A New Parameter Related to Loaf Volume Based on the First Derivative of the Alveograph Curve

K. ADDO,[1] D. R. COAHRAN,[2] and Y. POMERANZ[1]

ABSTRACT

Cereal Chem. 67(1):64–69

The recording unit of an alveograph was modified by attaching a computerized unit for automatic computation and storage of data. The modification allowed comparison of data collected manometrically with that obtained by the computer. The stored data was used via a software program to determine the first derivative of the alveograph curve. A new parameter (*DM*) based on the first derivative of the alveograph curve was developed. Alveograph indices of *P*, *L*, *W*, and *DM* were used to assess the baking qualities of six Midwestern hard red winter wheat flours (three, each, of good and poor breadmaking potential) and 22 Pacific Northwestern hard white winter and hard red spring wheat flours (covering a wide range of breadmaking potential). *DM* gave the highest correlations with both loaf volume and specific loaf volume for the 22 Pacific Northwestern flours (−0. 897 and −0.899, respectively, $P < 0.001$). Stepwise regression analysis produced a model in which *DM*, *P*, and water absorption explained over 90% of the variability in loaf volume potential.

The alveographic technique, originally developed in France as an empirical physical test to assess the breadmaking quality of soft wheat flours, is currently finding increasing use in many parts of the world. Much of the available information was summarized recently in *The Alveograph Handbook* by Faridi and Rasper (1987). Earlier attempts to relate alveograph parameters with baking quality of hard, high-protein wheat flours met with limited success and/or contrasting results. Khattak et al (1974) used the alveograph to evaluate hard red spring (HRS) wheats and reported low and nonsignificant correlations with loaf volume. It was concluded that the alveograph was not suitable for evaluating the breadmaking quality of HRS flours. Preston et al (1987) suggested that part of the problem in assessing the quality of HRS wheats with the alveograph under standard conditions (50% dough absorption) was related to the high starch damage levels in the flours. As starch damage increases, extensibility (*L*) of dough decreases and overpressure (*P*) increases. Such changes would normally be interpreted as an increase in inherent flour strength, rather than an increase in water absorption requirements due to increased starch damage. Weipert (1981), comparing the loaf volume of breads baked from German flours by the rapid-mix test, found considerable differences in correlations between alveogram indices and baking quality of tested flours. The strongest correlation was reported between loaf volume and swelling index, *G*, whereas *P* and *W* values appeared to be somewhat less reliable predictors of baking quality. However, the correlations involving *P* and *W* could be greatly improved by extending the dough mixing and resting times of the standard alveograph procedure (total 28 min) to 65 and even 135 min. More recently, Bettge et al (1988) used the alveograph to evaluate the breadmaking qualities of soft and hard wheat flours from the Pacific Northwest. In both wheat flour types, *L* produced the highest correlation with loaf volume and specific loaf volume.

In addition to the conventional alveograph indices, investigators have examined other quantitative aspects of the alveogram to relate the shape of the curve to the rheological and functional properties of dough. Bloksma (1957, 1958), using some simplifying assumptions, calculated the shapes of alveograms of viscous (Newton body), viscoelastic (Maxwell body), and plastic (Bingham body) substances and concluded that no physical reason exists for characterizing an alveogram by means of the maximum height of the curve as previously suggested by Scott Blair and Potel (1937). Instead, he suggested it be characterized by the volume (V_m) at which the maximum curve height occurs, because this volume depends on the relaxation time, provided the dough behaves as a Maxwell body. Bloksma also proposed that a flat alveogram maximum coupled with a high V_m may indicate a long relaxation time. On the other hand, if V_m is low, a flat maximum indicates considerable structural viscosity. Also, a high ratio between the pressure in the dough bubble at the moment that its volume equals 100 cm^3 (P_{100}) and the maximum pressure in the dough bubble at an arbitrary place (P_m) could indicate either a desirable long relaxation time or a harmful structural viscosity. More recently, Chen and D'Appolonia (1985), using a modified alveograph procedure, suggested that the difference between the height of the curve at the peak and the height of the curve measured at 2 cm after the peak might be a good indication of the protein content and wet gluten value of HRS wheat flour.

The effect of high starch damage on alveograph curves run under standard (fixed) conditions, and the fact that test baking of plant breeders' samples is normally conducted under optimized conditions, prompted several modifications of the procedure (Shogren et al 1963a,b; Khattak et al 1974; Chen and D'Appolonia 1985; Dexter et al 1985; Rasper et al 1985, 1986; Preston et al 1987). Attempts in our laboratory to improve prediction of breadmaking potential of wheat flours by optimizing water absorption and mixing time of hard wheat flours have been largely unsuccessful.

The objectives of the present study were to interpret the information provided by the alveograph and to use that information to predict breadmaking potential of flours milled from plant breeders' samples of hard wheat. To achieve these objectives, a new index based on the first derivative of alveograph curves was developed.

