

# Differences in the Aleurone Layer Fate Between Hard and Soft Common Wheats at Grain Milling

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## ABSTRACT

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In the milling process, efficient separation between the starchy endosperm and the other grain tissues is a key parameter estimated by ash measurement. Because this separation occurs near the aleurone layer interface, better understanding of this tissue fractionation is critical for a better analysis of the wheat milling behavior. Samples from hard and soft common wheat cultivars that had the same protein content were processed on a pilot mill, and whole grain meals or flour streams were analyzed for ash content. The para-coumaric acid (*p*-CA) and phytic acid flour contents were compared with ash measurement and used as markers

of the aleurone cell walls or aleurone cell content, respectively. A greater amount of phytic acid in hard wheat flour compared with soft wheat flour was found and reveals a distinct milling behavior between those wheat classes, mainly at the breaking step. Therefore simple ash content measurement is not sufficient to analyze flour purity. At the reduction stage, quantity of phytic acid increases with the other markers and may result from the overall mechanical resistance of the aleurone tissue. As a consequence, wheat hardness not only determines grain milling behavior but also affects flour composition.

Common wheat dry milling is a complex process that aims at separating the starchy endosperm from the other grain tissues and at gradual size reduction into flour. This process includes two major steps. In the break milling stage, wheat grain is opened and most of the endosperm that is to be recovered as flour is isolated from the other tissues. In the reduction milling stage, farina obtained in the first step is reduced into flour and any remaining particles from the bran and germ removed. At each of the milling stages, the type of flour produced is different as its originates from distinct parts of the grain and because the mechanical forces applied are different. At the end of the process, total flour is composed of a mix of each of the fractions obtained.

As flour composition determines functional and nutritional characteristics, the biochemical composition of the different flour stream fractions have been investigated by many workers (Nelson and McDonald 1977; Morrison and Hargin 1981; Prabhasankar et al 2000). It is now well established that proteins, phenolic acids, and ash contents increase from the first to the later passes of each milling step, but the histological and structural origins of these compounds have not been intensely investigated.

The ability to produce a large amount of flour with a controlled purity has been defined as the wheat milling efficiency (Abecassis 1993). Therefore, not only flour yield but also identification in the flour of tissues other than the starchy endosperm appears as a critical point to control flour purity and composition. This identification is possible because these tissues have a different chemical composition than the starchy endosperm (Hinton 1959; Mac Master et al 1971; Bacic and Stone 1981). The usual parameter to measure flour purity is the ash content. Indeed, gradient of cell compounds concentration occurs in the endosperm because starch concentration decreases and ash and protein concentration increase from the center to the periphery (Evers and Millar 2002). The inner endosperm may only contain 0.3% of the total ash content. However, wheat grains vary in the amount of ash they produce in their mill streams, and small variations in ash content of flours do not necessarily imply the presence of different amounts of other grain tissues (Abecassis 1993). Milling efficiency depends on three essential intrinsic grain parameters. First, the required energy to fracture the kernels and subsequent fractionation behavior depend

on endosperm hardness (Kilborn and Martin 1982; Davis and Eustace 1984). Second, flour purity and thus variable incorporation of the other grain tissues into flour largely depends on their friability (Peyron et al 2002). Finally, the degree of adhesion between the other grain tissues and the starchy endosperm could have consequences on the starch content of bran, the amount of flour obtained, and the flour purity. As an interface tissue between the starchy endosperm and the envelopes, but mainly found in bran fraction, the aleurone layer should be an interesting tissue to observe during milling to better describe the wheat behavior during fractionation and to better understand how separation occurs during milling.

