MINERAL COMPOSITION OF DEVELOPING WHEAT, RYE, AND TRITICALE

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ABSTRACT

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The deposition of minerals (K, Ca, Mn, Fe, Cu, Zn, and Br) in kernels of wheat, rye, and triticale grown side by side under the same agronomic and environmental conditions was followed from very early kernel development (4 weeks before maturity) up to full maturity. Results indicated that the minerals in kernels of triticale are deposited quite early in the development and in a similar pattern as that observed for kernels of the rye and wheat cultivars. There were, however, slight variations in redistribution, translocation, or dilution among cultivars as the kernels matured and the major components of cereal grains—starch and protein—were deposited and moisture content decreased.

Triticales planted in Colorado on plots immediately adjacent to wheats proved to be consistently higher in total ash and several essential minerals than the wheats (1). Variation in concentration of mineral elements has been attributed to the effects of soil, conditions of growth, water supply, time of sowing, and fertilizers, as well as to varietal differences (2,3,4). However, except for varietal differences, the above-mentioned factors cannot be used to explain the observed differences, since they were the same for all cultivars planted (1).

Higher mineral concentrations, however, might also be explainable as being due to differences in absorption and accumulation during kernel development. Such differences in accumulation of certain mineral elements have been demonstrated in wheat, barley, and soybeans (5,6). Several investigations have shown decreasing plant nutrient concentrations with increasing age of plants (7—9), while others have demonstrated an increase in concentrations at very early sampling dates, followed by dilution and translocation from various plant parts as crop growth increased until maturity (10).

It was the purpose of this study to follow the deposition of minerals in triticales, in comparison with that of cultivars of wheat and rye grown side by side under the same agronomic and environmental conditions during the 1974 crop year.

MATERIALS AND METHODS

Sample Identification

The samples included one wheat, three triticales, one rye, and one durum. The wheat cultivar, Colano, is a hard red spring type selected from the CIMMYT program and released by Colorado State University. One of the three triticales, 6-

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TA-206, is a tall spring type obtained from the Jenkins Research Foundation. The other two, RF720009 and RF720011, are semidwarf spring selections from the "Armadillo" cross obtained from the CIMMYT program. The spring rye was the cultivar Prolific. The durum, RF710066, is a spring semidwarf selection from the CIMMYT program.

The material was seeded in plots 24 rows wide, with a row length of 3.05 m and 25.4 cm between rows. The plots were planted on summer fallow ground at the Colorado State University Agronomy Research Center, Fort Collins, on April 10, 1974. No fertilizer was added. The plots received three irrigations of approximately 6.35 cm each, prior to the initial harvest.

Several rows of each cultivar were harvested July 8, 15, 22, 29, and August 6, respectively. Samples harvested July 8 were at the initial stage of kernel development.

The moisture contents of the samples at harvest are shown in Table I.

The grain samples were freeze-dried and ground in a micro mill. Samples of 300 mg were pressed into 3.18-cm diameter wafers for X-ray measurement.

X-Ray Fluorescence

X-Ray fluorescence analysis was performed with a Finnigan Model 80 spectrometer with a rhodium filtered X-ray tube operated at 40 kV. Samples were analyzed in a vacuum. Count rate was limited to 1000 cps. The data for the elements K, Ca, Mn, Fe, Cu, Zn, and Br were obtained simultaneously. Each sample was analyzed for 4 kiloseconds. The five samples of each cultivar were analyzed consecutively two or three times.

Calibration standards were prepared from 3.33-cm diameter circles of Whatman No. 1 filter paper impregnated with 11.6 $\mu g/cm^2$ of element for the elements heavier than Ca, and 11.6 $\mu g/cm^2$ of element for the lighter elements. The mineral concentrations for each sample were obtained using a numerical calculation employing the data from the sample, the results of the standard calibration, and fundamental X-ray constants (11).

