# Viscometric Indexes of U.S. Wheats and Flours of Widely Different Protein Contents and Breadmaking Quality

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**ABSTRACT**

Whole grain meals and flours milled from six U.S. hard red winter wheat varieties or selections from five crop years were evaluated for breadmaking properties. The wheats and flours varied widely in protein contents and functional (breadmaking) qualities of the proteins. Evaluation of breadmaking potential was based on a straight-dough procedure to determine water absorption, mixing time, loaf volume, and crumb grain and texture. Indirect methods for determining quality included the sedimentation test and flow curve indexes determined by a rotation viscometric method. The flow curve indexes were correlated with functional breadmaking properties. High, significant correlations were obtained between loaf volume and the tear point of a meal flow curve ($r = -0.923$, curvilinear) and loaf volume and flow quotient of a meal flow curve ($r = 0.954$). The rotation viscometric method is simple and rapid, requires small amounts of material (10 g), and can be performed on wheat meal or flour. Consequently, the method can be useful in screening large numbers of samples in plant breeding programs.

Several indirect testing methods are used to evaluate end-use properties of wheats in marketing channels, in processing and quality laboratories, and in plant breeding programs. A special place is reserved among these methods for instrumental techniques that measure rheological indexes of doughs. These include the farinograph, mixograph, and extensigraph, as well as other rheological methods that determine the consistency of the dough, describe its mixing tolerance, extensibility, and foremost, the important properties of water-binding capacity. Generally, these methods require large amounts of raw material (except for the mixograph, which thus far has found limited acceptance in Europe). The large amount of required test material limits the value of these analyses to the plant breeder in the early stages of plant breeding. Another important limitation is that some methods do not adequately describe the stickiness of a dough.

As part of an investigation designed to determine the presence of feed (nonbreadmaking) high-yielding European wheats in marketing channels in Europe, a rotation viscometric method was developed to measure the adhesive properties of doughs (Weipert 1976). This method was well suited for screening new wheat selections (Vettel 1980). Subsequent investigations have shown a high correlation between stickiness and consistency of the dough to water absorption, to rheological dough properties, and to overall breadmaking quality (Weipert 1977, 1978, 1980).

The universal rotation viscometer also can be used to measure flow and viscosity curves of water extracts, suspensions, and doughs, their time-dependent changes, and the effects of temperature, of structure and properties of grain components, and of enzymatic modifications on rheological parameters (Weipert 1981).

This study was designed to evaluate the usefulness of viscometer flow curves of U.S. wheats that vary widely in protein content and protein quality.

## MATERIALS AND METHODS

### Materials

Six hard red winter wheats grown in Manhattan, KS, in 1974, 1975, 1977, 1980, and 1981 were used. The wheats and their cereal identification (C.I.) or selection number (in Kansas), and designations for use in this paper were: Quivira/Tenmarq/Marquillo/Oro, C.I. No. 12995 (401); Shawnee, C.I. No. 14157 (402); Concho/2* Triumph, KS 644 (403); Chiefkan/Tenmarq, KS 501097 (404); Chiefkan/Tenmarq, KS 501099 (405); and Ottawa Selection, KS 699042 (406). Only C.I. Nos. 12995 (401) and 14157 (402) are considered cultivars (cultivated varieties); the others are selections grown for research purposes only and were never released as accepted varieties.

The wheats were milled on an Allis-Chalmers experimental mill to obtain straight-grade flours. The wheat and flour samples were stored at 4° C until they were ground or milled. Whole wheat samples were ground on a Weber pulverizer (Tecator Co., Inc.) to pass a screen with 0.024-in. round openings.

### Baking Procedure

The optimized procedure described by Finney (1984) was used for the baking tests with 100 g of flour (14% mb).

### Analytical Procedures

Protein (N × 5.7), ash, and moisture contents were determined by AACC methods (1976). Starch damage (amylose value) was determined by the method of Hampel (1952), and sedimentation value (indirectly) by near-infrared reflectance spectroscopy according to Bolling and Zwingelberg (1982).

### Flow Curves

*Rheological equipment.* The flow curves were plotted using a Haake Rotovisco RV-3 instrument (Haake Co., Inc., Karlsrube, W. Germany). This is a universal Searle-type viscometer, in which the viscosity of Newtonian and non-Newtonian liquids under stationary flow conditions can be displayed using a pair of coaxial cylinders or a cone-plate device. After imposing a shear force, an analysis is made of the flow in the measuring gap by taking into account the torque and shear rate, and the apparent viscosity is evaluated.

In this study, an SV II device (coaxial cup and spindle with smooth surface) was used; it requires a small amount of dough. A 1,000-MK head was chosen to measure the high dough consistency and a gear box ZG 10 for low shear rates. The flow curves were registered with a Rikadenki recorder in a t-x manner. The Haake Rotovisco RV-12 with an external speed programmer was used to record the flow curves. Other rotational viscosimeters in which the shear rate increases continuously can be used.

