Phytate Content of Soft Wheat Brans as Related to Kernel Size, Cultivar, Location, and Milling and Flour Quality Parameters

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ABSTRACT

The phytate content of wheat bran is of interest because bran, an important dietary fiber source, contains significant amounts of phytate, which has been reported to impair mineral retention under certain dietary circumstances. The purposes of this study were to examine the phytate content of brans from soft wheat cultivars as influenced by kernel size and growing location and to determine whether any relationships existed between phytate content and flour and milling quality parameters. The influence of kernel size upon bran phytate content was determined in six soft wheat cultivars. The phytate content was significantly greater (12–24%) in bran obtained from the larger kernels in three of the six cultivars. Phytate content of the brans from 15 soft wheat cultivars grown at three different locations during the same crop year was influenced strongly by environmental factors. For these cultivars, the phytate content of the bran was significantly ($P < 0.01$) correlated with the milling parameters percent flour extraction, endosperm separation index, and friability ($r = 0.53$, -0.41, and 0.47, respectively). These correlations suggest that endosperm is more easily separated from bran and reduced to flour when it is from soft wheats in which the bran phytate content is greater. The rankings of bran phytate content and milling and flour quality parameters were highly variable across cultivars and growing locations.

Phytic acid (*myo*-inositol 1,2,3,5/4,6-hexakis[dihydrogenphosphate]) is a compound found in most mature cereal seeds that provides from 40% to more than 80% of the total phosphorus in the seed (O'Dell et al 1972, Lolas et al 1976). It frequently occurs as phytin, a mineral storage material that is used to support seedling growth. In many cereals phytin is found in electron-dense particles called globoid crystals that consist mainly of a mixed magnesium and potassium salt of phytic acid (Lott and Ockenden 1986). A major part of the phytate in wheat grains is found in the aleurone layer (O'Dell et al 1972, Wada and Maeda 1980). During the milling process, most of these aleurone cells remain with particles of pericarp; hence phytate becomes concentrated in the bran fractions. Therefore, whole wheat may contain about 0.3% phytate and the bran may contain 5% (O'Dell et al 1972).

The potential for large amounts of phytic acid (IP6, the hexaphosphate ester of phytic acid) in a diet to cause negative mineral retention has been known for many years. A review by Morris (1986) addressed some of the complicated relationships between dietary mineral, protein, and phytate contents and mineral availability. In agreement with earlier investigations, current articles have presented evidence that, in humans, retention of calcium (Kies 1985), iron (Brune et al 1989, Halberg et al 1989), and zinc (Sandström et al 1987) can be decreased significantly by diets high in phytate. Evidence from feeding studies with suckling rats indicated that the phytate species IP6 and IP5, but not lower phytate esters, had antinutritive effects (Lonnerdal et al 1989).

The relationships of phytate content in bran to the milling properties and flour quality of wheat cultivars grown at different locations have not been investigated, to our knowledge. Flour quality and milling properties are known to be influenced both by cultivar type and by environmental conditions. Kernel hardness of winter wheats are influenced more by cultivar than by climatic conditions (Pomeranz et al 1985). Phosphorus concentrations in bran have a significant phenotypic correlation (Peterson et al 1986). A significant decrease in phytate content of wheat grown under dry land versus irrigated conditions has been reported (Bassiri and Nahapetian 1977). Relationships between the phytate content of bran and milling parameters or flour quality properties have not been reported and, a priori, it is not clear why any such relationships should exist.

The first objective of this study was to determine whether the phytate content of bran was influenced by kernel size. For this purpose, kernels from six cultivars were sifted into three size distributions. The second objective was to determine what relationships, if any, existed between bran phytate content and some milling and flour quality parameters of a set of 15 cultivars that were grown at three locations during the same crop year. The third objective was to examine the influences of environment and cultivar upon bran phytate content in comparison with these influences upon the other parameters. Typical milling procedures were used. Measurements of IP6, IP5, IP4, and starch content of the larger bran particles were included as part of the analytical scheme.

