Evaluation of Variation in Mineral Element Concentrations in Wheat Flour and Bran of Different Cultivars[1,2]

C. J. PETERSON, V. A. JOHNSON, and P. J. MATTERN[3]

ABSTRACT

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Flour and bran samples obtained from replicated trials of 27 varieties in the 12th International Winter Wheat Performance Nursery at six locations were analyzed, by energy-dispersive X-ray spectrometry, for concentrations of Mg, P, S, Cl, K, Ca, Mn, Fe, Cu, and Zn. Results indicated that the variation in these mineral element concentrations among genotypes is significant and stable, and may be as large as or larger than variation produced by environmental factors. Mineral element concentrations in flour generally show high, positive genetic correlation with protein content, indicating an added nutritional advantage of high-protein cultivars.

Determination of the appropriate nutrient addition levels for wheat products under the proposed U.S. fortification standards (NAS/NRC 1974) and expanded Canadian optional enrichment program (1978) requires thorough definition of natural nutrient concentrations in grain and flour. In several studies concerning the mineral element composition of wheat grain (Bassiri and Nahapetian 1977, Dikeman et al 1982, El Gindy et al 1957, Kleese et al 1968, Koivistoinen et al 1974, Murphy and Law 1974, Nahapetian and Bassiri 1976, Rasmusson et al 1971, White et al 1981), the importance of environmental and genetic factors affecting variation in mineral element concentrations has been evaluated. Results often have been inconsistent because of differences in production environments and in the degree of genetic diversity of cultivars examined.

Most studies of variation in wheat mineral composition that have examined the influence of genotype and environment have been based on analyses of whole grain. Because bran mineral concentration is much higher than endosperm mineral concentration, whole grain mineral values may be affected by variation in seed size and plumpness through their influence on the ratio of bran to endosperm. Thus, previously reported wide variations in whole-grain mineral concentrations may be due in part to genetic or environmental variation in seed size and configuration. Also, variation in the concentration of an individual mineral element in the endosperm may be relatively independent from variation in bran concentration of the same element. Bran and endosperm mineral elements may be influenced differently by environmental or genetic variation. Vogel et al (1976) found that protein concentration of endosperm was not highly correlated with bran protein concentration.

Analysis techniques for trace mineral determinations in foods have improved greatly in the last two decades, but agreement between laboratories often is poor because of different analytical equipment and procedures. Lorenz et al (1980) compared data from five laboratories that analyzed identical flour samples for Mg, Ca, Fe, and Zn concentrations. Substantial differences in the results occurred, probably because of the assortment of mineral-extraction methods and ashing procedures that can lead to serious losses or contamination. Recent advances in computer technology and high-resolution X-ray detectors have made energy-dispersive X-ray fluorescence spectrometry (EDXRF) a practical, rapid, and sensitive technique for quantitative analysis of mineral elements in biological materials. EDXRF provides the advantage of simultaneous multielement analysis and, because it is a nondestructive technique, losses encountered in chemical methods during dry ashing and acid extractions are avoided. Application of EDXRF to analysis of plant samples by Norrish and Hutton (1977), Hutton and Norrish (1977), Lorenz et al (1974), and Knudsen et al (1981) has shown that the degree of precision is comparable to those expected from other methods of analysis.

Environmental and genetic variation in mineral element concentrations of wheat flour and bran, and the relationships between mineral element concentrations, protein content, and grain yield were evaluated in this study. Application of X-ray fluorescence spectrometry to wheat flour and bran mineral analyses also was investigated.

MATERIALS AND METHODS

Grain from 27 varieties and lines from 14 countries grown in the 12th International Winter Wheat Performance Nursery (IWWPN) in 1980 was studied. Grain samples of the varieties were provided by IWWPN cooperators at Stillwater, OK; Lincoln, NE; Ithaca, NY; Davis, CA; University Park, PA; and Monsheim, West Germany. The nurseries were grown as randomized complete block experiments under dryland conditions at each location except Davis, CA, which was irrigated. Data on cultivar yields and 1,000-kernel weights were provided by the cooperators.

