Bread Volume Potential of Variable-Quality Flours with Constant Protein Level As Determined by Factors Governing Mixing Time and Baking Absorption Levels

S. P. ROELS, G. CLEEMPUT, X. VANDEWALLE, M. NYS, and J. A. DELCOUR[1]

ABSTRACT

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Six European wheat flours with varying breadmaking potentials (Apollo, Slejpner, Sperber, Camp Remy, Minaret, and Soissons; Glu-1 scores 4, 4, 7, 6, 9, and 10, respectively) and pentosan levels were brought to constant protein level with starch. Breads were baked in a straight-dough procedure with varying mixing times (MT) and baking absorption levels (BA). Response surface methodology showed that, among all realistic combinations of interdependent variables MT and BA, there is no optimum combination resulting in a superior bread loaf. Bread volumes increased with longer MT and higher BA levels, handling properties of the resulting doughs being the limiting factor. When flours of different cultivars, adjusted to a constant protein level, were baked with the same MT and BA (provided this resulted in a manageable dough), they yielded breads of essentially equal volume. The baking performance was thus determined by the MT and BA applied, and differences in breadmaking potential of such flours must be attributed to a great extent to factors governing the mixing and absorption level characteristics of the flour. Analysis of pentosan contents indicated that higher water-soluble pentosan levels resulted in lower BA levels and mixing tolerance (and thus lower bread volumes), and that an inverse relationship exists between the handling properties of a dough and the flour water-soluble pentosan content. At the same time, the Glu-1 score was in good agreement with the volume potentials and the MT of the different flours.

Baking absorption (BA) can be defined as the percentage of water necessary to yield a dough of the correct consistency after mixing. Working (1934) criticized this definition because: 1) the amount of mixing is not specified, 2) consistency at the time of molding the loaf is much more important, and 3) flours differing widely in protein quality or quantity must be mixed to different consistencies to produce the best possible bread. Working suggested using a centrifugation technique to determine water-absorbing capacity.

Today, BA is commonly determined subjectively by an experienced baker or with the aid of special devices such as a Simon water absorption meter, farinograph, or mixograph. In this article, BA means the subjectively determined absorption level. However, Holas and Tipples (1978) noticed that the subjectively determined BA of flour streams is not necessarily closely related to farinograph absorption. Analysis of the relative influence of flour components on baking and farinograph absorption showed that damaged starch, total pentosans, and α-amylase activity were positively correlated with farinograph absorption but negatively correlated with BA, and that farinograph and BA were negatively correlated. The authors found that BA was highly positively correlated with the ratio of wet gluten to total flour protein.

Lai et al (1989a, b) reported that, for wheat flours supplemented with bran and for whole wheat flours, the best loaf volumes were obtained with the highest water level possible that did not produce an excessively sticky dough. Loaf volumes not only depend on the amount of water added but also on the mixing time (MT) applied. Furthermore, MT and BA are interdependent; the required MT increases with higher BA levels. Therefore, for best loaf volume, it is necessary to optimize both MT and BA simultaneously (Montgomery 1976, Box et al 1978).

Recently, in our laboratory, Vanhamel et al (1993) studied the effect of water-soluble rye pentosans on wheat bread quality and found that the best loaf volumes were obtained under operating conditions close to the limits imposed by manageability. Burrows and McGuirk (1991) studied the effect of variation in water addition and degree of mixing on loaf volume for two (presumably Australian) wheat flours of varying protein content. For best loaf volume, they concluded that 3% less than the farinograph absorption is a good estimate for water absorption, but optimum MT vary for different cultivars. However, differences in protein quantity should be eliminated in objective quality comparisons between cultivars. Indeed, Aitken and Geddes (1939) and Markley et al (1939) found that farinograph water absorption and dough development time increased with higher protein content. Work by Finney (1943) and Finney and Barmore (1948) showed that, for a given wheat cultivar with a wide protein range (8–18%), a linear relationship exists between protein quantity and loaf volume where the slopes of the regression lines for different cultivars are a measure of protein quality.

The objective of the present study is to further elucidate the relationship between BA and MT and its implications with regard to loaf volume. Because of the heavy work load associated with such an experimental approach, this study was limited to six European wheat flours of varying breadmaking potential. We also studied how the pentosan content and the high molecular weight glutenin-subunit composition of the flours influence BA and MT characteristics.

