

Influence of Kernel Size and Shriveling on Soft Wheat Milling and Baking Quality

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ABSTRACT

Cereal Chem. 74(6):700–704

Small kernels of soft wheat are sometimes considered to be harder than larger kernels and to have inferior milling and baking characteristics. This study distinguished between kernel size and kernel shriveling. Nine cultivars were separated into large, medium, and small kernels that had no shriveling. Eleven cultivars were separated into sound, moderate, and severely shriveled kernels. Shriveling greatly decreased the amount of flour produced during milling. It adversely affected all other milling quality characteristics (ash content, endosperm separation index, and friability). Shriveled kernels produced flour that had inferior soft wheat baking qualities (smaller cookie diameter and higher alkaline water reten-

tion capacity). In contrast, test weight and milling qualities were independent of kernel size. Small, nonshriveled kernels had slightly better baking quality (larger cookie diameter) than larger nonshriveled kernels. Small kernels were softer than large kernels (measured by break flour yield, particle size index, and flour particle size). Small nonshriveled kernels did not have diminished total flour yield potential or other reduced flour milling characteristics. Those observations suggest a possibility of separating small sound kernels from small shriveled kernels to improve flour yield and the need to improve dockage testing estimation techniques to distinguish between small shriveled and small nonshriveled kernels.

The texture (softness) of soft wheat cultivars has critical influence on their milling and baking qualities. The measurement of kernel texture often is perceived to be influenced by kernel size. However, distinction is seldom made between the qualities of small kernels that are sound and properly filled during the grain-filling period and the qualities of small kernels that are shriveled and poorly filled during this time of maturation. Some eastern U.S. soft wheat often has a percentage of shriveling at harvest.

Soft wheat cultivars differ in their average kernel size and in the size distribution of their kernels. Some naturally large-kerneled cultivars can have twice the mean kernel diameter and weight as small-kerneled cultivars. If mixed, shriveled kernels of large-kerneled cultivars can be larger than sound, plump kernels of small-kerneled cultivars. Usually removing shriveled kernels also removes small, sound, good quality kernels, which has negative impact on the economics of milling.

MacMasters et al (1971) reviewed various observations made on the amount of wheat endosperm of sound kernels, which ranged from 81.7 to 88.3%. They reviewed reports that soft wheat has 2.1–3.2% germ, with small kernels having a slightly lower percentage of germ than large kernels, with the remaining percentage as bran. Typically during Allis-Chalmers milling at this laboratory, we observe that sound soft red winter wheats normally have ≈83% endosperm and 17% bran and germ (Yamazaki and Andrews 1982). However, shriveled kernels can have a substantially smaller ratio of endosperm to bran and germ. Since endosperm has greater density than bran, greater shriveling produces a lower ratio of endosperm to bran and germ, reducing the density of shriveled kernels. That reduced density allows for the separation of shriveled kernels from sound kernels using controlled air flow.

Millers find that milling a mixture of small and large kernels on a roller mill reduces the flour yield because roll gap settings cannot be optimized for either the small or the large kernels. Because

size mixtures are common and there is a tendency to associate small kernels with shriveled kernels, small kernels are often considered to have less potential flour yield and otherwise are considered to have generally inferior milling properties. If small kernels are in a mill mix, they usually lower the mill yield and, thus, the conclusion is that they are inferior in mill yield. If a mill mix is cleaned (aspirated or sieved) to remove shriveled kernels, generally small sound kernels are also removed. Then again, the conclusion is that small kernels are inferior. Normally, the miller can give little attention to the quality of small kernels unless wheat to the mill is first subdivided according to kernel size and the sizes are milled separately.

