Use of Aspiration and the Single Kernel Characterization System to Evaluate the Puffed and Shriveled Condition of Soft Wheat Grain

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ABSTRACT

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Shriveled kernels lower wheat test weight and reduce milling flour yields. Test weight is also lowered by rain-dry cycles that cause kernels to puff (exhibit, in part, loosened layers of pericarp). A numeric score was developed for degree of puffing and for degree of shriveling based on simple measurement devices. Wheat samples were evaluated for test weight and Single Kernel Characterization System (SKCS) hardness index, SKCS kernel weight, milling flour yield, and kernel density (hexane displacement). Those evaluations were performed before and after samples were air-aspirated to remove all shriveled kernels. Test weight, SKCS hardness index, and density of aspirated samples were used to develop a puffing score. Changes (resulting from aspiration) in test weight, SKCS kernel weight, and flour yield were used to develop a shriveling score. Higher puffing scores were related to elevated α-amylase activity. Puffed kernels were softer and were not associated with decreased flour yield. Puffing and shriveling scores were independent (poorly correlated), but together predicted 95% of the variation in original, nonaspirated test weight.

The cost of a wheat lot is based on the perceived value of that lot. Presently, perceived end-use value of wheat is largely based on wheat test weight and protein content. Unfortunately, those factors are highly influenced by the growing environment, directly modifying the milling and baking genetic potential of the wheat. Thus, in practice, commercial end-use value of wheat depends on its physical condition.

Test weight is the most common commercial measurement of wheat condition. Packing efficiency, kernel shape, kernel condition, and grain density greatly influence test weight measurement. Being one measurement, test weight cannot differentiate among those factors. Inherent grain shape and various seed coat characteristics, including surface texture and cleanliness particularly influence packing efficiency. However, kernel shape and packing efficiency in no way influence milling or baking qualities, while grain condition usually does.

Two main environmentally related factors influence kernel density. One factor is the extent of grain fill. Poor grain fill causes shriveled kernels. Shriveled kernels have less endosperm and, thus, less flour yield potential. The other main factor affecting kernel density is kernel puffing. Kernels become puffed when they expand (hydrate) during rain events, but do not contract to their exact prerain size on drying. Field rains loosen the bran layer (giving it a puffed appearance) and "disturb" the interior structure of the kernel (Swanson 1944). Field rains can lower No. 1 hard wheat grades to No. 3 and No. 4 (Swanson 1943). There are cultivar differences, but test weight can be reduced by as much as 5 lb/bu and endosperm interior may be changed from vitreous to mealy by rain events (Swanson 1943, 1944). Field rains were not observed to affect milling yield or breadbaking qualities. Herein, we refer to this loosened bran layer as "puffing". Repeated wet-dry cycles cause cracks in the endosperm of hard wheats, lowering their breaking strength and making them softer (Chung and Converse 1971). When wheat resists sprouting during rain events, often its milling quality and end-use potential are not damaged by the rain. In fact, during milling puffed wheat tends to release more higher value break flour.

Elevated temperature during the grain-filling period can cause kernel shriveling and reduce test weight (Shi et al 1994). Highly shriveled kernels of triticale matured earlier than nonshriveled kernels (Pena and Bates 1982). Shriveled kernels were not completely filled during endosperm development (Pena et al 1982). Shriveled durum kernels were correlated with low test weight and their semolina flours produced poor spaghetti color (Dexter and Matsuo 1981).

Flours milled from shriveled soft wheats were correlated with harder texture in wire-cut formula cookies (Gaines et al 1992). The effects of the kernel size (small, medium, and large) of sound, nonshriveled kernels were contrasted with the effects of shriveling (severe, moderate, and none) on milling and baking qualities of soft wheat cultivars (Gaines et al 1997). Nonshriveled kernel size did not significantly influence milling and baking qualities. Small kernels were softer in texture but did not have reduced flour yield. In contrast, shriveled kernels had greatly diminished milling and baking qualities. Shriveled kernels were softer in texture and milled very poorly. They had elevated protein content, higher alkaline water retention capacity, and reduced cookie spread.

