followed by 2–10 ml portions of distilled water at 3 ml/min.

The eluted volume was adjusted to 50 ml and a 2-ml aliquot was used for GLC analysis. The aliquot was pipetted into a 10-ml Teflon capped reaction tube (16 × 75 mm) and freeze-dried.

(*c*) *Derivatization.* To the reaction tube was added 0.5 ml of 3 *N* HCl in *n*-BuOH, which was then mixed on an ultrasonic mixer for 15 sec and esterified for 15 min at 100°. The excess butanolic HCl was evaporated from the sample by blowing dry nitrogen over the sample, which was maintained at 50° in a heating block.

One milliliter of anhydrous, redistilled dichloromethane and 0.3 ml of trifluoroacetic acid were added to each tube. The tubes were capped tightly. Acylation was allowed to proceed for 5 min at 150°. The procedure was carried out utilizing a heating block behind a safety shield.

(*d*) *GLC Conditions.* Ethylene glycol adipate was coated on 80–100 mesh acid-washed Chromosorb W, which had been dried at 140° for 12 hr as described by Roach and Gehrke (1969). The EGA column material was packed in 2 mm × 6 ft glass columns.

Resolution and identification were accomplished using a Hewlett-Packard Model 5750 gas chromatograph equipped with a dual column hydrogen flame ionization detector. The carrier gas was helium flowing at 30 ml/min. Runs were temperature programmed between 70 and 210° at 5°/min. The sample size was 2 μl.

Fatty Acid Analysis. (*a*) *Lipid Extraction and Derivatization.* The lipids were extracted from 10 g of each of the flours and 3 g of each of the grains using 75 ml of distilled diethyl ether. Extraction was carried out for 8 hr on a Goldfisch fat extractor. The ether extracts were partially evaporated, transferred to small vials, and evaporated to dryness under a stream of nitrogen before derivatization. Fatty acid methyl esters were prepared by the boron trifluoride method as outlined by the AOAC (1970).

(*b*) *GLC Conditions.* Separation of the fatty acid methyl ester mixtures was achieved on a Hewlett-Packard Model 402 flame ionization gas chromatograph equipped with a 6 ft × 4 mm i.d. glass column packed with 10% Silar-10C on 100–120 mesh Gas-Chrom Q. The unit was programmed from 130 to 200° at 1°/min. Both detector and injector temperatures were 250°. Nitrogen at a flow rate of 40 ml/min was used as the carrier. Compound retention times and areas were automatically recorded by means of a Hewlett-Packard Model 3370 B integrator. Standard methyl ester fatty acid mixtures were separated under identical conditions to establish compound identity.

RESULTS AND DISCUSSION

Grain Yield and Test Weight. Grain yields at all dryland locations were quite stable for both the wheats and the triticales (Tables I and II). The wheat cultivars consistently outyielded the triticales at all locations. Test weights were always lower in the triticales than in the wheats. The test weight difference between the two groups ranged between 10 and 15 lb per bushel. Triticales generally produced very shriveled kernel types under moisture stress.

Table III. Protein, Lysine, and Threonine Contents of Grains and Triticales

Cultivar	Colo. location	Grain			Flour		
		Protein,[a] %	Lysine, g/16 g of N	Threonine, g/16 g of N	Protein,[a] %	Lysine, g/16 g of N	Threonine, g/16 g of N
		Experiment 1					
Wheats							
Scout	Akron	11.3		2.85	9.8	2.06	2.59
	Burlington	11.1	2.64	2.64	9.3	1.69	2.13
	Springfield	16.3	2.20	3.47	13.4	1.90	3.25
	Fort Collins[b]	13.4	2.03	2.70	11.4	1.70	2.47
	Julesburg	12.8	2.91	2.93	10.9	1.95	2.76
	Nunn	12.8	2.16	2.48	10.9	1.41	2.05
Lancer	Akron	12.4	2.60	2.76	11.4	2.19	2.70
	Burlington	10.7	2.65	3.05	9.3	1.90	2.76
	Springfield	16.3	2.15	2.73	13.2	1.85	2.79
	Fort Collins[b]	12.7	1.93	3.03	10.6	1.63	2.56
	Julesburg	14.0		2.64	11.3	1.61	1.94
	Nunn	13.0	2.31	3.88	10.6	1.42	3.50
Triticale							
TR 131	Akron	18.8	2.74	3.19	14.3	2.04	2.63
	Burlington	15.0	2.68	3.42	11.9	1.35	3.31
	Springfield	19.7	2.07	3.46	15.8		
	Fort Collins[b]	17.6	2.04	2.76	13.5	1.92	2.22
	Julesburg	17.3	2.70	3.12	14.1	2.32	2.73
	Nunn	18.3	2.32	2.70	13.8	2.14	2.50
		Experiment 2					
Wheat							
Centurk	Akron	9.9	2.51	3.31	7.9		
	Springfield	17.3	2.60	2.45	13.8		
Triticale							
TR 385	Akron	12.8	2.02	2.86	10.4	1.82	2.11
	Springfield	17.1	2.00	2.86	13.5	1.57	2.67
TR 386	Akron	13.1	2.59	3.89	10.5	1.71	3.62
	Springfield	17.2	2.09	2.42	13.9	1.51	2.31