Conjecture is that pressure for higher agronomic field yields in modern cultivars sometimes results in cultivars having smaller mean kernel size and a wider distribution of kernel size. To increase grain yield, cultivars are released that produce smaller tertiary kernels between two rows of full-size kernels. Those smaller kernels develop later than the primary kernels. Being late, they do not fill out well during the grain-filling period and may become shriveled and softer, having less time to develop. Larger kernels develop toward the middle of the rachis in primary rows and flower and develop first. They have longer to mature and are the hardest kernels on the rachis (Gaines 1986). Kernel shriveling also can result from elevated temperature during the grain-filling period (Shi et al 1994). Pena and Bates (1982) observed that highly shriveled kernels of triticale matured more quickly than nonshriveled kernels and were not completely filled during grain development.

The prevailing view in the literature is that small kernels are softer than larger kernels, but some reports are contrary, depending on method of investigation. Most kernel texture studies do not report the amount of shriveling present in the small kernel fraction. Newton et al (1927) noticed that smaller kernels produced lower strain values when cracked. Softer wheat kernel texture (Miller et al 1981b) and softer barley kernel texture (Blum et al 1960) were observed among smaller kernels. Additionally, grinding resistance and particle size index have both shown smaller kernels to be softer (Pomeranz et al 1985). However, some methods of texture measurement have indicated that the energy, time to grind, or the crushing resistance of soft or small kernels was greater than that of larger or harder kernels, suggesting that they were harder than they actually were (Meppelink 1974; Obuchowski and Bushuk 1980; Hook and Wallington 1981; Miller et

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al 1981a, 1982; Gaines et al 1996). In some studies, kernels were made softer by increasing their moisture content, yet they were evaluated as being harder by some methods of texture evaluation and softer by other methods. Possibly, the wetter and softer samples clogged the burrs or surfaces of the grinding or crushing equipment, adding residence time in the grinding or crushing chamber and adding to the work requirement (Miller et al 1981a). Perhaps more practical estimates of kernel texture are those that occur during actual wheat milling (such as break flour yield) and by the measurement of milled flour particle size (laser-light defraction, near-infrared reflectance spectroscopy, and particle size index).

Shuey (1960) sieved wheat into large, medium, and small kernels and multiplied each fraction by a potential flour yield factor. The total of the three factors correlated well with actual commercial mill flour yield. The potential yield multiplication factor was progressively lower for the smaller kernels. Apparently, that procedure was an adjustment for shriveling among the samples evaluated, but no measurement of degree of shriveling was reported. Li and Posner (1987) evaluated large, medium, and small kernels for milling characteristics. They found reduced millability as kernel size decreased. However, their samples were apparently shriveled because, as kernel size decreased, test weight decreased, and ash and protein contents increased.

Certainly a mixture of small and large kernels passing through a roller mill will create difficulty to adjust for correct roll spacings. Ideally, break roll spacings should be set for the average kernel size. The more uniform the kernel size, the more effective the mill pass will be. Subdivision or separating a grain lot based on kernel size may improve flour yield. However, when size is a function of shriveling, flour yield may not improve.

Few reports of the influence of shriveling on the quality of end use products were found. Dexter and Matsuo (1981) associated shriveled kernels of durum with low test weight and poor spaghetti color. Gaines et al (1992) observed that harder texture of wire-cut formula cookies was associated with shriveled grain.

Those conflicting opinions and observations have led to the belief that small, sound kernels have inferior quality characteristics. Therefore, this report makes a distinction between small and large sound kernels and small and large shriveled kernels. The kernel characteristics and the milling and baking qualities of specific cultivars having large, medium, and small kernels that are free of shriveling are compared. The kernel characteristics and the milling and baking qualities of sound, moderately, and severely shriveled kernels of specific cultivars also are compared. A total of 20 soft wheat cultivars are evaluated.