MATERIALS AND METHODS

Flours

Six Midwestern plant breeders' hard red winter (HRW) flours from the 1979 crop year were obtained from the USDA Grain Marketing Research Laboratory in Manhattan, KS. Included were Quivira/Tenmarq/Marquillo/Oro (C.I. no. 12995), Shawnee (C.I. no. 14157), Concho/2* Triumph (KS 644), Chiefkan/Tenmarq (KS 501097), Chiefkan/Tenmarq (KS 501099), and Ottawa Selection (KS 699042). These samples included three samples each of good and poor breadmaking potential.

The USDA Western Wheat Quality Laboratory in Pullman, WA, provided 18 HRS and four hard white winter wheats from the 1987 crop year (grown in Oregon and Washington, respectively) chosen to represent a selection of crosses varying widely in genetic background and covering a wide range in breadmaking potential. The wheats were milled on a Buhler experimental mill into straight-grade flours.

---

[1] Dept. of Food Science and Human Nutrition, Washington State University, Pullman 99164-6376.

[2] R Design, West 700 Main St., Pullman, WA 99163.

Analytical Methods

Moisture and protein contents (N × 5.7) of the flours were determined by AACC methods 46-12 and 44-15A, respectively (AACC 1983).

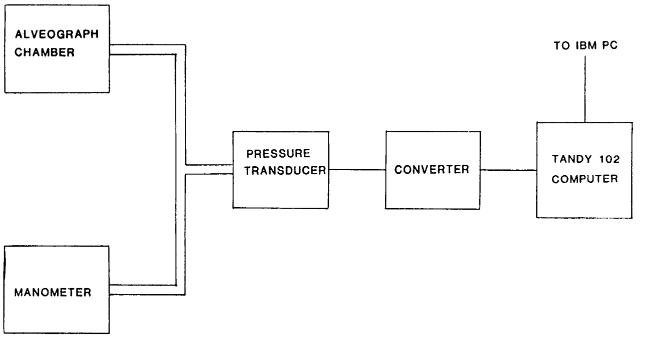

Fig. 1. A block diagram of the alveograph and the computer recording unit.

Baking Procedure

The optimized procedure of Finney (1984) was used for baking tests with 100 g of flour (14% mb). Optimum mixing time and water absorption were determined by mixograph analysis of the flours and by an experienced experimental baker. Specific loaf volume was calculated by dividing the total volume minus 400 by the flour protein content. The value of 400 cm^3 represents the volume of a loaf with no functional protein.

Alveograph Testing

Alveograph tests were performed under conditions of constant dough water content and mixing times using the standard AACC method 54-30 (AACC 1983). For data recording and storage, the alveograph was modified as follows: a pressure transducer was connected to the tube between the alveograph chamber and the manometer, maintaining the original overall length of the tube. The transducer output was read 16 times per second under computer control, and the readings were recorded by a Tandy model 102 portable computer. The data from the five replicate curves on each wheat sample were transferred to an IBM personal computer for analysis, plotting, and storage. Data for *P*, *L*, and *W* that differed by more than two standard deviations from the