MATERIALS AND METHODS

Samples and Analytical Methods

Six European wheats (Apollo, Slejpner, Camp Remy, Sperber, Minaret, and Soissons) with varying breadmaking potential were conditioned to 17% moisture and experimentally milled on a Buhler MLU-202 laboratory mill. Ash and moisture content were determined according to AACC methods 08-12 and 44-19, respectively (AACC 1983). Protein content was determined by a semimicro-Kjeldahl method (N $\times$ 6.25). Commercial wheat starch (Meriwit I, Amylum N. V., Aalst, Belgium) was added to the flours to yield 11.33% (db) protein. We felt comfortable doing so because two decades ago Hoseney et al (1971) showed that starch isolated from different wheat cultivars did not influence loaf volume of reconstituted flours to a great extent. Damaged starch was determined amperometrically with the SD_4-Chopin-Dubois device. Water-soluble and total pentosan content were determined according to Hashimoto et al (1987) with modifications described by Delcour et al (1989).

Mixograms and Farinograms

Mixograms were recorded with a 10-g mixing bowl (National Mfg., Lincoln, NE) according to AACC method 54-40A. Farinograms were recorded with a 50-g mixing bowl (Brabender, Duisburg, Germany) according to AACC method 54-21. The constant flour weight procedure was used. Farinograph absorption is based on dough consistency at the 500-BU line.

[1]Research assistant (Food Chemistry), graduate student (Food Chemistry), research assistant (Food Chemistry), research assistant, (Statistics), and professor, respectively. Research Unit, Katholieke Universiteit Leuven, Kardinaal Mercierlaan 92, B 3001 Heverlee, Belgium. Fax +32 16 29 38 05

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Test Baking

Wheat loaves (10 g) were baked using the Shogren and Finney (1984) procedure. Doughs were mixed with a 10-g pin mixer (National). Ingredients, other than flour and water, were sugar (sucrose) 6%, salt 1.5%, and shortening (Crisco, Procter and Gamble) 3%. Fermentation with Fermipan (0.076 g, Gist-Brocades) was 180 min, final proof was 57 min, and baking was 13 min at 232°C. Volume readings (in quadruplicate) were as described by Vanhamel et al (1991), whereby three independent volume readings give a reasonable power to discriminate between items that differ in volume by at least 1 cm^3.

Areas of Manageability

Before baking, areas of manageability for the six test flours were determined. Flour and all other ingredients, except yeast, were mixed with an amount of water for different periods of time. Appearance, manageability, and handling properties of the resulting dough were evaluated subjectively. Increasing absorption levels were tested until a manageable dough could no longer be obtained by combination of the absorption level tested and any MT. In the domain that yielded manageable doughs, we constructed octagons with angular points representing extreme conditions for BA and MT. Breads were prepared in triplicate from all the angular points and nine times from center points.

Response Surface Methodology

Baking results were statistically analyzed by response surface methodology (RSM) as described by Montgomery (1976) and Box et al (1978) to find optimum combinations for MT and BA for best loaf volumes.

Glu-1 and Rye-Modified Glu-1 Scores

The high molecular weight glutenin composition and the resulting Glu-1 and rye-modified Glu-1 scores were provided by P. I. Payne of Plant Breeding International, Cambridge, U.K.

Zeleny Sedimentation

The Zeleny sedimentation value was determined according to ICC standard 116 (ICC 1980).

RESULTS AND DISCUSSION

Analysis of Flour Samples and Areas of Manageability

Table I summarizes the protein and ash content data of the six European flours used in this study. Apart from protein content, the analyzed figures were quite comparable. Figure 1 shows the mixograms of the six test flours. Figure 2 shows the octagons constructed within the areas of manageability. Camp Remy and Sperber are two generally well-accepted good breadmaking cultivars. Apparently, this can be ascribed to the high BA levels and relatively short MT required to yield manageable doughs. In Europe, Apollo and Slejpner cultivars are rejected because of their low BA levels and mixing tolerance. Furthermore, they yield stiff doughs. Minaret and Soissons have a good breadmaking potential, although, in industrial practice, they are often refused because of long MT.