The suitability of energy dispersive X-ray fluorescence spectrometry as a method of nondestructive mineral determination for cereal grains has been shown in a previous paper (1).

RESULTS AND DISCUSSION

Mineral Contents on Dry Basis (ppm)

The mineral compositions of maturing wheat, rye, and triticale cultivars are

TABLE I
Moisture Content of Samples at Harvest

Cultivar	Moisture Content (%)				
	July 8	July 15	July 22	July 29	Aug. 6
Colano spring wheat	57.8	44.2	27.2	13.1	12.9
Durum wheat RF710066	64.0	41.1	36.6	16.9	11.8
Prolific spring rye	67.0	56.7	45.7	35.9	27.0
Triticale 6-TA-206	65.2	63.8	51.5	36.8	18.6
Armadillo triticale RF720009	58.2	48.3	38.2	19.1	13.3
Armadillo triticale RF720011	58.8	54.6	35.9	20.2	13.3

presented in Tables II and III. The relatively high mineral concentrations, but especially those of K and Ca, at very early stages of kernel development apparently occur as the result of a rather rapid uptake and redistribution by the plants. This may occur with any nutrient that is present in ample supply in readily available forms (12). In later stages of kernel development, dilution of the nutrient concentration and/or translocation is the dominant trend, while nutrient uptake by the plant slows (12).

At the very early stage of kernel development (4 weeks immature—kernel moisture approximately 60%), the three triticales had a higher K concentration than the wheat or rye cultivars. The rye, however, was higher in K than the wheats. Calcium was highest in the durum sample, followed by the tall triticale 6-TA-206 and the rye sample. The semidwarf Armadillo triticales had the lowest Ca contents at this stage of kernel development.

The concentration of K and Ca in the grain kernels decreased with degree of maturity. In the wheat samples—hard red spring and durum—the changes in K and Ca concentrations amounted to approximately 35 and 32%, respectively, between very early kernel development and final maturity, while in the rye cultivar these values were 23 and 60%, respectively. This indicates a greater redistribution of K in wheats compared to rye. Ca has the opposite trend of greater redistribution in rye compared to wheat. Approximate percentages are presented in the discussion considering the standard deviations observed during analyses of the samples. These standard deviations, which are in previously observed ranges (1), are shown in Tables II and III.

The kernels of the tall triticale 6-TA-206 showed the greatest change in K concentration (41%) and nearly as much change in Ca (55%) as the rye kernels did. The semidwarf Armadillo varieties incurred changes in mineral concentration in the kernels due to transfer, translocation, or simply deposition of starch and protein which averaged 30% for K and 35% for Ca—values which are similar to those observed for the wheat cultivars.

Kernels of triticale are considerably larger than those of wheat and rye, but change considerably in size and configuration when a certain low moisture content is reached. The sudden shriveling due to loss of moisture from the kernel also seems to coincide with the considerable decrease in K and Ca in the tall triticale 6-TA-206. The semidwarf Armadillo varieties exhibited considerably better kernel characteristics. The kernels were slightly plumper and not as shriveled at full maturity. They did not show the sudden and drastic moisture loss as did the tall variety, which might be an explanation for the lower redistribution loss of K and Ca in these varieties.

It has been suggested that the cell collapse and endosperm failure of triticale kernels is associated with the activity of α-amylase, which, in turn, is depending upon calcium ions for stability and activity. However, it appears unlikely that the changes in Ca content observed in developing kernels of triticale had any effect on enzyme activity. According to Reed (13), there is always enough Ca present to make the enzyme fully active. Traces of Ca present in starch are generally sufficient to supply Ca even to calcium-free enzymes (13).

