Alveograph Algorithms to Predict Functional Properties of Wheat in Bread and Cookie Baking[1]

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ABSTRACT

A total of 73 wheat samples (23 soft white winter, 20 soft white spring, 15 club, seven hard red winter, six hard red spring, and two hard white winter) were milled and analyzed for gross composition and flour texture (by near-infrared reflectance spectroscopy). The wheat flours were baked into cookies and bread and evaluated on an alveograph. A multivariable model produced the highest correlation coefficient using combinations of protein, hardness, and alveograph values *P*, *L*, and *W* to predict loaf volume, specific volume, and cookie diameter. Cookie diameter was predicted from *P* and protein ($r = 0.797$; standard error [SE] = 0.14 cm). Loaf volume was predicted ($r = 0.914$; SE = 68 cm^3) in soft wheats using alveograph *L* and *W* plus protein. In hard wheats, loaf volume was predicted ($r = 0.950$; SE = 49 cm^3) using alveograph *L* plus protein. Specific volume (an index of protein quality) could be predicted in hard wheats ($r = 0.946$; SE = 3.1 cm^3/% protein) using alveograph *P*, *W*, and hardness. In soft wheats, specific volume was predicted ($r = 0.855$; SE = 6.56 cm^3/% protein) using alveograph *L* and *W* plus hardness. The equations were verified using wheat flours with known gross composition and end-use parameters. Cookie diameter in soft wheat flour was predicted with $r = 0.934$ and an average residual of 0.06 cm. Loaf volume was predicted in hard wheat flours with $r = 0.939$ and an average residual of 33 cm^3.

Since the early studies of Chopin (1927), the alveograph has been used mainly to evaluate breadmaking quality of wheat flours (Bennett and Coppock 1956, Bloksma 1957, Chen and D'Appolonia 1985, Chopin 1927, Dubois 1984, Khattak et al 1974, Marcelle 1955). Some studies were conducted on the use of the alveograph in determination of cookie-making quality (Grebaut 1984, Rasper et al 1986) with rather limited success. Rasper et al (1986) suggested that the failure to relate alveogram indexes to cookie-baking performance reflects the limited sensitivity of the latter rather than the inadequacy of the rheological test to respond to quality differences in tested wheats. In studies of breadmaking quality of U.S. and Canadian (as in European) wheats, the main emphasis has been on the *W* value (Bloksma 1957, Faridi and Rasper 1987). It is of interest that Shogren et al (1963a,b) pointed to the low *L* values of U.S. hard red winter wheat flours. Chen and D'Appolonia (1985) reported that all three alveograph values (*P*, *L*, and *W*) were highly correlated with extensigraph values. However, only the *P* value was correlated (negatively) with flour protein, wet gluten, and loaf volume.

The objective of this study was to determine whether alveograph values alone or in combination with other parameters (such as protein content and hardness), could be used to develop algorithms to predict bread- and cookie-making properties of Pacific Northwest wheats. The results were also used to determine whether there were differences in alveograph parameters between winter and spring wheats.

Determination of appropriate end-use properties of wheat flours should be considered both for differentiation between low-protein soft and high-protein hard wheats and for fine differentiation among samples within each class. While the hard wheats are not likely to be used in production of cookies and cakes, soft and relatively high-protein wheats are used widely in bread production. Consequently, our statistical evaluation encompassed testing hard and soft wheats in breadmaking and soft wheats only in cookie-making.

MATERIALS AND METHODS

Samples of commonly grown wheat varieties and advanced experimental selections were obtained for this study from two locations (Pullman and Lind, WA) from the 1984 crop year. Included in this study set were 23 soft white winter (SWW), 20 soft white spring (SWS), 15 club, seven hard red winter (HRW), six hard red spring (HRS), and two hard white winter (HWW) wheats for a total of 73. These wheats were milled to approximately 72% extraction on a Buhler pneumatic mill. The resulting flours were analyzed for moisture, ash, and protein (methods 46-12, 44-16, and 8-01, respectively; AACC 1983). The hardness value was a number derived by near-infrared reflectance, arbitrarily scaled using one wavelength (1,680 nm) from a Technicon IA 400 (Bruinsma and Rubenthaler 1978). The scale of hardness ranged from zero to 129.0, with hard wheat flours averaging 95.5 and soft wheat flours averaging 32.5 (Table I).