TABLE I
Protein, Ash, and Damaged Starch Content of Six European Wheat Flours and the Amount of Starch Added to Yield Constant Protein Flours

Cultivar	Protein (db)	Ash (db)	Starch[a]	Damaged Starch[b]
Apollo	11.33	0.54	0	19.00
Slejpner	12.04	0.60	5.94	21.10
Sperber	12.96	0.53	11.61	21.40
Camp Remy	12.56	0.53	9.84	20.40
Minaret	11.95	0.52	5.20	19.50
Soissons	12.60	0.55	10.11	19.90

[a] Amount of starch added (%) to yield flours of 11.33% (db) protein level.
[b] UCD = Units Chopin Dubois.

Breadmaking

The loaf volumes of breads produced from the six European flours are low because of the dilution with commercial wheat starch and the use of a lean baking formula (without oxidants). RSM

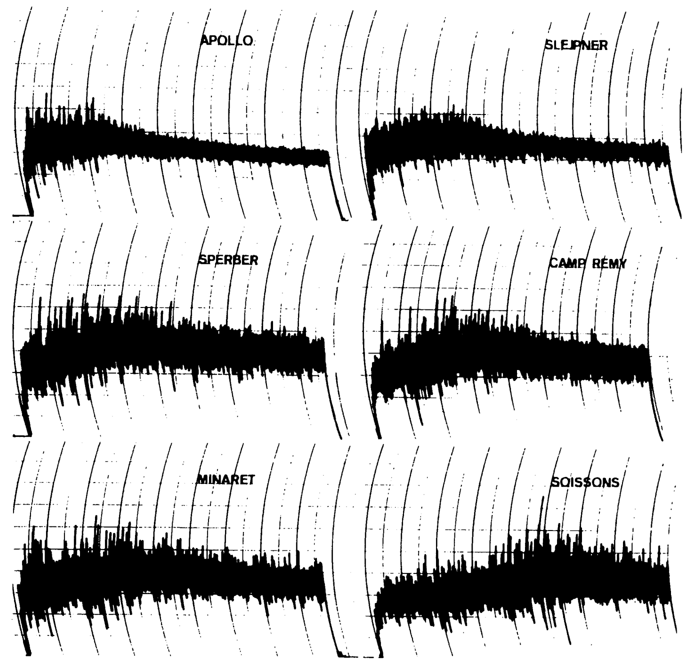

Fig. 1. Mixograms of six European wheat flours with constant protein level. Absorption levels are given in Table IV.

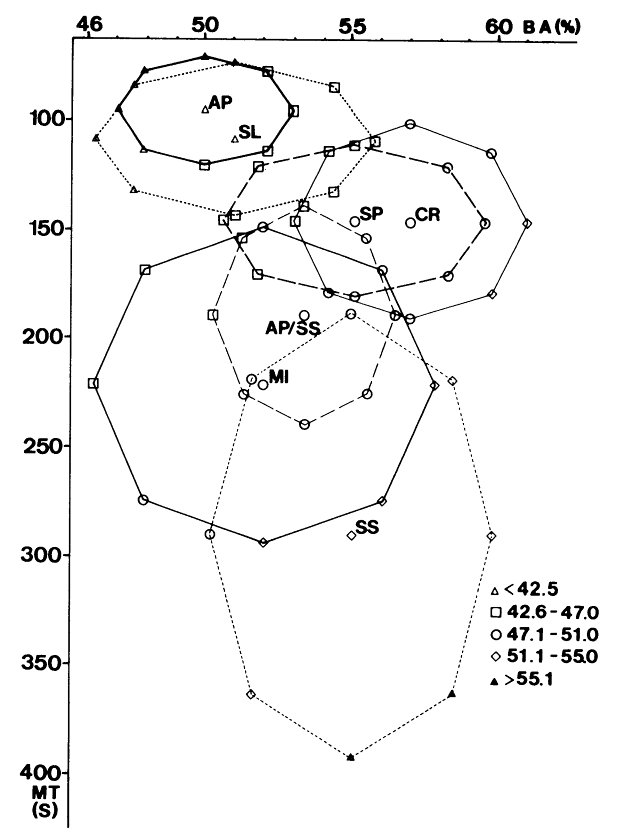

Fig. 2. Effect of variable water absorption levels and mixing times on loaf volume potential for six European wheat flours with constant protein level. Octagons for a particular cultivar were constructed around the center points with the codes for the different cultivars as given in Table II. AP = Apollo, SL = Slejpner, SP = Sperber, CR = Camp Remy, MI = Minaret, SS = Soissons. Symbols represent volume classes (cm^3).

