Optimizing Grinder Type and Methods of Expressing Wheat Meal Particle Size for Wheat Texture (Hardness or Softness) Measurement and Near-Infrared Reflectance Spectroscopy

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ABSTRACT

The grinding characteristics of three wheat grinders (LabConco, Falling Number KT-3303, and Udy cyclone) were compared by measuring the particle size of meals produced, using four sieving techniques and five Microtrac laser light-scattering optical measurements. Seven wheat samples used in the evaluation represented a wide range of texture (hardness or softness). The LabConco-ground meals were coarser than the others, and samples were best differentiated by sieving the meals to determine particle size distribution or means as an assessment of wheat texture. Meals produced by the Falling Number grinder were of generally intermediate particle size distribution, and samples were best differentiated by analyzing meal particle size with the Microtrac instrument. The Udy cyclone produced meals having much finer mean particle size, more narrow particle size distributions, and overall the best differentiation among wheat samples (using the Microtrac). Therefore, the Udy/Microtrac combination was the best procedure for evaluating the texture of wheat samples with equal, if not better, statistical power than a (more coarse) grinder and sieving combination commonly used for particle size index testing.

Texture (often termed hardness or softness) measured on bulk samples of wheat cultivars is genetically controlled but influenced by environment, grain moisture, and protein content (Simmonds 1974, Trupp 1976, Stenvert 1977, Yamazaki and Donelson 1983, Pomeranz et al 1985). It has been suggested that relative wheat texture is a function of the extent of bonding between starch granules and protein (Simmonds 1974), or of the quantity and degree of order and continuity of the endosperm protein matrix (Stenvert 1977).

When wheat kernels are ground into meal or milled into flour, soft wheats break into smaller particles than do hard wheats. Several texture measurement techniques have been used to express relative wheat texture based on the relative particle size of ground meals; these include light microscopy, sedimentation, centrifugation, sieving, laser light scattering, and near-infrared reflectance spectroscopy (Bruinsma and Rubenthaler 1978, Miller et al 1982). Several recent studies utilized the particle size index (PSI) method, a grinding and sieving method of texture evaluation (Bruinsma and Rubenthaler 1978, Osborn et al 1981, Williams 1983).

The PSI test uses a grinder to produce a meal that is sieved for a set time through a prescribed sieve size. The greater the percentage of meal passing through the screen, the smaller the average particle

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size and the softer the wheat. The best grinder for PSI determinations is usually considered one that can produce a large range in mean particle size data among wheat cultivars and especially among wheat classes (Bruinsma and Rubenthaler 1978; Williams 1979, 1983). These grinders are often the single-pass, burr-type, which produces a relatively coarse meal. It is thought that meals of relatively coarse particle size are more indicative of grain texture than meals of finer particle size produced by other grinder types (Williams 1984). As discussed here, this is probably because the PSI test relies on sieving to measure the particle size of the meal produced.

The commonly used LabConco burr-type grinder is no longer manufactured and is being replaced with smaller burr-type grinders such as the Falling Number grinders. Also, many facilities now possess near-infrared spectroscopy instruments that are often accompanied by a Udy cyclone impeller-type grinder, which produces a relatively fine particle size, governed by the size of the outlet screen from the residence chamber. What is certain, however, is that the choice of grinder type used to produce wheat meal for subsequent texture assessment greatly affects the particle size, shape, and distribution of meals (Watson et al 1976), and the particular method of texture assessment must be optimized for the grinder type.

In this study, three grinders (the LabConco, Falling Number, and Udy cyclone) were compared for characteristics of meals produced for wheat texture evaluations. Particle sizes of the meals were measured by four sieving techniques and five Microtrac laser light-scattering data modes. The objectives were to determine which, if any, grinder is superior for each method of particle size evaluation, and which measurement of particle size is best for each grinder when evaluating the relative texture of bulk wheat samples.

MATERIALS AND METHODS

Wheats

Seven wheat cultivars from four wheat classes representing the maximum range of kernel texture likely to be encountered during wheat hardness testing were evaluated in triplicate. Cultivars, classes, break flour yields, protein and ash contents (AACC 1983), and alkaline water retention capacities (Yamazaki et al 1968) are presented in Table I.

Grinders and Grinding Procedures

Each of the seven wheats was divided into three 200-g lots and tempered overnight to 13% moisture. The three lots were ground by a LabConco laboratory grinder (model 600) at the 0.023-in. setting, a Falling Number model KT-3303 grinder (3,450 rpm) with medium burrs at the closest setting, or a Udy cyclone grinder equipped with a 1.0-mm screen.