Sample Preparation

Ten-gram samples were tempered to 16% moisture by adding distilled water 24 hr before milling on a Brabender Quadraplex experimental mill. Bran and endosperm were separated by sifting samples on a Strand Shaker for 90 sec at 225 rpm, using U.S. Standard Sieve no. 70 with 210-μm mesh openings. An extraction rate of approximately 60% resulted.

The term "bran" as used in this study refers to all kernel components except the white flour fraction at 60% extraction rate. Bran samples were ground through a 0.5-mm screen in a Udy Cyclone sample mill to provide uniform particle size. Bran and flour samples then were placed in a controlled-humidity cabinet (Mattern and Bishop 1973) at 46% relative humidity to improve pelleting characteristics. Samples were pelleted for X-ray analysis by pressing 0.5 g of each sample into a 32 mm-diameter disk, using a potassium-bromide die. A pressure of 33,000 psi was applied with a Carver Laboratory press (model M) and was held for 30 sec before release.

X-Ray Analysis for Mineral Elements

Mineral element measurements were made on the pellets by EDXRF, using modifications of the method of Knudsen et al (1981). The procedure was modified as follows: Mg, P, S, and Cl were determined simultaneously with 8 kV applied to the X-ray tube for an accumulation of 60 sec of live time; and a second pass of 150 sec of live time at 35 kV with a 0.05-in. Ag filter was used for the determination of K, Ca, Mn, Fe, Cu, and Zn. Tube amperages were selected to allow less than 30% dead time. The instrumentation uses

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[2] Mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture or University of Nebraska over other firms or similar products not mentioned.

[3] Graduate research assistant and leader, wheat research, USDA-ARS; and professor of agronomy, respectively, University of Nebraska-Lincoln, Lincoln 68583.

software to correct for background and overlap of spectrum peaks. Mineral values were expressed as the ratio of integrated counts under the peak of an element in the sample to that of a reference peak for the element. Standard curves were used for conversion into concentrations.

Standard curves were prepared by addition of mineral salts in ethyl alcohol to the control flour and bran samples. The alcohol was evaporated, and each sample was blended thoroughly and brought to a uniform moisture level before pelleting for mineral element analysis. A standard curve was calculated on a dry weight basis for each element by linear regression of the peak area ratio on the mineral concentration of the sample (the concentration added plus the calculated endogenous concentration) including a zero-zero intercept. National Bureau of Standards wheat flour (1567) and rice flour (1568) standards (Alvarez and Rook 1978) were used to evaluate calibration curves.

Protein and Moisture Determinations

One gram of each sample (d.b.) was analyzed for nitrogen using the macro-Kjeldahl procedure (approved method 46-12) (AACC 1969). Protein was calculated, using 5.7 as the factor to convert N to protein. Moisture levels were determined for bran and flour controls used in the production of standard curves and protein samples, using the AACC oven method 44-16 (AACC 1969).

Statistical Analysis

A weighted analysis of variance was performed for each variable, based on the method of Steel and Torrie (1960) because unequal replications were used at the various locations. Genetic correlations were calculated by the method of Falconer (1960).

RESULTS AND DISCUSSION

X-Ray Spectrometry

Analysis of National Bureau of Standards (NBS) wheat and rice flour samples by X-ray fluorescence spectrometry (Table I) showed relatively good agreement between EDXRF and NBS certified values (Alvarez and Rook 1978) for Fe, Cu, and Zn levels. The concentrations of K, as determined by EDXRF, were substantially higher, and for Ca slightly higher, than the NBS values. With the exceptions of K and Mg, mineral element concentrations in flour summarized in Tables II and III compared favorably with previously reported values. The values for K and Mg were higher than corresponding flour concentrations determined by Czerniejewski et al (1964), Farrell et al (1967), and Zook et al (1970). Norrish and Hutton (1977) found that values for Mg, S, Cl, and K concentrations in plant material by X-ray analyses were consistently higher than values obtained by chemical methods.