In this study, we used two different biochemical markers to follow the aleurone cell contents or aleurone cell walls and we compared those markers with ash measurement. Phytic acid (myo-inositol 1, 2, 3, 4, 5, 6 hexakisphosphate), the major form of grain phosphorus storage, which is particularly concentrated in the aleurone cell content granules, was used as a relevant marker to follow the aleurone cell contents (Lasztity 1990; Antoine et al 2002; Raboy 2003). For the aleurone cell wall components, para-coumaric acid (*p*-CA) was chosen among phenolic acids esterified to arabinoxylans, as it is particularly concentrated in the aleurone layer cell walls (Antoine et al 2004). Those two markers were quantified in flours produced at the milling steps to follow the aleurone cell contents or aleurone cell wall fate during milling wheat samples that represented variability in milling fractionation behavior.

## MATERIALS AND METHODS

### Wheat Samples

Common wheat (*Triticum aestivum* L.) from cultivars with different kernel hardness (measured by NIRS analysis) were selected (Soissons, Camp Rémy, Apache, Caphorn as hard/medium hard, and Crousty, Scipion, and Ornicar as soft). All samples were harvested in France in 2002 and the test weight mean values were 81.1 kg/hL for hard wheats and 77.9 kg/hL for soft wheats. The protein content of each batch was determined by NIRS analysis (Approved Method 39-70A, AACC 2000) and batch samples of each cultivar with a protein content of 10.9–11.3% were evaluated in this study. Wheats were cleaned to remove impurities and stored at room temperature before milling.

### Milling Fractions

Cleaned wheat (10 kg) from each sample was conditioned to 17.0% moisture content and tempered 24 hr before milling. Tem-

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pered samples were then milled on a pilot mill (Siraga, ENSMIC, Paris, France) equipped with four break rolls, four sizing rolls, and six reduction rolls as described by Willm (1995a). This milling process produced four break (B1 to B4), four sizing (S1 to S4), and six middling (R1 to R6) flours, two bran, and two short fractions. Each fraction was collected, and yield was expressed as weight percentage of the total recovered products. Total flour was obtained by mixing fractions according to respective yield. The collected samples and total flour were stored at 4°C.

### Moisture, Ash, and Phytic Acid Contents

Moisture and ash contents were determined according to standard methods ISO 711-1978 and to Approved Method 08-12 (AACC 2000), respectively. Phytic acid was measured at 500 nm from acidic extract of ground wheat meals or mill flour fractions using a colorimetric method described by Latta and Eskin (1980) and modified by Vaintraub and Lapteva (1988). A standard curve was obtained with corn phytate (P-8810, Sigma) solutions of known concentrations.

### Phenolic Acids Analysis

Ground wheat meals or flours (100 mg) were treated at 35°C for 2 hr with 2.0M sodium hydroxide (10 mL) in the dark and under Argon to prevent hydroxycinnamate oxidation. After addition of an internal standard, 2,3,5-tri-methoxy-(*E*)-cinnamic acid (TMCA, T-4002, Sigma Chemical Co., St. Louis, MO), the solution was adjusted to pH 2.0 with 4M hydrogen chloride, and phenolic acids were extracted twice with diethyl ether. Ether phases were evaporated in the presence of Argon and the dry extract was dissolved in aqueous methanol (50:50, v/v), filtered (0.45 µm), and injected (20 µL) on an Alltima R18 column (5 µm, 250 × 4.6 mm, Alltech, Deerfield, IL) for RP-HPLC analysis. Elution was obtained at 1 mL/min and 35°C by increasing acetonitrile concentration in sodium acetate buffer (50 mM, pH 4.6). A linear gradient was performed with the following steps: 15:85 to 35:65 in 24 min, 35:65 to 60:40 in 0.5 min, 60:40 to 15:85 in 4.5 min, and 15:85 for 5 min and UV was detected at 320 nm with a 996-photodiode array detector (Waters, Milford, MA). Phenolic acids were identified by absorption spectra and quantified relative to the internal standard response and the corresponding commercial product.

### Statistical Analysis

Analysis of variance and Student's test were conducted to identify differences among means ( $n = 7$ ) using Statgraphic software (Manugistics, Rockville, MD). Results from ground wheat

meals, total flours, head-end, and tail-end flour streams were analyzed independently. Statistical significance was considered using  $P < 0.05$ .