We are not aware of a published objective method to determine the degree of wheat puffing or shriveling. However, it is desirable to objectively assess puffing and shriveling in a wheat sample. This study employs common and accessible equipment (a grain aspirator, a wheat test-weight apparatus, and the Single Kernel Characterization System instrument) to establish tabulated puffing and shriveling scores for soft wheats. Additionally, it characterizes the relationship between puffing, shriveling, and test weight among soft wheats.

MATERIALS AND METHODS

Wheats

Two sets of soft wheats were evaluated. The "rain set" consisted of four soft wheats that were harvested from the same four fields in Alabama in 1996, before and after a significant rain event. Rains varied from 1.0 to 1.5 cm and harvest was interrupted from three to seven days.

Totaling 218 samples, the other set, consisted of 37 soft wheat cultivars (Arthur, Auburn, Becker, C983, C9474, Caldwell, Cardinal, Chelsea, Clemens [3], Ernie [2], Excel, Freedom, Genessee, Geneva, Hancock, Hillsdale, Jackson, Key 88, Florida 302, Mallard, Pioneer 2510, Pioneer 2545, Pioneer 2548 [2], Pioneer 2550, Pioneer 2555, Pioneer 2568, Pioneer 2684 [3], Stacy, Tyler [2], and Wakefield) and 181 commercial market samples of soft red

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[1] U.S. Department of Agriculture, Agricultural Research Service, Soft Wheat Quality Laboratory, Ohio Agricultural Research and Development Center, Ohio State University, Wooster, OH 44691. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of a product by the U.S. Department of Agriculture, and does not imply its approval to the exclusion of other products that also can be suitable.

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wheats grown in Arkansas, Louisiana, Missouri, Mississippi, and Tennessee. Commercial wheats were collected during the 1996 harvest by the USDA Grain Inspection, Packers and Stockyards Administration (GIPSA).

Aspiration

All wheats were separated into two lots. One lot was aspirated in an air vortex cleaner (laboratory model, Rapsco, Bookshire, TX) to remove the shriveled, shrunken, and broken kernels. The amount removed varied with the condition of the sample. Aspiration continued until virtually all shriveled, shrunken, and broken kernels were removed, as determined by visual inspection. The procedure did not produce uniformity of kernel size, because it did not remove all of the small sound kernels, but left a range of sound kernel size. The large relative velocity (air velocity vs. kernel velocity) in the aspiration tube and the large size of wheat kernels were too large to produce a Reynolds number small enough such that Stokes Law could apply to the aspiration process. Thus, aspiration did not separate kernels based on the square of the kernel size, as Stokes Law would indicate (Bache and Johnstone 1992). Stokes Law applied to very small particles (pieces of dust and chaff). Wheat kernels were removed based on density. When the drag force on low-density, shriveled kernels was equal or greater than their mass, they were aspirated out of the sample. The drag force on higher density, sound kernels was less than their mass and they were not aspirated from the sample.