TABLE I
Mineral Element Concentrations Obtained in NBS[a] Certified Flour Samples by Energy-Dispersive X-Ray Fluorescence (EDXRF)

NBS Flour Sample	Mineral Element (μg/g, d.b.)				
	K	Ca	Fe	Cu	Zn
Wheat					
NBS[a]	1,360 ± 40	190 ± 10	18.3 ± 1.0	2.0 ± 0.3	10.6 ± 1.0
EDXRF	1,762 ± 67	217 ± 10	18.5 ± 0.9	2.8 ± 0.2	11.1 ± 0.5
Rice					
NBS[a]	1,120 ± 20	140 ± 20	8.7 ± 0.6	2.2 ± 0.3	19.4 ± 1.0
EDXRF	1,459 ± 67	173 ± 10	9.9 ± 0.9	2.8 ± 0.2	21.0 ± 0.5

[a] National Bureau of Standards samples. Values reported by Alvarez and Rook (1978).

The K and Mg discrepancies may reflect losses from ashing or digestion of samples. The X-ray analysis method involves only grinding and pelleting of sample material and avoids the potential losses of other procedures. The limitations of the X-ray technique in flour analysis were reflected in the high CV values obtained for Mn, Fe, and Cu. Low concentrations of these mineral elements in flour approach the detection limits of the X-ray instrument. The concentrations of the other elements in flour were well above the detection limits of X-ray, and the CV values were low.

EDXRF bran mineral concentrations obtained in this study (Table IV) were lower than those reported by Czerniejewski et al (1964) and Farrell et al (1967) for Mg, P, K, Fe, Cu, and Zn. This probably resulted from the lower extraction rate of 60% used in preparation of the EDXRF samples. The reduced extraction rate increased the amount of endosperm remaining in the bran samples, diluting the bran mineral content. Average bran mineral element concentrations were well above the detection limits of the X-ray instrumentation, and the CV values were relatively low.

Analysis of Variance

Production site, varietal differences, and the interaction of location and varietal effects had a highly significant ($P < 0.01$) influence on each of the minerals studied in flour and bran. These sources of variation also significantly affected flour and bran protein concentration and grain yields.

Location Effects

The six research stations supplying material for analysis were diverse environmentally and geographically for wheat production. This diversity is readily apparent from the range of protein concentrations and grain yields, both of which are strongly influenced by the production environment. Mean flour protein concentrations ranged from 10.2 to 17.1%, bran protein concentrations from 12.6 to 20.0% (Table II), and yield from 31.6 to 73.7 q/ha across locations.

The effect of environment on flour mineral element concentrations, although significant, was limited. Ranges in the

TABLE II
Mean Concentration of Mineral Elements and Protein in Flour and Bran of 27 Varieties of Winter Wheats from Six Locations

Location	Protein (%, d.b.)	Mineral Element (μg/g, d.b.)									
		Mg	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn
					Flour						
Lincoln, NE	17.1	872	796	2,175	756	1,511	244	6.2	12.2	2.2	8.7
Stillwater, OK	15.6	876	882	2,057	842	1,519	233	6.9	10.4	3.1	8.2
Monsheim, West Germany	13.3	777	856	1,660	551	1,510	214	6.0	12.2	3.1	5.3
Ithaca, NY	13.1	825	846	1,908	661	1,477	211	5.5	9.3	2.5	5.8
University Park, PA	11.6	790	886	1,754	532	1,655	179	4.6	8.2	2.5	6.5
Davis, CA	10.2	874	850	1,446	701	1,959	185	5.1	9.2	2.4	6.0
					Bran						
Lincoln, NE	20.0	3,417	5,947	2,784	861	10,274	1,211	137	116	7.2	80.7
Stillwater, OK	19.2	3,826	6,939	2,724	947	9,293	1,310	148	100	11.9	75.5
Monsheim, West Germany	16.5	3,346	6,918	2,238	633	9,372	939	125	94	10.8	51.1
Ithaca, NY	16.4	3,668	7,412	2,565	680	10,682	1,030	133	105	9.7	69.5
University Park, PA	14.7	3,348	7,344	2,402	613	11,177	747	105	72	9.6	68.3
Davis, CA	12.6	3,453	6,262	1,972	940	11,345	626	116	78	8.7	64.1

location means for most minerals were relatively small, from 777 to 876 μg/g for Mg, 796 to 886 for P, 4.6 to 6.9 for Mn, 8.2 to 12.2 for Fe, 2.2 to 3.1 for Cu, and 5.3 to 8.7 for Zn. Flour S, Cl, K, and Ca concentrations were somewhat more variable for locations, from 1,446 to 2,175 μg/g for S, 532 to 842 for Cl, 1,477 to 1,959 for K, and 179 to 244 for Ca.