## RESULTS AND DISCUSSION

### Wheat Samples and Milling Process

Wheat samples were selected on the basis of similar protein content ≈11% (dm) and divided into two classes according to grain hardness estimated by NIRS analysis (hard 64–84 and soft 14–24). Samples were treated in the same conditions with a pilot mill that well describes the milling behavior observed by commercial millers for a given sample (Willm 1995a). Mean yield values of each of the milling fractions of the two hardness classes are reported in Table I. Milling behavior of the samples were typical of hard and soft wheat cultivars. As previously observed, soft wheats produce more break flour than hard wheat grains that produce more farina (Willm 1995a). Break flour production was 12.5–21.2% and farina was 46.7–63.2%. Production of large farina particles for the first sizing roll is usually highly linked to endosperm hardness on the mill. Such differences in the farina production affects the sized reduction stage feeding (Willm 1995b). Consequently, hard wheats display a lower flour yield at the breaking stage but produce more flour during the reduction stages. Soft wheat samples produced more coarse bran than hard wheats, as was expected.

Even if hardness has important consequences in milling behavior, it usually shows little influence on flour yield at a given purity as measured by the ash content. Wheat hardness does not explain much more than 10% yield variability in flour yield (Fowler and De La Roche 1975). However, in the present study, hard wheat exhibited a slightly higher mean yield which was also observed by Bass (1988). Soissons showed the best milling efficiency with a 81.5% flour yield at 0.5% ash level. One hard and one soft wheat (Camp Rémy and Ornicar, respectively) had good milling efficiency (79.7 and 78.5% flour yield at the 0.5% ash level). Two other hard and soft wheats (Caphorn and Crouty, respectively) showed poor milling efficiency (73.5 and 71%). The other samples produced intermediate milling efficiency values (≈75%). Therefore, the milling behavior of the samples analyzed in this study represented the typical variability observed in French common wheat milling efficiencies.

### Ash Content as a Marker of Bran

Common wheat endosperm contained only 25% of the grain minerals (Abecassis 1993). Therefore, ash content is mainly con-

TABLE I  
Flour, Short, and Bran Fractions Mean Yield Value (% w/w) for Hard and Soft Wheat Classes<sup>a</sup>

	Flours			Farina	Bran		Shorts		Total Flour	
	Break	Sizing	Reduction		Coarse Bran	Fine Bran	Brown Shorts	Shorts	Total Flour	0.5% Ash Level
Hard wheats	14.0 (8.8)	29.2 (9.9)	36.7 (8.8)	61.3 (3.4)	4.8 (13.8)	4.0 (14.3)	8.5 (0.9)	2.9 (1.0)	79.9 (1.1)	76.3 (5.2)
Soft wheats	20.7 (4.5)	31.5 (2.6)	25.3 (8.3)	49.9 (6.5)	6.6 (10.4)	4.9 (9.4)	8.1 (0.5)	3.1 (0.4)	77.5 (0.5)	74.9 (3.8)

<sup>a</sup> Values in parentheses are the coefficient of variation.

TABLE II  
Ash Content (% dm) of Wheat Meals, Flours, and Flour Fractions from Head and Tail Rolls at Break, Sizing, and Reduction Milling Step<sup>a,b</sup>

	Grains	Total Flour	Head-End Flour Streams			Tail-End Flour Streams		
			Break B1	Sizing S1	Reduction R1	Break B4	Sizing S4	Reduction R6
Hard wheats	1.60x (0.07)	0.54y (0.04)	0.48a (0.04)	0.34a (0.10)	0.35a (0.05)	1.98b (0.21)	2.07b (0.29)	1.77ab (0.20)
Soft wheats	1.62x (0.01)	0.52y (0.05)	0.37a (0.07)	0.41a (0.03)	0.39a (0.06)	1.39a (0.23)	1.80ab (0.13)	1.62ab (0.04)
Effect of fraction				ns				ns
Effect of hardness				ns				**
Fraction × hardness				*				ns

<sup>a</sup> Values followed by the same letter are not significantly different ( $P < 0.01$ ). Values in parentheses are the standard deviation.