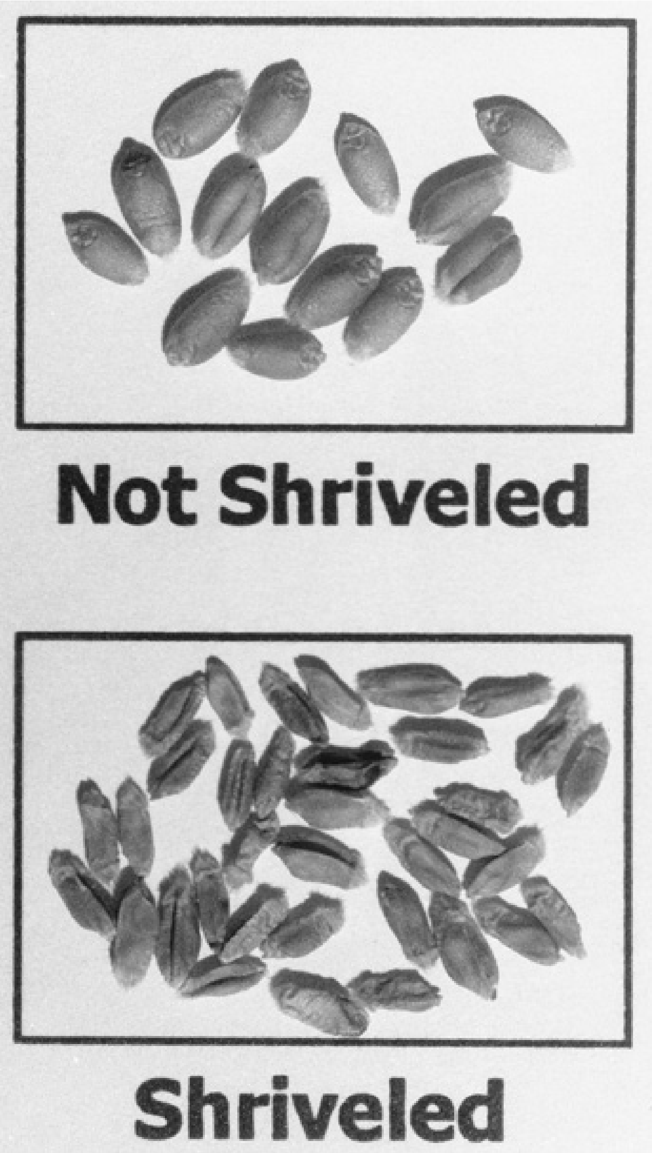

Fig. 1. Sound nonshriveled kernels and severely shriveled soft wheat kernels.

Milling and Analyses

Samples were tempered to 15% moisture and milled on a modified Brabender Quadrumat Jr. mill using the procedure of Finney and Andrews (1986). The procedure was modified by substituting a 40-mesh (470 μm) screen for the 54-mesh (290 μm) screen and increasing sieving time to 90 sec.

Density was determined by hexane displacement. In a 50-mL graduated cylinder, 12 g of wheat was placed into 15 mL of hexane and the expanded volume was read. Density was calculated. Test weight was determined using Approved Method 55-10 (AACC 1995). A Single Kernel Characterization System (SKCS) model 4100 (Perten Instruments North America, Springfield, IL) was used to obtain hardness index, kernel weight, and kernel diameter. The α-amylase activity was determined using Approved Method 22-06 (AACC 1995).

Analysis

All data measurements were duplicated and the data were analyzed by analysis of variance (ANOVA), least significant difference (LSD), and multiple linear regression, and simple linear correlation using Statistica PC statistics program (StatSoft, Tulsa, OK).

RESULTS AND DISCUSSION

Test weight of soft wheat cultivars is used to indicate the general overall condition of the grain. Test weight is influenced by many factors, including fungal infection, insect damage, natural kernel shape and density, foreign material, broken and shriveled kernels, agronomic practice, the quest for higher field yield, and puffed, weathered seedcoats. Therefore, a lowered test weight measurement represents the result of exceedingly complex and variable influences. Lower test weight may, or may not, indicate lowered grain quality if no other information is available. However, without knowing the cultivars, the question is “lowered from what?” What would the test weight have been if any particular lot had been completely sound, not shriveled, and not puffed?

Shriveled grain has a shrunken, nonfilled appearance. Severely shriveled wheat is shown in Fig. 1 compared to sound nonshriveled wheat. Shriveled kernels are diminished in nearly all milling and baking quality attributes (Gaines et al 1997). A kernel with