*Preparation of doughs.* Preparation of doughs for flow curve measurement and recording requires the use of a separate mixer. A 3 Mix 300 mixer (R. Krups Co., Solingen, W. Germany) at speed III (about 1,700 rpm) was used to produce a homogenous and coherent dough from 10 g of flour or wheat meal. Part of the dough was transferred with a spatula into the viscometer cup. The dough temperature was kept at 30° C.

Generally, doughs are prepared with a constant water absorption of 54% for flour and 58% for wheat meal (Weipert 1977, 1980, 1981). Preparation of the doughs from U.S. flours and meals

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used in this study was modified because they differed from most European wheats in protein contents and gluten properties. The high protein content, high water absorption, and high breadmaking strength were compensated for by increasing the water absorption (to a basic level of 60% in flour and 64% in wheat meal), decreasing the flour sample (from 10 to 9 g), and increasing the mixing time (from 10 to 11 sec). An additional series of tests on doughs was conducted in which water absorption was adjusted according to the protein contents of flours. Assuming a water absorption of 60.0% in a flour containing 11.0% protein, the amount of water was increased by 1.5% per 1.0% increase in protein (K. F. Finney, *personal communication*).

*Determination and evaluation of flow curves.* After 2 min of relaxation time, the flow curves (stress-shear rate curves) were recorded while the shear rate was increased continuously 2.5 rpm/min. The shear stress (Fig. 1) rises with increased rotational velocity, reaches a maximum, flattens, and falls. The fall is caused when the dough tears away from the rotating sensor; this point also denotes the end of the measurement.

Several characteristic indexes can be read directly from the flow curves. Two sets were deemed to be particularly useful for determination of processing values: the apparent viscosity index at the characteristic shear rate, $\eta(D_{char})$, and an apparent shear rate at the tear point, D $(\tau_{max})$.

The dough in these determinations is a two-phase system with shear-thinning (viscoelastic flow) properties. They are characterized by a flow curve that is curved toward the strain axis and a shear stress that decreases with increased shear rate. Therefore, unlike pure Newtonian fluids, viscosity comparisons of flow curves are valid only if the shear is the same for all determinations. The value for the apparent shear rate, D, occurred at the tear point of the most rigid dough and is expressed in pascal seconds (Pa·s).

A valid measurement in a rotational viscometer is predicated on friction and adhesive tension between the rotating device (spindle) and the measured material. At the point in which the flow curve reaches the "tear point," the contact between the spindle and the dough is disrupted and the measurement is completed. The critical shear rate was chosen in this work to be a numerical index of dough stickiness or adhesive tension and was expressed in $Ds^{-1}$ (Fig. 1).

A high viscosity index and an abrupt (short) tear indicate desirable processing parameters; a low viscosity index and a late tear describe undesirable properties. A single value to characterize dough properties, flow quotient, was defined by dividing the apparent viscosity index by the apparent critical shear rate at the tear point (Fig. 1). This empirical value expresses both curve parameters and is more powerful than each separately. The quotient can be used to differentiate and evaluate the breadmaking potential of wheats.

By following the course and the form of the flow curves, we could obtain an empirical assessment of breadmaking quality without actual calculation of the curve parameters. A steep curve with a low critical shear rate indicates a highly elastic dough with desirable surface properties: short and dry rather than moist. A satisfactory characteristic is predicated, however, on a high curve with a high apparent viscosity index in $D_{char}$. The height of the curve is related to water-binding capacity and dough consistency and thereby, probably, also to good gas retention capacity and to a high loaf volume. A low curve, especially if combined with a high critical shear rate at the tear point, describes an inelastic, low-consistency dough that tends to slacken and become sticky. These parameters can be used to screen and classify wheat types that vary in breadmaking potential. Type A wheats are strong, have excellent breadmaking potential, and can be blended with large amounts of weak wheats; type B wheats have intermediate breadmaking potential; and type C wheats do not produce satisfactory bread unless blended with type A wheats (Fig. 2). This method of characterization is useful in screening for wheat quality in plant breeding programs. Alternatively, a flow curve of a specific shape and type can be seen as an objective in plant breeding and large-scale testing and screening.