[a] 14% moisture basis. [b] Irrigated.

Table IV. Correlation Coefficients

	Correlation	Expt 1	Expt 2
Wheats	Grain protein vs. lysine content in protein of grain	−0.49	
	Flour protein vs. lysine content in protein of flour	0.39	
	Flour yield vs. lysine content in protein of flour	−0.25	
Triticales	Grain protein vs. lysine content in protein of grain	−0.25	−0.47
	Flour protein vs. lysine content in protein of flour	0.53	−0.87
	Flour yield vs. lysine content in protein of flour	−0.25	−0.96

The best triticale test weight recorded was under irrigation at Fort Collins. This location also produced the highest yields of both wheats and triticales.

Flour Extraction. Flour yields of the wheat samples and the triticales are presented in Tables I and II. Flour yields of the triticales were considerable lower than those obtained for the wheats, which confirms results previously reported by Lorenz (1972). This is due mainly to the differences in kernel characteristics of the grains. The flour yields of the wheat cultivar Scout ranged from 65.4% for the sample grown at Springfield to 68.8% for the sample from Nunn. Lancer produced a flour yield range from 63.8% at Julesburg to 73.0% at Fort Collins. Triticale TR131, which was the only variety grown at the six locations in Colorado, ranged from a flour yield of 44.7% for the Julesburg sample to 50.3% for the sample grown in Fort Collins.

Protein Content. Protein content varied considerably depending on the locations at which the samples were grown. This was true for the wheats as well as for the triticales as seen in Table III.

The grain protein varied from a low of 11.1% at Burlington to a high of 16.3% at Springfield. Lancer varied in protein content from 10.7 to 16.3%, the lowest protein Lancer being harvested in Burlington and the highest protein sample coming, again, from Springfield.

The TR131 triticales, which were grown on plots adjacent to the wheats at the six Colorado locations, invariably produced grain protein contents higher than those of the wheats. The Springfield and Burlington locations again showed the highest (19.7%) and lowest (15.0%) protein contents, respectively.

Kernel development as indicated by test weight is a major consideration in grain production. Test weight is quite sensitive to environmental conditions and will reflect specific moisture and temperature stresses at the time of kernel development. The triticales measured in this experiment all had significantly lower test weights than the wheats.

Flour protein content depends on flour yields. Since these yields were considerably higher for the wheats than for the triticales, the triticales suffered a greater average

Table V. Fatty Acid Composition, as Percentage of Total GLC Composition, of Grain from Two Wheat and Triticale Cultivars Grown at Akron, Colorado