TABLE II
Baking Absorption (BA) and Mixing Time (MT) Coded and Decoded Variables for Six European Wheat Flours Adjusted to Constant Protein Level

Coded		Apollo		Slejpner		Sperber		Camp Remy		Minaret		Soissons	
BA	MT	BA (%)	MT (sec)	BA (%)	MT (sec)	BA (%)	MT (sec)	BA (%)	MT (sec)	BA (%)	MT (sec)	BA (%)	MT (sec)
−1.41	−1.41	47.0	70	46.2	73	50.6	110	53.0	100	46.2	148	50.2	187
−1.00	−1.00	47.9	77	47.6	84	51.9	120	54.2	113	48.0	169	51.6	218
0.00	0.00	50.0	95	51.0	108	55.1	145	57.0	145	52.0	221	55.0	289
1.00	1.00	52.1	113	54.4	132	58.3	170	59.8	178	56.2	274	58.4	362
1.41	1.41	53.0	120	55.8	143	59.6	180	61.0	190	57.8	295	59.8	392

TABLE III
Equations (Coded Variables) Predicting Loaf Volumes (cm^3) of Breads Prepared with Flour from Six European Wheat Cultivars Adjusted to Constant Protein Level[a]

Cultivar	Equation
Apollo	$Vol = 41.95 + 1.57 \times BA + 1.12 \times MT + 0.15 \times BA^2 - 0.34 \times MT^2 + 0.11 \times BA \times MT$ ($r^2 = 0.85$)
Slejpner	$Vol = 42.46 + 1.99 \times BA + 1.33 \times MT - 0.29 \times BA^2 - 0.23 \times MT^2 - 0.07 \times BA \times MT$ ($r^2 = 0.94$)
Sperber	$Vol = 47.15 + 1.88 \times BA + 0.73 \times MT - 0.83 \times BA^2 - 0.31 \times MT^2 - 0.33 \times BA \times MT$ ($r^2 = 0.66$)
Camp Remy	$Vol = 49.02 + 1.80 \times BA + 1.22 \times MT - 0.09 \times BA^2 + 0.26 \times MT^2 - 0.33 \times BA \times MT$ ($r^2 = 0.76$)
Minaret	$Vol = 50.42 + 2.67 \times BA + 1.77 \times MT - 0.65 \times BA^2 + 0.26 \times MT^2 + 0.34 \times BA \times MT$ ($r^2 = 0.86$)
Soissons	$Vol = 52.10 + 1.87 \times BA + 2.43 \times MT - 0.55 \times BA^2 + 0.72 \times MT^2 - 0.46 \times BA \times MT$ ($r^2 = 0.88$)

[a] BA = baking absorption level, MT = mixing time.

TABLE IV
Determination of Baking Conditions with Mixograph[a], Farinograph,[b] or Octagon Evaluation,[c] for Six European Wheat Flours Adjusted to Constant Protein Level[d]

Cultivar	MA	MT	FA	MT	BA	MT	MA-BA[e]	FA-BA[f]
Apollo	57.0	120	53.2	101	52.1	113	+ 4.9	+ 1.1
Slejpner	58.0	117	57.4	117	54.4	132	+ 3.6	+ 3.0
Sperber	58.0	196	57.1	189	59.6	145	− 1.6	− 2.5
Camp Remy	62.0	174	57.0	134	59.8	178	+ 2.2	− 2.8
Minaret	58.0	202	54.4	158	56.2	274	+ 1.8	− 1.8
Soissons	63.0	322	56.5	256	58.4	362	+ 4.6	− 1.9

[a] MA MT = mixograph absorption (%) + mixing time (sec).
[b] FA MT = farinograph absorption (%) + mixing time (sec) corresponding to this absorption level, determined with the mixograph
[c] BA MT = baking absorption + mixing time yielding the highest loaf volume.
[d] All absorption results expressed on 14% mb.
[e] MA−BA = mixograph absorption − baking absorption.
[f] FA−BA = farinograph absorption−baking absorption.

analysis of the octagons showed that, for each flour, loaf volume can be expressed as:

$$\text{Volume (cm}^3) = \text{Intercept} + a \times BA + b \times MT + c \times BA^2 + d \times MT^2 + e \times BA \times MT \quad (1)$$

with BA and MT as coded variables to facilitate statistical analysis.