A cookie diameter algorithm verification set was composed of six commercial SWW, club, and SRW wheats from the United States and France. Each was evaluated as mentioned above. A loaf volume algorithm verification set was composed of five plant breeders' HRW samples from the 1979 crop year grown in Kansas and 13 plant breeders' HRW and HRS samples from the 1987 crop year grown in the Pacific Northwest. Each was evaluated in accordance with the above procedures.

Since hard and soft flours generally perform well in only some of a wide range of potential end-use products, the sample set was separated into two parts according to their marketing classes (hards and softs). The soft white (SWW and SWS) and club wheat flours were baked into cookies using the micro baking test method (AACC method 10-52). The result of the cookie test is expressed as the average diameter (cm) of one cookie.

All wheats, regardless of class, were baked into 100-g loaves using the optimized straight-dough breadmaking method (AACC 10-10B). The resulting loaf volume (cm^3) was measured by a volume displacement method. The specific volume of the loaf was calculated as:

$$\text{Specific volume} = (\text{loaf volume} - 400)/\text{protein } (14\% \text{ mb})$$

The 400 cm^3 base offset represents the volume of loaf produced if all the protein components of the flour are removed or if no functional protein is present (Hoseney 1986). Because the base loaf volume due to nonprotein fractions is removed, specific volume expresses the volume (cm^3) of bread expected to be produced for each percent increase in protein. Specific volume is an indicator of protein quality (Rubenthaler and Pomeranz 1987).

The flours were tested on a Chopin MA 82 alveograph. A 2.5% sodium chloride solution was used to hydrate a 250-g sample of each flour to the level specified by AACC method 54-30 (129.4 ml

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at 14% moisture). Mixing at 24°C totaled 8 min including a 1-min scrapedown period after the first minute of mixing. Five dough pieces were produced from each sample and allowed to rest for 20 min at 25°C. At the end of the resting period, each sample was inserted into the alveograph. A bubble was blown and the resulting air pressure profile was recorded on a recording manometer. Each chart was analyzed for several factors: *P*, the maximum overpressure needed to blow the dough bubble; *L*, the average abscissa at bubble rupture; and *W*, the deformation energy (Faridi and Rasper 1987). These variables were derived using the standard alveograph template charts. The variables represent the average of five curves from five dough patties, with abnormal curves (greater than two standard deviations from the mean) not included in calculations.

Statistical methods were employed to determine if functional properties of wheats could be predicted by the use of an algorithm incorporating alveograph data and minimal other information. Specifically, *P*, *L*, *W*, protein, and hardness (determined by the near-infrared reflectance [NIR] method) were used alone or in combination to predict loaf volume or specific volume for all flours or cookie diameter for soft wheat flours. A stepwise forward regression program (PC-SAS Proc Reg with method = MAXR) was employed to find the best one-variable model, the best two-variable model, and so on. The MAXR method finds the one variable model with the highest correlation coefficient (*r*). Then the variable producing the greatest increase in *r* is added. Once the two-variable model is obtained, the variables in the model are compared to those not in the model, and if other variables produce a higher *r*, a switch is made, continuing until the best *r* for each set of variables is found (SAS Institute 1985).

Two separate regressions were run: one incorporating *P*, *L*, *W*, and protein and the other incorporating *P*, *L*, *W*, protein, and hardness. Each regression is discussed in turn. The algorithms derived for specific volume do not include protein as a variable, because protein has already been used to derive the dependent variable, specific volume.

TABLE I
Summary of Variable Parameters of Wheat Flours

Variable	Minimum	Maximum	Mean	SD
Soft wheat flour ($n = 58$)				
Protein (14% mb)	6.00	11.70	9.36	1.65
Ash (14% mb)	0.32	0.46	0.39	0.03
Hardness	0.00	76.00	32.47	17.22
Cookie diameter (cm)	8.52	9.47	8.89	0.23
Loaf volume (cm^3)	500.00	1,065.00	807.21	162.61
Specific volume	10.20	62.26	42.37	12.32
P	24.48	91.03	43.81	12.45
L	22.05	158.76	98.07	37.75
W	24.00	226.00	107.38	39.66
Hard wheat flour ($n = 15$)				
Protein (14% mb)	7.70	13.00	10.95	1.66
Ash (14% mb)	0.32	0.44	0.38	0.03
Hardness	61.00	129.00	95.53	18.25
Loaf volume (cm^3)	630.00	1,105.00	936.20	145.20
Specific volume	29.87	60.26	48.16	8.50
P	60.72	146.30	94.96	23.98
L	40.74	129.00	91.45	28.67
W	186.00	366.00	265.53	50.17
Hard red spring flour ($n = 6$)				
Protein (14% mb)	10.60	13.00	11.78	0.76
Ash (14% mb)	0.32	0.44	0.39	0.04
Hardness	61.00	101.00	86.17	17.12
Loaf volume (cm^3)	980.00	1,105.00	1,054.67	45.64
Specific volume	61.86	73.58	68.50	5.44
P	60.72	82.06	72.31	7.09
L	100.32	129.00	115.92	9.78
W	233.00	309.00	269.67	34.23
Hard red winter flour ($n = 9$)				
Protein (14% mb)	7.70	12.40	10.40	1.90
Ash (14% mb)	0.33	0.40	0.37	0.02
Hardness	73.00	129.00	101.78	17.04
Loaf volume (cm^3)	630.00	1,000.00	857.22	134.35
Specific volume	49.35	63.60	58.02	4.11
P	90.75	146.30	110.06	18.26
L	40.74	108.10	75.13	25.09
W	186.00	366.00	262.78	60.42