	Wheat				Triticale			
	Scout		Lancer		TR 131		TR 385	
Fatty acid	Grain	Flour	Grain	Flour	Grain	Flour	Grain	Flour
C_{8}	1.2	1.0	1.5	1.3	1.2	1.0	1.0	1.5
C_{10}	1.5	1.4	1.5	1.6	1.3	1.4	1.7	1.3
C_{11}	0.5	0.5	0.4	0.3	0.4	0.5	0.2	0.3
C_{12}	1.7	1.5	1.1	0.7	1.3	1.0	1.5	1.3
C_{13}	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
C_{iso-14}	0.5	0.5	0.4	0.5	0.3	0.3	0.3	0.3
C_{14}	2.0	2.0	1.5	1.4	1.4	1.1	1.0	0.9
$C_{14:1}$	0.6	0.6	0.5	0.5	1.0	1.4	0.5	0.8
C_{15}	0.6	0.6	0.6	0.5	0.8	1.1	0.5	0.9
C_{iso-16}	0.5	0.6	0.5	0.6	0.8	1.0	0.5	0.6
C_{16}	18.3	18.7	17.9	18.5	17.0	16.5	16.7	16.1
$C_{16:1}$	1.4	1.5	1.1	1.4	1.5	1.9	0.9	1.3
C_{18}	1.4	1.5	1.1	1.2	1.2	1.0	1.1	0.7
$C_{18:1}$	8.4	8.0	8.3	8.2	8.4	8.0	9.3	9.0
$C_{18:2}$	56.0	55.8	58.6	57.8	57.9	58.3	58.3	58.4
$C_{18:3}$	3.4	3.6	3.1	3.5	4.0	3.7	4.2	3.9
C_{20}	1.5	1.7	1.4	1.5	1.2	1.5	2.0	2.4

Table VI. Fatty Acid Composition, as Percentage of Total GLC Composition, of Wheat (Scout), and Triticale (TR 131) Grain Grown at Different Locations

	Wheat (Scout) at location						Triticale (TR 131) at location					
Fatty acid	Akron	Bur-lington	Spring-field	Ft. Collins	Jules-burg	Nunn	Akron	Bur-lington	Spring-field	Ft. Collins	Jules-burg	Nunn
C_{8}	1.2	1.1	1.3	1.2	1.3	1.0	1.2	1.3	1.2	1.0	1.1	1.0
C_{10}	1.5	1.5	1.4	1.4	1.5	1.5	1.3	1.4	1.6	1.5	1.3	1.2
C_{11}	0.5	0.5	0.5	0.4	0.4	0.5	0.4	0.3	0.4	0.3	0.5	0.4
C_{12}	1.7	1.4	1.7	1.5	1.6	1.3	1.3	1.4	1.5	1.6	1.5	1.6
C_{13}	0.5	0.5	0.5	0.4	0.5	0.5	0.3	0.3	0.3	0.2	0.3	0.3
C_{iso-14}	0.5	0.5	0.4	0.5	0.5	0.6	0.3	0.2	0.3	0.3	0.3	0.3
C_{14}	2.0	1.6	1.6	1.8	1.7	1.6	1.4	1.5	1.4	1.6	1.8	1.5
$C_{14:1}$	0.6	0.6	0.8	0.6	0.5	0.5	1.0	0.9	1.0	0.8	0.9	1.0
C_{15}	0.6	0.6	0.6	0.5	0.6	0.5	0.8	0.8	0.8	0.7	0.8	0.5
C_{iso-16}	0.5	0.6	0.5	0.6	0.6	0.4	0.8	0.7	0.7	0.8	0.7	0.9
C_{16}	18.3	18.3	18.2	18.1	17.8	18.2	17.0	17.1	17.0	17.4	17.6	17.2
$C_{16:1}$	1.4	1.3	1.4	1.2	1.3	1.0	1.5	1.6	1.5	1.4	1.5	1.5
C_{18}	1.4	1.2	1.1	1.3	1.3	1.5	1.2	1.3	1.4	1.6	1.3	1.9
$C_{18:1}$	8.4	8.5	8.2	8.3	8.5	8.5	8.4	8.5	9.0	8.7	8.5	8.9
$C_{18:2}$	56.0	57.2	57.3	57.6	57.4	57.8	57.9	57.8	56.8	57.1	56.8	57.0
$C_{18:3}$	3.4	3.4	3.0	3.2	3.0	3.1	4.0	3.5	3.5	3.8	3.7	3.5
C_{20}	1.5	1.2	1.5	1.4	1.5	1.5	1.2	1.4	1.5	1.2	1.4	1.0

protein loss (3.5%) than the wheats (2.2%) milling the grains into flour. However, even with the greater protein losses in milling the grain into flour, the TR131 flours were higher in protein than the flours milled from the Scout and Lancer controls grown in the same location.