MATERIALS AND METHODS

Wheats

The influence of kernel size on soft wheat quality was evaluated using nine soft wheat cultivars: Adena, Argee, Caldwell, Fla 301, Severn, Frankenmuth, Hart, Titan, and Tyler. Grain was sized using the Carter-Day modified dockage tester into three fractions (large, medium, and small). Each fraction was cleaned on the dockage tester, relying on air aspiration (squirrel-cage fan speed 2,215 rpm) to remove the lower density shriveled kernels. Then as appropriate for the range in kernel size of each cultivar, the dockage tester used three of four screens with round holes (openings of 4.0, 3.6, 3.2, and 2.8 mm dia) to produce fractions of large, medium, and small kernels. Kernel fractions were tempered overnight to 15% moisture and milled using an Allis-Chalmers mill and a Quadrumat Jr. mill according to Approved Methods (AACC 1995).

The influence of shriveled kernels on soft wheat quality was evaluated using 11 soft wheats: 10 soft red winter wheats (Argee, Blackhawk [2], Blueboy [2], Fairfield, Hart, Logan [2], and Ohio 185) and one soft white club wheat (Paha). All wheats were milled using a Quadrumat Jr. mill. A larger quantity of six wheats was sufficient to allow milling on an Allis-Chalmers mill. Grain was separated into shriveled fractions using a modified Carter-Day dockage tester. In this procedure, the squirrel-cage fan speed

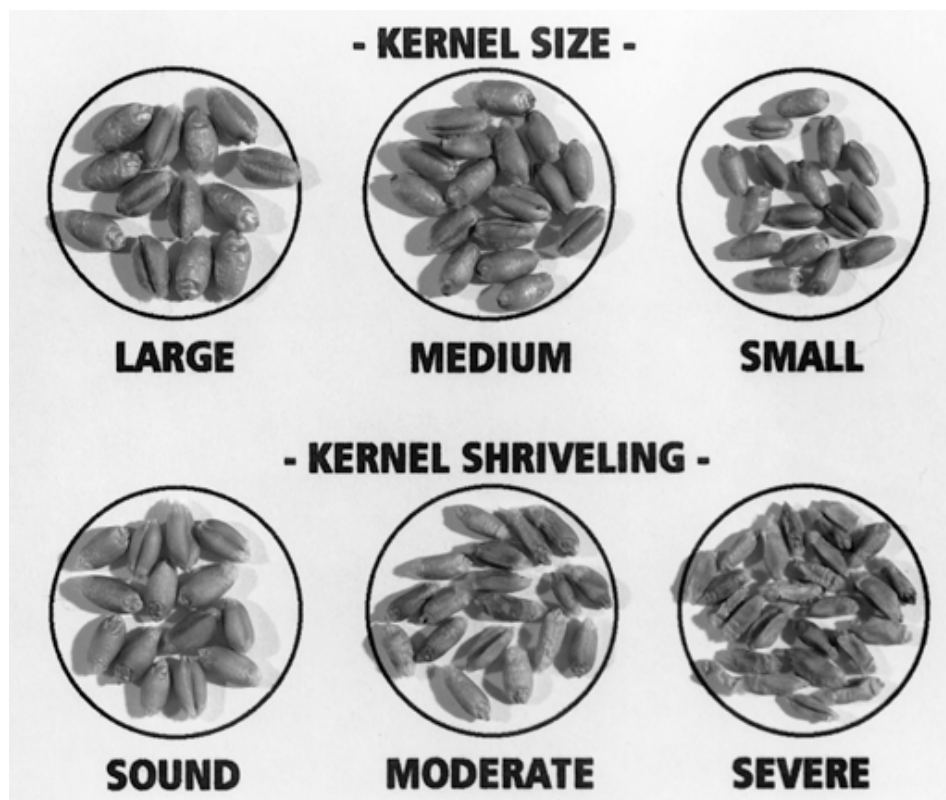


Fig. 1. Argee cv.: large, medium, and small sound, unshriveled kernels (top). Titan cv.: sound, moderately, and severely shriveled kernels (bottom).

was increased to $\approx 2,215$ rpm; an adjustable baffle plate restricted air flow, allowing removal of shriveled grain; air flow was adjusted to remove the most severely shriveled grain and readjusted to remove moderately shriveled grain. Several passes were made until only a very small percentage of severely shriveled grain was being removed. The air flow was increased to remove moderately shriveled grain and the sample was processed several times until only a very small percentage of moderately shriveled grain was being removed. Then the air flow was increased to produce a fraction that was free of shriveled grain. Each cultivar was cleaned using the same air settings.