The initial concentrations of Mn, Fe, and Zn varied only slightly among grain varieties. Although amounts of these mineral elements were lower in the fully matured kernels than in those 4 weeks immature, the changes in concentration on a dry matter basis were not as drastic as those for K and Ca. The Cu

TABLE II
Mineral Composition of Maturing Wheat and Rye Cultivars (ppm—Dry Basis)[a]

	K	Ca	Mn	Fe	Cu	Zn	Br
Colano spring wheat							
4 weeks immature	4887 ± 63	548.0 ± 84	55.1 ± 4.4	49.0 ± 3.6	7.3 ± 0.3	23.8 ± 1.1	15.9 ± 0.1
3 weeks immature	3606 ± 57	433.9 ± 83	55.0 ± 2.6	45.1 ± 1.1	6.3 ± 0.0	25.6 ± 0.3	16.3 ± 0.5
2 weeks immature	3302 ± 77	414.2 ± 64	54.0 ± 0.1	54.1 ± 2.1	6.5 ± 0.5	28.6 ± 1.0	12.9 ± 0.7
1 week immature	3283 ± 14	369.6 ± 9	51.5 ± 0.8	46.3 ± 2.4	6.5 ± 0.0	27.4 ± 0.8	30.4 ± 0.1
Full maturity	3070 ± 33	383.9 ± 34	52.1 ± 1.1	45.5 ± 2.6	6.7 ± 0.1	23.9 ± 0.0	27.7 ± 1.0
Durum RF710066							
4 weeks immature	5761 ± 126	2800 ± 66	44.2 ± 2.4	45.4 ± 10.2	6.1 ± 0.4	25.0 ± 0.7	17.0 ± 0.8
3 weeks immature	4330 ± 61	2066 ± 31	43.5 ± 3.9	46.4 ± 12.1	5.9 ± 0.3	22.0 ± 0.3	21.2 ± 0.1
2 weeks immature	3956 ± 96	1878 ± 48	43.8 ± 4.3	53.0 ± 9.4	5.4 ± 0.3	27.7 ± 1.0	24.3 ± 0.6
1 week immature	3943 ± 30	1871 ± 15	40.2 ± 1.8	49.1 ± 5.5	5.8 ± 0.2	24.9 ± 0.6	26.4 ± 0.7
Full maturity	3922 ± 20	1861 ± 10	41.0 ± 10.1	40.7 ± 10.9	5.7 ± 0.9	22.0 ± 1.1	25.1 ± 0.0
Prolific spring rye							
4 weeks immature	6464 ± 15	886 ± 20	34.2 ± 1.2	56.2 ± 2.6	5.6 ± 0.3	33.4 ± 0.5	18.1 ± 0.2
3 weeks immature	5746 ± 30	537 ± 33	35.2 ± 1.8	57.4 ± 3.9	5.7 ± 0.0	30.9 ± 1.5	14.6 ± 0.1
2 weeks immature	5271 ± 42	390 ± 20	30.2 ± 0.0	52.5 ± 0.8	5.3 ± 0.3	25.1 ± 0.1	7.9 ± 0.3
1 week immature	4893 ± 71	401 ± 20	31.8 ± 0.0	55.2 ± 2.1	5.7 ± 0.0	32.7 ± 0.1	9.3 ± 0.7
Full maturity	4964 ± 57	346 ± 82	33.6 ± 1.0	46.5 ± 3.8	5.4 ± 0.1	26.7 ± 0.5	10.4 ± 0.7

[a] Average of two or three separate determinations.

TABLE III
Mineral Composition of Maturing Triticales (ppm—Dry Basis)[a]