Lysine Content. The amino acid composition of dietary protein is a major determinant of the ability of that protein to support growth and maintenance in man and animals. Since the biological value of a protein, especially in relation to growth needs, depends on the proportion of the most limiting amino acid(s) in the protein, this value can be improved by reducing the deficit in supply of the limiting amino acids.

Lysine is the first limiting amino acid in wheat and threonine is considered to be the second limiting amino acid (Jansen, 1974; Ahmed and McDonald, 1974). These are the two amino acids considered in this paper, even though complete amino acid patterns of all wheats and triticales were determined. The other amino acids, besides lysine and threonine, are simply of minor importance and would only fill rather lengthy and unnecessary tables. The data are available upon request.

Lysine data have been published by Villegas et al. (1968, 1970) for 25 triticale varieties or crosses developed at the University of Manitoba. Ruckman et al. (1973) reported lysine contents of several California-grown triticale varieties. All these varieties were spring varieties and they were higher in lysine than hard red spring wheats.

This study was conducted with winter varieties. Lysine data of the triticales and the wheat controls are presented in Table III. In experiment 1, lysine values for the triticale grains ranged from 2.04 g/16 g of N to 2.74 g/16 g of N with

Table VII. Unsaturated, Short-Chain, and Odd-Chain Fatty Acid Compositions, as Percentage of Total GLC Composition, of Wheat and Triticale Cultivars

Cultivar	Location	% unsaturated fatty acid[a]		% short-chain fatty acid[b]		% odd-chain fatty acid[c]	
		Grain	Flour	Grain	Flour	Grain	Flour
Scout	Akron	69.8	69.5	8.5	8.0	1.6	1.6
	Burlington	71.0	70.9	7.7	7.2	1.6	1.6
	Springfield	70.8	70.7	8.2	6.7	1.6	1.5
	Ft. Collins	70.9	71.2	7.8	6.6	1.3	1.4
	Julesburg	70.7	71.4	8.0	7.0	1.5	1.5
	Nunn	70.9	70.6	7.5	6.7	1.5	1.7
All location av		70.7	70.7	8.0	7.0	1.5	1.6
Akron–Springfield av		70.3	70.1	8.3	7.3	1.6	1.5
Lancer	Akron	71.6	71.4	7.4	6.8	1.5	1.3
	Burlington	70.7	70.5	8.0	7.0	1.6	1.6
	Springfield	71.1	71.5	7.5	6.7	1.5	1.6
	Ft. Collins	71.3	71.1	7.5	6.9	1.5	1.6
	Julesburg	70.8	71.2	7.8	6.6	1.7	1.6
	Nunn	70.1	70.5	7.9	7.3	1.6	1.5
All location av		70.9	71.0	7.7	6.9	1.6	1.5
Akron–Springfield av		71.4	71.4	7.4	6.7	1.5	1.4
TR 131	Akron	72.8	73.3	7.2	7.0	1.5	1.9
	Burlington	72.3	73.9	7.3	7.3	1.4	1.6
	Springfield	71.8		7.7		1.5	
	Ft. Collins	71.8	71.7	7.3	7.1	1.2	1.6
	Julesburg	71.4	71.3	7.7	7.3	1.6	1.7
	Nunn	71.9	73.1	7.3	7.0	1.2	1.4
All location av		72.0	72.4	7.4	7.1	1.4	1.6
Akron–Springfield av		72.3	73.3	7.5	7.0	1.5	1.9
TR 385	Akron	73.2	73.4	6.5	6.7	1.0	1.5
	Springfield	73.7	74.9	6.5	6.5	0.8	1.1
Av		73.4	74.1	6.5	6.6	0.9	1.3
TR 386	Akron	73.3	74.1	6.2	5.9	1.1	1.3
	Springfield	73.9	75.7	6.4	5.9	1.0	1.0
Av		73.6	74.9	6.3	5.9	1.0	1.1

[a] $C_{14:1}$, $C_{16:1}$, $C_{18:1}$, $C_{18:2}$, $C_{18:3}$. [b] C_8, C_{10}, C_{11}, C_{12}, C_{13}, C_{iso-14}, C_{14}, $C_{14:1}$. [c] C_{11}, C_{13}, C_{15}.

a mean of 2.33 g/16 g of N. The wheat controls Scout and Lancer produced an average lysine content of 2.39 g/16 g of N. Individual lysine values varied considerably depending upon variety and location, which has also been shown in the studies of Villegas et al. (1968, 1970) and Ruckman et al. (1973). In experiment 2, the triticale grain proteins had an average lysine content of 2.18 g/16 g of N while the wheat showed a value of 2.55 g/16 g of N.