Evaluations

The fractions of each cultivar were evaluated for test weight, protein content, 1,000 kernel weight (TKW), Allis-Chalmers flour yield, and break flour yield, Quadrumat Jr. flour yield, wheat ash, wheat protein, and particle size index according to Approved Methods (AACC 1995). From Allis-Chalmers milling, endosperm separation index (ESI) and friability were evaluated according to Yamazaki and Andrews (1982). ESI is an indication of the ease of milling wheat on the front portion of the mill, and friability is an indication of the ease of milling on the back portion of the mill. From Quadrumat Jr. milling, softness equivalent was evaluated according to Finney and Andrews (1986). Softness equivalent is highly associated with break flour yield from a larger mill. During Allis-Chalmers millings, roll separations were adjusted to accommodate the shriveled fractions. Quadrumat Jr. mill roll separations were fixed the same for all fractions. Flours were evaluated for ash, protein content, alkaline water retention capacity (AWRC), particle size (median volume diameter), and sugar-snap cookie diameter according to Approved Methods (AACC 1995). Three highly correlated methods were used for particle size evaluation: 1) particle size, determined by laser light scattering of flour particles; 2) particle size index, determined by grinding wheat and sieving for a proscribed time; and 3) milling parameter, break flour.

For some cultivars, there was not enough fractionated sample to perform all quality evaluations on the small kernel fraction or on the severely shriveled fraction. Evaluations were replicated and analyzed for difference among means by the Duncan's multiple

range test procedure using Statistica PC statistics program (StatSoft, Inc., Tulsa, OK). There was no appropriate test for cultivar differences, and cultivar-by-treatment interactions were unimportant.

RESULTS AND DISCUSSION

Figure 1 shows the typical appearance of sound wheats (large, medium, and small kernels) and shriveled wheats (sound, moderate, and severe). They were chosen to represent a large range in milling quality, flour particle size, and TKW. Their qualities were typical of their class.

Kernel Quality Characteristics

Soft wheat kernel characteristics are shown in Table I. Test weights of large, medium, and small kernels were not significantly different. However, the test weights of the shriveled samples were reduced by 33% to a low of 39.8 lb/bu. The TKW values varied with treatment kernel size and extent of shriveling. TKW values decreased 49% (22.6 g) from large to small kernels. TKW values decreased an even larger 66% (12.3 g) from sound to severely shriveled kernels.

For both milling systems, as kernel size decreased, the wheats tended to become softer, especially among the small kernels. Allis-Chalmers break flour and Quadrumat Jr. softness equivalent both indicated a progressively softer trend from large to small kernels. Break flour increased 17% and softness equivalent increased 12% from large to small kernels. There was less of a trend among the shriveled wheat set, because shriveling (especially among severely shriveled kernels) reduces the total endosperm in the kernel. Thus, break flour potential also is reduced. From sound to moderately shriveled kernels, particle size index significantly increased 11%, indicating softer kernels.

Milling Quality Characteristics

Table II shows the milling characteristics for both sets of wheat treatments. The difference in milling characteristics between the two sets of soft wheats was dramatic. Mean flour yields across cultivars for large, medium, and small kernels were not statisti-

TABLE I
Influence of Kernel Size and Kernel Shriveling on Soft Wheat Kernel Characteristics^a

Treatment	Test Weight (lb/bu)	1,000 Kernel Weight (g)	Break Flour (%)	Softness Equivalent (%)	Particle Size Index (%)
Kernel size					
Large	61.6a	44.1a	29.6a	50.1a	...
Medium	61.8a	35.3b	30.8a	51.6a	...
Small	61.4a	22.6c	34.5b	56.1b	...
Shriveling					
Sound	59.3a	36.4a	31.1a	...	44.7a
Moderate	50.6b	18.1b	34.7a	...	49.5b
Severe	39.8c	12.3c	30.7a	...	47.4ab