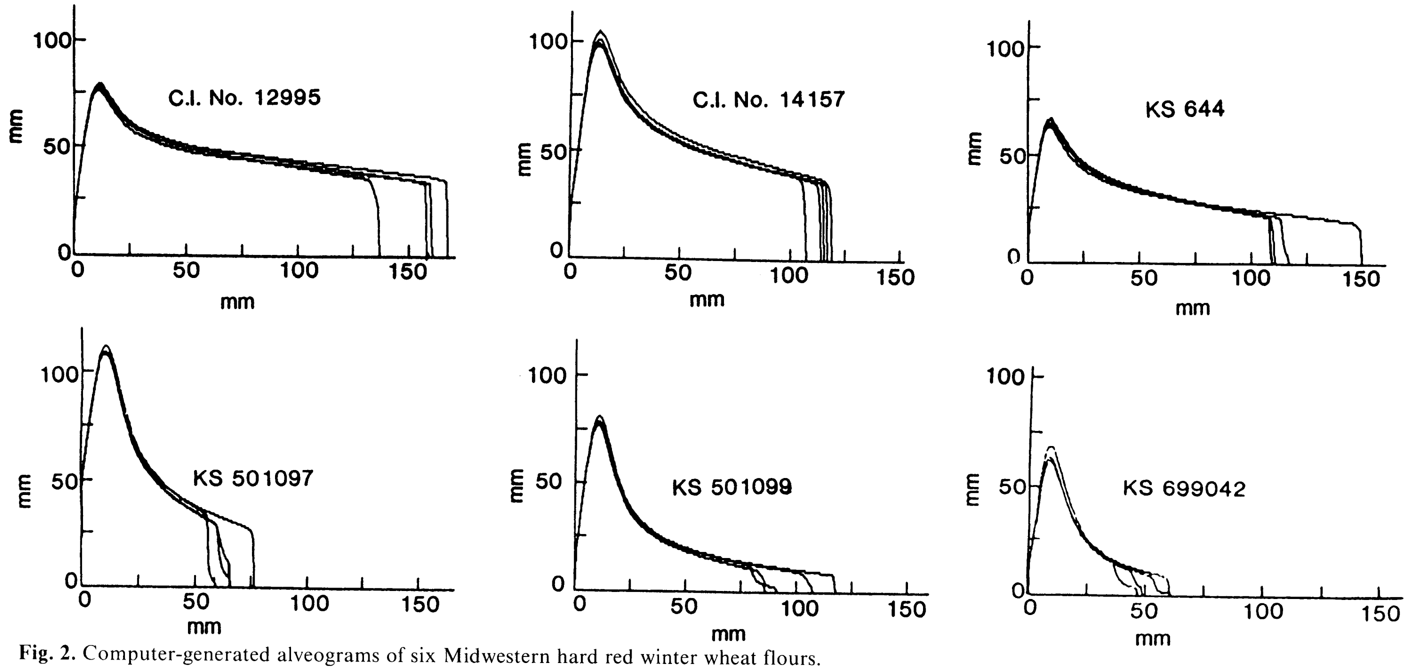

Fig. 2. Computer-generated alveograms of six Midwestern hard red winter wheat flours.

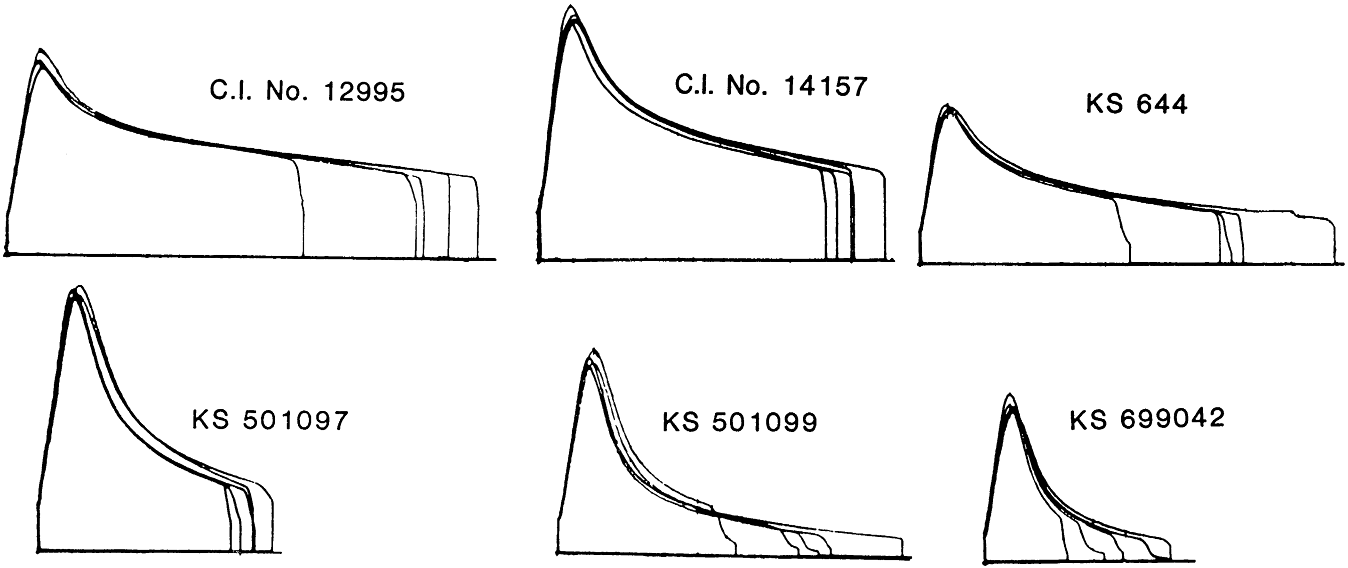

Fig. 3. Standard alveograph manometric profiles of six Midwestern hard red winter wheat flours.

mean were automatically excluded from calculation of the averages. This modification of the alveograph does not interfere with the use of the manometer, allowing the comparison of data collected manometrically with that collected by the computer. Figure 1 shows a block diagram of the alveograph and the computer recording unit.

First Derivative

A software program utilizing three-step moving averages of the data points (16 points/sec or 16 points/5.5 mm) was used to plot the first derivative curve of the average of the alveograph curves.

TABLE I

Computer-Generated Alveogram and Other Quality Parameters for Six Midwestern Hard Red Winter Wheat Flours

Sample	Flour Protein (N × 5.7, %)	Water Absorption (%)	Mixing Time (min)	Average Alveogram Parameters *P* (mm)	*L* (mm)	*W* ($\times 10^{-4}$ J)	*DM*[a]	Loaf Volume (cm^3)	Specific Volume (cm^3/1% protein)
Qv/Tm/Mq/Or (C.I. 12995)	12.5	67.5	5.0	77	155	429	1.65	1,005	48.4
Shawnee (C.I. 14157)	11.4	63.0	3.8	99	113	375	2.11	945	47.6
Concho/2* Triumph (KS 644)	10.5	64.0	3.5	64	121	242	1.91	870	44.7
Chiefkan/Tenmarq (KS 501097)	13.4	65.0	1.3	107	65	223	4.71	770	28.0
Chiefkan/Tenmarq (KS 501099)	13.8	64.0	1.6	78	102	160	4.57	745	25.1
Ottawa Selection (KS 699042)	12.1	59.0	1.3	64	50	82	4.55	595	16.1

[a] An index based on the first derivative of the alveograph curve and defined as the negative of the minimum value of the first derivative of the curve. See text for details.