This indicates clearly that winter triticales (TR131, TR385, and TR386), grown at relatively high elevations in Colorado, do not show a lysine advantage, as has been shown with spring triticales in studies by Villegas et al. (1968, 1970). On the basis of lysine content of protein, Ruckman et al. (1973) reported a lysine advantage of triticales, but on the basis of lysine yield per acre, there was no advantage.

Lysine values of flour proteins from the wheat and triticale grains likewise did not show any significant differences, as would be expected. Average values were 1.76/16 g of N and 1.82 g/16 g of N for the wheat and triticale flours, respectively.

Villegas et al. (1970) reported that the lysine content in protein of triticale is inversely related with protein content ($r = -0.50$). Colorado-grown winter triticales also showed a negative correlation as seen in Table IV. In experiment 1, the correlation coefficient was −0.25, while in experiment 2, this coefficient was −0.47. A negative correlation between lysine content in protein of wheat and protein content, as found in this study ($r = -0.49$), has been reported by many research workers (Larsen and Nielsen, 1966; Chopra and Sidhu, 1967; Deosthale et al., 1969; Villegas et al., 1968, 1970).

In experiment 1, there were no significant correlations between flour protein and lysine content of the flour and between flour extraction and lysine content of the flour for both the wheats and the triticales. In experiment 2, these correlations between triticale flour protein and lysine content ($r = -0.87$) and between triticale flour extraction and lysine content ($r = -0.96$), however, were highly significant as seen in Table IV. The correlation coefficient for the wheat in experiment 2 could not be calculated, since only one variety (Century) was planted at only two locations.

The difference in the significance of the correlations between experiments 1 and 2 is due to the considerable differences in triticale flour extraction rates, shown in Table II. While in experiment 2 the flour extraction rates for varieties TR385 and TR386 averaged 53.8%, this value was only 46.5% for variety TR131 in experiment 1.

Threonine Content. Threonine values for wheat and triticale grains and flours by Chen and Bushuk (1969), Bushuk (1974), and Ahmed and McDonald (1974) indicate a higher threonine content in triticale compared with wheat. This trend has also been observed with winter wheat and triticale varieties grown in Colorado.

Threonine data of the Colorado-grown samples are presented in Table III. Threonine values varied considerably depending upon variety and location, as did the lysine values. In experiment 1, threonine values for the triticale grains ranged from 2.70 g/16 g of N to 3.46 g/16 g of N with a mean of 3.11 g/16 g of N. The wheat varieties Scout and

Lancer produced an average threonine value of 2.93 g/16 g of N. In experiment 2, the triticale grain protein had an average threonine content of 3.01 g/16 g of N, while the wheat showed a value of 2.88 g/16 g of N.

There were, however, no differences in the average threonine contents of the flours milled from these grains (triticale flour, 2.68/16 g of N; wheat flour, 2.62 g/16 g of N). This is due to the tremendous difference in average flour extraction (66.7% vs. 49.5%) between wheat and triticale, caused by the shriveled condition of the triticale kernels.

While average lysine contents of Colorado-grown winter triticales did not exceed the lysine contents of the control winter wheat, average threonine contents of the triticales did exceed those of the wheat varieties, as has been reported with spring triticales.

Fatty Acid Composition. A total of 17 fatty acids were identified and measured in this study. Included in these were several odd-chain fatty acids (C_{11}, C_{13}, C_{15}), the presence of which had been reported previously in wheat and triticale by Lorenz and Maga (1972) and in rye by Klyushkina et al. (1970). In addition, several previously unreported branched-chain fatty acids ($C_{iso\text{-}14}$, $C_{iso\text{-}16}$) were detected in both wheat and triticale. Previously, branched C_{12} and C_{13} fatty acids had been reported in wheat by Pomeranz (1971). The efficiency of the gas chromatographic coating material (Silar-10C) used in this study resulted in a relatively effective fatty acid separation.