RESULTS AND DISCUSSION

Soft Wheat Flour Analysis

Cookie Diameter. As can be seen from the *r* values of the regressions for cookie diameter, none of the alveograph values, either alone or in combination, produced a very high correlation with cookie diameter (Table II). In selecting a "best" equation to predict an experimental parameter, a series of compromises must be made. The correlation coefficient must be balanced against the level of significance of the model to prevent overfitting the data or settling on a model of less than maximum correlation. However, additional regressors sometimes increase the correlation coefficient by increments too small to justify their use.

Protein had the highest correlation coefficient with cookie diameter, followed by alveograph *W*. Both factors are negatively correlated with cookie diameter. *P* was the next most important factor in producing the best two-variable model. Judging strictly on the basis of simple correlation, *W* should have been the next, most obvious candidate for inclusion in the model, but since the statistical process looks at the variables taken together rather than individually, the *W* value is excluded at this point from the two-

TABLE II
Simple Correlation Coefficients for Parameters in Soft Wheat Flours ($n = 58$)[a]

Variable	*L*	*W*	Protein	Hardness	Cookie Diameter	Loaf Volume	Specific Volume
P	−0.480 0.0001	0.486 0.0001	−0.483 0.0001	0.045 0.7367	−0.247 0.0617	−0.345 0.0080	−0.242 0.0671
L	...	0.323 0.0134	0.747 0.0001	−0.294 0.0252	−0.277 0.0352	0.845 0.0001	0.750 0.0001
W		...	0.217 0.1022	−0.340 0.0089	−0.511 0.0001	0.506 0.0001	0.530 0.0001
Protein			...	−0.075 0.5761	−0.545 0.0001	0.788 0.0001	0.541 0.0001
Hardness				...	−0.002 0.9862	−0.439 0.0006	−0.552 0.0001
Cookie diameter					...	−0.447 0.0004	−0.287 0.0291
Loaf volume						...	0.937 0.0001

[a] In each correlation, the upper numbers are correlation coefficients and the lower numbers are probability levels.

variable model.

The two-term model produced an r of 0.797 with a significant F value of 48.12 (Table III). The one-variable model had a far lower r of 0.545 and a lower F value of 23.66. The addition of other variables (W, L, and hardness) produced only minor increases in r, from 0.797 to 0.804, and a decrease in F value to 18.97. Although the F value of the five-variable model was still significant, the observed decrease indicates a trend toward overfitting the model.

The results indicate that L, W, and hardness factors are not significant contributors (P values greater than 0.10) to the model's predictive power. Their partial F values are poor when compared to those of P and protein.

The alveograph values P, W, and L, even in combination with protein and hardness were not sufficient to produce an algorithm of substantial predictive power ($r^2 = 0.804^2 = 0.646$) as they predicted less than two-thirds of the variability. A general evaluation is possible from the equation utilizing P and protein to differentiate the worst (smallest) cookie diameters from the best (largest) cookie diameters. Hardness alone or in combination with other parameters did little to explain variability in cookie diameter. While hardness is distinctly different between the hard and soft wheat flours (average values in Table I and Fig. 1), there is a wide (even overlapping) range in values in the two classes.

In confirmation tests on the cookie diameter algorithm using P and protein, the correlation coefficient between actual and predicted cookie diameter was 0.934 and the average residual was 0.06 cm (Fig. 2). This degree of correlation was surprising due to the relatively lower r of the calibration algorithm (0.797). The slope of the regression line for the verification set was not statistically different from that of the calibration set.