Decoded variables and the equations resulting from the RSM procedure for the six test flours are summarized in Tables II and III. Figure 2 and Table III show that loaf volumes obtained for each flour depend on the BA level and MT applied; loaf volumes increase with higher BA levels and longer MT. No optimum combination of BA and MT for loaf volume was found within the areas of manageability. For example, the highest loaf volume (44.9 cm^3) was obtained for Slejpner with 54.4% BA and 132-sec MT. Best possible loaf volumes were obtained with the highest BA levels and longest MT possible. Manageability of the resulting doughs was the limiting factor. Crumb structure of 100-g loaves was evaluated by experienced bakers. Special attention was paid to the crumb structures of the loaves from the center points and to the combination of BA level and MT that resulted in the best loaf volume. Except for Sperber, all the crumb structures of the breads with highest loaf volumes were better (Apollo and Soissons) or comparable (Slejpner, Camp Remy, and Minaret) to the crumb structures of the breads from the center point combination. Minaret and Soissons had the best crumb structure, but the crumb of Minaret appeared more white than Soissons. The crumb of Sperber was slightly better than that of Camp Remy. Both crumb structures were acceptable. Slejpner and Apollo both had a coarse crumb structure that appeared green (underoxidized).

Mixograph, Farinograph, and Baking Results

Table IV lists the water absorption levels determined with the mixograph and farinograph and the BA levels that resulted in the highest loaf volume. The absorption levels determined by the mixograph and farinograph can only be used as rough estimates for BA.

Damaged starch level and protein level contribute to farinograph water absorption. Several studies (Greer and Stewart 1959; Meredith 1966; Farrand 1969, 1972) showed that starch damage can affect BA and the meaning of conventional rheologic parameters. For the six test flours with constant protein content, farinograph absorption did indeed increase with higher starch damage ($r^2 = 0.79$, $n = 6$). This is in accordance with results of Tipples et al (1978), who found that starch damage was the strongest single predictor for farinograph absorption; the next parameter of importance was the protein content. Consequently, farinograph absorption of flour samples with constant protein level must be greatly influenced by starch damage. The significant correlation that we obtained between farinograph absorption and starch damage was for flour samples with minor differences in starch damage. However, we observed no such relationship between damaged starch and BA or mixograph absorption. It is unclear to us whether the absence of this relationship can be ascribed to the differences in mixing action between the Brabender farinograph and the pin mixers used in the baking procedure. Table IV shows that we could not generalize the conclusion of Burrows and McGuirk (1991) that water addition of 3% less than the farinograph absorption was the optimum in terms of loaf volume for the two flours used in their work.

Factors Governing BA and MT Characteristics Governing Breadmaking Potential

Figure 2 shows that, for the wheat flours under study, those requiring high BA levels and long MT yielded the highest loaf volumes. Furthermore, when these flours with a constant protein level yield manageable doughs for the same BA and MT, they essentially yield the same volume. When the combination of 54.5% BA and 180-sec MT was used, this resulted in manageable doughs giving equal volumes for Soissons, Minaret, Sperber, and Camp Remy. It appeared that higher volumes could be obtained when a longer MT was used for Soissons and Minaret or a higher BA level was used for Sperber and Camp Remy. This implies that the breadmaking potential of such flours can be attributed to a great extent to factors governing the MT and BA level characteristics of the flour. Further evidence for this observation stems from the fact that a mixture of 50% Apollo and 50% Soissons (at the same protein level) results in a flour with intermediate MT and BA level characteristics. Furthermore, loaf volumes obtained from this mixture were again adequately predicted from the BA level and MT used.

Statistical analysis of the data obtained from the flour samples with constant protein level, and produced with a laboratory mill yielding comparable degrees of starch damage, resulted in a model that predicts loaf volume when MT (sec) and BA level (%) of a flour are known:

$$\text{Vol (cm}^3) = 12.44 + 0.30\ (\text{BA}) \times \log\ (\text{MT}) \qquad r^2 = 0.93 \qquad (2)$$

Figure 3 shows the predicted versus observed loaf volumes for the six test flours baked with varying MT and BA levels. Our model extends the findings by Finney and Shogren (1972) that, for hard winter wheat flours with constant protein level of 13% representing a wide range in baking quality, loaf volume increased with MT; however, above a certain mixing level, no further volume increase was observed.