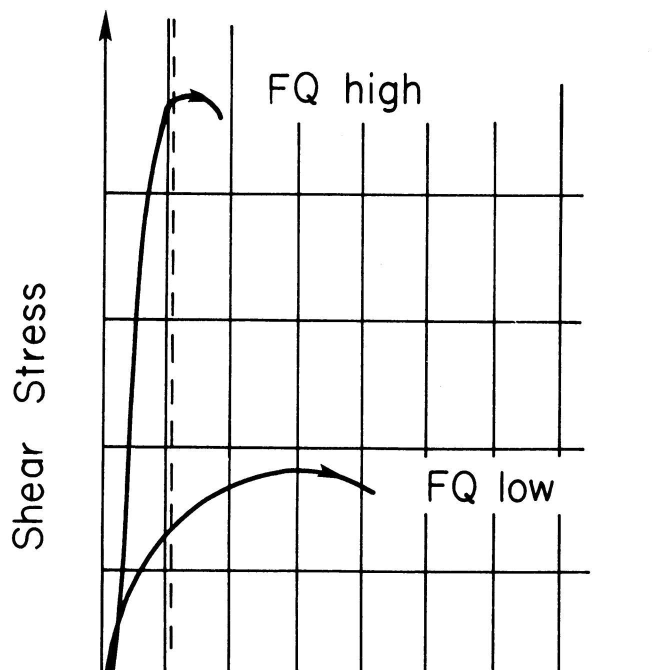


**Fig. 1.** Schematic flow curves of wheat flour doughs. FQ high and FQ low represent good and poor breadmaking quality, respectively. Viscosity index is calculated at $D_{char}$ (dashed vertical line) and the tear point D $(\tau_{max})$ is read off the points marked by arrows.

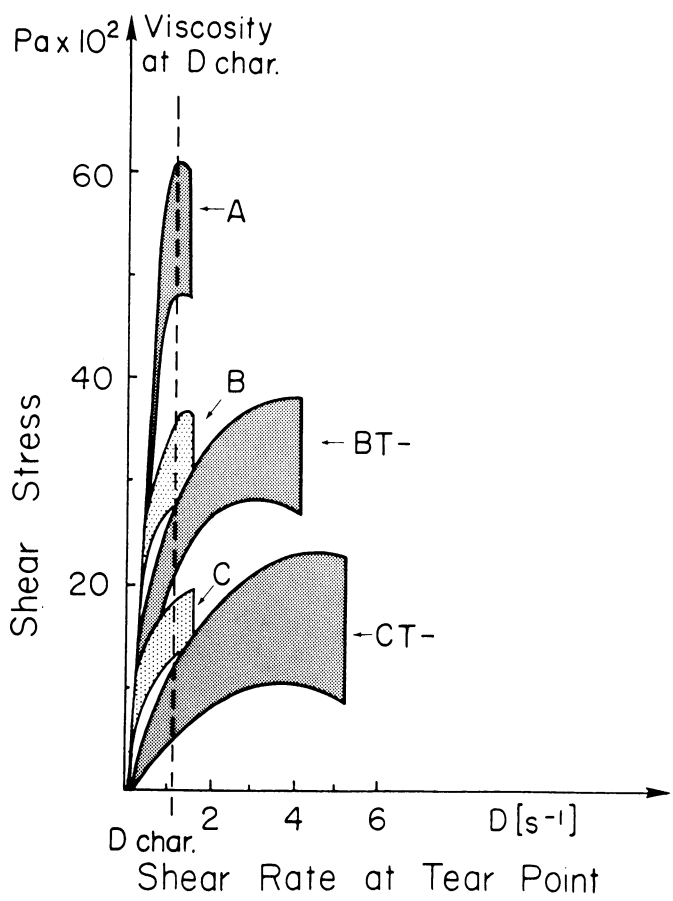


**Fig. 2.** Schematic evaluation of wheat quality from flow curves. **A, B,** and **C** denote good, medium, and poor breadmaking quality, respectively. **T** denotes, in addition, slack and sticky dough properties.

## RESULTS

Ranges and averages of some wheat and flour characteristics are summarized by year in Table I and by selection or variety in Table II. The largest consistent variations were by year in wheat and flour protein contents. Generally, variations in flour yield were larger from year to year than among the selections or varieties. Variations in wheat and flour ash by year or by variety or selection were comparable. Variations in water absorption from year to year were much larger than by selection or variety (Tables I and II) and reflect differences in protein contents.

Damaged starch, measured as amylose, was high in practically all samples; the values for 1974 and especially 1977 were relatively low and were not related to the protein contents of the wheats from various years (Tables I and II). The selections KS 501097 and 501099 stand out as particularly hard and have higher amylose (starch damage) values than the other wheats. For European, semisoft wheats, amylose values of 110 to 200 are satisfactory; values below 110 are too low and above 200 uncommonly high (though acceptable). There were consistent and substantially larger variations in mixing time by selection or variety (Table II) than by year (Table I). C.I. 12995 was consistently the wheat with the longest mixing time, and KS 501099 and KS 699042 had the shortest mixing times. There were large variations in loaf volume, both by year and by variety or selection. Whereas the yearly variations in loaf volume were the result of differences in protein content (Table I), the variations in loaf volume by variety or selection were attributable to differences in genetically controlled breadmaking potential of the wheat proteins. This is confirmed by comparing the specific loaf volumes (calculated as the cubic centimeter increase in loaf volume per 1% of protein above the basic volume of 250 $cm^3$ of a bread containing no functional gluten proteins). Thus, there are practically no differences in average specific loaf volume from year to year (Table I) and more than twofold differences among the selections/varieties. The varieties C.I. 12995 and C.I. 14157 were substantially better in overall