Bread loaf volume. Alveograph L was the single best regressor when attempting to predict loaf volume for soft wheat flours ($r = 0.845$, F value = 139.50, Table IV). The best equation that did not include hardness was one incorporating L, W, and protein ($r = 0.914$, F value = 91.18). Even though soft wheat flours were not developed for pan bread production, the incorporation of L, W, and protein yielded a satisfactory model for loaf volume prediction.

The addition of NIR hardness to the model improved the algorithm (of L, W, and protein) from $r = 0.914$ to $r = 0.935$. This four-regressor model (using L, W, protein, and hardness) was a good predictor of loaf volume in soft wheats. The alveograph L and W values alone, however, measured breadmaking potential accurately and produced an acceptable predictor of the end-use bread baking utility of the flour.

Specific volume. Specific volume of the soft wheat flours was best correlated at the single variable level with alveograph L ($r = 0.750$, $F = 72.11$, Table V). The addition of other regressors (W and hardness) allowed specific volume to be predicted with an $r = 0.855$ and $F = 48.91$. These were the same variables used to predict loaf volume in soft wheat flours, with the exception of flour protein. However, flour protein is incorporated into the equation used to calculate specific volume, therefore protein is not used again as a regressor. Thus, specific volume, an index of breadmaking quality of gluten proteins, can be predicted in soft wheats ($r = 0.855$). The percentage of variability explained by the combined L, W, and hardness parameters is 73.1% ($r^2 = 0.855^2 = 0.731$), or about three-fourths of the total.

TABLE III
Multiple Correlation Coefficients from Stepwise Regressions for Soft Wheat Flour Cookie Diameter and Related Parameters ($n = 58$)

Regression[a]	Partial F	Partial P	Total r	Total F
Cookie diameter vs.			0.545	23.66
Protein	23.66	0.0001		
Cookie diameter vs.			0.797	48.12
P+	51.32	0.0001		
Protein	87.02	0.0001		
Cookie diameter vs.			0.801	32.33
P+	46.38	0.0001		
L+	0.91	0.3456		
Protein	57.06	0.0001		
Cookie diameter vs.			0.803	24.07
P+	13.93	0.0005		
L+	1.29	0.2612		
W+	0.39	0.5326		
Protein	52.25	0.0001		
Cookie diameter vs.			0.804	18.97
P+	12.33	0.0009		
L+	1.13	0.2925		
W+	0.50	0.4820		
Protein +	45.81	0.0001		
Hardness	0.13	0.7225		

[a] F = confidence level, P = probability level, and r = correlation coefficient. Final equation: cookie diameter = 10.58 − 0.01(P) − 0.12(protein); standard error = 0.14 cm. Verification samples: $n = 7$, $r = 0.934$ (actual vs. predicted), standard error = 0.05 cm, range = 8.21–9.31 cm, mean = 8.96 cm.

Hard Wheat Flour Analysis

A statistical treatment similar to that performed on the soft wheat flour results was performed on the hard wheat flour results.