MATERIALS AND METHODS

Sample Preparation

Kernels from six cultivars of soft wheat grown at various locations and during different crop years (CY) were examined. The cultivars were Hart and Severn (CY 1983); Frankenmuth, Adena, and Titan (CY 1985); and Florida 301 (CY 1986). Frankenmuth is a white cultivar; the remainder are red. Kernels of each cultivar were cleaned and sieved into three size distributions, using two appropriate sieves with square openings of 7/64, 8/64, 9/64, or 10/64 in. (i.e., openings of about 2.8, 3.2, 3.6, or 4.0 mm). Shriveled and broken kernels were discarded before sieving.

A second group of 15 soft wheat cultivars was grown at nurseries located at East Lansing, MI (Michigan State University); Lafayette, IN (Purdue University); and Pullman, WA (Washington State University). The harvested wheat was cleaned, and grossly shriveled and broken kernels were discarded before milling. The rainfall at Lafayette was below normal, and wheat from that location contained many lightly shriveled kernels that were included in the samples. Seven of the cultivars were red wheats: Arthur, Auburn, Caldwell, Cardinal, Hillsdale, Pioneer 2550, and Tyler. Eight of the cultivars were white wheats: Augusta, Crew, Daws, Frankenmuth, Hill 81, Lewjain, Nugaines, and Stephens.

All wheats were milled at the Soft Wheat Quality Laboratory in a modified Brabender Quadrumat Jr. mill twice modified to handle small quantities (1,500-g samples) of wheat (Yamazaki and Andrews 1982, Finney and Andrews 1986). The bran was collected and stored in a cold room at 2–3°C until it was transported to the National Center for Agricultural Utilization Research for storage at below 0°C until used. After each sample had equilibrated to room temperature, it was gently sieved by hand through a 10- and a 20-mesh screen (1.91- and 0.86-mm square openings, respectively). Brans collected over the two

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screens were used in this study, and the data from the two distributions were pooled.

Measurements of Phytate

Bran flakes, about 200 mg, were sonicated in 5.0 ml of 0.5*N* HCl to extract phytate, as previously described (Lehrfeld 1989). Amounts of IP6, IP5, and IP4 in the bran flakes were measured by a slightly modified ion-pair chromatography method described by Lehrfeld (1989).

A brief description emphasizing modifications in the procedure is given below.

Mobile phase. The mobile phase was prepared by mixing 560 ml of HPLC-grade methanol and 440 ml of 0.035*M* formic acid. Ten milliliters of tetrabutylammonium hydroxide (40%, w/w, solution in water) was added, and the pH was adjusted to 4.2–4.3 by the addition of 5*M* sulfuric acid. The solution was filtered through a nylon membrane (47 mm, 0.45-μm pore size) and deaerated by stirring in vacuo for 3–5 min.

Chromatography. The mobile phase was pumped through the heated (40°C) PRP-1 5-μm (150 × 4.1 mm) column (Hamilton Co., Reno, NV) at a rate of 0.8 ml/min. The injection volume was 20 μl.

Measurement of Starch

Enzymatic determinations of starch were accomplished by a procedure used by Salomonsson et al (1984). Duplicate samples of bran flakes (300–450 mg) were weighed into 25-ml thick-walled Pyrex-glass tubes that could be sealed tightly with Teflon-lined screw caps.

Acetate buffer (0.1*M*, pH 4.8, 20 ml) and thermostable α-amylase (E.C. 3.2.1.1, Termamyl 120 L, Novo A/S, Bagsvaerd, Denmark, 132 KNU/g, 80 μl) were added, and the tubes were placed in boiling water for 30 min. During the 30-min incubation, the sealed tubes were shaken a minimum of three times. After removal from the boiling water, the tubes were allowed to cool to about 50°C, and suspended amyloglucosidase from *Aspergillus niger* (E.C. 3.2.1.3 Sigma, A-3514, 150 μl) was added. The test tubes were capped, placed at 55°C in a water bath, and shaken overnight. After the test tubes were cooled to room temperature and centrifuged (3,500 rpm, 10 min, i.e., about 2,800 × *g*), glucose concentrations were measured in 10-μl aliquots of the supernatants by a glucose oxidase procedure (Sigma Diagnostics Glucose [Trinder], procedure No. 315, Sigma, St. Louis, MO). The starch content of each bran fraction was assayed in duplicate.