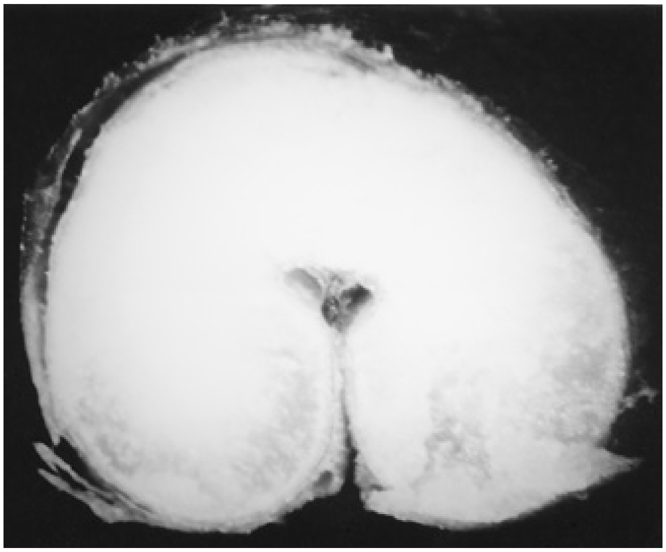

Fig. 2. Cross-section of a soft wheat kernel with a loose, puffed pericarp layer on the left side.

TABLE I
Effect of Aspiration and Rain on Kernel Quality Characteristics

Treatment	Test Weight (lb/bu)	Density (g/cm^3)	Flour Yield (%)	Weight (mg)	Diameter (mm)	Hardness (HI)[a]
Original, prerain	58.5c[b]	1.31ab	67.8b	25.9b	1.99b	21.7a
Original, postrain	57.0d	1.28c	66.9b	26.4b	2.00b	15.5ab
Aspirated, prerain	61.5a	1.34a	70.1a	32.3a	2.34a	17.3a
Aspirated, postrain	60.0b	1.30bc	69.7a	33.7a	2.37a	9.7b

[a] HI = hardness index of aspirated samples measured using the Single Kernel Characterization System (SKCS).

[b] Means followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE II
Correlation Coefficients[a] Among Kernel Characteristics for Original Samples, Aspirated Samples, and Changes (Differences) in those Characteristics Due to Aspiration

	Test Weight	Kernel Weight	Hardness Index	Flour Yield	Kernel Density
Original samples					
Test weight	0.33	0.34	0.32	0.33	0.80
Kernel weight		0.92	–0.24	0.37	0.25
Kernel diameter			–0.20	0.45	0.21
Hardness index				0.10	0.48
Flour yield					0.28
Aspirated samples					
Test weight	–0.14	–0.11	0.52	0.19	0.79
Kernel weight		0.82	–0.14	0.01	–0.00
Kernel diameter			–0.08	0.18	–0.06
Hardness index				0.24	0.56
Flour yield					0.22
Difference data (change) resulting from aspiration					
Test weight	0.68	0.70	–0.30	0.65	0.64
Kernel weight		0.93	–0.59	0.60	0.46
Kernel diameter			–0.57	0.66	0.49
Hardness index				–0.53	–0.30
Flour yield					0.40

[a] Correlation coefficients >±0.13 are significantly different ($P < 0.05$).

puffed, loose pericarp is shown in Fig. 2. Rain causes wheat kernels to swell. However, subsequent drying does not return some layers of the pericarp to their original prerain size, leaving some of the pericarp layers to exhibit a loose or puffed appearance (left side of kernel slice in Fig. 2).

Influence of Rain on Kernel Condition

The rain sample set had harvest interrupted by a rain event. Rain created softer wheats as indicated by SKCS hardness index and also reduced wheat test weight and density (Table I). Aspirating away shriveled kernels raised test weight and flour yield and increased SKCS kernel weight and diameter. When prerain and postrain data were each combined across cleaning treatment (data not shown), rain created greater change in kernel texture ($P < 0.05$) and aspiration created greater change in test weight, flour yield, kernel weight, and kernel diameter ($P < 0.05$). Importantly, aspiration did not return the density of the kernels that received rain to the density of the aspirated samples that did not receive rain, suggesting that all of the kernels were puffed by rain.

The samples that received rain were puffed by the cycle of wetting and drying. Wheat puffing was characterized by decreased grain density, test weight, and hardness (of aspirated samples), but not by decreased flour yield. Wheat shriveling was characterized by the change (increase) due to aspiration in kernel size and weight, test weight, and flour yield. Because test weight is associated with both shriveling and puffing, it cannot be a good predictor of either if both are present, as they often are among eastern U.S. soft wheat samples.