	K	Ca	Mn	Fe	Cu	Zn	Br
Triticale 6-TA-206							
4 weeks immature	8254 ± 237	1011 ± 43	60.0 ± 1.8	51.2 ± 0.3	7.3 ± 0.5	35.2 ± 0.1	34.0 ± 0.7
3 weeks immature	6439 ± 94	751 ± 75	60.6 ± 2.7	48.3 ± 7.2	6.2 ± 0.1	33.5 ± 0.2	47.3 ± 1.6
2 weeks immature	5524 ± 112	528 ± 27	47.9 ± 1.9	61.8 ± 2.9	6.6 ± 0.7	26.9 ± 1.7	30.2 ± 1.5
1 week immature	4958 ± 78	476 ± 54	48.2 ± 4.9	53.6 ± 2.9	7.3 ± 0.5	26.7 ± 1.6	21.2 ± 0.3
Full maturity	4845 ± 29	457 ± 77	45.8 ± 3.9	40.8 ± 6.5	7.3 ± 1.3	25.2 ± 0.5	22.7 ± 0.7
Armadillo triticale RF720009							
4 weeks immature	6395 ± 75	405 ± 3	55.0 ± 2.9	58.8 ± 6.2	8.1 ± 0.0	29.6 ± 0.1	22.0 ± 0.5
3 weeks immature	5092 ± 41	280 ± 22	44.3 ± 3.5	51.5 ± 1.8	6.6 ± 0.1	27.7 ± 0.6	20.0 ± 0.6
2 weeks immature	4772 ± 81	223 ± 23	45.1 ± 3.1	48.4 ± 0.1	7.3 ± 0.2	23.3 ± 0.2	20.6 ± 0.6
1 week immature	4128 ± 153	210 ± 32	44.4 ± 1.2	51.0 ± 2.6	7.4 ± 0.2	25.5 ± 0.5	28.7 ± 0.6
Full maturity	4296 ± 127	233 ± 60	38.7 ± 0.0	49.0 ± 1.5	7.2 ± 0.2	25.5 ± 0.1	28.3 ± 2.1
Armadillo triticale RF720011							
4 weeks immature	6123 ± 122	339 ± 60	57.4 ± 9.1	49.0 ± 5.9	6.6 ± 0.3	31.0 ± 1.3	23.3 ± 0.3
3 weeks immature	5284 ± 43	228 ± 86	54.1 ± 11.1	54.7 ± 3.8	5.8 ± 0.7	30.0 ± 1.7	24.9 ± 1.9
2 weeks immature	4634 ± 30	188 ± 70	49.9 ± 10.5	42.6 ± 2.3	5.8 ± 1.3	25.4 ± 0.9	18.2 ± 1.8
1 week immature	4615 ± 56	209 ± 43	50.7 ± 5.7	44.6 ± 5.4	5.8 ± 1.0	25.2 ± 1.8	20.5 ± 1.3
Full maturity	4447 ± 89	233 ± 63	49.1 ± 3.3	40.9 ± 3.7	6.3 ± 0.3	23.3 ± 0.8	22.0 ± 0.9

[a] Average of two or three separate determinations.

concentration showed essentially no change as the kernels of the different cereal grains matured.

Br was detected in relatively high amounts in all cereal grains, which confirms earlier reports (1). The element cannot be measured by atomic absorption and, therefore, is rarely reported. There is seldom a biological material, however, which does not contain the element (14).

The importance of Br in human nutrition has not been completely elucidated. Thus far, no beneficial or detrimental effects have been shown from the amount present in our food supply.

In rye and the tall triticale 6-TA-206, Br concentrations decreased with increasing maturity, while in both wheat samples—hard red spring and durum—and in the Armadillo cultivar RF720009, increases were observed. Concentrations of Br in the second semidwarf cultivar did not change with maturity, which indicates that absorption, dilution, or translocation of mineral elements vary with the grain variety under consideration. Interestingly, the change in Br with maturity does not generally follow the trend of any of the other measured elements—indicating a separate distribution mechanism altogether.

Mineral Contents on Per Kernel Basis (ppm)

While the cereal chemist and the food technologist like to look at mineral data expressed on a 14% moisture basis or on a dry matter basis as shown in Tables II and III, the plant breeder and geneticist are accustomed to looking at such data expressed on a per kernel basis, which, because of the constantly changing moisture levels in these kernels during development, shows different trends.