TABLE II

Correlation Coefficients Between Averaged Alveogram and Other Quality Parameters of Six Hard Red Winter Wheat Flours from the Midwest

Parameter	Water Absorption	Mixing Time	Alveograph *P*	*L*	*W*	*DM*	Loaf Volume	Specific Volume
Protein	0.214	−0.506	0.365	−0.272	−0.242	0.698	−0.314	−0.536
Water absorption	···	0.578	0.318	0.739	0.725	−0.455	0.770	0.634
Mixing time		···	−0.084	0.914*[a]	0.897*	−0.966**	0.917**	−0.929**
P			···	−0.115	0.355	0.147	0.259	0.152
L				···	0.820*	−0.852*	0.900*	0.865*
W					···	−0.815*	0.971**	0.914*
DM						···	−0.869*	−0.943**
Loaf volume							···	0.968**

[a] ** and * = Significant at $P<0.01$ and $P<0.05$, respectively.

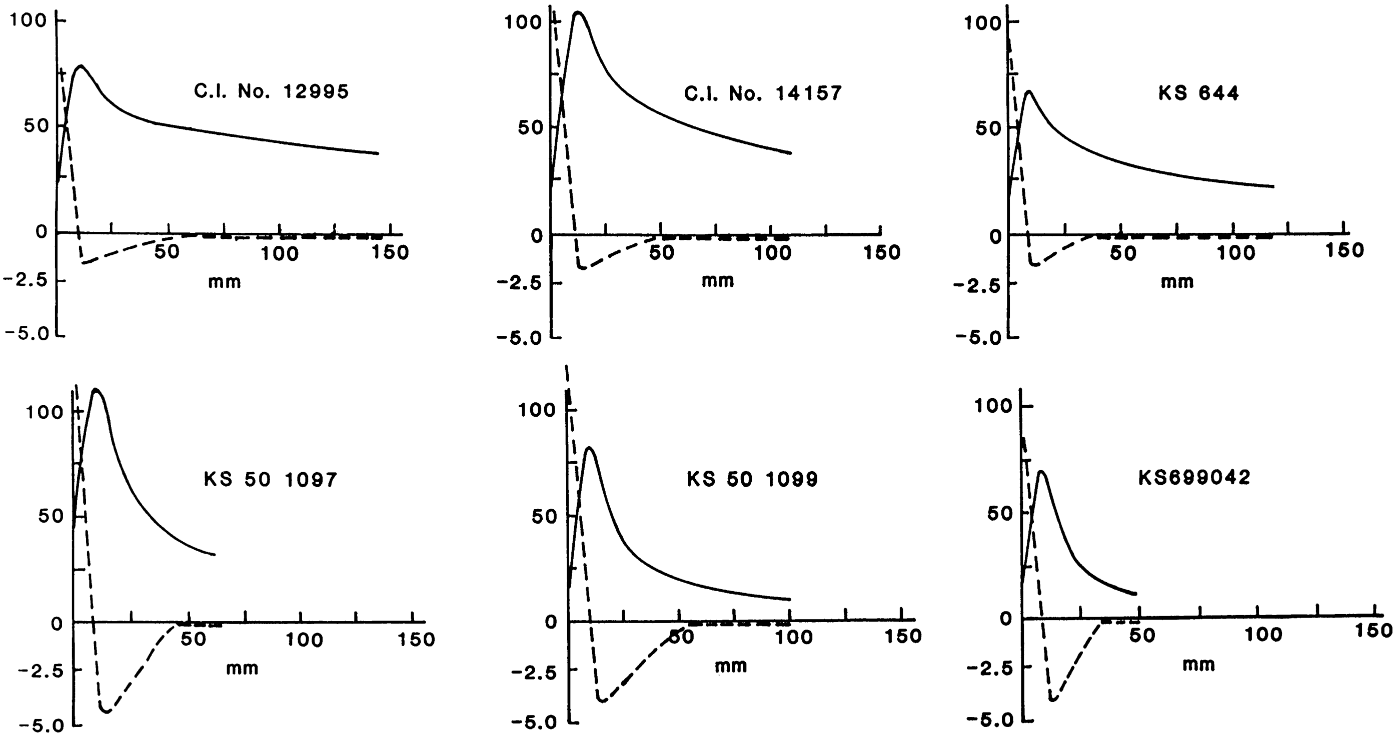

Fig. 4. Smoothed representation of averaged alveograph curves and their corresponding first derivative curves. Positive y-axis represents hydrostatic pressure in millimeters (mm); negative y-axis represents the first derivative (hydrostatic pressure in mm/length in mm). X-axis represents the length (extensibility) of the alveograph curve in millimeters.