Mineral elements in the bran component were more strongly influenced by production environment than in the flour (Table II). Variations of P, S, Cl, K, and Ca concentrations across locations were relatively wide, but less for Mg, Mn, Fe, Cu, and Zn.

Varietal Differences

The 27 varieties and experimental lines in the 12th IWWPN represent the better germ plasm in use by wheat-breeding programs worldwide. The cultivars are diverse in genetic makeup, agronomic characteristics, and origin. They differ widely in seed size, kernel texture, and productivity. Both soft and hard wheats were included in the nursery. They exhibited a wide range in flour protein concentrations (from 10.8 to 16.6%), bran protein concentrations (from 15.4 to 18.3%), and mean grain yield (from 34.0 to 57.2 q/ha) (Tables III and IV).

The variation found in flour mineral element concentrations among varieties shown in Table III appeared to be as large as or larger than the variation produced by differences in production environments (Table II). The ranges of 649–1,095 μg/g in P and 1,270–1,995 μg/g in K among varieties were larger than the variation produced by locations. Ranges among varieties of 757–906 μg/g for Mg and 1,485–2,151 μg/g for S also were somewhat larger than location ranges. Variation in Ca, Mn, Fe, Cu, and Zn concentrations among varieties was slightly larger than that associated with locations. Chloride concentration, which ranged from 540 to 791 μg/g over varieties, was the only mineral element in flour for which the varietal effects were smaller than location effects.

Variations found in bran mineral element concentrations among varieties are shown in Table IV. Varietal differences ranged from 2,940 to 4,191 μg/g Mg, 5,714 to 8,404 μg/g P, and 9,080 to 11,925 μg/g K, which were larger than the variation associated with locations. The range in Mn concentration among varieties was slightly larger, while variations in Cl, Fe, Cu, and Zn were slightly smaller than those associated with locations. Varietal differences in S and Ca concentrations were significant, but ranges were markedly less than those associated with locations.

Genetic variation in the mineral concentrations of flour and bran, although significant, did not appear as wide as had been suggested by Nahapetian and Basiri (1976) in their study of whole grain composition. Wide variations due to environment, noted by White et al (1981), also were not found. The influence of environment on flour and bran mineral element composition indicated by this study was comparable to that of whole grain presented by Koivistoinen et al (1974) and Dikeman et al (1982). Varietal differences also were found to be comparable to those found by Koivistoinen et al (1974), but were notably wider than those reported by Dikeman et al (1982). This was not surprising, since the cultivars in the IWWPN were much more genetically diverse than were the hard red wheats from the Southern Regional Performance Nursery tested by Dikeman et al (1982).

TABLE III
Mean Concentration of Mineral Elements and Protein in Flour for 27 Winter Wheat Varieties over Six Locations