Other Measurements

Moisture, protein, ash contents, and alkaline water retention capacity of flours were determined in duplicate by AACC methods 44-15A, 46-11A, 08-01, and 56-10, respectively (AACC 1983). Six important milling and baking parameters—straight grade flour yield, in percent (EXT); break flour yield, in percent; endosperm separation index, in percent (ESI); friability; alkaline water retention capacity; and cookie diameter—were used to evaluate wheat flours (Finney et al 1987). Some comments and definitions of ESI and friability, as used by the USDA ARS Soft Wheat Quality Laboratory, are presented in the appendix to this article.

The content of starchy endosperm (flour) adhering to the bran fractions was estimated to obtain approximate values of bran phytate contents on a "flour free" basis. We assumed that such a calculation would be useful in removing a potential bias when comparing the phytate contents of the brans.

The amount of endosperm that adheres to the bran particles is variable and depends on several factors. The protein content of the endosperm associated with the bran was estimated to be the same as that of the flour milled from the wheat samples. This protein estimate is likely to be low, for studies have shown that the protein content of the starchy endosperm decreases as a function of distance from the exterior to the center of the kernel (MacMasters et al 1971). For calculation purposes, we considered endosperm to be flour that consisted of two components: starch and protein. Since 100% minus percent protein is estimated to

TABLE I
Contents of IP6[a] and Starch, Estimated Contents of Endosperm and of IP6 in Endosperm-Free Brans, Protein Contents of Straight-Grade Flours Obtained from Different Size Distributions of Soft Wheat Kernels, and Percent Weight Fraction Values of Size Distributions[b]

Sample[c]	IP6 in Bran[d] (%)	Estimated IP6, Without Endosperm (%)	Kernel Weight Fraction (%)	Starch in Bran (%)	Protein in Flour (%)	Estimated Weight Endosperm in Bran (%)
Adena						
OV 9/64	4.48 Ac (0.18)[e]	5.71 Ac (0.20)	16.2	19.6	9.3	21.6
Th 9/64, Ov 7/64	4.01 bc (0.30)	5.24 bc (0.41)	79.1	21.3	9.2	23.4
Th 7/64	3.19 Ab (0.04	4.22 Ab (0.08)	4.8	22.4	8.7	24.4
Florida 301						
Ov 10/64	4.78 A (0.17)	5.50 A (0.19)	3.6	11.4	13.4	13.1
Th 10/64, Ov 8/64	4.61 B (0.10)	5.44 B (0.17)	81.5	12.9	12.4	14.6
Th 8/64	3.74 AB (0.16)	4.43 AB (0.19)	14.9	13.5	13.5	15.6
Frankenmuth						
Ov 10/64	5.41 A (0.11)	6.56 A (0.14)	5.3	15.8	9.9	17.5
Th 10/64, Ov 8/64	5.12 b (0.37)	6.27 b (0.37)	88.0	16.8	9.9	18.6
Th 8/64	4.63 Ab (0.24)	5.76 Ab (0.22)	6.7	17.9	9.4	19.7
Hart						
Ov 8/64	5.11 (0.16)	6.32 (0.22)	20.6	17.1	11.3	19.3
Th 8/64, Ov 7/64	5.05 (0.11)	6.33 (0.12)	72.1	18.1	10.9	20.3
Th 7/64	4.86 (0.12)	6.13 (0.17)	7.3	18.1	10.9	20.3
Severn						
Ov 9/64	5.91 (0.32)	7.03 (0.34)	11.2	14.3	10.2	15.9
Th 9/64, Ov 7/64	5.54 (0.29)	6.78 (0.31)	86.6	16.5	9.5	18.2
Th 7/64	5.39 (0.18)	6.70 (0.28)	2.2	17.9	8.8	19.6
Titan						
Ov 9/64	4.91 (0.30)	5.99 (0.38)	10.6	16.3	9.1	17.9
Th 9/64, Ov 7/64	5.07 (0.20)	6.41 (0.27)	86.8	19.1	9.1	21.0
Th 7/64	4.66 (0.19)	6.10 (0.24)	2.7	21.5	9.2	23.7