Particle Size and Distribution Measurements

Break flour yield was determined by the method of Finney and Andrews (1986). PSI was determined by the method of Yamazaki and Donelson (1983) using a LabConco grinder (as above) and Tyler metal sieve having 425-μm openings. PSI data are expressed at a standardized 11% moisture content. The PS50 data (the particle size at cumulative 50% of the size distribution) were determined with a Ro-tap sieving system, using screen sizes with 75-, 150-, 246-, 417-, and 600-μm openings and sieving for 10 min.

A Microtrac laser light-scattering particle size analyzer model 7991-0 with a dry powder attachment was used to determine the following five measurements: particle surface area, mean particle diameter, median particle diameter, particle diameter at cumulative 10% of the portion of the sample analyzed by the instrument, and particle diameter at cumulative 90%. The Microtrac evaluated particles from 1.9 to 176 μm.

The single-screen sieving methods used Tyler metal sieves (20-cm diameter) having openings of 425, 250, and 105 μm. Planetary sieving action was supplied by a Rotomatic sifter operating at 190 rpm, having a 10-cm throw. Sieving times were 30 sec for the 425- and 250-μm screens and 2 min for the 105-μm screen.

Near-Infrared Reflectance Spectroscopy

Near-infrared spectra were obtained on all 63 samples (3 grinders × 7 cultivars × 3 replications) using a Technicon InfraAlyzer 500. Data were collected from 1,100 to 2,498 nm at 2-nm intervals.

RESULTS AND DISUCSSION

Although no longer manufactured, the LabConco grinder has often been used to grind bulk wheat samples for texture analyses by various PSI methods that use single sieves (of various sizes, depending on the procedure) to assess the particle size of ground meals as estimates of wheat texture. Therefore, the LabConco grinder and several sieves were included in this study for comparison with two newer grinders, the Falling Number KT-3303 and Udy cyclone, and with the Microtrac optical (laser light-scattering) method of particle size analysis.

Wheat Texture Range and Variance

The wheat cultivars evaluated represented almost the entire range of wheat texture. In addition, the four soft wheats represented most of the range of soft wheat texture. Break flour yield, a sensitive measure of wheat texture, ranged from 20.7 to 42.5% among durum and hard wheats and from 45.0 to 67.1% among soft wheats (Table I). The durum wheat and two hard wheats had more protein than did the soft wheats, as is normally expected. The alkaline water retention capacities show all wheats to be representative of their wheat classes. The ash contents show that all wheats were sound and unshrivelled. Except for Logan, the softest wheat, all other wheats were reduced to meals with no statistical difference in variance, even though the harder wheats took longer to grind and required a slower feed rate.

Particle Size Distributions

Figure 1 shows the cumulative particle size distribution of the means of the 21 meals (seven wheats and triplicate grindings) compiled from the Ro-tap data. The LabConco grinder produced relatively coarse meal up to 70% cumulative weight. The Falling Number grinder produced meals of intermediate particle size up to 70% cumulative weight. The Falling Number meals had the largest particle size for the remaining 30% of the particle size distribution ($P = 0.01$). The Udy cyclone grinder, being a residence chamber grinder with a 1-mm outlet screen, produced a much finer grind with less than 10% of the meal larger than 425 μm. Without an analysis of reproducibility (shown below), one might conclude that the Udy cyclone grinder would be unsuitable for wheat texture measurements because of the narrow range in particle size distribution it produces.

TABLE I
Wheat Cultivar, Class, Crop Year, Break Flour Yield, Protein and Ash Contents, and Alkaline Water Retention Capacity of Seven Wheats

Cultivar	Class[a]	Crop Year	Break Flour Yield[b] (%)	Protein[b] (%)	Wheat Ash[b] (%)	Alkaline Water Retention Capacity[b] (%)	Variance[c]
Vic	Durum	1983	20.7	14.0	1.49	82.7	4.05 ab
Len	HRS	1983	33.4	15.6	1.90	72.6	3.81 ab
Shawnee	HRW	1981	42.5	12.6	1.84	72.7	7.69 b
Hillsdale	SRW	1983	45.0	10.3	1.63	60.5	10.12 b
Favor	SWW	1981	57.6	9.5	1.59	56.5	5.72 ab
Caldwell	SRW	1983	63.1	9.3	1.60	58.3	7.81 b
Logan	SRW	1983	67.1	10.4	1.72	57.6	2.09 a

[a] HRS = hard red spring, HRW = hard red winter, SRW = soft red winter, SWW = soft white winter.
[b] Calculated on 14% mb. Variance of triplicate grindings pooled across six particle size measurements and three grinders. (The PS50 data were not included as their variance was proportional to the mean.) Variances followed by the same letter are not significantly different at the $P = 0.05$ level of probability.