Loaf volume. The best single predictor of the loaf volume of

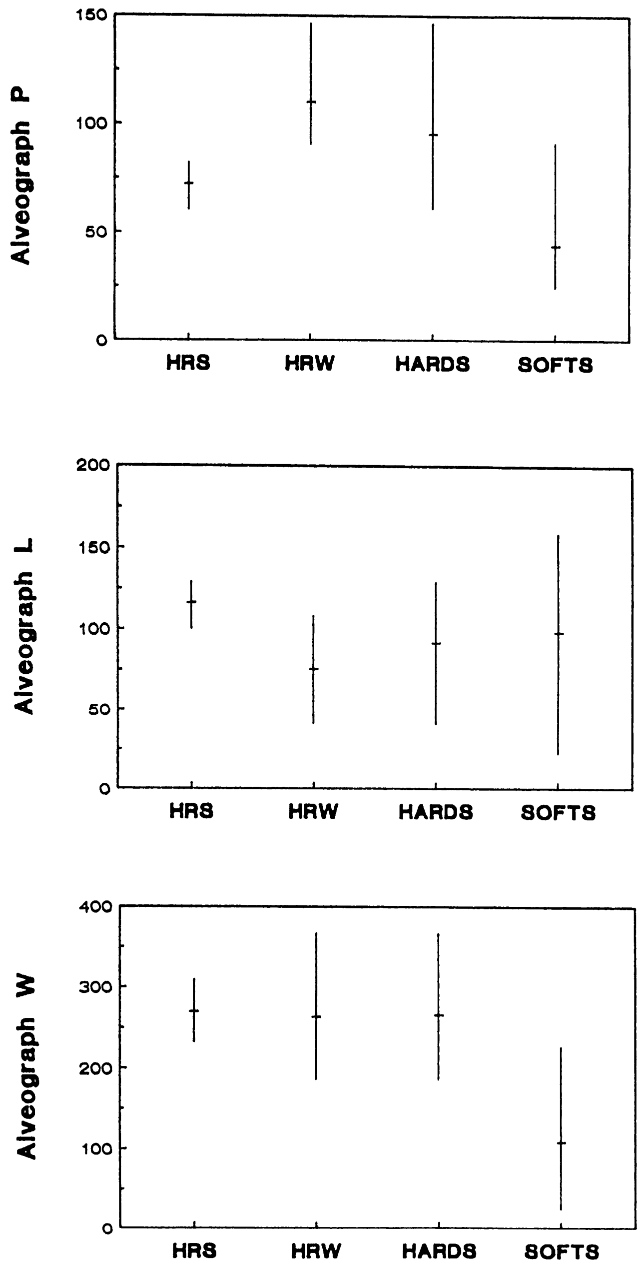

Fig. 1. Range and mean for alveograph P, L, and W for hard red spring, hard red winter, total hard, and total soft wheats.

hard wheats was L, producing an r of 0.900 (Table VI). Shogren et al (1963) also found that L was most highly correlated with loaf volume in U.S. style bread baked from U.S. wheat flours. This is in contrast to earlier findings which found W to be the best single predictor of loaf volume in Dutch type breads produced with European flours (r = 0.48, Bloksma 1957). P is a measure of elasticity in dough, L is measure of extensibility, and W is a measure of "strength" as calculated by a combination of P and L (Faridi and Rasper 1987). The importance of L as a regressor implies that U.S. wheats have sufficient elasticity to produce an acceptable loaf, but that additional L (extensibility) is required to moderate the "buckiness" or high elasticity of the doughs. European wheats have a lower P (Faridi and Rasper 1987), and L is not as important as a moderating influence on elasticity. Therefore, as a combination measure, W is an important correlator with loaf volume in European wheats.

There were differences in alveograph values between winter and spring hard red wheat flours milled from wheats grown in the Pacific Northwest (Table I, Fig. 1). While W was approximately the same among winter and spring hard wheat flours (average 263 vs. 270), P was lower in HRS than in HRW wheats (average 72.3 vs. 110.1). L was lower in HRW than in HRS wheats (average 75.1 vs. 115.9). These data indicate rheological differences exist between HRS and HRW wheats, even though the average protein for each class differed by only 1.4% (HRW = 10.40 vs. HRS = 11.78, on average). In other studies (Chen and D'Appolonia 1985, Rasper et al 1986), the alveograph parameters were markedly different due to modifications in the procedure. Those modifications masked the importance of L in predicting flour functionality in hard wheat flours.

In hard wheats, a two-factor regression incorporating L and protein produced a satisfactory algorithm for the prediction of loaf volume (r = 0.950, F = 55.08, Table VII). Higher r values can be reached with the addition of other regressors, but gains were small (F value varies little and r increases from 0.950 to 0.982, or explaining an additional 6.1% of the variability, from 90.3 to 96.4%). Still, the correlation of 0.950 is high and explains over 90% of the variation; thus it enables estimations of loaf volume to be made using only the flour protein and alveograph L.

Confirmation tests of the model using L and protein were performed on 18 samples of HRW and HRS wheats. In each case, substantial residuals (actual minus predicted loaf volume) were

TABLE IV
Multiple Correlation Coefficients from Stepwise Regressions for Soft Wheat Flour Loaf Volume and Related Parameters (n = 58)

Regression[a]	Partial F	Partial P	Total r	Total F
Loaf volume vs.			0.845	139.50
L	139.50	0.0001		
Loaf volume vs.			0.880	94.46
L+	126.36	0.0001		
W	14.87	0.0003		
Loaf volume vs.			0.914	91.18
L+	31.40	0.0001		
W+	21.50	0.0001		
Protein	19.86	0.0001		
Loaf volume vs.			0.915	92.39
L+	23.50	0.0001		
Protein +	27.72	0.0001		
Hardness	22.34	0.0001		
Loaf volume vs.			0.935	92.16
L+	23.35	0.0001		
W+	15.75	0.0002		
Protein +	34.13	0.0001		
Hardness	16.51	0.0002		
Loaf volume vs.			0.939	76.86
P+	2.84	0.0978		
L+	12.19	0.0010		
W+	14.38	0.0004		
Protein +	25.31	0.0001		
Hardness	13.10	0.0007		

[a] F = confidence level, P = probability level, r = correlation coefficient. Final equation: Loaf volume = 142.83 + 2.07(L) + 1.11(W) + 36.56(protein); standard error = 67.83 cm^3.