[a] Phytic acid.
[b] All values in table reported on a dry weight basis. Within a variety, values not followed by letters were not significantly different. Within each variety, values in a column with the same letter are significantly different. Capitals, $P < 0.001$; lower case, $P < 0.05$.
[c] Th = through sieve size, Ov = over sieve size.
[d] Pooled data of $n = 6$, three values from each sieved bran distribution, except for Titan, where $n = 3$ (Th 7/64 seed, Ov 10 bran not available).
[e] Standard deviation of means are given in parentheses.

equal the percent starch in the flour, and since the weight percent starch in the bran fraction had been measured, the following definition was used to estimate the amount of endosperm in a sieved bran fraction: Dry wt. % endosperm = 100 × dry wt. % starch/(100 − dry wt. % protein in flour associated with a bran fraction).

Statistical Calculations

All calculations were done on a personal computer using programs and procedures provided by the SAS Institute Inc. (SAS 1987).

RESULTS AND DISCUSSION

The data in Table I demonstrate that for three of the varieties, Adena, Florida 301, and Frankenmuth, the phytate content of bran from kernels in the smallest size distribution was significantly lower than that for kernels in the larger distributions. For these three cultivars, the weight percent of the smallest kernel fractions was 4.8–14.9. Bran of the smaller kernels contained about 12–26% less phytate than that from the two larger sizes. For Adena, significant differences in phytate content were found between all three size distributions. Thus, for some cultivars, the bran phytate content was related to kernel size.

The statistical significance of differences in percent IP6 between the size distributions was essentially unaltered when calculated on a "flour-free" basis. This result, that the significance of comparisons between bran phytate and other parameters was independent of the estimated endosperm content of the bran, was mirrored in all other comparisons presented in this study. The weight percent endosperm values are composed of two terms: starch and protein, wherein the protein content of flour (column 6 in Table I) varies from 8.7 to 13.5%. Differences in protein content of wheat endosperm starch between the exterior and the center of the kernel are reported to range from 4.1 to 9.1 percentage points (MacMasters et al 1971, Table XVI). Assuming that the percent protein values of the flour were representative of endosperm located half the distance from the kernel center to the kernel exterior, the endosperm located near the exterior might contain an additional 5 percentage points of protein. If, in fact, the protein content of flour associated with the bran was 5 percentage points greater, the consequence would be an average underestimate of 1.2 (SD = 0.2) percentage points of endosperm in the bran. The amounts of endosperm calculated to be in the bran fractions range from 13.1 to 24.4% (column 7 in Table I). Although these estimates are uncertain because the protein content of the endosperm adhering to bran might be higher than that measured for flour, the variation in estimated adhering-endosperm content among brans of different cultivars did not affect comparisons made in this study. The finding that significance levels between size distributions of a specific cultivar were the same for bran with and without flour suggests that the wheats were milled uniformly.

Only trace amounts of IP3 (<0.03% of total IP6 + IP5 + IP4) were found in samples from both groups of cultivars. Very small amounts of IP4 (<0.08 %) were measured. Average values of IP5 in brans from the first group of six cultivars were low and ranged from 0.25 to 0.59 wt. %, or from about 5 to 10% of the IP6 present. Table II presents IP6 and IP5 values for cultivars at each location. IP6 means are significantly different among the locations but not between red and white cultivars at a location. Our values of IP5 and IP6 are within the range reported for raw wheat bran by Sandberg and Ahderinne (1986).

Pooled means of parameters from 15 cultivars grown at each location are listed in Table III. Differences were tested by *t*-tests of least square means in an analysis of variance procedure. Phytate content differences among the three locations were highly significant, as were differences in flour protein content. Starch contents of the bran were not significantly affected by environment and, of the remaining parameters, cookie diameter was least affected. Differences between means for at least one pair of locations were highly significant for the remaining parameters. Thus, bran phytate content and flour protein content were affected by environmental factors and bran starch content was not.