<sup>b</sup> \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; ns, not significant.

centrated in the bran, and ash measurement is the usual parameter to assess flour purity and, consequently, wheat milling efficiency. Table II shows the ash content mean values of soft and hard wheat meal, total flours, or head-end and tail-end flour streams from each break, sizing, and reduction stages. Whole grain meal and total flour ash contents were in accordance with previous reports obtained from samples of different origins (Willm and Fourre 1998; Berton et al 2002). In the first milling streams, that is, flours from the first break roll (B1), sizing roll (S1), and reduction roll (R1), no significant differences were observed from hard and soft wheat cultivars. The low ash concentration measured in flours obtained from the first milling streams supported a preponderance of the starchy endosperm produced there, whereas flours from the tail-end of the mill (B4, S4, R6) were particularly rich in ash. Conversely, hardness has a significant effect on ash content of flours from the tail-end milling streams and more precisely between the break and the reduction flours. Results show that hard wheat flours from the tail-end milling streams have a higher ash content than the corresponding soft wheat flours. Consequently, hard wheat flours exhibited a higher increasing rate of the flour ash content along the milling process. Nevertheless, the important standard deviations indicate that classification according to hardness does not explain all the variability in flour ash content. Indeed, ash content of endosperm could greatly vary so that differences in flour ash content would not always mean differences in bran incorporation. Thus, assessment of bran fractionation requires the use of more specific tissue markers to further describe the contribution of different grain tissue to flour.

Separation between bran and the starchy endosperm occurs near the aleurone layer at the interface between the tissues, which shows a different structure and biochemical composition than the rest of the endosperm (Hinton 1959; Morrison et al 1975; Pomeranz 1988; Dobraszick 1994). Thus, study of the aleurone layer distribution and damage appears interesting to follow along the milling steps. That will indicate grain fractionation behavior relative to the mechanical constraints applied to separate the tissues. Measurement using biochemical markers has been successfully used to monitor bran fractionation (Peyron et al 2002; Antoine et al 2004). Therefore, molecular markers from either the aleurone cell content or the aleurone cell wall material were analyzed in the flours to describe the fate of the aleurone layer during milling.

### *p*-Coumaric Acid as a Marker of Aleurone Cell Walls

*p*-CA is one of the phenolic acids linked to cell wall polysaccharides (Smith and Hartley 1983; Hartley and Ford 1989). It has been used as a marker of aleurone cell wall material as it is three to five times more concentrated in the aleurone layer than in envelopes and is absent from endosperm (Antoine et al 2004). Thus, to follow the aleurone cell walls, *p*-CA concentration was measured in flours and the mean values reported in Table III.

Soft and hard wheats exhibited similar *p*-CA average content ( $2.2 \pm 0.6 \times 10^{-3}$  %, dm). No significant differences appeared between hard and soft wheat total flours and flours from the first milling streams. However, flour from the head of the breaks (B1) contained significantly more *p*-CA than other flours from the front of the mill. In tail-end flour streams, similar *p*-CA content was also found for both soft and hard wheats, except the break flour (B4) from hard wheat grains, which is significantly enriched in *p*-CA compared with the respective flours from soft wheats. Therefore, *p*-CA enrichment of the fractions appears mainly at the break flour milling stage and any difference between hard and soft wheat was only significant at the last break stage. As flour *p*-CA content could either originate from tissue damage or incorporation of the aleurone layer into the fraction, examination of the aleurone cellular content marker distribution is needed.