Finney et al (1985) also compared the baking quality of wheat cultivars grown in Europe and in the U.S. They corrected the observed loaf volumes to a constant protein basis (13.5%). Using an equation done by Shogren and Finney (1984) to correct loaf volumes (100 g) to 10-g loaves, we obtained an equation analogous to equation (2). The intercept and slope of this equation (3), fitting that done by Finney et al (1985), were higher at the higher protein level. Comparison of the two equations shows that, for the same BA-MT combination, higher protein flour yields higher loaf volumes:

$$\text{Vol (cm}^3) = 31.58 + 0.43\ (\text{BA}) \times \log\ (\text{MT}) \qquad r^2 = 0.79$$

Significance of Findings

We concluded that BA and MT greatly affect the baking potential of wheat flour. The next obvious question was: Which factors govern these characteristics?

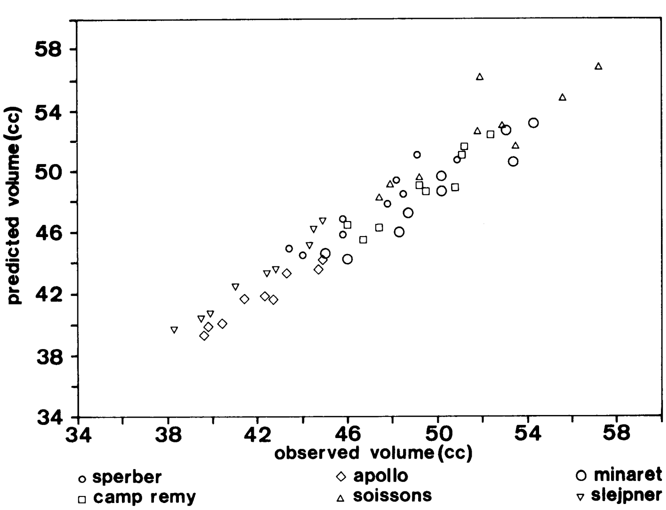

Fig. 3. Predicted (see equation 2) versus observed loaf volume (cm^3) for varying water absorption levels and mixing times for six European wheat flours with constant protein level.

TABLE V
Water-Soluble, Insoluble, and Total Pentosan Content (%) of Six European Wheat Varieties Adjusted to Constant Protein Level

Cultivar	Water-Soluble Pentosans	Total Pentosans	Insoluble Pentosans[a]
Apollo	0.66	1.67	1.01
Slejpner	0.58	2.05	1.47
Sperber	0.48	1.64	1.16
Camp Remy	0.42	1.60	1.18
Minaret	0.50	1.50	1.00
Soissons	0.30	1.29	0.99

[a] Calculated as the difference between total pentosan and water-soluble pentosan content. Expressed on a dry basis.

Pentosans can absorb large quantities of water (Kulp 1968a, Jelaca and Hlynka 1971) and influence MT when isolated and added to a flour. We determined water-soluble, insoluble, and total pentosan content of the six test flours. Results are shown in Table V. The water-soluble pentosan content of the two cultivars with a translocated chromosome consisting of the long arm of 1B and the short arm of 1R from rye (Apollo and Slejpner) was significantly higher than that of the other wheat cultivars. This most likely is a happenstance. Recently, Biliaderis et al (1992) found no significant differences between the water-soluble pentosan content of 35 cultivars with 1B/1R translocation and 36 normal wheat lines.

When considering the water-soluble pentosan content and the relative positions of the octagons shown in Figure 2, two effects can be seen.

1. The BA level increases when the water-soluble pentosan content decreases (for the series Apollo, Slejpner, Sperber, and Camp Remy). The same holds true for a second series (Apollo, Slejpner, Minaret, and Soissons).

2. MT required for optimum development is reduced with higher water-soluble pentosan content. Again, this is true for the series Apollo, Slejpner, Sperber, and Camp Remy and for a second series of Apollo, Slejpner, Minaret, and Soissons.

