The Relationship of Bromate Requirement and Sugars in Breadmaking and Implications for Loaf Volume Potential of Hard Red Spring Wheat Flours[1]

J. D. C. FIGUEROA[2] and K. KHAN[3]

Cereal Chem. 68(3):284–290

ABSTRACT

The hard red spring wheat cultivars Coteau, Len, and Tammy, grown at two locations in North Dakota in 1987 and selected on the basis of bromate requirements, were compared for sugars using gas chromatography and phenol-sulfuric acid methods. The chromatograms of sugars from the Osborne fractions of Coteau, which usually requires bromate, showed low levels of sugars in the albumin, glutenin, and residue fractions. Similar sugar patterns were found in soft red winter wheat. Flours with bromate requirements had low farinograph absorptions, short mixing and arrival times, high protein, and low sugar contents compared to flour without bromate requirements. The level of sugar in flours from the same location was usually lower in cultivars that required bromate than in those that did not require bromate. Variations in sugar content were also observed among locations.

Potassium bromate ($KBrO_3$) was recommended as a "bread improver" as early as 1916 (Kohman et al 1916, Read and Haas 1937, Thewlis 1974, Fitchett and Frazier, 1986). Since then, potassium bromate and potassium iodate (KIO_3) have been used in breadmaking and have undergone intensive investigations (Read and Haas 1937, Fitchett and Frazier 1986). Potassium bromate has become the most used maturing agent, commonly added to flour regardless of whether or not the flour has been previously treated in the mill with a maturing agent (Joiner et al 1963). When optimal levels of potassium bromate are added, dough properties, loaf volume, and quality of bread are improved (Kohman et al 1916, Sullivan et al 1940, Finney 1943, Hoseney et al 1972, Patil et al 1976, and de Stefanis et al 1988). However, there has been discussion as to the need for supplemental treatments at the baking stage of flours already maturated at the mill (Joiner et al 1963). Overtreatment can produce worse results than no treatment at all (Sullivan et al 1940), since wide variations can occur in oxidation requirements due to differences in flour types, locations, and years (Joiner et al 1963).

Many theories have been generated to explain the mechanism of action of potassium bromate. Jorgensen (1936) proposed that the benefits derived from the use of bromate in flour come from the inhibitive activity of bromate on the proteases in the flour. This theory was rejected by Read and Haas (1937). Sullivan et al (1940) suggested that the oxidation mechanism involves the protein fractions of flour. The most accepted explanation at present is that sulfhydryl groups on the protein molecules are changed to disulfides by maturating agents such as bromate, to produce the improving effects on dough and bread.

Sullivan et al (1940) found that glutathione from germ was responsible for reducing activity in wheat. They tried to relate the amount of glutathione to bromate requirements. However, flour with poor baking quality did not show the expected higher glutathione content and did not respond to bromate. Sullivan et al (1940) and Baker et al (1942) also suggested that gluten—not lipids, starch, sugars, or diastatic enzymes—seemed to be involved in the oxidizing bromate response. Finney (1943), Hoseney et al (1972), Patil et al (1976), and Marais and

[1]Published with the approval of the Director of the Agricultural Experiment Station, North Dakota State University, Fargo, 58105, as Journal Series No. 1906.
[2]Graduate student (Present address: INIFAP Apartado Postal No. 10, Chapingo, Mex., 56230, Mexico.
[3]Associate Professor, Department of Cereal Science and Food Technology, North Dakota State University, Fargo, 58105.

D'Appolonia (1981) found that the reaction of doughs to oxidizing agents was located either in the gluten or the water-soluble portion of dough. Higher protein contents gave a greater bromate response (Sullivan et al 1940, Finney 1943, Hoseney et al 1972) and also decreased mixing time (Finney 1943, Hoseney et al 1972).

Marais and D'Appolonia (1981) showed that the albumin fraction appeared to cause more "oldness" in bread, thus implicating these proteins in the bromate reaction. Patil et al (1976) and Ali and D'Appolonia (1979) showed that water-soluble pentosans had an oxidizing effect in baking. They also showed that pentosans and bromate, in the absence of other water-soluble components, had an additive effect of overoxidation in bread, resulting in depressed loaf volume.