Data Range Between Grinders

Analyses of variance of the nine particle size measurements from the seven meals analyzed in triplicate on each grinder were computed to compare grinders and to determine which methods of analyzing meal particle size are optimum for each grinder (Table II). The LabConco grinder generally produced a larger range of sieving data among wheat means. It also produced a higher between-wheat variance, an estimate of the range between wheat means that is less affected by extreme values than are raw values, which may distort the estimate of the normal population range. Because the Udy grinder produces a relatively fine and narrow particle size distribution, the wheat ranges and between-wheat variances were correspondingly small. Falling Number meals had intermediate values of range and between wheat-variances.

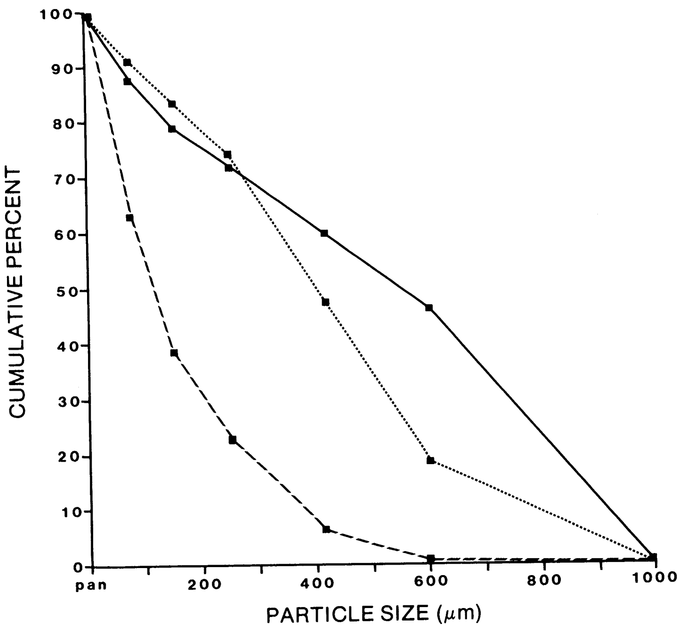

Fig. 1. Cumulative weight percent and particle size distributions of the means of seven wheat meals ground through LabConco, Falling Number, and Udy cyclone grinders. The solid line represents the LabConco grinder, the dotted line represents the Falling Number grinder; and the dashed line represents the Udy cyclone grinder.

Replication Variance

Variance resulting from replication of triplicate grindings pooled across the seven wheats shows the two grinders that produced the coarser meals, the LabConco and Falling Number grinders, had smaller replication variance when meal particle size was measured by sieving methods. Conversely, the Udy cyclone, which produced the smallest particle size distribution, produced meals which were better replicated by the Microtrac method of particle size analysis (which analyzed particle size from 1.9 to 176 μm). Overall, the Udy cyclone produced significantly ($P = 0.05$) more consistent grindings than did the other two grinders: total replication variances were 14.3, 161.8, and 210.5 for the Udy, LabConco, and Falling Number grinders, respectively.

Optimum Combinations of Grinder and Particle Size Measurement

A comprehensive estimate of the best combination of grinder and method of particle size measurement is the relative sizes of the *F* ratios of the analyses of variance, which are the ratios of the estimates of range (between-wheat variance) to the estimates of replication error. The largest *F* ratios among the sieving methods were found for the LabConco grinder, whereas the largest *F* ratios among the Microtrac data were from the Udy cyclone grinder. Again, the Falling Number meals were generally intermediate. The more coarsely ground LabConco meals were easier to sieve, producing the relatively small standard error-to-range ratios.

TABLE II
Analysis of Variance of Nine Particle Size Measurements of Seven Wheats Ground in Triplicate by Three Grinders