Statistical Analysis

Data were analyzed using the statistical analysis system as described by the SAS Institute (1985).

RESULTS AND DISCUSSION

Computer-generated alveograms and the corresponding standard analog manometric profiles of the six Midwestern HRW flours are shown in Figures 2 and 3. C.I. no. 12995, C.I. no. 14157, and KS 644 are flours of good breadmaking potential, whereas KS 501097, KS 501099, and KS 699042 are flours of poor breadmaking potential. The corresponding alveograph and other flour quality data are presented in Table I. None of the usual alveograph indices distinguished consistently between the two groups of flours in terms of their breadmaking potential. Samples 501097 and 501099, for instance, which are nearly isogenic lines, produced widely differing *P*, *L*, and *W* values. On the other hand, the two groups are clearly distinguished by their differences in specific volumes and mixing times. Also, an examination of the curves (Fig. 2), revealed a rather unique trend in terms of the slope immediately following the overpressure. In general, the flours of good breadmaking potential showed a gradual drop after the maximum overpressure was attained, whereas those of the poor breadmaking potential showed a drastic drop after the maximum overpressure.

This general trend in curve shape prompted an estimation of the first derivatives of the averaged curves of the alveograms of the six flours. The six averaged curves and their corresponding first derivative curves, showing a clear distinction between the two groups of flour, are presented in Figure 4.

To assign a quantitative meaning to this distinction, the minimum point on the first derivative curve was defined as *DM* (Fig. 4). *DM* was obtained by selecting the corresponding minimum value from the set of data points used to plot the derivative curve and generated by the computer. The corresponding *DM* values are also presented in Table I. In general, the flours of good breadmaking potential produced lower *DM* values than those of poor breadmaking potential. Table II shows correlations between loaf volumes, the alveograph indices (including *DM*), and other quality parameters for the six HRW samples. Scatter plots between loaf volumes, specific volumes, the alveograph indices *W*, and *DM* are shown in Figure 5. The relationship between *W* and loaf volume points to a rather continuous spectrum, whereas the *DM* index clearly distinguishes between the two groups of flours. The correlation coefficient between protein

TABLE III

Range and Mean Parameters of Four Hard White Winter and 18 Hard Red Spring Flours from Wheats Grown in the Pacific Northwest

Parameter	Range	Mean
Hard white winter ($n = 4$)		
Flour protein (%, N × 5.7)	9.0-11.2	10.6
Water absorption (%)	62.0-65.5	63.9
Mixing time (min)	2.8-4.3	3.7
P (mm)	71.3-118.0	91.1
L (mm)	69.0-136.3	108.8
W (×100^{-4} joules)	257.0-339.0	301.1
DM	3.1-4.6	3.5
Loaf volume (cm^3	705.0-910.0	837.6
Specific volume (cm^3/ 1% protein)	33.9-45.7	41.6
Hard red spring ($n = 18$)		
Flour protein (%, N × 5.7)	11.0-14.0	12.2
Water absorption (%)	63.5-71.9	68.2
Mixing time (min)	1.7-9.5	4.0
P (mm)	49.0-143.0	98.7
L (mm)	65.8-143.5	103.0
W (×10^{-4} joules)	105.0-579.3	345.3
DM	1.3-4.7	3.1
Loaf volume (cm^3)	700.0-1,100.0	906.7
Specific volume (cm^3/ 1% protein)	31.6-52.3	43.2