Cultivar	Cultivar Origin	Protein (%, d.b.)	Mineral Element (μg/g, d.b.)									
			Mg	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn
Atlas 66	USA, NC	16.6	868	949	2,151	540	1,375	206	5.9	12.3	3.3	8.8
NE 7060	USA, NE	15.6	888	937	2,040	697	1,730	230	8.3	11.5	3.2	7.7
Odessa 4	USSR	15.3	890	1,014	2,104	598	1,363	221	5.3	12.7	3.3	8.3
JO 3057	Finland	15.3	852	978	2,027	656	1,568	198	7.5	12.0	3.1	7.7
Aura	Finland	14.9	906	1,095	2,077	659	1,914	224	8.8	12.1	2.7	9.3
GK-Tiszataj	Hungary	14.9	897	944	1,950	645	1,563	251	6.7	11.1	2.6	7.2
Kopara	New Zealand	14.7	867	946	1,989	791	1,757	210	5.3	9.5	2.4	8.3
Lovrin 24	Romania	14.5	900	984	1,983	648	1,511	187	6.0	12.7	2.9	7.9
WWP 4394	Austria	14.1	842	845	1,956	716	1,396	203	6.3	9.8	2.8	6.4
Alcedo	E. Germany	14.0	892	926	1,921	670	1,708	199	6.4	11.0	2.4	7.9
Martonvasari 5	Hungary	14.0	820	876	1,903	637	1,411	208	6.0	10.7	2.8	7.3
Martonvasari 6	Hungary	13.7	806	869	1,821	677	1,601	206	5.9	9.8	2.8	6.3
Lethbridge 1327	Canada	13.6	822	825	1,898	622	1,270	244	5.5	8.9	2.6	6.0
NSR-1	Yugoslavia	13.6	835	890	1,787	637	1,637	190	6.0	10.6	2.6	6.6
Bezostaya 1	USSR	13.2	845	873	1,780	659	1,507	187	4.7	10.4	2.9	6.8
Adam	Austria	13.1	863	843	1,847	650	1,995	234	4.6	10.5	2.4	6.3
Hachiman-Komugi	Japan	12.8	782	802	1,740	729	1,556	199	4.2	9.4	2.6	6.1
Bastion	Netherlands	12.7	774	748	1,684	790	1,790	248	5.6	8.5	2.5	6.0
Downy	USA, IN	12.7	784	713	1,734	616	1,484	220	5.4	10.3	2.3	7.0
Jana	Poland	12.6	814	774	1,660	703	1,602	176	4.3	9.3	2.4	6.2
Trakia	Bulgaria	12.5	847	840	1,854	789	1,870	211	5.4	10.2	2.6	6.0
Clement	Netherlands	12.3	785	662	1,620	733	1,858	237	5.3	9.6	2.3	5.9
Doina	Romania	12.1	773	713	1,680	735	1,575	197	4.1	8.9	2.6	5.4
TAM W-105	USA, TX	12.0	856	846	1,651	611	1,461	203	6.5	10.4	2.2	5.4
TX 71A562-6	USA, TX	11.9	812	812	1,598	655	1,576	214	3.3	8.4	2.3	5.2
Blueboy	USA, NC	11.2	789	649	1,581	708	1,702	202	5.1	8.1	2.3	5.6
Houser	USA, NY	10.8	757	686	1,485	621	1,554	189	5.9	8.0	2.5	5.6
Mean		13.3	837	855	1,801	681	1,617	211	5.8	10.3	2.7	6.6
Range (minimum)		10.8	757	649	1,485	540	1,270	176	3.3	8.0	2.2	5.2
Range (maximum)		16.6	906	1,095	2,151	791	1,995	251	8.8	12.7	3.3	9.3
LSD[a]		1.2	69	108	147	61	202	30	1.7	2.0	0.4	1.4
CV[b]		4.6	10.8	5.6	4.6	4.8	8.2	13.0	31.2	22.8	20.5	14.0

[a] Least significant difference: $P = 0.05$.

[b] Coefficient of variation.

Correlations of Mineral Elements with Protein

Mineral elements are essential components of plant metabolism and often accumulate in seeds. With the exception of K, phenotypic correlations of minerals with flour protein were positive and highly significant, and ranged from 0.31 to 0.92 (Table V). Sulfur and Zn with r-values of 0.92 and 0.73, respectively, were the elements most highly correlated with protein. The close relationship between flour mineral elements and flour protein was noted after the removal of environmental influences from phenotypic correlations. High, positive genotypic correlations of Mg, P, S, Fe, Cu, and Zn

TABLE IV
Grain Yields, 1,000-Kernel Weights, and Mean Concentration of Mineral Elements and Protein in Bran for 27 Winter Wheat Varieties over Six Locations