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE II
Influence of Kernel Size and Kernel Shriveling on Soft Wheat Kernel Milling Characteristics^a

Treatment	Allis-Chalmers Flour Yield (%)	Quadrumat Jr. Flour Yield (%)	Flour Ash (%)	Wheat Ash (%)	Endosperm Separation Index (%)	Friability (%)
Kernel size						
Large	77.2a	71.4a	0.386a	...	9.9a	28.6a
Medium	76.9a	71.4a	0.375a	...	10.0a	28.7a
Small	76.5a	70.5a	0.384a	...	10.7a	28.7a
Shriveling						
Sound	75.5a	74.5a	0.389a	1.645a	12.4a	26.4a
Moderate	68.0b	68.4b	0.451b	1.818b	17.5a	23.2a
Severe	58.2c	60.2c	0.532c	2.091c	25.4b	18.9b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

cally different from both the Allis-Chalmers and the Quadrumat Jr. mills. Compared to sound kernels, mean flour yield of severely shriveled wheats was reduced 23 and 19% from the Allis-Chalmers and Quadrumat Jr. mills, respectively. A difference of only 1.5% flour yield can have a very large impact on the profitability of a commercial flour mill. Severely shriveled kernels produce less flour because they have less endosperm relative to their bran and germ, as evidenced by their higher wheat ash content.

Flour ash also was not different among the flours of the large, medium, and small sound kernels. However, the flour and wheat ash of the moderately and severely shriveled kernels were significantly higher. Severely shriveled kernels had a 37% increase in Allis-Chalmers flour ash and a 27% increase in wheat ash compared to that of sound kernels. The Allis-Chalmers flour ash content of the moderately shriveled kernels (0.45%) would not be acceptable in this laboratory's routine cultivar testing program. The higher ash contents also reflect the greater ratio of bran to endosperm in shriveled grain.

Lower ESI values indicate greater ease of separation between the endosperm and the seed coat during milling. Mean ESI values were not statistically different for large, medium, and small kernels. Shriveled kernels had extremely poor ESI values. The shriveled kernels had ESI values that were 105% greater than sound kernels.

Higher friability values indicate greater ease of producing late break stream flour and reduction flour. Mean friability values also were not statistically different for large, medium, and small kernels. In contrast, shriveled kernels had very poor friability values, that were reduced 29% from sound kernels. When milling shriveled grain, the additional quantity of bran on the break side contributes to lowered friability values. The ratio of bran to endosperm among large, medium, and small sound kernels stays nearly constant and does not affect milling quality.

Baking Quality Characteristics

The effects of kernel size and kernel shriveling on soft wheat baking quality are shown in Table III. Large, medium, and small kernels were not significantly different in mean flour protein content. In contrast, shriveling induced changes in protein content appeared to greatly influence all baking qualities. Flour protein and wheat protein contents were 18 and 19% higher, respectively, for severely shriveled kernels compared to sound kernels.

Probably because smaller sound kernels were softer, their flours produced significantly larger (2%) cookies. The AWRC was not different for large, medium, and small kernels. Those observations suggest that there is no detrimental influence on baking quality that results from the size of sound soft wheat kernels. However, in contrast, as kernel shriveling increased to severe, cookie diameter decreased 8% and AWRC increased 17%. The cookie diameter and AWRC of the severely shriveled grain are unacceptable in this laboratory's cultivar testing program. Those observations indicate substantially reduced end use baking potential for soft wheat flour produced from shriveled kernels.

CONCLUSIONS

Sound, nonshriveled wheat cultivars were segregated into large, medium, and small kernels. Kernel characteristics, soft wheat milling qualities, and soft wheat end-use qualities were not influenced by kernel size, except that small kernels tended to be softer in kernel texture and produce flour that baked slightly larger cookies. Most importantly, the milling and baking properties of smaller kernels were not found to be inferior to larger kernels, but were equivalent to those of larger kernels.