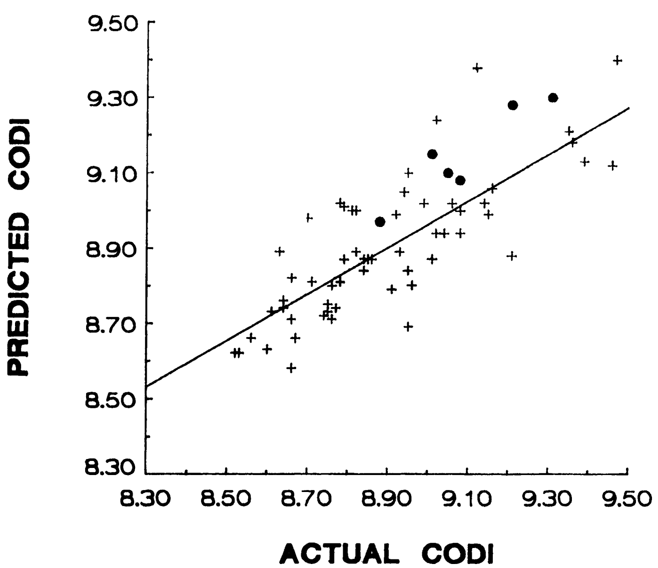

Fig. 2. Actual versus predicted cookie diameter, uncorrected for offset, for calibration set (+) r = 0.797 and confirmation set (●) r = 0934.

TABLE V
Multiple Correlation Coefficients from Stepwise Regression for Soft Wheat Flour Specific Loaf Volume Related Parameters (n = 58)

Regression[a]	Partial F	Partial P	Total r	Total F
Specific volume vs.			0.750	72.11
L	72.11	0.0001		
Specific volume vs.			0.827	59.33
L+	65.72	0.0001		
Hardness	20.91	0.0001		
Specific volume vs.			0.855	48.91
L+	58.92	0.0001		
W+	9.57	0.0031		
Hardness	15.15	0.0003		
Specific volume vs.			0.863	38.61
P+	2.80	0.0999		
L+	14.61	0.0003		
W+	10.80	0.0018		
Hardness	13.31	0.0006		

[a] F = confidence level, P = probability level, and r = correlation coefficient. Final equation: Specific volume = 22.59 + 0.19(L) + 0.07(W) − 0.21(hardness); standard error = 6.56 cm^3/% protein.

TABLE VI
Simple Correlation Coefficients for Parameters in Hard Wheat Flours (n = 15)[a]

Variables	L	W	Protein	Hardness	Loaf Volume	Specific Volume
P	−0.693	0.179	−0.192	0.253	−0.481	−0.622
	0.0042	0.5236	0.4934	0.3623	0.0694	0.0133
L	···	0.531	−0.766	0.019	0.900	0.860
		0.0419	0.0009	0.9462	0.0001	0.0001
W		···	0.726	0.381	0.679	0.542
			0.0022	0.1611	0.0054	0.0371
Protein			···	−0.025	0.884	0.657
				0.9295	0.0001	0.0077
Hardness				···	−0.118	−0.168
					0.6744	0.5500
Loaf volume					···	0.930
						0.0001

[a] In each correlation the upper numbers are correlation coefficients and the lower numbers are probability levels.

produced (169 cm^3 for the 1979 crop and 139 cm^3 for the 1987 crop, on average). When these average yearly residuals were subtracted from the predicted loaf volumes, the average deviation from the actual loaf volume dropped 58 cm^3 to 8 cm^3 in the 1979 crop and 24 cm^3 in the 1987 crop (Figs. 3 and 4); the average for the two years being 33 cm^3.

The average residual appears to be constant within a crop year, since the 1987 crop year had average residuals of 139 cm^3 in spring wheat and 140 cm^3 in winter wheats. The correlation coefficients were 0.904 for the 1979 crop and 0.952 for the 1987 crop, the average for the two years being 0.939. The slopes of the regression functions in the verification sets were statistically the same as that of the calibration set.