Significant correlations between measurements taken over all cultivars and locations are presented in Table IV. Two of these correlations, ESI with friability, and ESI with EXT, were also significant within each location. The phytate content of bran, corrected or not for flour content, was correlated with the milling parameters ESI, EXT, and friability. ESI, which is a measure of the energy required to separate the endosperm from the kernel, was negatively correlated with phytate content. Thus, endosperm was separated better from wheats in which the phytate content of the bran was higher. Friability, which is a measure of the energy required to grind flour, and EXT were both correlated

TABLE II
Phytate Content[a] of Brans from Cultivars Grown at Three Locations

	Crop Location					
	Michigan		Indiana		Washington	
	IP6	IP5	IP6	IP5	IP6	IP5
Red cultivars						
Arthur	6.37	0.29	3.66	0.16	4.97	0.14
Auburn	5.31	0.27	2.75	0.09	4.23	0.18
Caldwell	5.22	0.27	3.36	0.16	4.73	0.18
Cardinal	5.03	0.25	2.57	0.13	3.45	0.18
Hillsdale	5.34	0.25	3.11	0.09	4.05	0.12
Pioneer 2550	5.05	0.27	2.88	0.16	...	...
Tyler	4.85	0.24	2.93	0.19	3.30	0.16
Average[b]	5.31 Ab		3.04 Ac		4.12 bc	
(SD)	(0.50)		(0.37)		(0.67)	
White cultivars						
Augusta	4.72	0.26	2.72	0.12	3.92	0.20
Crew	5.71	0.30	2.66	0.13	4.07	0.18
Daws	5.92	0.28	2.99	0.13	3.83	0.15
Frankenmuth	5.11	0.26	3.62	0.12	3.97	0.16
Hill 81	6.08	0.29	3.37	0.12	4.45	0.15
Lewjain	5.13	0.29	3.05	0.14	4.04	0.15
Nugaines	5.19	0.20	2.58	0.10	3.39	0.14
Stephens	5.51	0.24	4.21	0.13	3.79	0.16
Average	5.42 AB		3.15 Ac		3.93 Bc	
(SD)	(0.46)		(0.56)		(0.30)	

[a] Percent dry weight basis. Pooled values for each cultivar are an average of six measurements, three each from brans collected over 10- and 20-mesh screens.

[b] Within each row, means with the same letter are significantly different. Capitals, $P < 0.001$; lower case, $P < 0.01$. Within each location, there is no significant difference between means of red and white cultivars.

TABLE III
Attribute Means[a] of Soft Wheat and Corresponding Brans and Flours Grown at Three Locations

	Crop Location		
Variable[b]	Michigan	Indiana	Washington
IP6 in bran,[c] %	5.37 A (0.47)[d]	3.10 A (0.45)	4.01 A (0.48)
IP6 "flour free,"[c] %	6.62 A (0.49)	3.92 A (0.55)	5.02 A (0.55)
Starch in bran,[c] %	17.2 (2.7)	19.1 (1.8)	18.2 (2.3)
AWRC, %	50.1 A (1.8)	51.0 B (2.4)	53.7 AB (1.3)
Break flour, %	31.9 A (2.9)	30.4 B (2.3)	24.9 AB (2.6)
Flour ash, %	0.42 A (0.04)	0.42 B (0.06)	0.35 AB (0.02)
Flour protein, %	10.6 A (0.7)	11.9 A (1.3)	8.85 A (0.6)
Friability, %	27.8 A (0.9)	26.1 AB (1.3)	27.7 B (0.8)
Cookie diameter, cm	18.3 a (0.3)	18.0 (0.4)	17.8 a (0.3)
ESI, %	10.6 a (1.1)	12.2 aB (1.7)	10.1 B (1.2)
EXT, %	76.6 A (0.9)	74.6 AB (1.6)	76.9 B (0.9)
Test weight, lb/bu	61.1 Ab (1.0)	59.0 bC (2.4)	64.2 AC (1.1)

[a] Capitals, $P < 0.001$; lower case, $P < 0.01$. P = Probability of no significant difference between means in a row. Values with same letter are significantly different.

[b] IP6 = phytic acid, AWRC = alkaline water retention capacity, ESI = endosperm separation index, EXT = straight-grade flour yield.