Water-Soluble Pentosan Content and BA Level

D'Appolonia and Kim (1976) reported that adding pentosans to dough results in stiffer, drier doughs because an amount of the water added is immobilized. Water-soluble pentosans are very hydrophylic; they are capable of absorbing 10 times their weight of water (Kulp 1968a). It is well-accepted that such pentosans absorb an amount of water very quickly. Negative effects of pentosans on the quality of bread were also reported by Kulp and Bechtel (1963) and Kulp (1968b), who found loaf volume increases for tailings isolated from flours and treated with enzymes hydrolyzing arabinoxylans. D'Appolonia et al (1970) purified water-soluble pentosans isolated from hard red spring and soft wheat. They found only very slight, if any, volume increases when the purified fractions were added to gluten starch loaves. More recent findings of Weegels et al (1991c) showed that cellulases and hemicellulases improve the coagulation of gluten by removing the steric hindrance of hemicellulose linked to gluten. D'Appolonia et al (1990) also found pentosan-type material to be closely associated with gluten. According to these authors, the carbohydrate and protein components may be covalently linked. In our findings, it appears that water-soluble pentosans have a negative effect on the manageability and, consequently, on the breadmaking potential of wheat flours. The negative effect of water-soluble pentosans on dough manageability and breadmaking potential could be the result of 1) immobilization of an amount of water necessary for the complete hydration of the gluten, and/or 2) the interference of pentosans during the aggregation of the glutenin molecules.

Weegels et al (1991a) proposed a tentative model for the assembly of the glutenin matrix. An immediate reaction of thiol groups of glutenin molecules with each other was considered to be highly unlikely because of their low concentration. They assumed that, in a first step, hydrophobic gliadins interact with hydrophobic sites on the C- and N-terminal regions of the glutenins. These interactions would allow sulfhydryl groups, which are then juxtaposed, to form disulfide bondings. Thus, hydrophobic gliadins facilitate the formation of the glutenin matrix.

Van Lonkhuijsen et al (1992) found evidence for the importance of hydrophobic gliadins in breadmaking. They noted a good correlation between the hydrophobicity of the gliadins as determined by reverse-phase high-performance liquid chromatography and the breadmaking quality. Some early eluting (hydrophilic) gliadins are negatively related to breadmaking quality, whereas a hydrophobic gliadin is positively related. Weegels et al (1991b) confirmed the statistical relation by a large-scale (60 g) fractionation of gliadin. Four out of five fractions influenced loaf volume as predicted by the Van Lonkhuijsen equation. Further evidence for the importance of hydrophobic gliadins was found by Basuki et al (1991). Gluten isolated from wheat cultivars differing widely in quality showed only small differences. During isolation, a hydrophilic fraction of the 70% ethanol extract disappeared to a large degree. Finally, modifying gluten using proteases with high activity for hydrophilic gliadins improved the quality of the gluten (Weegels et al 1991c). Thus, hydrophobic gliadins seem to facilitate the formation of the glutenin matrix, whereas hydrophilic gliadins seem to be rather detrimental.

One could speculate that the steric hindrance of hydrophilic pentosans (present in greater amounts in our poor quality cultivars) is similar to the way hydrophilic gliadins disturb the gluten aggregation. He and Hoseney (1991) and He et al (1991) showed that gluten were easier to extract from a poor quality flour than from a good quality flour. They showed that the extracted flour protein of poor and good quality flour (99% and 98%, respectively) in a 1% sodium dodecyl sulfate extract had the same relative viscosity and, thus, the same average molecular weight. Therefore, they concluded that the difference in extractability was due to the fact that the poor quality flour gluten has less tendency to interact with itself. Again, this difference could be caused by steric hindrance of pentosans that disturb the gluten aggregation. Figure 4 shows an inverse relation exists between the water-soluble pentosan content and the Zeleny sedimentation value for the six test flours with constant protein level. The sedimentation seems influenced by the amount of water-soluble pentosans present, and higher amounts more readily disturb the flocculation of the gluten proteins.

Water-Soluble Pentosan Content and Mixing Requirement

According to Finney et al (1982), mixing requirement is governed by glutenin quality, and loaf volume is governed by gliadin quality. Cultivars with short mixing requirement almost invariably have poor loaf volume potential; cultivars with medium or long mixing requirement almost invariably have a good loaf volume potential (Finney and Yamazaki 1967). Thus, glutenin quality indirectly controls loaf volume potential.