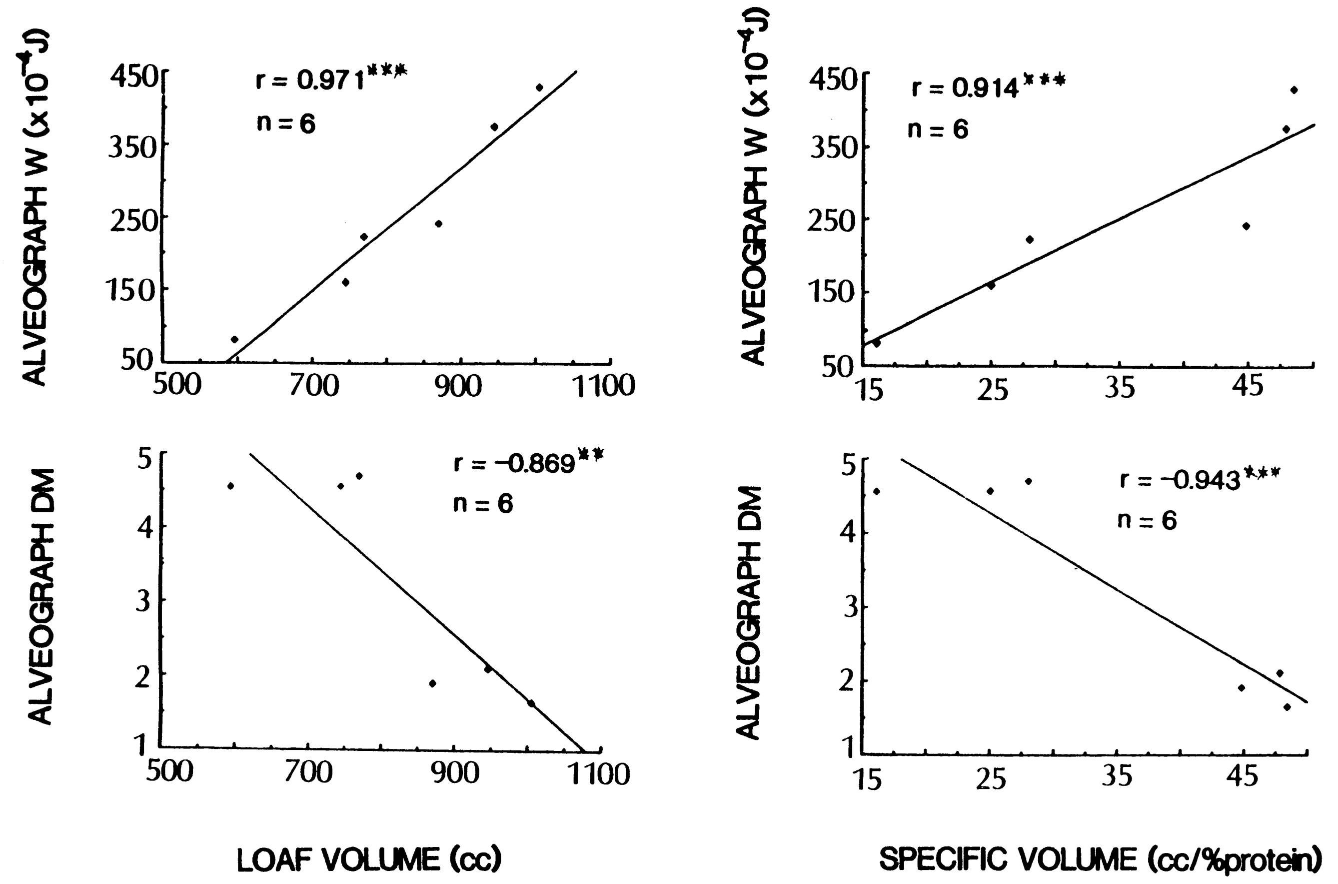

Fig. 5. Relationships between loaf volume and alveograph parameters and between specific volume and alveograph parameters for six Midwestern hard red winter wheat flours.

TABLE IV
Correlation Coefficients Between Averaged Alveogram and Other Qualtiy Parameters of Pacific Northwestern (PNW) Flours (top right) and PNW plus Midwest Flours (lower left)[a]

Parameter	Protein	Water Absorption	Mixing Time	Alveograph				Loaf Volume	Specific Volume
				P	*L*	*W*	*DM*		
Protein	···	0.738***[b]	0.638**	0.215	0.148	0.566**	−0.712***	0.822***	0.586**
Water absorption	0.459*	···	0.452*	0.155	0.047	0.337	−0.434*	0.586**	0.398
Mixing time	0.397*	0.518**	···	0.170	−0.034	0.399	−0.678***	0.700***	0.504*
P	0.177	0.299	0.202	···	−0.345	0.655***	0.192	0.115	−0.261
L	0.019	0.234	0.182	−0.249	···	0.410	−0.625**	0.494*	0.640**
W	0.324	0.496**	0.516**	0.632***	0.518**	···	0.519*	0.699***	0.431*
DM	−0.281	−0.392*	−0.691***	0.151	−0.717***	−0.586**	···	−0.897***	−0.899***
Loaf volume	0.514**	0.641***	0.743***	0.198	0.608***	0.778***	−0.860***	···	0.859***
Specific volume	0.127	0.549**	0.599***	−0.008	0.703***	0.622***	−0.867***	0.867***	···

[a] The samples contained 22 PNW and six Midwestern flours.
[b] ***, **, and * = Significant at $P < 0.001$, $P < 0.01$, and $P < 0.05$, respectively.