**TABLE I**
**Ranges and Averages (By Year) of Some Wheat, Flour, and Loaf Characteristics**

| | 1974 | | 1975 | | 1977 | | 1980 | | 1981 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Assay | Range | Av. | Range | Av. | Range | Av. | Range | Av. | Range | Av. | LSD[a] |
| Test weight (lb/bushel) | 60.6–62.9 | 61.7 | 59.5–62.5 | 60.6 | 57.5–59.6 | 58.3 | 59.7–62.5 | 61.0 | 52.3–59.1 | 56.5 | ··· |
| Flour yield, % | 73.6–75.4 | 74.7 | 73.4–74.5 | 73.8 | 69.6–73.0 | 71.6 | 69.5–72.2 | 71.2 | 68.1–71.3 | 69.2 | 1.6 |
| Wheat ash, % (14% mc) | 1.42–1.54 | 1.49 | 1.61–1.75 | 1.67 | 1.61–1.75 | 1.68 | 1.41–1.55 | 1.46 | 1.52–2.01 | 1.64 | 0.13 |
| Wheat protein, % (14% mc) | 10.7–12.4 | 11.5 | 12.9–14.6 | 13.6 | 16.2–18.3 | 17.0 | 13.8–15.5 | 14.8 | 17.9–22.3 | 19.8 | 2.2 |
| Flour ash, % (14% mc) | 0.35–0.45 | 0.42 | 0.39–0.47 | 0.43 | 0.35–0.46 | 0.41 | 0.30–0.45 | 0.39 | 0.41–0.57 | 0.47 | ··· |
| Flour protein, % (14% mc) | 10.2–11.2 | 10.6 | 11.7–13.4 | 12.5 | 15.1–16.2 | 15.6 | 12.6–14.7 | 13.5 | 18.6–21.6 | 19.2 | 0.67 |
| Water absorption, % (14% mc)[b] | 69.7–76.0 | 72.5 | 62.5–65.7 | 63.8 | 66.3–67.9 | 67.0 | 60.9–63.7 | 62.3 | 58.9–60.4 | 59.5 | 2.9 |
| Sedimentation value | 16–40 | 31.2 | ··· | ··· | 25–74 | 54.0 | 30–54 | 42.0 | 30–72 | 53.8 | ··· |
| Damaged starch (amylose value) | 138–353 | 239 | ··· | ··· | 72–173 | 108 | 260–571 | 419 | 255–523 | 407 | 173 |
| Bake mixing time (minutes) | 1.75–9.50 | 3.90 | ··· | ··· | 1.00–6.625 | 3.30 | 1.25–6.25 | 3.02 | 0.75–5.00 | 2.48 | 3.72 |
| Loaf volume ($cm^3$) | 568–875 | 761 | ··· | ··· | 669–1,187 | 1,007 | 715–1,041 | 895 | 693–1,286 | 1,041 | 75 |
| Specific loaf volume ($cm^3$/1% protein) | 28.4–57.9 | 47.3 | ··· | ··· | 26.0–62.5 | 48.9 | 35.0–59.5 | 48.0 | 20.5–59.5 | 41.8 | 17.3 |

[a] Least significance of the mean (0.05 level).
[b] Corrected according to protein content.