Grain fatty acid composition data for typical wheat and triticale cultivars grown at the same location are given in Table V. As can be seen, no significant difference in fatty acid composition was apparent among the two wheat cultivars or triticale cultivars nor was there any significant difference between wheat and triticale. Overall, the triticale cultivars were slightly lower in stearic acid than the wheats. The opposite was found to be true for spring wheat and triticale samples (Lorenz and Maga, 1972). Also, the major fatty acid, linolenic acid, was slightly higher in the triticale samples.

Milling only produced minor differences in fatty acid composition (Table V). In the case of wheat the relative amount of linolenic acid decreased slightly in going from grain to flour whereas in the case of triticale no change was noted.

From viewing data typical of the study (Table VI) it is apparent that surprisingly few differences in fatty acid composition were noted as influenced by location. For example, for the wheat variety Scout, linolenic grain fatty acid composition only varied from a low of 56.0% to a high of 57.8%. For triticale TR131 linolenic grain fatty acid composition ranged from 56.8 to 57.9%. Irrigated samples of both wheat and triticale from the Fort Collins station were not significantly different in fatty acid composition from the other nonirrigated samples.

Although overall fatty acid compositions did not appear to be different, an effort was made to more closely examine fatty acid data. For example, the relative amounts of unsaturated fatty acids were calculated and summarized in Table VII. Thus, more obvious differences in fatty acid composition became apparent. Wheat grain unsaturated fatty acid composition averaged 70.7% for Scout grown over the six locations and 70.9% for the wheat cultivar Lancer. However, all triticale cultivars grown at the same locations had higher levels of grain unsaturated fatty acids. In the case of TR131 the unsaturated fatty composition averaged 72.0% and even higher levels (73.4 and 73.6%) were found in TR385 and 386.

There were also differences in unsaturated fatty acid levels due to milling (Table VII), especially for the triticale cultivars where higher levels were found in the flour than in the grain. No differences between unsaturated fatty acid amounts in grain or flour were found with the wheats.

Another class of fatty acids, that was calculated independently, was the relative percentage short-chain fatty acids (Table VII). As can be seen, all triticales, but especially TR385 and TR386, were lower in grain short-chain fatty acids than the two wheat cultivars. Milling also influenced short-chain fatty acid levels in most cases. Lower short-chain fatty acid levels were present in the flour, with the triticale cultivars being lower than the wheats.

When only relative percentage odd-chain fatty acids were considered (Table VII), essentially no difference was found when comparing wheat grains and flours. However, in the case of the three triticale cultivars, the level of odd-chain fatty acids was significantly lower in TR385 and 386 when compared to TR131 in both the grains and flours. In comparing wheat and triticale cultivars, triticale cultivars TR385 and 386 were lower in odd-chain fatty acid levels than TR131 and the two wheats. No significant difference was found among TR131 and the two wheats.

The ratios of branched to parent fatty acids were obtained (Table VIII). From these data it is obvious that in the case of $C_{iso\text{-}16}$ the only major difference among all samples is the fact that triticale TR131 was higher than all other grains and flours. With $C_{iso\text{-}14}$ more differences were detected. All triticales were lower in $C_{iso\text{-}14}$ than the wheats and in most cases the flours contained more than the grains.

In addition to the above general comments on fatty acid composition, analysis of variance, least significant difference, and interaction plot calculations were performed on the data presented in Tables VII and VIII. As expected, analysis of variance calculations demonstrated significantly

Table VIII. Branched-Chain Fatty Acid Composition, as Percentage of Total GLC Composition, of Wheat and Triticale Cultivars