Specific volume. In soft wheats, L, W, and hardness produced the most useful algorithm for prediction of specific volume. For hard wheats, the substitution of P for L (when W, which is partly dependent on L, was present in the model) produced the best three-parameter algorithm ($r = 0.946$, $F = 31.36$, Table VIII). As a single parameter, the high ($r = 0.860$) correlation of L with specific volume and loaf volume of hard wheats indicates that it is a relatively good single predictor of both.

Confirmation tests were not performed for the specific volume algorithm, since the NIR calibration for hardness was changed after the original algorithms were developed. Since the specific volume algorithm incorporates a factor for hardness, altering the way in which hardness is calculated would have an effect on the predicted value for specific volume. There are, however, no indications that these algorithms would not perform as well as the loaf volume algorithms did.

NIR Hardness in Hard and Soft Flours

The use of NIR hardness did not have a major impact on the algorithms formed to predict the functionality of hard and soft wheat flours. Since the samples were separated according to their market class, the variability of hardness within a group was low. Although hardness values overlap between hard and soft wheats, within each group the effect of hardness was generally not as important as other factors (protein, L, W, and P) in forming predictive algorithms.

CONCLUSIONS

The alveograph is designed to evaluate the functionality of flour proteins, especially the gluten fraction. When samples are separated into their market classes, the three alveograph factors (P, L, and W in addition to flour protein and hardness) can predict the functionality of the flour as represented by cookie diameter, loaf volume, or specific volume.

Cookie diameter in soft wheat flours was predicted by P and protein ($r = 0.797$). The importance of the gluten proteins in cookie baking is limited because the gluten is not fully developed in the cookie dough. Since the alveograph measures the contribution (effect) of the gluten fraction, cookie diameter is a difficult end-use property to predict with a model that primarily incorporates alveograph factors. Confirmation tests, however, were surprisingly accurate in predicting cookie diameter.

For both hard and soft flours, loaf volume was better predicted

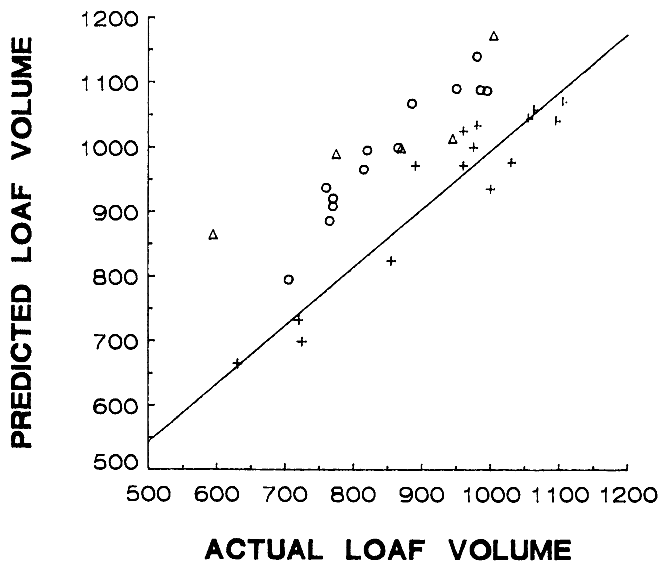

Fig. 3. Actual versus predicted loaf volumes, uncorrected for offset, for calibration set (+) $r = 0.950$, 1979 crop year (Δ) $r = 0.904$, and 1987 crop year (o) $r = 0.952$.

TABLE VII
Multiple Correlation Coefficients from Stepwise Regression of Hard Wheat Flour Loaf Volume Related Parameters ($n = 15$)

Regression[a]	Partial F	Partial P	Total r	Total F
Loaf volume vs.			0.900	55.54
L	55.54	0.0001		
Loaf volume vs.			0.950	55.08
$L+$	14.71	0.0024		
Protein	11.17	0.0059		
Loaf volume vs.			0.957	39.72
$L+$	16.25	0.0020		
Protein +	11.30	0.0063		
Hardness	1.79	0.2084		
Loaf volume vs.			0.968	54.83
$L+$	54.53	0.0001		
$W+$	19.06	0.0011		
Hardness	12.43	0.0048		
Loaf volume vs.			0.973	44.08
$L+$	25.65	0.0005		
$W+$	5.75	0.0375		
Protein +	1.68	0.2240		
Hardness	7.29	0.0223		
Loaf volume vs.			0.981	65.50
$P+$	42.04	0.0001		
$W+$	21.98	0.0009		
Protein +	12.05	0.0060		
Hardness	7.63	0.0200		
Loaf volume vs.			0.982	47.53
$P+$	4.24	0.0697		
$L+$	0.07	0.8006		
$W+$	11.29	0.0084		
Protein +	5.95	0.0374		
Hardness	5.98	0.0371		