**TABLE II**
**Ranges and Averages (by Selection or Variety) of Some Wheat, Flour, and Loaf Characteristics**

| | 12995 (401) | | 14157 (402) | | KS 644 (403) | | KS 501097 (404) | | KS 501099 (405) | | KS 609042 (406) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Assay | Range | Av. | Range | Av. | Range | Av. | Range | Av. | Range | Av. | Range | Av. | LSD[a] |
| Test weight (lb/bushel) | 56.2–60.9 | 59.1 | 56.5–60.8 | 59.3 | 58.5–62.9 | 61.1 | 58.2–61.3 | 60.0 | 56.8–61.0 | 59.8 | 52.3–62.9 | 58.9 | ··· |
| Flour yield, % | 70.0–74.3 | 72.4 | 71.3–74.6 | 72.7 | 67.2–75.4 | 72.4 | 69.5–74.6 | 71.7 | 68.6–73.6 | 71.3 | 68.1–75.4 | 71.9 | 4.0 |
| Wheat ash, % (14% mc) | 1.41–1.63 | 1.54 | 1.44–1.71 | 1.58 | 1.48–1.66 | 1.56 | 1.42–1.69 | 1.56 | 1.44–1.66 | 1.54 | 1.54–2.01 | 1.72 | 0.20 |
| Wheat protein, % (14% mc) | 11.5–20.7 | 15.4 | 11.7–19.6 | 15.2 | 11.7–17.9 | 14.6 | 10.7–19.0 | 14.9 | 10.3–19.4 | 14.7 | 10.5–22.3 | 16.5 | 5.0 |
| Flour ash, % (14% mc) | 0.35–0.50 | 0.42 | 0.40–0.50 | 0.44 | 0.30–0.41 | 0.36 | 0.43–0.46 | 0.45 | 0.43–0.45 | 0.44 | 0.36–0.57 | 0.44 | ··· |
| Flour protein, % (14% mc) | 10.8–20.1 | 14.4 | 10.0–18.6 | 14.0 | 10.4–17.4 | 13.6 | 10.2–18.7 | 14.2 | 10.4–19.1 | 14.2 | 11.2–21.6 | 15.1 | 4.73 |
| Water absorption, % (14% mc)[b] | 61.9–73.8 | 65.1 | 62.4–71.5 | 64.6 | 59.2–69.7 | 63.9 | 66.3–71.7 | 64.9 | 59.2–72.3 | 64.9 | 60.4–76.0 | 66.3 | 6.0 |
| Sedimentation value | 40–70 | 56.6 | 37–70 | 55.8 | 39–74 | 59.2 | 27–45 | 33.8 | 28–40 | 34.0 | 16–30 | 25.4 | ··· |
| Damaged starch (amylose value) | 95–366 | 249 | 102–378 | 249 | 72–260 | 181 | 173–571 | 377 | 217–523 | 398 | 99–404 | 232 | 195 |
| Bake mixing time (minutes) | 5.00–9.50 | 6.87 | 4.25–5.75 | 5.00 | 2.125–3.375 | 2.80 | 0.875–2.00 | 1.41 | 0.75–1.75 | 1.25 | 0.875–1.625 | 1.19 | 3.16 |
| Loaf volume ($cm^3$) | 825–1,245 | 1,075 | 875–1,328 | 1,102 | 873–1,286 | 1,050 | 705–875 | 821 | 722–844 | 795 | 568–715 | 661 | 231 |
| Specific loaf volume ($cm^3$/1% protein) | 49.5–61.2 | 55.9 | 57.2–62.5 | 58.9 | 52.9–59.5 | 55.5 | 33.4–44.6 | 40.0 | 29.7–45.4 | 38.5 | 20.5–35.0 | 27.5 | 10.5 |

[a] Least significant difference of the mean (0.05 level).
[b] Corrected according to protein content.

breadmaking potential than the selections KS 501097 and KS 501099; KS 699042 was the poorest, and K 644 was intermediate. Combined effects of both protein content and protein quality are demonstrated for the high-intermediate quality (401, 402, and 403) and to a lesser degree for the low-poor quality (404, 405, and 406) wheats.

Differences in sedimentation values by year (Table I) were caused mainly by differences in protein content. When the sedimentation values were divided by protein contents, the specific sedimentation values ranged only from 2.71 to 3.18. Differences in sedimentation values by selection or variety (Table II) were caused mainly by differences in protein quality. When the sedimentation values were divided by protein contents, the specific sedimentation values ranged from 1.54 to 4.06.

Figure 3 compares flow curves of meals from six selections from four crop years; effects of protein content and protein quality (among varieties) are indicated. The curves for selections 401, 402, and 403 show steep and generally high curves; the higher the protein, the higher the curve. The curve for selection 406 is consistently low and has delayed tear characteristics. Flow curves of selections 404 and 405 are intermediate-low and, generally, show a late tear point at a relatively high apparent viscosity index. Ranking of the flow data corresponds to, or reflects, both the effects of genetically governed varietal properties and environmental conditions, as expressed through the effect on protein content within a wheat selection.

Flow curves, as affected by variety and environmental conditions, are more consistent for doughs prepared from flours (Fig. 4) than for doughs prepared from meals (Fig. 3). This is particularly evident for the curves from the crop year 1981 evaluated at a constant water addition, which results in a high dough viscosity index; the results are affected by the high protein content and high water-binding capacity (Table I). The curves for flour doughs have a somewhat lower curve height but mainly a lower apparent shear rate at the tear point of the curve than the corresponding curves for meal doughs. The lower tear point of the