Cultivar	Location	% $C_{iso\text{-}14}$ to total C_{14}		% $C_{iso\text{-}16}$ to total C_{16}	
		Grain	Flour	Grain	Flour
Scout	Akron	16.1	16.1	2.5	2.9
	Burlington	18.5	19.2	3.0	2.9
	Springfield	14.3	19.1	2.5	2.4
	Ft. Collins	17.2	18.2	3.0	2.4
	Julesburg	18.5	19.1	3.1	2.4
	Nunn	22.2	26.1	2.0	2.4
All location av		17.8	19.6	2.7	2.6
Akron–Springfield av		15.2	17.6	2.5	2.7
Lancer	Akron	16.7	20.8	2.6	2.9
	Burlington	18.5	19.2	2.5	2.9
	Springfield	16.7	25.0	3.0	2.9
	Ft. Collins	15.4	20.8	2.6	2.4
	Julesburg	15.4	19.1	2.0	2.5
	Nunn	14.8	19.2	3.0	2.4
All location av		16.2	20.6	2.6	2.7
Akron–Springfield		16.7	22.9	2.8	2.9
TR 131	Akron	11.1	16.7	4.2	5.2
	Burlington	7.7	11.1	3.6	3.1
	Springfield	11.1		4.2	
	Ft. Collins	11.1	11.1	4.1	3.6
	Julesburg	10.1	12.9	3.5	3.4
	Nunn	10.7	10.7	4.6	4.1
All location av		10.3	13.9	4.0	3.9
Akron–Springfield av		11.1	16.7	4.2	5.2
TR 385	Akron	16.7	15.0	2.8	3.3
	Springfield	9.5	9.1	2.3	2.8
Av		13.1	12.1	2.5	3.0
TR 386	Akron	12.5	18.8	2.2	2.7
	Springfield	17.7	17.7	2.7	3.2
Av		15.1	18.2	2.5	2.5

different F values when the cultivars Scout and Lancer were compared at six locations to TR-131 in percent unsaturated fatty acid. TR-131 was also significantly different than Scout and Lancer in flour percent short-chain and odd-chain fatty acids. When the analysis of variance test was performed on the above three cultivars with respect to ratio of percent C_{iso-14} to total C_{14}, significant F values were obtained for both grains and flours whereas in the case of the C_{iso-16} ratio to C_{16}, significant differences were only noted for the grains and not the corresponding flours. Analysis of variance calculations of cultivars TR-385 and TR-386 grown at two locations revealed the same significant differences as above. Also, the same significant differences were noted when least significant intervals were calculated and plotted. In addition, interaction plots were prepared that verified that varietal differences were indeed significant but that location was not.

Generally, it can be concluded that, even though there were slight differences in fatty acid composition between the winter wheat and winter triticale cultivars, the effect of location had a more pronounced influence on total protein and amino acid content than on fatty acid composition.

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Chemical and Nutritional Modifications of Sunflower Proteins Due to Alkaline Processing. Formation of Amino Acid Cross-Links and Isomerization of Lysine Residues

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Treatment of sunflower protein isolates with sodium hydroxide reduces their content of cystine, arginine, threonine, serine, isoleucine, and lysine, in agreement with known data from alkaline hydrolysis of proteins. Unusual amino acid residues are formed during these treatments; using ion-exchange chromatography and high-voltage paper electrophoresis, alloisoleucine, ornithine, lysinoalanine, and lanthionine were identified. The presence of the latter two compounds indicates the formation of cross-links in the protein and may explain observed changes in the in vitro proteolytic digestibility. The formation of ornithine and the decrease in arginine content appear to be the best indicators of the severity of the alkaline processing. Severe treatments with sodium hydroxide (>0.2 *M*, 80°, 1 hr) also provoke a marked degree of isomerization of the L-lysine residues into D-lysine, as demonstrated by both enzymatic and microbiological methods of analysis.

Alkaline processing of proteins is increasingly applied in the technological treatments of foods and feeds by solubilization and purification, to destroy toxic contaminants (Screenwasamurthy, 1967), to obtain functional properties, including the formation of textured vegetable protein fibers (*Nutr. Rev.*, 1967).

It is well known that severe alkaline treatments can cause chemical modifications of amino acid residues: destruction of cystine, arginine, threonine, serine, and lysine residues (Mellet, 1968; Blackburn, 1968; Parisot and Derminot, 1970). Formation of new cross-linked compounds also takes place.

The formation of lysinoalanine (LAL) has been demonstrated in acid hydrolysates of various alkali-treated proteins such as lysozyme, keratin, ribonuclease, wool, silk, and soy protein isolate (Bohak, 1964; Patchornick and Sokolovsky, 1964; Corfield and Wood, 1967; Miró and Garcia-Dominguez, 1967; Mellet, 1968; Asquith and Garcia-Dominguez, 1968; De Groot and Slump, 1969; Asquith et al., 1969). LAL was probably formed by the condensation of an ϵ-amino group of a lysine residue with a dehydroalanyl residue, leading to cross-links within or between polypeptide

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