At the present time, the use of bread and dough improvers is common practice in the United States, Canada, Australia, and the United Kingdom (Thewlis 1974). However, Japan and the countries of the European Economic Community are more restrictive in their use of bromates, except for the United Kingdom, Denmark, Holland, and Eire, where bromate is still used (Thewlis, 1974). In the remaining European Economic Community countries, ascorbic acid is the substance acceptable for use as a dough and bread improver (Thewlis 1974, Kamman 1984, Fitchett and Frazier 1986).

In the United States, Food and Drug Administration regulations limit the levels of all oxidants, except for ascorbic acid (Kamman 1984) to 75 ppm of flour. Potassium bromate is allowed at a maximum of 50 ppm in the United Kingdom (Thewlis 1974, Fitchett and Frazier 1986), and potassium iodate is forbidden there (Fitchett and Frazier 1986).

Since the United States exports large amounts of wheat to some of those countries, it is important to understand the overall behavior of wheat flour to meet the needs and demands of those countries that import U.S. wheat. The design and development of new wheat varieties that produce bread with good quality characteristics, with the use of zero or low levels of oxidation requirements, should be an important goal of cereal chemists. The objective of this study, therefore, was to investigate the relationship between the sugar content of flour, protein fractions, and oxidation requirements such as the use of potassium bromate in the breadmaking process.

MATERIALS AND METHODS

Wheat Flour Samples

The hard red spring (HRS) wheats were grown in different locations in North Dakota and the hard red winter (HRW) wheat cultivars were grown in different locations in Kansas, with the exception of the HRW wheat Roughrider, which was grown in North Dakota. The soft red winter (SRW) wheats were grown in Ohio in 1987. Composites were prepared at protein levels of 10–12% (as-is moisture basis) for each class of wheat from several locations. Five HRS wheats (Len, Butte, Era, Marshall, and Coteau), three HRW wheats (Eagle, Newton, and Roughrider), and three SRW wheats (Adder, Fairfield, and Titan) were selected on the basis of their protein levels. This maintained uniform protein levels among the wheat classes to minimize the effect of protein quantity on other quality parameters. In addition, flours of Coteau, Len, and Tammy, grown at both Langdon and Minot, ND, in 1987, were selected to investigate bromate requirements. Ten other flours of HRS wheat cultivars (Minnpro, Marshall, Butte, Columbus, Amidon, Celtic, Laura, Kenyon, Len, and Leif), each grown at seven locations in North Dakota (Williston, Hettinger, Fargo, Dickinson, Minot, Langdon, and Carrington) in 1988, were used to test the model developed for bromate requirements.

Protein Determination and Fractionation

Protein content was determined according to AACC approved method 46-11A (AACC 1983). The protein fractionation procedure was the Osborne procedure modified by Chen and Bushuk (1970).

Breadmaking Quality

The baking procedure was the straight-dough lean formula of D'Appolonia et al (1970). The baking formula consisted of 100 g of flour (constant moisture basis), 3% cake yeast, 5% sugar, 1% salt, 0.1% ammonium phosphate, 15 SKB units of fungal amylase, and variable absorption and mixing time. The dough was fermented in a cabinet at 30°C and 78% relative humidity, with two punches during a 3-hr fermentation and a proof period of 55 min, and then baked at 230°C for 25 min. Loaves were baked simultaneously with and without 10 ppm of potassium bromate for each cultivar.

Physical Dough Properties

A farinograph was used to measure rheological properties of the doughs according to AACC approved method 54-21 (AACC 1983).

Gas Liquid Chromatography

The method of hydrolysis of Osborne fractions and flour for quantitative analysis of monosaccharides was the same as that of McMaster and Bushuk (1983), except that 15–20 mg of Osborne fractions and flour samples were used instead of 10 mg.

Derivatives were prepared following the procedure of McGinnis (1982). The aldononitrile acetate derivatives of sugars were separated and identified by gas chromatography. The sample injected was 2.0–2.5 μl. Separation was achieved on a Hewlett Packard 5840A gas chromatograph equipped with a glass column (6 ft length, 4 mm internal diameter) packed with 1% diethylene glycol adipate on Chromosorb W-HP (100–120 mesh) Analab and a flame ionization detector. Nitrogen was used as the carrier gas at a flow rate of 23 ml/min. The oven temperature was raised from 155 to 255°C at 2°C/min and maintained at 255°C for 32 min. The injection port and detector temperature were 290 and 350°C, respectively.