Cultivar	Grain Yield (q/ha)[a]	1,000-Kernel Weight (g)[b]	Protein (%)	Mineral Element (μg/g, d.b.) Mg	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn
Atlas 66	38.0	36.0	17.7	3,272	6,373	2,563	709	9,551	888	115	101	10.4	71.3
NE 7060	46.6	38.6	17.6	4,015	7,732	2,441	741	10,433	982	156	104	11.3	76.1
Odessa 4	49.4	45.5	16.5	3,811	7,173	2,514	640	9,080	1,049	140	102	9.8	70.1
JO 3057	37.1	31.4	18.3	3,454	7,179	2,623	736	10,594	953	139	101	10.6	68.4
Aura	34.0	31.5	17.7	4,191	8,404	2,597	730	11,925	1,055	155	109	10.6	84.9
GK-Tiszataj	51.9	40.7	16.8	3,646	7,147	2,393	717	10,133	1,085	144	101	9.9	70.6
Kopara	38.5	33.6	17.2	3,763	7,566	2,544	840	11,823	1,173	135	95	9.2	76.9
Lovrin 24	54.6	42.4	16.4	3,428	6,916	2,398	735	9,693	920	122	103	9.8	69.1
WWP 4394	55.7	38.0	16.2	3,460	6,548	2,489	815	9,532	877	128	94	9.5	65.9
Alcedo	47.6	35.8	16.5	3,752	7,174	2,408	772	10,958	942	134	103	9.8	70.3
Martonvasari 5	49.5	42.7	15.7	3,683	6,766	2,353	718	9,536	1,000	147	103	9.1	76.9
Martonvasari 6	49.2	41.6	16.2	3,527	6,819	2,353	763	10,388	1,031	128	91	8.9	66.3
Lethbridge 1327	43.4	39.1	16.2	3,526	6,818	2,526	719	9,668	1,159	118	93	9.9	66.1
NSR-1	48.0	41.6	16.2	3,536	6,714	2,324	746	10,218	778	129	96	9.5	65.1
Bezostaya 1	47.1	39.8	15.8	3,644	7,030	2,337	726	9,941	1,012	138	138	9.2	70.1
Adam	46.6	36.4	16.1	3,768	6,997	2,431	722	11,385	1,076	120	98	9.5	71.2
Hachiman-Komugi	47.2	38.6	17.1	3,230	6,699	2,518	839	10,179	893	111	86	9.9	62.3
Bastion	40.0	35.1	16.3	3,139	6,249	2,356	919	10,527	1,083	119	81	9.3	64.9
Downy	45.2	33.0	16.6	3,390	6,342	2,525	771	9,897	968	124	91	8.4	62.8
Jana	43.8	34.3	17.0	3,363	6,774	2,440	836	11,050	119	119	90	9.1	73.3
Trakia	53.3	40.5	15.8	3,569	6,799	2,509	904	11,344	1,107	129	87	9.3	63.3
Clement	53.5	36.2	16.7	2,940	5,714	2,397	857	9,918	800	111	92	9.8	64.4
Doina	55.4	36.5	16.4	3,090	6,291	2,476	903	10,155	797	114	87	9.5	64.8
TAM W-105	55.9	33.7	16.1	3,547	6,407	2,359	707	9,240	990	131	72	8.3	57.0
TX 71A562-6	53.6	32.6	15.4	3,558	6,451	2,279	786	10,631	985	106	82	9.5	58.0
Blueboy	57.2	35.6	16.1	3,187	6,039	2,481	892	10,439	1,097	110	90	9.1	64.0
Houser	52.1	36.5	16.9	3,195	6,613	2,471	782	11,456	886	116	86	10.8	68.7
Mean	49.6	40.0	16.4	3,528	6,807	2,410	793	10,262	974	128	93	9.9	66.8
Range (minimum)	34.0	31.4	15.4	2,940	5,714	2,279	640	9,080	778	106	72	8.3	57.0
Range (maximum)	57.2	45.5	18.3	4,191	8,404	2,623	919	11,925	1,173	156	109	11.3	84.9
LSD[c]	9.0	4.4	1.1	294	635	146	93	873	133	18	10	1.2	9.5
CV[d]	11.4	5.9	3.7	6.7	6.4	3.4	7.7	6.4	7.9	9.7	9.8	10.2	8.9

[a] Average from five locations only.
[b] Average from two locations only.
[c] Least significant difference: $P = 0.05$.
[d] Coefficient of variation.