[c] Bran properties expressed as percent dry weight. Flour and milling parameters expressed on 14.5% moisture basis.

[d] Standard deviation of means are given in parentheses.

TABLE IV
Significant[a] Correlation Coefficients Among Phytate and Wheat Quality Parameters

	ESI[b] (%)	EXT[c] (%)	Friability (%)	Flour Protein (%)	Flour Ash (%)	Test Weight (lb/bu)	Cookie Diameter (cm)
IP6,[d] %	−0.41*	0.53**	0.47*	...	...	...	...
ESI, %	...	−0.94**	...	...	...	−0.59**	...
EXT, %	...	...	...	...	...	0.67**	...
AWRC,[e] %	...	...	...	−0.39*	...	0.44*	−0.79**
Break flour, %	...	...	...	0.44*	0.58**	−0.62**	...
Flour ash, %	0.42*	−0.43*	−0.42*	0.73**	...	−0.73**	...
Flour protein, %	0.57**	−0.62**	−0.55**	...	...	−0.79**	...
Friability, %	−0.85**	0.82**	...	...	...	0.50**	0.43*

[a] Probability of correlation not being significant: * = $P < 0.01$, ** = $P < 0.001$. Correlation coefficients with $P > 0.01$ not listed.
[b] Endosperm separation index.
[c] Straight-grade flour yield.
[d] Phytic acid. Corresponding values for IP6 "flour free" differ by 0.01.
[e] Alkaline water retention capacity.

TABLE V
Estimates of Ratio of Environmental Influences to All Other Influences[a] for Percent Bran Phytate Content (IP6) and Flour Quality and Baking Parameters

Variable[b]	Environmental Influences/All Other Influences
IP6, %	6.75
Flour protein, %	2.63
Test weight, lb/bu	2.47
Break flour, %	1.94
EXT, %	1.12
AWRC, %	0.89
Flour ash, %	0.80
Friability, %	0.76
ESI, %	0.57
Cookie diameter, cm	0.34
Starch, %	0.11

[a] The ratio is σ_L^2/σ_R^2, where σ_L = variation due to location differences and σ_R = residual variation due to all other influences.
[b] EXT = straight-grade flour yield, ESI = endosperm separation index, AWRC = alkaline water retention capacity.

positively with bran phytate content. Since friability, EXT, and ESI were strongly correlated with each other, it is not surprising that all three were correlated with IP6. We infer from these three correlations that, in general, endosperm in wheat kernels that yielded bran with higher phytate levels was easier to separate and fracture than was endosperm from wheat that yielded less phytate in bran. Reasons for this behavior are unclear. We did not find significant correlations between IP6 and protein content. However, Raboy et al (1991) report a significant correlation between protein content and total phytate content in hard red winter wheat cultivars.

Values of bran phytate content and milling and flour quality parameters were highly variable across cultivars and growing locations. Attempts were made to investigate relationships between variety and the effects of environment upon the parameters in Table III. Following an approach in a study involving 12 locations (Baenziger et al 1985), variety responses to environment were estimated by regressing the variety mean on the environmental index values. (The environmental index values were calculated by subtracting the grand mean from the mean at each location). Another approach involved ranking each variety within each parameter and location and then calculating rank correlations (a high rank correlation could be an indicator of a high genetic component to variance). A third approach consisted of calculating parameter means over the three locations and using the corresponding coefficients of variation (CVs) as a measure of environmental influences. The CVs for a given parameter were averaged across the 15 cultivars. Those cultivars for which CV values were relatively high or low when compared with the other cultivars were defined as being less or more environmentally stable, respectively, with respect to the given parameter. These approaches did not yield consistent results. We concluded that the relationships among the parameters, the cultivars, and the locations were not simple and that our database was too limited to examine the interactions in meaningful detail.