It is reasonable to interpret differences in mixing requirement and, hence, glutenin quality in terms of the tendency of the glutenin molecules to interact with themselves or other flour constituents.

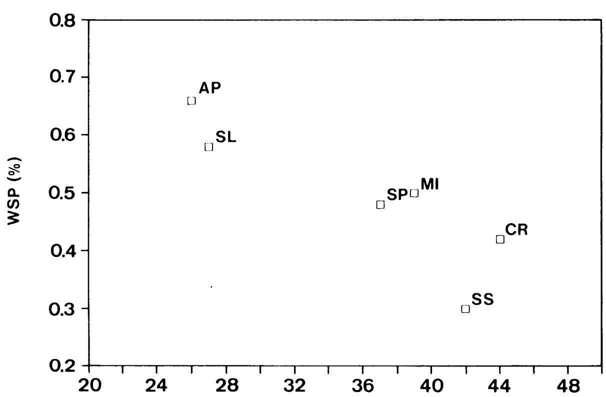

Fig. 4. Relationship between water-soluble pentosan (WSP) content and Zeleny sedimentation value of six European wheat flours with constant protein level. AP = Apollo, SL = Slejpner, SP = Sperber, CR = Camp Remy, MI = Minaret, SS = Soissons.

Good quality glutenin preferentially interacts with other glutenin molecules. This interaction can be promoted by good quality (hydrophobic) gliadins. However, more work input is required to form a gluten matrix, resulting in long MT. Poor quality glutenin interacts more readily with other flour constituents, resulting in a less uniform gluten matrix that requires less work input and short MT.

It is striking that the relative position of the areas of manageability correlates well with the Glu-1 score (Figure 2 and Table VI) developed by Payne et al (1987). The mixing characteristics correlate quite well with the Glu-1 scores, supporting the data of Finney et al (1982) that glutenin quality governs mixing requirement. It must be stressed that, in practice, the two samples with the high Glu-1 score, Minaret and Soissons, are often rejected because of their mixing characteristics.

CONCLUSION

Six European wheat flours of varying breadmaking potential, brought to a constant protein level, required different BA levels and MT conditions to yield manageable doughs. For each flour studied, loaf volumes increased with higher BA and longer MT. However, no optimum for loaf volume was found in the area representing all realistic combinations of BA and MT. Furthermore, flours of different quality with constant protein level that are processed at the same BA and MT yield loaves of essentially equal volume. Based on this observation, we developed a model to predict loaf volume when BA and MT are known. Loaf volume is greatly determined by factors governing the BA and MT characteristics of a flour. Analysis of pentosan contents indicated that poor quality flours (with short MT and low BA level) had higher amounts of water-soluble pentosans than the good quality flours. Furthermore, an inverse relationship exists between water-soluble pentosan content and the Zeleny sedimentation value.

Obviously, gluten quantity and quality are important characteristics for the baking potential of wheat flour. However, neutralizing the effect of protein quantity, as we did in this work, makes it equally obvious that processing conditions such as MT and BA levels determine loaf volume potential, and differences between breads from 10 g of our flour prepared under equal MT and BA conditions become negligible. Under experimental conditions, gluten quality in a similar way as what was discussed for pentosans, has to do with the way it influences the MT and BA characteristics of a particular flour and with the way it interacts with other flour components.

We realize that, in our work, we considered only a limited number of samples. Nevertheless, we are convinced that this experimental approach, including baking trials under different MT and BA conditions and the standardization of the flour protein content, has been rewarding.

ACKNOWLEDGMENT

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TABLE VI
High Molecular Weight Subunit Composition, Glu-1 Score, and Rye-Modified Glu-1 Score of Six European Wheat Cultivars

Cultivar	Subunit Composition 1A	1B	1D	1B/1R Translocation	Glu-1 Score	Rye-Modified Glu-1 Score
Apollo	N	6+8	2+12	1B/1RS	4	3
Slejpner	N	6+8	2+12	1B/1RS	4	3
Sperber	N	7+9	5+10		7	7
Camp Remy	2*	7	3+12		6	6
Minaret	1	7+9	5+10		9	9
Soissons	2*	7+8	5+10		10	10

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