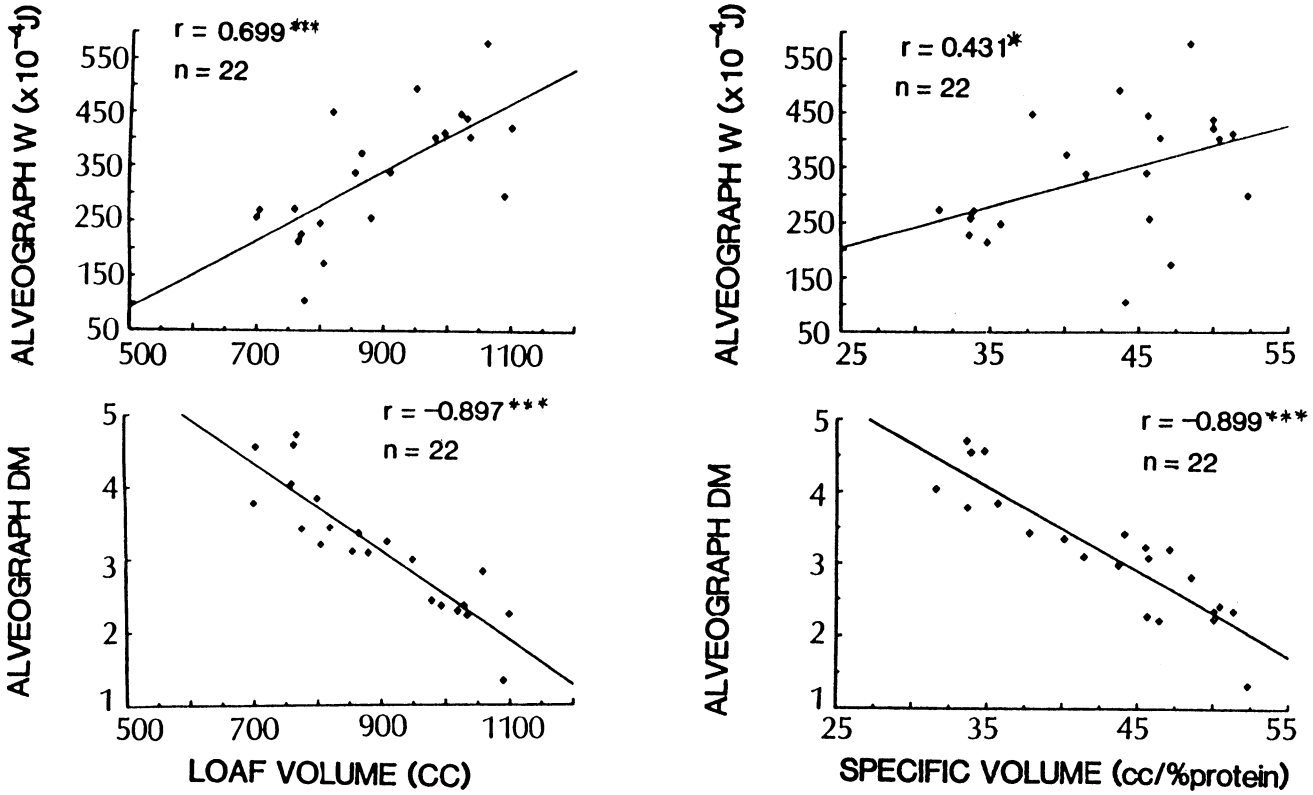

Fig. 6. Relationships between loaf volume and alveograph parameters and between specific volume and alveograph parameters for 22 Pacific Northwestern wheat flours.

content and loaf volume for the six samples described in Table I was only −0.314 (not significant), reflecting the wide range in breadmaking potential of the proteins (a three-fold range in specific loaf volume). Specific volume was highly and positively correlated with mixing time ($r = 0.930$, $P < 0.01$) and negatively correlated with *DM* ($r = -0.943$, $P < 0.01$).

The significance of the *DM* index was evaluated in relation to breadmaking potential of a number of hard wheat flours from the Pacific Northwest (PNW). The ranges and mean parameters of the flour samples are presented in Table III. Correlation coefficients between loaf volumes, the alveograph indices, and other quality parameters for the 22 PNW flours, alone and in combination with the six Midwestern flours, are shown in Table IV. The corresponding scatter plots for *W* and *DM* are presented in Figure 6. *DM* gave the highest single-parameter correlation ($r = -0.897$, $P < 0.001$) with loaf volume, and also with specific loaf volume ($r = -0.899$, $P < 0.001$) an index of protein breadmaking quality. When the 22 PNW samples were pooled together with the six Midwestern samples used for the preliminary study, the correlations between *DM* and loaf volume and between *DM* and specfic loaf volume decreased slightly (from −0.897 to −0.860, $P < 0.001$, and from −0.899 to −0.867, $P < 0.001$, respectively) due to the fact that the sets of samples were from two different populations. Whereas the samples described in Table I were selected to cover a wide range in functional breadmaking protein quality (specific loaf volume from 16.1 to 48.4), the samples described in Table III covered a more narrow range of protein quality (specific loaf volume from 31.6 to 52.3). In Table IV, the correlation coefficient between protein content was as high as 0.822 ($P < 0.001$) for loaf volume but only 0.586 ($P < 0.01$) for specific loaf volume and −0.712 for *DM*, indicating (as expected) that protein content explained only part of the variability in rheological properties and overall breadmaking potential. The negative correlation (r −0.678, $P < 0.001$) between *DM* and mixing time is also of interest because it points to various expressions of the rheological properties determined by the two parameters.