In contrast, all grain, milling, and baking characteristics evaluated on sound, moderately, and severely shriveled grain were strongly influenced by the degree of shriveling. Shriveling greatly reduced test weight. Compared to sound kernels, shriveled kernels

had greater wheat and flour protein content, reduced flour yield, increased milling ESI, reduced milling friability, increased flour ash, increased kernel softness, decreased cookie diameter, and increased AWRC. All of those characteristics indicate reduced soft wheat quality.

Millers have found some utility in the use of test weight and ash for most of this century. Perhaps the observed dramatic increase in flour ash among shriveled kernels (which corresponds to reduced test weight) may have been a reason why test weight and ash have remained popular. They are relatively inexpensive indicators of grain condition. Soft wheat milling and baking qualities are increasingly adversely affected as shriveling increases. Clearly and ideally, it is the degree of shriveling, not the lower test weight or higher flour ash, that should be directly evaluated as a quality characteristic.

The quantity of endosperm available as break or total flour is limited by the shriveled nature of wheat kernels. Shriveled kernels contain less flour, however smaller nonshriveled kernels, of even the very small size evaluated in this study, did not have diminished total flour yield potential, diminished break flour, or diminished reduction flour milling characteristics. Small, sound kernels have approximately the same ratio of bran to endosperm as do large, sound kernels and will produce the same amount of flour relative to that ratio, when mill settings are appropriately optimized.

Some previous observations made using the Single Kernel Characterization System indicated that smaller kernels are often incorrectly evaluated as apparently harder (Gaines et al 1996). However, in that study, softness evaluation by Quadrumat Jr. milling and a prediction equation for kernel softness showed that small kernels were, in fact, more soft. Importantly, the present data also show that small nonshriveled and shriveled kernels are more soft than larger kernels.

Milling on a fixed roll gap system (Quadrumat Jr.) or a variable roll gap system (Allis-Chalmers) made no observable difference on the relative flour yield of the two treatments, size and shriveling. Both systems were equally efficient at milling kernels of uniform size, producing similar response to size and shriveling treatments. Neither system would be as effective if large and small kernels were mixed in the mill grist. That may be why (together with the fact that small kernels are often shriveled) that small kernels are sometimes considered to have reduced milling qualities. However, all of the above observations suggest the need for a more widespread recognition of the benefit of separating small sound kernels from small shriveled kernels to improve flour yield. Of course, a more ideal situation would be the release of cultivars that exhibit a greater tendency toward uniformity of kernel size.

The very poor quality of shriveled kernels, suggest that standards for measuring dockage percentage in soft wheat grading may need to be revised as not all shriveling is included in the

TABLE III
Influence of Kernel Size and Kernel Shriveling
on Soft Wheat Baking Characteristics^a

Treatment	Flour Protein (%)	Wheat Protein (%)	Cookie Diameter (cm)	AWRC ^b (%)
Kernel size				
Large	8.6 a	...	17.6 a	51.7 a
Medium	8.4 a	...	17.7 a	51.8 a
Small	8.2 a	...	18.0 b	51.5 a
Shriveling				
Sound	8.7 a	10.8 a	17.9 a	52.0 a
Moderate	9.3 ab	11.6 a	17.3 b	56.4 b
Severe	10.3 b	12.9 b	16.5 c	60.9 c

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Alkaline water retention capacity.

dockage estimate. Any shriveling in a sample diminishes its value. Sometimes small sound kernels are included as dockage. Additionally, there likely is a relatively high critical endosperm (flour) to bran ratio among slightly shriveled kernels that degrades the color (ash) of flour.

ACKNOWLEDGMENT

We greatly appreciate the invaluable assistance of Barbara Gibson of the USDA ARS Soft Wheat Quality Laboratory, Wooster, OH.

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[Received March 31, 1997. Accepted August 27, 1997.]