TABLE V
Phenotypic and Genotypic Correlation Coefficients of Protein and Mineral Element Concentrations in Winter Wheat Flour and Bran with Protein, Grain Yield, and 1,000-Kernel Weight

	No. of Locations	Type of Correlation[a]	Protein	Concentrations of Mineral Elements Mg	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn
						Flour							
Flour protein	6	P	···	0.35**[b]	0.37**	0.92**	0.32**	−0.42**	0.55**	0.52**	0.59**	0.31**	0.73**
		G	···	0.89	0.88	0.96	−0.35	−0.17	0.21	0.64	0.94	0.88	0.95
Grain yield	5	P	−0.52**	−0.36**	−0.17*[b]	−0.61**	−0.60**	0.04	−0.31**	−0.23**	−0.01	0.12	−0.61**
		G	−0.65	−0.20	−0.56	−0.59	0.14	−0.12	−0.06	−0.54	−0.44	−0.42	−0.72
1,000-Kernel weight	2	P	−0.64**	−0.38**	0.25	−0.68**	−0.70**	−0.13	−0.42**	−0.11	0.07	0.68**	−0.68**
						Bran							
Bran protein	6	P	···	0.22**	0.03	0.88**	0.15*	−0.32**	0.76**	0.52**	0.69**	0.12	0.48**
		G	···	0.13	0.48	0.62	−0.18	0.36	−0.25	0.31	0.46	0.74	0.55
Grain yield	5	P	−0.53**	−0.36**	−0.08	−0.66**	−0.40**	−0.14	−0.51**	−0.37**	−0.39**	0.00	−0.73**
		G	−0.73	−0.40	−0.65	−0.49	0.24	−0.49	−0.09	−0.45	−0.61	−0.35	−0.73
1,000-Kernel weight	2	P	−0.86**	0.03	0.54**	−0.86**	−0.72**	−0.54**	−0.58**	−0.17	−0.50**	0.81**	−0.74**

[a] P = Phenotypic; G = genotypic.
[b] *, ** = Significant at $P = 0.05$ and $P = 0.01$, respectively.

TABLE VI
Phenotypic and Genotypic Correlation Coefficients Between Winter Wheat Flour and Bran Concentrations of Mineral Elements and Protein

Correlation Coefficients	Protein	Mineral Elements									
		Mg	P	S	Cl	K	Ca	Mn	Fe	Cu	Zn
Phenotypic	0.88**[a]	0.48**	0.65**	0.82**	0.85**	0.60**	10.71**	0.65**	0.59**	0.67**	0.76**
Genotypic	0.49	0.92	0.85	0.47	0.88	0.80	0.55	0.85	0.84	0.76	0.79

[a] ** = Significant at $P = 0.01$.

concentrations with protein were found with values ranging from 0.88 to 0.96. Manganese concentration showed a lower genotypic correlation of only 0.64. The flour concentrations of Cl, K, and Ca were relatively independent of protein.

Correlations between protein and mineral concentrations in bran were lower than those determined in flour. In bran, minerals are most likely bound to phytate and fiber. Phytate is a P storage compound containing from 40 to 94% of the total P in grain, and has been found in insoluble forms as the salts of Mg, Ca, and K (Bassiri and Nahapetian 1977). Phenotypic correlations of P and Cu with bran protein were nonsignificant, whereas phenotypic correlations of Mg and Cl with protein were significant. Low and negative phenotypic correlations were noted for K and bran protein. Positive phenotypic correlations with bran protein were significant for Ca, Mn, Fe, and Zn, and ranged from 0.48 to 0.76. Like that of flour protein, S showed the highest phenotypic correlation with bran protein (0.88). After removal of environmental influences, genotypic correlations of Mg, S, Mn, Fe, Cu, and Zn with protein, although positive, were significantly lower in bran than those found in flour. In contrast to its positive phenotypic correlations with flour and bran protein, Ca showed a low negative genotypic correlation with bran protein. Although no phenotypic correlation of P with bran protein was noted, a positive genotypic correlation of 0.48 indicates that significant amounts of nonphytate P may be associated with protein.