Mineral contents expressed on a per kernel basis are shown in Tables IV and V. The differences in trends from those shown in Tables II and III are due to the fact that total kernel content, including moisture, is taken into account.

K content of all kernels of the different cereal grains increased with maturity, indicating continuous deposition of the element into the kernels as they mature. Generally, the triticales showed the highest K content 4 weeks before maturity and at full maturity, followed by the rye and wheat cultivars.

Levels of Ca in kernels of wheat increased with maturity, while those of the triticales and the rye cultivars fluctuated, showing a decrease up to about 2 weeks before maturity, followed by an increase at full maturity. Overall, the durum cultivar contained the highest amount of Ca 4 weeks before maturity and at full maturity, followed by the tall triticale 6-TA-206, the rye, and the Armadillo triticales, making it again impossible to associate α-amylase activity and kernel shriveling with Ca content.

Expressing Mn, Fe, Zn, Cu, and Br contents on a per kernel basis showed increased amounts with maturity, indicating continuous deposition of these elements into the kernels as they matured. At full maturity, kernels of Colano spring wheat contained the highest and those of rye the lowest amounts of Mn. The values for the triticales were in between these extremes. The values for Fe, Zn, and Cu showed little difference among cultivars. While the values for Br in the kernels of the different cereal grains increased, the amount of Br in the rye sample at full maturity was considerably lower than in all other cultivars.

CONCLUSION

In conclusion, it can be stated that the minerals in kernels of triticale are

TABLE IV
Mineral Composition of Maturing Wheat and Rye Cultivars (per kernel basis—ppm)[a]

	K	Ca	Mn	Fe	Cu	Zn	Br
Colano spring wheat							
4 weeks immature	2062 ± 27	231.2 ± 36	23.2 ± 1.9	20.7 ± 1.5	3.1 ± .1	10.0 ± .5	6.7 ± .0
3 weeks immature	2012 ± 32	242.1 ± 47	30.7 ± 1.4	25.2 ± .6	3.5 ± .0	14.3 ± .2	9.1 ± .3
2 weeks immature	2404 ± 56	301.5 ± 47	39.3 ± .1	39.4 ± 1.5	4.7 ± .4	20.8 ± .7	9.4 ± .5
1 week immature	2853 ± 12	321.2 ± 8	44.7 ± .7	40.2 ± 2.1	5.6 ± .0	23.8 ± .7	26.4 ± .1
Full maturity	2674 ± 29	334.4 ± 30	45.3 ± 1.0	39.6 ± 2.3	5.8 ± .1	20.8 ± .0	24.1 ± .9
Durum RF710066							
4 weeks immature	2074 ± 45	1008.0 ± 24	15.9 ± .9	16.3 ± 3.7	2.2 ± .1	9.0 ± .2	6.1 ± .3
3 weeks immature	2550 ± 36	1216.9 ± 18	25.6 ± 2.3	27.3 ± 7.1	3.5 ± .2	12.9 ± .2	12.5 ± .1
2 weeks immature	2508 ± 61	1190.6 ± 30	27.8 ± 2.7	33.6 ± 6.0	3.4 ± .2	17.6 ± .6	15.4 ± .4
1 week immature	3277 ± 25	1554.8 ± 12	33.4 ± 1.5	40.8 ± 4.6	4.8 ± .2	20.7 ± .5	21.9 ± .6
Full maturity	3459 ± 18	1641.4 ± 9	36.2 ± 8.9	35.9 ± 9.6	5.0 ± .8	19.4 ± 1.0	22.1 ± .0
Prolific spring rye							
4 weeks immature	2133 ± 5	292.4 ± 7	11.3 ± .4	18.5 ± .9	1.8 ± .1	11.0 ± .2	6.0 ± .1
3 weeks immature	2488 ± 13	232.5 ± 14	15.2 ± .8	24.8 ± 1.7	2.5 ± .0	13.4 ± .6	6.3 ± .0
2 weeks immature	2862 ± 23	211.8 ± 11	16.4 ± .0	28.5 ± .4	2.9 ± .2	13.6 ± .1	4.3 ± .2
1 week immature	3136 ± 46	257.0 ± 13	20.4 ± .0	35.4 ± 1.4	3.6 ± .0	21.0 ± .1	6.0 ± .4
Full maturity	3624 ± 42	252.6 ± 60	24.5 ± .7	33.9 ± 2.8	3.9 ± .1	19.5 ± .4	7.6 ± .5