### Phytic Acid as a Marker of Aleurone Cell Contents

The aleurone layer contains cells rich in niacin or phytic acid (Morrison et al 1975). Phytic acid is not a specific marker of the aleurone tissue because 10–15% of total phytic acid has been reported to be in the germ (Lasztity 1990). However, it could be used to follow the aleurone cellular content (Antoine et al 2002). Indeed, it was found mainly concentrated in this tissue. Moreover, only a very small quantity of germ is incorporated in flour during milling (Kent et al 1949). Therefore the proportion of phytic acid originating from the germ in flours does not need to be considered. Measured amounts of phytic acid in total flours and head-end and tail-end flour streams are reported in Table IV. Phytic acid content in wheats varied from 11.2 mg/g to 19.7 mg/g but no significant difference was observed between mean values from hard and soft wheat samples. However, phytic acid concentration of flour fractions and total flours varied significantly according to hardness, suggesting that differences occurred at the milling pro-

TABLE III  
*p*-Coumaric Acid Content ( $\times 10^{-3}$  %, dm) in Wheat Meals, Flours, and Flour Fractions<sup>a,b</sup>

	Grains	Total Flour	Head-End Flour Streams			Tail-End Flour Streams		
			Break B1	Sizing S1	Reduction R1	Break B4	Sizing S4	Reduction R6
Hard wheats	2.19x (0.67)	0.29y (0.03)	0.43a (0.10)	0.16b (0.04)	0.10b (0.03)	2.6a (0.77)	1.48b (0.34)	1.45b (0.43)
Soft wheats	2.40x (0.73)	0.23y (0.04)	0.37a (0.12)	0.12b (0.01)	0.15b (0.05)	1.15b (0.26)	1.09b (0.25)	1.66b (0.51)
Effect of fraction				**			ns	
Effect of hardness				ns			*	
Fraction $\times$ hardness				ns			*	

<sup>a</sup> Values followed by the same letter are not significantly different ( $P < 0.01$ ). Values in parentheses are the standard deviation.

<sup>b</sup> \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; ns, not significant.

TABLE IV  
Phytic Acid Content (% , dm) in Wheat Meals, Flours, and Flour Fractions<sup>a,b</sup>

	Grains	Total Flour	Head-End Flour Streams			Tail-End Flour Streams		
			Break B1	Sizing S1	Reduction R1	Break B4	Sizing S4	Reduction R6
Hard wheats	1.58x (0.26)	0.37y (0.08)	0.26a (0.13)	0.28a (0.09)	0.24ab (0.07)	1.86a (0.24)	1.77a (0.39)	1.43ab (0.26)
Soft wheats	1.49x (0.32)	0.19z (0.07)	0.10b (0.01)	0.16ab (0.01)	0.16ab (0.02)	1.36ab (0.29)	1.36ab (0.12)	1.27b (0.13)
Effect of fraction				ns			ns	
Effect of hardness				**			**	
Fraction $\times$ hardness				ns			ns	

<sup>a</sup> Values followed by the same letter are not significantly different ( $P < 0.01$ ). Values in parentheses are the standard deviation.

<sup>b</sup> \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; ns, not significant.

cess. First, phytic acid content difference appeared clearly in total flours, indicating enrichment of the cellular content of the aleurone cell material in the hard wheat flours compared with the soft wheat flours.

Higher phytic acid concentration was observed among hard wheat flours all along the milling process, suggesting that the fate of the aleurone layer cell material content is linked to wheat hardness. Furthermore, the phytic acid content difference between hard and soft wheat flours was more pronounced at the breaking stage (rather three times more phytic acid in B1 flour from hard wheat samples) and at the sizing stage. Comparison with the *p*-CA variability suggest that phytic acid content was clearly different between hard and soft wheat flours, even if the fractions show the same amount of aleurone cell walls or ash content. Given that the proportion of the aleurone cell content and the aleurone cell walls were the same in wheats, differences must occur during the milling process. Additionally, these results suggest that the break and the sizing stages are critical steps to distinguish between hard and soft wheats.