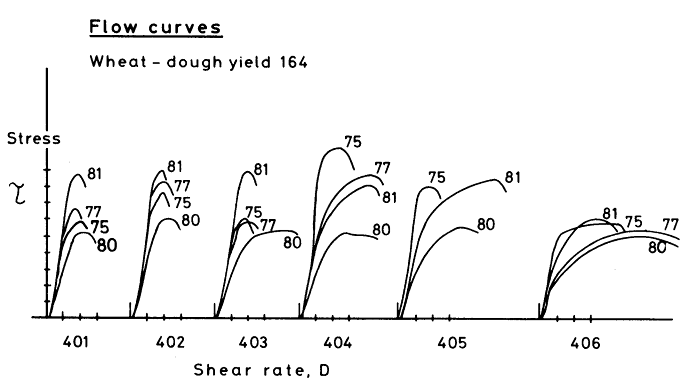


**Fig. 3.** Flow curves from meal doughs with constant water absorption (six wheat varieties or selections for four years).

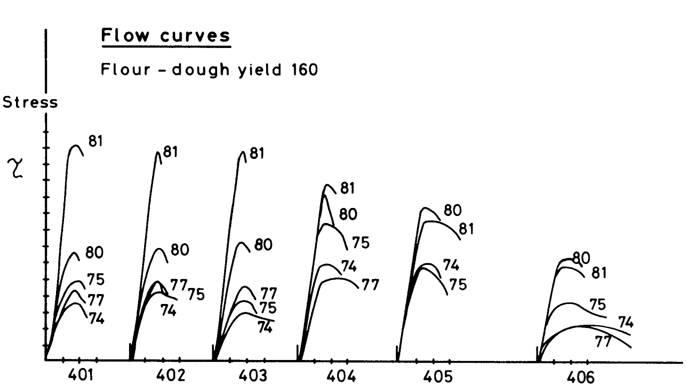


**Fig. 4.** Flow curves from flour doughs with constant water absorption (six wheat varieties for five years).

flour doughs, even though smaller than in meal doughs, still makes possible a satisfactory differentiation of dough properties. Selection 406 is characterized in the flour dough more conspicuously than in the meal dough by a low curve with a late tear point, confirming the highly undesirable quality characteristics of this selection.

Differences in the forms of flow curves of meal and flour doughs reflect differences in properties that relate to composition of wheat and flour components as well as breadmaking potential of the milled products.

If we assume that the water-binding capacity of a dough is foremost affected by the gluten proteins (provided the amounts of pentosans and the level of starch damage are fairly constant), then it is possible to calculate an approximate water absorption or optimum dough yield by taking into account the amount of protein in the flour. We have done this by assuming that a 1.0% increase in protein content requires a 1.5% increase in water absorption. The protein levels of the flours and the corresponding corrected dough absorptions were summarized in Tables I and II. Differences among selections for a given year are smaller than differences among various crop years. Wheat of the crop year 1981 was extremely high in protein content and of the crop year 1974 extremely low in protein content. The protein contents of wheats from the other three years are intermediate and normal.

Based on the protein contents, the calculated water absorptions of the tested flours ranged from 58.9 to 76.0%. Those water absorptions were used to obtain the flow curves summarized in Tables III and IV. A comparison of all flow curves, both with fixed and corrected water absorption, showed that the flow curves of selections 401, 402, and 403 were basically the same (with the exception of samples from 1977), that in selection 406 there were only small deviations, and that for 404 and 405 there was a large difference, depending on the water absorption that was used, constant (Fig. 4) or corrected (Fig. 5).

These results indicated that dough consistency is affected not only by the protein content of the flour; another factor that may govern water absorption of wheat flour dough is the amount of mechanically damaged starch. If the flow curves are considered in light of the amylose values as an index of starch damage (Tables I and II), it is possible to explain the low viscosity indexes of the doughs in the crop year 1977 for the selections 401, 402, and 403 in which a low starch damage and thereby reduced water binding capacity has been determined. A high viscosity index in the dough of selection 406 from 1980 can be explained by insufficient water addition for a flour in which starch damage was high. Selections 404 and 405 were hard and their starch was highly damaged during the milling process. Deviations from the normal starch damage values, which frequently take place depending on the hardness of the wheat, can influence dough viscosity indexes and be mistaken for protein effects. Those effects can influence the course of the flow curve in general, and the viscosity index in particular. As a

**TABLE III**
**Stress-Strain Curves of Whole Wheat Meals and Flours; Averages (by Year) of Viscosity[a] and Strain[b]**

| Assay and Material | 1974 | 1975 | 1977 | 1980 | 1981 | LSD[c] |
|---|---|---|---|---|---|---|
| Meals | | | | | | |
| Viscosity, Pa·s | ··· | 3,880 | 3,249 | 2,251 | 3,745 | 933 |
| Strain, $Ds^{-1}$ | ··· | 2.43 | 3.08 | 3.23 | 2.99 | 1.73 |
| Flours[d] | | | | | | |
| Viscosity, Pa·s | 2,542 | 2,682 | 2,216 | 4,092 | 4,930 | 1,433 |
| Strain, $Ds^{-1}$ | 2.06 | 1.78 | 1.90 | 1.59 | 1.88 | 0.59 |
| Flours[e] | | | | | | |
| Viscosity, Pa·s | 2,982 | 2,712 | 1,680 | 2,894 | 2,257 | 446 |
| Strain, $Ds^{-1}$ | 2.19 | 2.11 | 2.19 | 2.05 | 2.39 | 0.62 |

[a] At $D_{char.}$

[b] At $\tau_{max.}$

[c] Least significant difference of the mean (0.05 level).