Puffing Estimate

The 214 samples were evaluated as original (nonaspirated) samples, aspirated samples, and as difference data (change from original values to aspirated values) resulting from aspiration. The kernel characteristic that was best correlated with test weight of original (nonaspirated) kernels was change in density (Table II). Because rain wets all kernels in a field and puffs and lowers the density of those kernels, associations with kernel density can be used to estimate puffing in aspirated samples. Specifically, after shriveled kernels are removed by aspiration, kernel density was correlated with increased kernel hardness and higher test weight. The equation for predicting the density of aspirated samples (r^2 = 0.66, $P < 0.001$) is:

$$D_A = 0.559 + 0.000616(\mathrm{HI}_A) + 0.0124(\mathrm{TW}_A)$$

where D_A = density of aspirated samples, HI_A = SKCS hardness index of aspirated samples, and TW_A = test weight of aspirated samples. The puffing regression equation was then normalized to a scale of 1–13 to produce a puffing score (Table III) using the equation:

$$\text{Puffing score} = 84.41 - (D_A \times 58.735)$$

Puffing scores of 1–2 represent essentially no puffing, scores of 3–5 represent light puffing, scores of 6–9 represent moderate puffing, and scores of 10–13 represent heavy puffing.

Shriveling Estimate

Among the original samples, higher flour yield was weakly associated with larger, heavier kernels (Table II). Compared to that relationship, the change in flour yield after aspiration to remove shriveled kernels was more highly correlated with change in kernel size and weight. Thus, larger increases in flour yield and the greater increases in test weight resulted from removing the more highly shriveled kernels. Those parameters were used to establish

TABLE III

Puffing Score[a] Based on the Test Weight and Single Kernel Characterization System (SKCS) Hardness Index (HI) of Aspirated Wheats

	Test Weight (lb/bu)													
HI	**66.1–67.0**	**65.1–66.0**	**64.1–65.0**	**63.1–64.0**	**62.1–63.0**	**61.1–62.0**	**60.1–61.0**	**59.1–60.0**	**58.1–59.0**	**57.1–58.0**	**56.1–57.0**	**55.1–56.0**	**54.1–55.0**	**53.1–54.0**
45.1–50.0	1	2	2	3	4	5	5	6	7	8	8	9	10	10
40.1–45.0	1	2	3	3	4	5	6	6	7	8	8	9	10	11
35.1–40.0	1	2	3	4	4	5	6	6	7	8	9	9	10	11
30.1–35.0	2	2	3	4	4	5	6	7	7	8	9	10	10	11
25.1–30.0	2	2	3	4	5	5	6	7	8	8	9	10	10	11
20.1–25.0	2	3	3	4	5	6	6	7	8	8	9	10	11	11
15.1–20.0	2	3	4	4	5	6	6	7	8	9	9	10	11	12
10.1–15.0	2	3	4	4	5	6	7	7	8	9	10	10	11	12
5.1–10.0	2	3	4	5	5	6	7	8	8	9	10	10	11	12
0.1–5.0	3	3	4	5	6	6	7	8	8	9	10	11	11	12
–4.9 — –0.0	3	4	4	5	6	6	7	8	9	9	10	11	12	12
–9.9 — –5.0	3	4	4	5	6	7	7	8	9	10	10	11	12	12
–14.9 — –10.0	3	4	5	5	6	7	8	8	9	10	10	11	12	13
–19.9 — –15.0	3	4	5	6	6	7	8	8	9	10	11	11	12	13
–24.9 — –20.0	4	4	5	6	6	7	8	9	9	10	11	12	12	13

[a] Scoring values: 1–2 = no appreciable puffing; 3–5 = light puffing; 6–9 = moderate puffing; 10–13 = heavy puffing.