### Incorporation Profile and Relationship Between Markers

The three biochemical markers used in this study, ash as the usual indicator of flour purity, and phytic acid or *p*-CA as markers for aleurone layer cell contents or aleurone cell walls, respectively, show differential concentration in flour streams according to wheat hardness and milling stage. Hard wheat flours from the front of the mill contained a higher concentration of phytic acid than respective soft wheat flours, but had the same ash content. Incorporation of the aleurone cell contents and aleurone cell wall material were dissociated and varied according to the milling fraction considered. Thus, relationship between markers is complex and was analyzed separately in head-end and tail-end flour streams without distinction between wheat harness class (Table V). Among head-end flour streams from each break, sizing, and reduction milling stage (B1, S1, R1), significant correlation between ash and *p*-CA content was observed, indicating that the increase in ash content of those fractions could be linked to *p*-CA incorporation within flours. Conversely, phytic acid content does not appear linked to ash or *p*-CA content, suggesting that incorporation of the

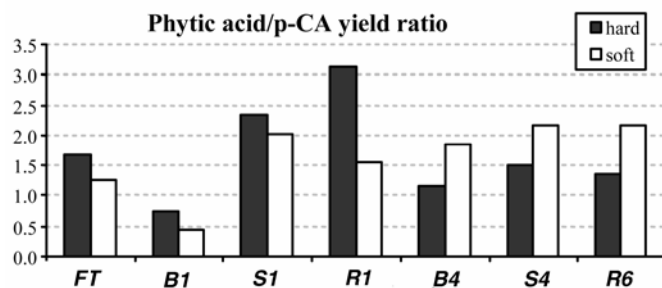
aleurone cell contents in the first milling passes of each stage is independent of the presence of the aleurone cell walls. In contrast, among the flours from the tail-end flour streams at each milling step (B4, S4, R6), all three markers were correlated, indicating that flour ash content could, in this case, result from the incorporation of both the aleurone cell contents and aleurone cell walls.

As the concentration of each fraction could also result from the proportion of each of the other tissues composing the flours, the distribution of the aleurone layer was observed as the percent yield of the phytic acid and *p*-CA markers in each flour (Fig. 1). Differences in the phytic acid/*p*-CA ratio all along the milling process were observed and confirm that aleurone tissue components are not incorporated in the same proportion but depend on the milling stage and on wheat hardness. Differences between hard and soft wheat flours are evident among total flours and flours from front of the mill at each milling step where phytic acid/*p*-CA ratio in hard wheat flours was greater than from soft wheat flours. Furthermore, the phytic acid/*p*-CA ratio increases from B1 to R1 for hard wheat flours, suggesting an increase in the proportion of the aleurone content from the break to the reduction stage. Phytic acid/*p*-CA ratio is particularly high during the farina reduction stages and reveals a greater extraction of the aleurone cell contents. However, in soft wheat flours, the distribution is quite different, as the highest phytic acid/*p*-CA ratio appears at the sizing stage.

Among the tail-end flour streams, the phytic acid/*p*-CA ratio appears similar within each hardness class, whatever the milling stage. This suggests that, at the end of each stage, aleurone fractionation was more likely to be a function of tissue friability. Soft wheat flours (B4, S4, R6) from these rolls contain a greater proportion of phytic acid, indicating that incorporation of the aleurone cell contents occurs later in the milling process.

Because most of the differences between aleurone cellular content from hard and soft wheats appear during the first steps of the breaking and sizing stages, this suggests a unique and distinct behavior in wheat kernel rupture for those wheat hardness classes. Indeed, on the first break roll, wheat kernels opened up and behaved differently under milling shearing forces depending on wheat hardness. Soft wheat endosperm tends to fracture through cells producing irregular particles. However, a higher proportion of fractures in hard wheat endosperm follow cell boundaries (Greer and Hinton 1950; Dobraszczyk 1994; Evers and Millar 2002).