[d] In doughs with constant water absorption.

[e] In doughs with water absorption corrected for protein content.

TABLE IV

Stress-Strain Curves of Whole Wheat Meals and Flours; Averages (by Selection or Variety) of Viscosity[a] and Strain[b]

| Assay and Material | 12995 (401) | 14157 (402) | KS 644 (403) | KS 501097 (404) | KS 501099 (405) | KS 609042 (406) | LSD[c] |
|---|---|---|---|---|---|---|---|
| Meals | | | | | | | |
| Viscosity, Pa·s | 3,299 | 3,984 | 3,213 | 3,516 | 3,299 | 2,389 | 1,463 |
| Strain, $Ds^{-1}$ | 2.02 | 1.95 | 2.08 | 3.36 | 3.42 | 4.86 | 1.33 |
| Flours[d] | | | | | | | |
| Viscosity, Pa·s | 3,238 | 3,407 | 2,944 | 4,507 | 4,178 | 2,273 | 1,920 |
| Strain, $Ds^{-1}$ | 1.70 | 1.62 | 1.78 | 1.96 | 2.05 | 2.37 | 0.53 |
| Flours[e] | | | | | | | |
| Viscosity, Pa·s | 2,228 | 2,682 | 2,228 | 3,678 | 2,800 | 1,637 | 1,406 |
| Strain, $Ds^{-1}$ | 2.07 | 1.76 | 1.89 | 2.36 | 2.40 | 2.67 | 0.50 |

[a] At $D_{char}$.
[b] At $\tau_{max}$.
[c] Least significant difference of the mean (0.05 level).
[d] In doughs with constant water absorption.
[e] In doughs with water absorption corrected for protein content.

TABLE V

Summary of Simple and Multiple Linear and Curvilinear Relations

| Variables | Correlation Coefficient ($r$) |
|---|---|
| Wheat protein vs. viscosity of the meal | 0.474 |
| Dough viscosity (wheat) vs. (sedimentation value × 42.1) + (protein × 185) + (damaged starch × 0.36) | 0.834 |
| Dough viscosity (wheat) vs. sedimentation value | 0.720 |
| Dough viscosity (flour) vs. (sedimentation value × 39.3) + (protein × 65.4) + (damaged starch × 7.71) | 0.881 |
| Tear point of the stress-strain curve vs. sedimentation value | |
| Linear | −0.816 |
| Curvilinear[a] | −0.919 |
| Sedimentation value vs. flow quotient of wheat stress-strain curve | 0.886 |
| Loaf volume vs. viscosity of meal stress-strain curve | 0.813 |
| Loaf volume vs. tear point of meal stress-strain curve | |
| Linear | −0.842 |
| Curvilinear[b] | −0.923 |
| Loaf volume vs. flow quotient of meal stress-strain curve | 0.954 |
| Loaf volume vs. (wheat viscosity × 0.091) − (D × 85.1) | 0.905 |

[a] Parabole $y = a + b/x$.
[b] Hyperbole $y = x/(a + bx)$.

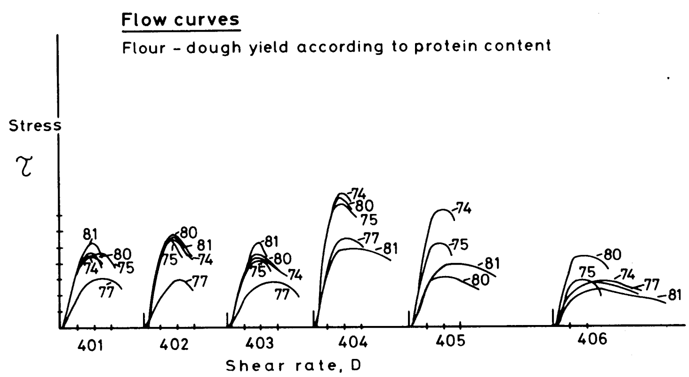


**Fig. 5.** Flow curves from flour doughs with water absorption corrected by protein content (six wheat varieties for five years).

result, the use of a correction factor for water absorption based on protein content is valid only provided flours with a relatively narrow range of starch damage are used.