TABLE IV

Shriveling Score[a] Based on Change in Test Weight and Single Kernel Characterization System (SKCS) Kernel Weight (KW) Resulting from Aspiration

	Test Weight (lb/bu)										
KW (mg)	**0.0–1.0**	**1.0–2.0**	**2.0–3.0**	**3.0–4.0**	**4.0–5.0**	**5.0–6.0**	**6.0–7.0**	**7.0–8.0**	**8.0–9.0**	**9.0–10.0**	**10.0–11.00**
0.0–1.0	1	2	3	4	4	5	6	7	8	9	10
1.0–1.5	1	2	3	4	5	5	6	7	8	9	10
1.5–2.0	1	2	3	4	5	6	6	7	8	9	10
2.0–2.5	1	2	3	4	5	6	7	7	8	9	10
2.5–3.0	2	2	3	4	5	6	7	8	8	9	10
3.0–3.5	2	3	3	4	5	6	7	8	9	9	10
3.5–4.0	2	3	4	4	5	6	7	8	9	10	10
4.0–4.5	2	3	4	5	5	6	7	8	9	10	11
4.5–5.0	2	3	4	5	6	6	7	8	9	10	11
5.0–5.5	2	3	4	5	6	7	7	8	9	10	11
5.5–6.0	2	3	4	5	6	7	8	8	9	10	11
6.0–6.5	3	3	4	5	6	7	8	9	9	10	11
6.5–7.0	3	4	4	5	6	7	8	9	10	10	11
7.0–7.5	3	4	5	5	6	7	8	9	10	11	11
7.5–8.0	3	4	5	6	6	7	8	9	10	11	12
8.0–8.5	3	4	5	6	7	7	8	9	10	11	12
8.5–9.0	3	4	5	6	7	8	8	9	10	11	12
9.0–9.5	3	4	5	6	7	8	9	9	10	11	12
9.5–10.0	4	4	5	6	7	8	9	10	10	11	12
10.0–10.5	4	5	5	6	7	8	9	10	11	11	12
10.5–11.0	4	5	6	6	7	8	9	10	11	12	12
11.0–11.5	4	5	6	7	7	8	9	10	11	12	13
11.5–12.0	4	5	6	7	8	8	9	10	11	12	13
12.0–12.5	4	5	6	7	8	9	9	10	11	12	13
12.5–13.0	4	5	6	7	8	9	10	10	11	12	13

[a] Scoring values: 1–2 = no appreciable shriveling; 3–5 = light shriveling; 6–9 = moderate shriveling; 10–13 = heavy shriveling.

a shriveling score based on change in flour yield. The equation for predicting change in flour yield due to aspiration ($r^2 = 0.47$, $P < 0.001$) is:

$$\Delta FY = 0.217 + 0.397(\Delta TW) + 0.131(\Delta Wt)$$

where ΔFY = change in flour yield, ΔTW = change in test weight, and ΔWt = change in SKCS kernel weight. The shriveling regression equation was then normalized to a scale of 1–13 to produce a puffing score (Table IV) using the equation:

$$\text{Puffing score} = -0.613 + (\Delta FY \times 2.17)$$

where ΔFY = change in flour yield. Shriveling scores of 1–2 represent no appreciable shriveling, scores of 3–5 represent light shriveling, scores of 6–9 represent moderate shriveling, and scores of 10–13 represent heavy shriveling.

Confirmation of Puffing and Shriveling Scores

Scores for puffing and shriveling were poorly correlated ($r = 0.23$, $P < 0.05$) because the causes of puffing and shriveling are naturally independent. Puffing scores were correlated with kernel hardness index ($r = -0.66$, $P < 0.001$), indicating that puffed kernels are softer. In addition, puffing score was poorly correlated with original (nonaspirated) flour yield ($r = -0.25$, $P < 0.001$) and change in flour yield due to aspiration ($r = -0.09$, $P = 0.17$). Those observations confirm those of Swanson (1943, 1944) that milling yield is unaffected by rain events.

Original test weight was predicted from puffing and shriveling scores ($r^2 = 0.95$, $P < 0.001$) as:

$$TW = 68.58 - (0.788 \times SC) - (1.07 \times PS)$$

where TW = original, nonaspirated test weight, SC = shriveling score, and PS = puffing score. That relationship is shown in Fig. 3.