Although Dikeman et al (1982) detected few significant correlations between the mineral elements and protein levels of hard red wheat grain, Lorenz and Loewe (1977) found K, Fe, and Zn concentrations to be positively correlated with protein in hard and soft wheat blends. In addition, Lorenz et al (1980) found positive correlations between Fe, Mg, and Zn concentrations and protein in commercially milled flours. The generally high positive correlations of mineral elements with protein in this study suggest an added nutritional advantage of high protein in wheat cultivars. The increased mineral element concentrations associated with increased protein concentration could be of significant value, especially for those mineral elements that are considered inadequate in diets.

Correlations of Mineral Elements with Grain Yield and Kernel Weight

The influences of cultivar grain yield and seed size on mineral element concentrations were substantial and similar to their effects on grain protein. Higher grain yields and kernel weights tended to be associated with a general decrease in concentrations of protein and mineral elements. Phenotypic correlations of flour S, Cl, and Zn concentrations with grain yield (Table V) ranged from −0.60 to −0.61 and were larger than the negative phenotypic correlation of −0.52 between protein and grain yield. Magnesium, P, Ca, and Mn also showed significant negative phenotypic correlations with yield, but were lower and ranged from only −0.17 to −0.36. Potassium, Fe, and Cu concentrations appeared to be unaffected by grain yield. Genotypic correlations of flour P, S, Mn, Fe, and Cu with grain yield ranged from −0.42 to −0.59 and were lower than the protein-yield correlation of −0.65. A relatively high negative genotypic correlation of −0.72 was found between Zn and grain yield. Magnesium, Cl, K, and Ca concentrations in flour showed only limited genotypic relationships with grain yield.

The influence of kernel weight on the concentration of several of the mineral elements and flour protein was substantial. Negative phenotypic correlations were found for S, Cl, Cu, and Zn with kernel weight and were comparable to the protein-kernel weight correlation of −0.64. The association of Mg and Ca concentrations with kernel weight was relatively low but significant and negative. Phosphorus, K, Mn, and Fe concentrations appeared to be unaffected by variation in kernel weight. The positive phenotypic correlation of 0.68 for Cu content with kernel size was in contrast to the other mineral element correlations.

The relationships between mineral element concentrations in bran and grain yield were similar to those found in flour. Phenotypic correlations with grain yield were negative and highly significant for Mg, S, Cl, Ca, Mn, Fe, and Zn and were comparable to the −0.53 correlation of protein with grain yield. Genotypic correlations of grain yield with bran Mg, K, and Fe content were negative, but larger than those found in flour.

The mineral element concentrations in bran were influenced more by variation in kernel weight than they were in the flour. Except for Mg, Mn, and Cu, a strong negative phenotypic correlation of bran protein with kernel weight was found for each of the elements.

Correlations Between Mineral Elements in Flour and Bran

Vogel et al (1976) found correlations of bran protein with endosperm protein to be relatively low, suggesting that wheat with high endosperm protein may not necessarily have high concentration of bran protein. Similar tendencies were noted with correlations between flour and bran mineral element concentrations (Table VI). While phenotypic correlations between flour and bran concentrations of S, Cl, and Zn were high (0.76–0.85), phenotypic correlations for the remaining mineral elements ranged from only 0.48 to 0.71, which would indicate that the mineral element concentrations in flour and bran were not as closely related. Removal of environmental influences showed that the genotypic correlations between bran and flour concentrations of protein and S were low (less than 0.50). Genotypic correlations were high for most other mineral elements and ranged from 0.76 to 0.92. This indicates that a closer relationship between bran and flour mineral element concentrations exists than is evident from the phenotypic correlations. Calcium concentrations in bran and flour showed the highest degree of independence with a genotypic correlation of 0.55.

CONCLUSIONS

Significant variation in mineral element composition of wheat grain has been previously established. In this study, significant variation also was found in the mineral element composition of wheat flour and bran fractions. The variability could be attributed to environmental and genetic factors and their interaction. Several mineral elements showed high positive correlations with protein content in both flour and bran. Although a low milling extraction was used in this study, the information presented should be of value to nutritionists.

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