Furthermore, the characteristics of bran obtained from those classes are also related to wheat hardness. First, hard wheats usually produce less coarse bran in milling than soft wheat (Table I). The smaller bran particles of hard wheat suggest that more aleurone cells should be opened, allowing the liberation of their content. Second, separation between starchy endosperm and the other grain tissues also appears more effective among hard wheats because hard wheat bran has lower starch content (Bass 1988). Thus, the greater elimination of the subaleurone portion of hard wheat could imply greater damage to bran and the greatest loss of the aleurone cell contents in the first flours. Thereafter, discrimination between the aleurone cell wall content is possible because of the particle size differences. Indeed, aleurone cell inclusions containing phytates measure <4 μm (Morrison et al 1975) and



**Fig. 1.** Ratio of phytic acid to *p*-CA yield in each milling flour. Yield of each marker was calculated as marker content × fraction yield/grain marker content × 100. FT is ratio for total flour; B1, S1, R1 are ratios for head-end flour streams from break, sizing, and reduction stages, respectively. B4, S4, R6 are ratios for tail-end flour streams from break, sizing, and reduction stages, respectively.

**TABLE V**  
Correlation Between Marker Contents in Head-End and Tail-End Flour Streams

	Head-End Flour Streams (B1, S1, R1)			Tail-End Flour Streams (B4, S4, R6)		
	Ash	<i>p</i> -CA	Phytic Acid	Ash	<i>p</i> -CA	Phytic Acid
Ash	–	×	×	–	×	×
<i>p</i> -CA	<b>0.45</b>	–	×	<b>0.56</b>	–	×
Phytic acid	0.26	0.24	–	<b>0.77</b>	<b>0.61</b>	–

<sup>a</sup> Values in bold represent significant correlation at *P* < 0.05 (Pearson test).

could easily be incorporated into flours. Aleurone cell walls, showing adhesion to the other outer layers, could remain attached to the largest size fraction and remain associated with the bran fraction (Antoine et al 2004).

Therefore, differences in the wheat response to shearing forces applied to separate the starchy endosperm from the bran could explain the variations observed in the flour contents and the phytic acid enrichment among hard wheat flours. A significant relationship ( $R^2 = 0.70$ ) could be found between the phytic acid content of flour from the first break roll (B1) and the coarse bran production during milling.

At the reduction stages, the phytic acid/p-CA ratio increases in hard wheat flours compared with soft wheat, suggesting that the farina reduced in these steps consisted of a more peripheral part of the kernel and still contained part of the outer layers. The greater incorporation of aleurone tissue content in flours could be attributed to an increasing pressure of the starchy endosperm on this outer layer. During reduction, mainly compression forces are applied to the farina fraction that corresponds to the harder part of the grain recovered after the initial breaking step. Then, composition of the reduction flours seems to originate mainly from the difference in the mechanical properties of the aleurone layer and the starchy endosperm.

In tail-end flour streams, the ratio between the aleurone content and aleurone cell walls remains constant. The ratio must be related more to the overall tissue friability than to the grain rupture behavior. From soft wheats, a higher proportion of the aleurone content is recovered in these fractions and correlates with lower damage of the aleurone layer occurring at grain opening in the first milling steps. As a consequence, difference in the flour composition and enrichment of the hard wheat flour in the content of the aleurone layer must influence the nutritional and technological properties (Antoine et al 2002). Indeed, the aleurone layer contains a number of compounds considered beneficial to nutritional balance (vitamins, minerals, essential amino acids) even if the role of phytic acid is controversial (Thompson 1993; Hartland and Morris 1995). However, it also contains lipids and enzymes (Morrison 1978) that could have adverse effects on the storage stability of flours and on end-use product characteristics.

## CONCLUSIONS

Wheat hardness is an important milling factor that affects the energy necessary to reduce wheat kernels to a flour particle size. Wheat hardness not only influences the way the kernels break apart during milling but also influences the origin of the tissue incorporated into flour. Major differences in the aleurone cell contents in flours from hard and soft wheats occur at the first break of the milling sequence. Those differences reveal how differently hard and soft wheats respond to the shearing forces applied at the break milling stages to separate the starchy endosperm from bran at the aleurone interface. At the subsequent reduction stages of milling, differences between flours more probably result from the overall mechanical properties of the tissues. Consequently, wheat hardness affects the histological composition of the flours.

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