Particle Size Method	Mean	Range	Between-Wheat Variance	Replication Variance	*F* Ratio[a]
LabConco grinder					
Through 425-μm screen (%)	38.3	38.9	500.8	4.195	119.4
Through 250-μm screen (%)	31.0	38.0	415.9	2.606	159.6
Through 105-μm screen (%)	15.7	25.2	206.4	1.801	114.6
Ro-tap PS50 (μm)	524	418	66,036	1,418	46.6
Microtrac surface area (m^2/cm^3)	0.14	0.12	0.003719	0.0005047	7.4
Microtrac mean diameter (μm)	80.5	30.8	392.0	4.975	78.8
Microtrac median diameter (μm)	71.7	58.8	1,189	18.98	62.6
Microtrac cumulative 10% (μm)	23.2	19.8	148.5	2.864	51.9
Microtrac cumulative 90% (μm)	154.6	11.9	47.82	2.940	16.3
Falling Number grinder					
Through 425-μm screen (%)	48.1	36.4	286.1	36.84	7.8
Through 250-μm screen (%)	28.9	29.6	254.0	5.169	49.1
Through 105-μm screen (%)	12.4	20.3	122.2	3.251	37.6
Ro-tap PS50 (μm)	403	200	9,939	1,826	5.4
Microtrac surface area (m^2/cm^3)	0.13	0.11	0.002260	0.000338	6.7
Microtrac mean diameter (μm)	87.2	30.3	340.1	3.246	104.8
Microtrac median diameter (μm)	81.6	50.1	911.6	16.44	55.4
Microtrac cumulative 10% (μm)	25.4	27.7	243.4	1.612	151.0
Microtrac cumulative 90% (μm)	158.3	11.2	28.67	2.360	12.1
Udy cyclone grinder					
Through 425-μm screen (%)	84.7	14.7	109.0	7.561	14.4
Through 250-μm screen (%)	72.7	14.9	36.49	7.767	4.7
Through 105-μm screen (%)	44.0	18.5	86.34	5.799	14.9
Ro-tap PS50 (μm)	112	968	3,003	94.48	31.8
Microtrac surface area (m^2/cm^3)	0.16	0.10	0.002898	0.00009523	30.4
Microtrac mean diameter (μm)	68.9	30.8	345.6	1.790	193.0
Microtrac median diameter (μm)	56.0	44.1	789.1	4.367	180.7
Microtrac cumulative 10% (μm)	19.4	14.8	50.31	0.9766	51.5
Microtrac cumulative 90% (μm)	143.4	22.6	200.7	5.531	36.3

[a] All *F* ratios are significant at the $P = 0.01$ level of probability.

TABLE III
Near-Infrared Reflectance Spectroscopy Best Three Wavelengths for Correlations with PSI,[a] PS50, and Microtrac Mean Volume Diameter (MVD) Data for Wheat Meals Ground by Three Grinders

	PSI		PS50		MVD	
Grinder	Wavelengths (nm)	R^2	Wavelengths (nm)	R^2	Wavelengths (nm)	R^2
LabConco	1,338		1,778		1,206	
	1,580		2,042		1,228	
	2,240	0.99	2,350	0.99	1,668	0.96
Falling number	1,118		1,162		1,338	
	1,866		1,448		1,382	
	2,284	0.98	1,602	0.89	1,734	0.96
Udy cyclone	1,800		1,448		1,514	
	2,020		1,602		1,602	
	2,350	0.99	2,416	0.94	2,196	0.99

[a] PSI = particle size index.

Being much finer and narrower in particle size range, the Udy cyclone meals were more difficult to sieve to produce sufficiently reproducible data relative to the range, especially among the soft wheats, which tended to "ball up" or blind the sieving screens.

The Microtrac was limited to measuring particles less than 176 μm, and thus could read only the smallest 20% of the LabConco and Falling Number meals. However, the Microtrac was able to analyze approximately 60% of the Udy ground meal, allowing relatively large F ratios. The Falling Number grinder was the best at producing meals for only one of the nine particle size methods (the Microtrac cumulative 10% values). However, it was generally better paired with Microtrac data than with sieving data.

Implications for PSI Testing

Several methodologies for PSI tests are reported for assessing wheat texture (Obuchowski and Bushuk 1980, Miller et al 1982, AACC 1983, Yamazaki and Donelson 1983, Williams and Sobering 1986). They use several grinders or mills (LabConco, Falling Number KT-30 and KT-3303, Brabender Micro Hardness Tester, Quadrumat Junior mill) and various sized sieves (425-, 125-, 106-, and 74 μm openings). The present study indicates that better PSI data (larger F ratios) would be expected from a grinder producing relatively coarse meal and that choice of sieve size is of secondary importance. Certainly, a grinder that produces a relatively fine particle size distribution would be a poor choice if the meals must be sieved. The relatively fine grinding Udy cyclone grinder, coupled with the Microtrac mean or median diameter analyses (which produce large F ratios), appears to produce wheat texture evaluation data equivalent to, if not slightly better than, the grinding/sieving (PSI) methods.

Implication for Near-Infrared Reflectance Spectroscopy

Good correlations ($R^2 > 0.89$) were obtained for all three grinders between near-infrared reflectance spectroscopy data (using three best wavelengths) and PSI, PS50, and Microtrac MVD data (Table III). Although promising, these results must be considered as only indicative because there were only 21 samples (7 wheats, 3 replications) from each grinder. However, these data suggest that the relative texture of wheat cultivars may be determined by near-infrared reflectance spectroscopy on an instrument calibrated with either PSI, PS50, or Microtrac MVD data from either of the three grinders studied, even though their grinds ranged from relatively fine, to medium, to coarse, and from a relatively narrow to a wide particle size distribution.

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