[a] Average of two or three separate determinations.

TABLE V
Mineral Composition of Maturing Triticales (per kernel basis—ppm)[a]

	K	Ca	Mn	Fe	Cu	Zn	Br
Triticale 6-TA-206							
4 weeks immature	2872 ± 82	352 ± 15	20.9 ± .6	17.8 ± .1	2.5 ± .2	12.2 ± .0	11.8 ± .2
3 weeks immature	2331 ± 34	272 ± 27	21.9 ± 1.0	17.5 ± 2.6	2.2 ± .0	12.1 ± .1	17.2 ± .6
2 weeks immature	2679 ± 54	256 ± 13	23.2 ± .9	30.0 ± 1.4	3.2 ± .3	13.0 ± .8	14.6 ± .7
1 week immature	3133 ± 49	301 ± 34	30.5 ± 3.1	33.9 ± 1.8	4.6 ± .3	16.9 ± 1.0	13.4 ± .2
Full maturity	3944 ± 24	372 ± 63	37.3 ± 3.2	33.2 ± 5.3	5.9 ± 1.1	20.5 ± .4	18.5 ± .6
Armadillo triticale RF720009							
4 weeks immature	2673 ± 31	169 ± 1	23.0 ± 1.2	24.6 ± 2.6	3.4 ± .0	12.4 ± .0	9.2 ± .2
3 weeks immature	2632 ± 21	145 ± 11	22.9 ± 1.8	26.6 ± .9	3.4 ± .1	14.2 ± .3	10.3 ± .3
2 weeks immature	2949 ± 50	138 ± 14	27.9 ± 1.9	29.9 ± .1	4.5 ± .1	14.4 ± .1	12.7 ± .4
1 week immature	3340 ± 124	170 ± 26	35.9 ± 1.0	41.2 ± 2.1	6.0 ± .2	20.6 ± .4	23.2 ± .5
Full maturity	3725 ± 110	202 ± 52	33.6 ± .0	42.5 ± 1.3	6.2 ± .2	22.1 ± .1	24.5 ± 1.8
Armadillo triticale RF720011							
4 weeks immature	2523 ± 50	140 ± 25	23.6 ± 3.7	20.2 ± 2.4	2.7 ± .1	12.8 ± .5	9.6 ± .1
3 weeks immature	2399 ± 20	104 ± 39	24.6 ± 5.0	24.8 ± 1.7	2.6 ± .3	13.6 ± .8	11.3 ± .9
2 weeks immature	2970 ± 19	120 ± 45	32.0 ± 6.7	27.3 ± 1.5	3.7 ± .8	16.3 ± .6	11.7 ± 1.2
1 week immature	3683 ± 45	167 ± 34	40.4 ± 4.5	35.6 ± 4.3	4.6 ± .8	20.1 ± 1.4	16.4 ± 1.0
Full maturity	3855 ± 77	202 ± 55	42.6 ± 2.9	35.5 ± 3.2	5.2 ± .3	20.2 ± .7	19.1 ± .8

[a] Average of two or three separate determinations.

deposited quite early in the development and in a similar pattern as observed for kernels of the wheat and rye cultivars. There are, however, slight variations in redistribution, translocation, or dilution among cultivars as the kernels mature and the major components of a cereal grain kernel—starch and protein—are deposited and moisture content decreases.

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