The regression indicates that the theoretical maximum test weight is ≈67 lb/bu (from scores of 1 for puffing and shriveling). The slopes of the reduction in test weight resulting from puffing and shriveling are similar. The regression shows that test weight was reduced ≈1 lb/bu for each unit of puffing or shriveling score.

Since puffing alone did not reduce flour yield, and it often increases valuable break flour yield, it would appear reasonable to adjust test weight upwards 1 lb/bu for each puffing score unit. Such an adjustment may result in a better indication of the true negative association between test weight and shriveling, the relationship that does affect flour yield.

α-Amylase activities of the 181 GIPSA samples were evaluated. The α-amylase activity is a quality parameter that is independent of the measurements from which the puffing and shriveling scores were derived. The α-amylase activity increased ($P < 0.05$) in those samples with puffing scores of 5–9, but there was no elevated enzyme activity below a puffing score of 5. In contrast, samples at all levels of shriveling had various levels of elevated α-amylase activity. Therefore, puffing and shriveling scores were consistent with the association of increased rainfall and α-amylase activity. Shriveling was independent of rain events and α-amylase activity. Increased rain events increased puffing and α-amylase activity.

CONCLUSIONS

Whereas aspiration can remove unsound, shriveled, and broken kernels, it cannot remove all puffed kernels because rainy periods will likely puff all kernels in a field. Even after aspiration, wheat lots that are puffed typically will have lower test weight, will be more soft, and will have lower density than nonpuffed wheat lots. A puffing score was devised and based on the density, test weight, and SKCS hardness index of aspirated samples. Puffed grain was not detrimental to grain condition and should not be considered less valuable, unless that grain is also shriveled or has been field sprouted. Within the scope of this study, puffed kernels did have diminished milling quality.

Because shriveled kernels are less dense, they are easily removed by aspiration. A shriveling score was based on the amount of change between nonaspirated and aspirated samples in test weight, kernel weight, and flour yield. Shriveled kernels have demonstratively reduced value for soft wheat milling and baking (Gaines et al 1997).

Raw test weight values can be improved to better represent the true value of the wheat from the farmer to the miller by adjusting test weight values for puffing score. Thus, the grain trade could better predict milling properties and grain condition by knowing how much shriveling and puffing influence the prediction of grain milling and end-use qualities. Certainly, knowledge of bulk density (test weight) is essential for the estimation of storage and shipping volumes and for the use of some grain separation devices such as gravity tables. However, test weight itself may not be a grading necessity if shriveling, α-amylase activity, protein content, and cultivar names are known. This study documents why Swanson (1944) stated that " . . . the farmer who has weathered wheat is unduly penalized because major emphasis is placed on test weight in grading . . . "

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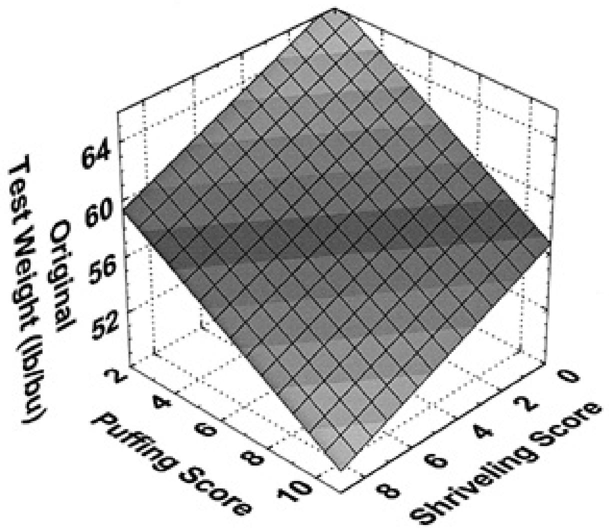

Fig. 3. Relationship between puffing score, shriveling score, and original test weight of nonaspirated samples.

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