## DISCUSSION AND CONCLUSIONS

Dough has been described as "the most complicated rheological material at present known to man" (Reiner cited in Muller 1973). The method for determining flow curves of wheat flour doughs, including the equipment and the procedure, has potential both in terms of the information provided and simplicity of the determination. A correlation exists between the parameters of a flow curve and the breadmaking potential of European wheats (Weipert 1980). We report here the use of flow curves to evaluate U.S. varieties and selections when tested by flow curves and standard U.S. methods. Several limitations of the findings should be stated. The varieties or selections used in this study varied widely both with regard to protein contents and protein quality. Such a variation is not likely to be encountered in actual testing of wheats in marketing channels or in quality control in mills or bakeries. Such a variation might be encountered, however, in testing germ plasm in plant breeding where the proposed method could be used as a screening test to cull out inferior varieties and concentrate on those with desirable rheological properties. On the other hand, the observation that there exists a high positive correlation ($r = 0.864$) between the flow curves of wheat meal and wheat flour doughs, as reported by Weipert in 1980, could not be confirmed for the samples used in this study.

The apparent viscosity index of the flow curves as defined in this study is not governed by the protein content of the meal or the flour alone. This results in a low correlation coefficient of 0.474 (Table V). The correlation between protein content and other parameters of the flow curve showed an even lower coefficient. This is not surprising, as samples varied widely in protein quality parameters that were evaluated. It is possible, however, to predict an apparent viscosity index through the calculation of multiple linear regressions and correlation coefficients that take into account the sedimentation value as an index of protein quality, the protein content of the meal, and the amylose value as an index of starch damage. It is thereby shown that the flow curve measures the potential performance of the dough as determined by a combination of methods: as affected by the quality and quantity of proteins and starch damage.

The correlation between flow curve data and sedimentation value was high. The correlation between the apparent viscosity index and sedimentation value was 0.720 and between sedimentation value and tear point −0.919. The second correlation, however, is not linear. The correlation between flow quotient and sedimentation value was 0.886.

Finally, the parameters of flow curves showed a positive correlation with results of the baking test. That correlation was 0.813 for the apparent viscosity index, −0.842 for the tear point, and 0.954 for the flow quotient. A high correlation for the latter was confirmed by calculation of a multiple linear correlation of 0.905, which is somewhat smaller than the simple correlation of 0.954.

The correlations of the flow curves of the flour doughs were not as high as those of the meal and were in the range of 0.52–0.66. Still, flow curves can be useful in evaluation and screening of hard, relatively high-protein, strong wheats and in plant breeding programs. The curves describe the physical properties of doughs at the time of the test to the extent that those properties govern the breadmaking potential. This then provides information correlated with end-use properties and of potential use both in plant breeding and in research.


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## LITERATURE CITED


AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 08-11, approved October 1976; Method 44-15A, approved April 1967; and Method 46-11, approved April 1961. The Association: St. Paul, MN.

BOLLING, H., and ZWINGELBERG, H. 1982. Infrarotspektroskopie–Moeglichkeiten und Grenzen ihrer Anwendung in der Muellerei. Muehle Mischfuttertechnik 119:550.

FINNEY, K. F. 1984. An optimized straight-dough breadmaking method after 44 years. Cereal Chem. 61:20.

HAMPEL, G. 1952. Die exakte Bestimmung der Staerkebeschaedigung und des Totmahlens durch die Amylosezahl. Getreide Mehl Brot 12:16.

MULLER, H. G. 1973. An Introduction to Food Rheology. Heinemann: London.

VETTEL, F. 1980. Erfahrungen in der praktischen Winterweizenzuechtung bei der Untersuchung "nicht backfaehiger Weizen mit nachlassenden Teigen und schmierenden bzw. klebenden Teigoberflaechen" unter Verwendung des Rotationsviskosimeters. Getreide Mehl Brot 34:230.

WEIPERT, D. 1976. Messung der adhaesiven Teigeigenschaften mit einem Rotationsviskosimeter. Getreide Mehl Brot 30:219.

WEIPERT, D. 1977. Aufnahme von Fliesskurven zur Beurteilung der Teigeigenschaften. Rheol. Acta 16:449.

WEIPERT, D. 1978. Rheologische und rheometrische Probleme zur Charakterisierung von Roggen- und Weizenmehlteigen. Muehle Mischfuttertechnik 115:281.

WEIPERT, D. 1980. Einsatz eines Rotationsviskosimeters zur Erfassung der Qualitaetseigenschaften von Weizen. Getreide Mehl Brot 34:113.

WEIPERT, D. 1981. Einsatz rheologischer Messungen zur Beschreibung der Beschaffenheit der Korninhaltsstoffe des Getreides. Rheol. Acta 20:605.


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