A stepwise regression analysis produced a model in which *DM*, *P*, and water absorption explained 91.2% of the variability in loaf volume potential (Table V). It is of interest that the equation

TABLE V
Stepwise Regression Procedure for the Dependent Variable Loaf Volume for Pacific Northwestern (PNW) and PNW plus Midwestern Flours[a]

Variable Entered	Model R^2	F	Prob $>F$
PNW Flours			
Alveogram *DM*	0.805	82.57	0.0001
Alveogram *P*	0.891	77.73	0.0010
Absorption	0.912	62.12	0.0539
Prediction equation:			
Loaf volume = 615.31 + 1.484 (*P*) − 128.20 (*DM*) + 7.97 (water absorption)			
PNW + Midwestern flours			
Alveogram *DM*	0.740	73.85	0.0001
Alveogram *W*	0.854	19.52	0.0002
Absorption	0.904	12.63	0.0016
Protein	0.927	6.96	0.0147
Prediction equation:			
Loaf volume = 218.96 − 74.59 (*DM*) + 0.33 (*W*) + 18.64 (protein) + 8.55 (water absorption)			

[a] The samples contained 22 PNW and six Midwestern flours, respectively.

did not include protein content, presumably because much of the correlation between protein content and loaf volume is expressed by the relationship between loaf volume and *DM* and between loaf volume and water absorption. If the six Midwestern samples are included in the stepwise regression procedure, 92.7% of the variability can be explained. The terms included in the prediction equation are in addition to *DM*, water absorption, protein, and *W* (in place of *P*).

Compared with the usual alveograph indices, the new index *DM* appears to be suitable for evaluation of breadmaking potential of hard wheat flour samples.

ACKNOWLEDGMENTS

The financial assitance of Tripette et Renaud of Paris, France, to K. Addo is gratefully acknowledged. The authors also thank A. Bettge for writing the software program for the first derivative, and Z. Czuchajowska for helpful suggestions.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Method 44-15A, approved October 1975, revised October 1981: Method 46-12, revised November 1983; Method 54-30, approved October 1984. The Association: St. Paul, MN.

BETTGE, A., RUBENTHALER, G. L., and POMERANZ, Y. 1989. Alveograph algorithms to predict functional properties of wheat in bread and cookie baking. Cereal Chem. 66:81.

BLOKSMA, A. H. 1957. A calculation of the shape of the alveograms of some rheological model substances. Cereal Chem. 34:126.

BLOKSMA, A. H. 1958. A calculation of the shape of the alveograms of materials showing structural viscosity. Cereal Chem. 35:323 .

CHEN, J., and D'APPOLONIA, B. L. 1985. Alveograph studies on hard red spring wheat flour. Cereal Chem. 30:862.

DEXTER, J. E., PRESTON, K. R., TWEED, A. R., KILBORN, R. H., and TIPPLES, K. H. 1985. Relationship of flour starch damage and flour protein to the quality of Brazilian style hearth bread and remix pan bread produced from hard red spring wheat. Cereal Foods World 30:511.

FARIDI, H. A., and RASPER, V. F. 1987. The Alveograph Handbook. Am. Assoc. Cereal Chem.: St. Paul, MN.

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

KHATTAK, S., D'APPOLONIA, B. L., and BANASIK, O. J. 1974. Use of the alveograph for quality evaluation of hard red spring wheat. Cereal Chem. 51:355.

PRESTON, K. R., KILBORN, R. H., and DEXTER, J. E. 1987. Effects of starch damage and water absorption on the alveograph properties of Canadian hard red spring wheats. Can. Inst. Food Sci. Technol. J. 20(2):75.

RASPER, V. F., HARDY, K. M., and FULCHER, G. R. 1985. Constant water content vs. constant consistency techniques in alveography of soft wheat flours. Pages 51-74 in: Rheology of Wheat Production. H. Faridi, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

RASPER, V. R., PICO, M. L., and FULCHER, R. G. 1986. Alveography in quality assessment of soft white winter wheat cultivars. Cereal Chem. 63:395.

SAS INSTITUTE. 1985. SAS User's Guide: Statistics. The Institute: Cary, NC.

SCOTT BLAIR, G. W., and POTEL, P. 1973. A preliminary study of the physical significance of certain properties measured by the Chopin Extensimeter for testing flour doughs. Cereal Chem. 14:257.

SHOGREN, M. D., FINNEY, K. F., BOLTE, L. C., and HOSENEY, R. C. 1963a. A modified alveograph technique for hard winter wheat flour. Agron. J. 55:19.

SHOGREN, M. D., FINNEY, K. F., HOSENEY, R. C., and BOLTE, L. C. 1963b. Correlations of certain properties of the alveogram with important hard winter wheat quality characteristics. Agron. J. 55:21.

WEIPERT, P. 1981. Teigrheologische Untersuchungsmethoden und ihre Einsatzmoglichkeiten im Muhlenlaboratorium. Getreide Mehl Brot 35(1):5. (Original not seen; cited by Faridi and Rasper 1987.)

[Received December 28, 1988. Revision received June 17, 1989. Accepted July 26, 1989.]