As has been done in previous studies (Pomeranz et al 1985, Peterson et al 1986), we also obtained estimates of variance components associated with location and parameters (Table III). An analysis of variance was run for each variable, with location (environment) as a main effect. A variance estimation procedure (SAS 1987) was used to estimate variation due to location differences (σ_L^2) and the residual variation (σ_R^2). The component σ_R^2 includes a genetic (cultivar) term, a genetic-by-location term, and an error term, each of which may be significant. We consider the ratio σ_L^2/σ_R^2 to be suggestive of environmental variance relative to "all other" influences, with the possibility that the genetic and genetic-by-location terms may be substantial. This ratio is listed in Table V for each variable studied. (Lukow and McVetty [1991] demonstrated that the breadmaking quality parameters of eight hard red spring semidwarf wheat cultivars were significantly affected by both cultivar and environment and that cultivar-by-environment effects were relatively small in magnitude for most parameters).

Values in Table V indicate that, in brans, IP6 is affected mainly by environmental influences (in agreement with the results in Table II), whereas starch content is affected mainly by other influences. Our value of 2.6 for the ratio of environmental influences to all other influences for flour protein agrees well with the estimates of 3.3 and 3.2 obtained by Pomeranz et al (1985) and Peterson et al (1986), respectively, for the ratio of environmental to genetic influences. Since 85–90% of the phosphorus content of wheat bran arises mainly from phytate (Lolas et al 1976), it appears that our conclusion that IP6 content is affected mainly by environment might conflict with that of Peterson et al (1986), who reported that the phosphorus content of wheat bran is similarly affected by environment and genetics (i.e., variance components, environment:genetics = 0.89). The differences in our results may reflect differences between measuring phytate rather than total phosphorus content and/or our limited database.

CONCLUSIONS

In this study, the phytate content of the bran was related to kernel size for some cultivars, such that bran from larger kernels contained more phytate. Our concern that variation in endosperm adhering to the bran might confound the interpretation of data was unfounded. In this study, relationships between IP6 content and other variables were independent of flour content.

Perhaps the most interesting and potentially useful finding was that significant, although moderate, correlations exist between the phytate content of bran and the milling parameters ESI, EXT, and friability. We infer from these correlations that endosperm is more easily separated from bran and reduced to flour in soft

spring wheats in which the bran has a higher IP6 content. It seems worthwhile to consider a further study using greater numbers of red and white cultivars and replicates so that effects of color and estimates of genetic versus environmental effects could be estimated more accurately.

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APPENDIX

The following are the Allis-Chalmers milling definitions used by the USDA ARS Soft Wheat Quality Laboratory.

Endosperm Separation Index (ESI)

Once the wheat kernel has been operated by the initial corrugated break roll action, subsequent corrugated break rolls are used to separate floury endosperm from the seed coat. Aside from coarse scalp bran, fine bran, nonreduced endosperm, and (depending on the hardness of the wheat) variable amounts of flour are produced by the corrugated rolls. Nonreduced endosperm is diverted to smooth rolls to be crushed to flour fineness while simultaneously limiting the reduction of fine bran. Wheats in which the bran and endosperm are difficult to separate also produce bran-free middlings stock (i.e., nonreduced endosperm), which is comparatively more difficult to reduce with smooth rolls than is bran-free middlings stock from wheats in which the bran and endosperm are more easily separated.

ESI is calculated by adding three fractions: 1) scalp bran from the first and second break coarse middling stock after one smooth roll pass, 2) fine bran produced by the intermediate break rolls, and 3) the bran from the last break. That quantity is divided by the total experimental flour recovery. Then the theoretical bran (14.5%) and the theoretical germ (2.5%), i.e., 17% of that total, is subtracted to yield theoretical flour (endosperm) remaining attached to the bran. The lower the value is, the better the separation was between endosperm and bran. Therefore, the lower the ESI value is, the better the wheat is for milling.

Friability

Friability is the propensity of the wheat endosperm conglomerates after breakage by the mill break rolls to be reduced to flour particle size. It is a measure of the energy required per unit of flour extracted from wheat and is defined as the quantity of straight grade flour divided by the total amount of stock, minus initial wheat weight, that has passed through the break and reduction rolls. Thus, that figure is a percent of flour obtained from the amount of stock worked on by the sets of rolls in the mill. When the total amount of stock worked on is lower, the percent friability is higher and less energy is required to obtain a unit of flour.

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