[a] F = confidence level, P = probability level, r = correlation coefficient. Final equation: Loaf volume = 236.34 + 2.73(L) + 41.07(protein); standard error = 49.15 cm^3. Verification samples: $n = 18$ (5 from 1979 and 13 from 1987); r = 0.904 and 0.952 (actual vs. predicted), respectively; standard error = 58 and 24 cm^3, respectively; range = 595–1,173 cm^3; mean = 848.

TABLE VIII
Multiple Correlation Coefficients from Stepwise Regressions of Hard Wheat Flour Specific Volume Related Parameters ($n = 15$)

Regression[a]	Partial F	Partial P	Total r	Total F
Specific volume vs.			0.860	36.82
L	36.82	0.0001		
Specific volume vs.			0.879	20.43
$L+$	39.37	0.0001		
Hardness	1.79	0.2053		
Specific volume vs.			0.946	31.36
$P+$	46.06	0.0001		
$W+$	53.42	0.0001		
Hardness	7.18	0.0214		
Specific volume vs.			0.950	22.98
$P+$	8.99	0.0134		
$L+$	0.67	0.4323		
$W+$	13.01	0.0048		
Hardness	7.41	0.0215		

[a] F = confidence level, P = probability level, r = correlation coefficient. Final equation: Specific volume = 49.30 − 0.24(P) + 0.13(W) − 0.13(hardness); standard error = 3.10 cm^3/% protein.

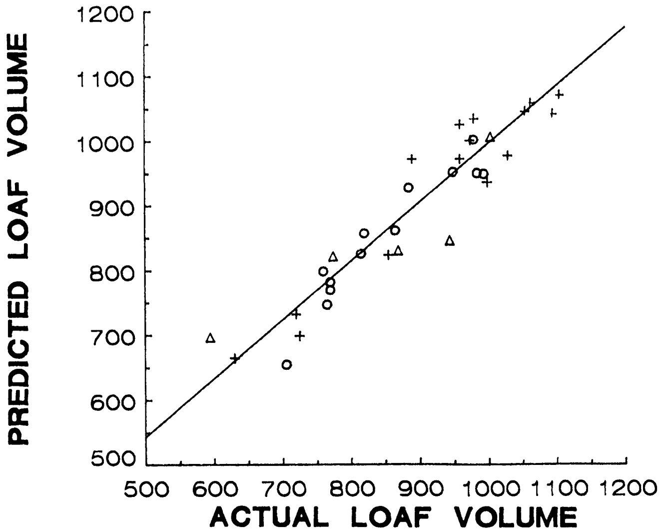

Fig. 4. Actual versus predicted loaf volumes, corrected for average offset, for calibration set (+), 1979 crop year (Δ), and 1987 crop year (o) $r = 0.950$.

than specific volume by the alveograph values with protein and hardness, although the difference was minimal in hard flours. Loaf volume was predicted with the use of *L* and protein in hard wheats ($r = 0.950$) and with *L*, *W* and protein in soft wheats ($r = 0.914$). These models predict 84 to 90% of the variation present. Because loaf volume is dependent on protein content and quality, that level of predictive ability was expected.

Specific volume prediction was successful in hard wheats, when used with a 400 cm^3 offset, and yielded useful algorithms. The *r* value of 0.946 for the algorithm incorporating *P*, *W*, and hardness was sufficient for predicting functionality. For soft wheats, the best algorithm for specific volume (400 cm^3 offset) used *L*, *W*, and hardness ($r = 0.855$).

The high correlation between loaf volume and specific loaf volume is of interest. One explanation is that as total protein content increases, percentage of storage proteins increases (Pomeranz 1971). Consequently, the high-protein flours were high in total protein and in the percentage of total gluten proteins that are functional in breadmaking.

For Pacific Northwest soft and hard wheat flours, the alveograph value *L* alone appeared to predict a major part of the functional properties of protein(s), which are responsible for the flour's performance in loaf volume formation ($r = 0.845$ in soft wheats and $r = 0.900$ in hard wheats). The proteins are most likely of the gluten type.

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