Total Sugar Extraction.

Sugars were extracted from flour (50 mg) by adding 1 ml of 0.05M acetic acid, vortexing for 10 min, and then centrifuging at 12,000 $\times$ g for 10 min. The supernatant was decanted. An aliquot of 50 μl was diluted with 950 μl of distilled water and used for determination of sugars.

Sugar Determination

Sugar content was estimated by the phenol-sulfuric acid method of Dubois et al (1956), in which 1 ml of sugar extract is treated with 1 ml of a 5% solution of phenol and 5 ml of concentrated sulfuric acid. After 20 min, the absorbance was read at 490 nm. The amount of sugar in the unknown samples was estimated from a standard curve prepared with glucose.

RESULTS AND DISCUSSION

Sugar Analysis of HRS, HRW, and SRW Wheats

The sugars were analyzed on a gas chromatograph using aldononitrile acetate derivatives. Figure 1 shows the chromatogram of sugar standards with retention times in minutes for each sugar.

Table I shows the amount of sugars within the same Osborne fractions. Titan, a weak (based on farinograph curve) SRW wheat, did not show sugars in some fractions. The strong (based on farinograph curve) SRW wheat, Adder, had sugar patterns similar to those of HRS and HRW wheats. Surprisingly, Coteau, a HRS wheat, was similar to Titan, a SRW wheat, in the amount of sugar it had in the albumin, glutenin, and residue fractions from the Osborne solubility procedure. The gliadin fraction of Coteau, however, showed a small amount of sugars, while the globulin fraction showed levels similar to those of the other HRS and HRW wheats. Marais and D'Appolonia (1981) reported that Coteau generally required bromate for expression of good loaf volume. This observation led us to investigate whether other HRS wheats that required bromate also had amounts of sugars similar to that in Coteau. However, since the Osborne fractionation is time-consuming, we decided to use the flour itself for estimating

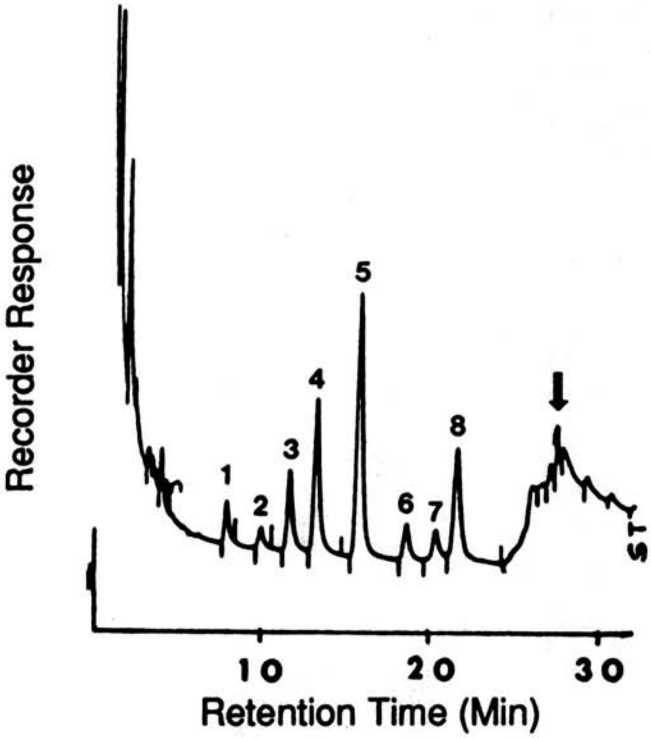

Fig. 1. Gas chromatogram of aldononitrile acetate derivative of sugars with the retention times in parenthesis. 1, rhamnose (7.92); 2, fucose (9.94); 3, arabinose (11.64); 4, xylose (13.17); 5, methyl-α-glucopyranoside (internal standard) (17.76); 6, mannose (18.70); 7, glucose (20.58); 8, galactose (21.83); arrow, solvent peak.

the sugars.

As shown in Figure 2, extracts from Coteau flour also showed low levels of sugars, mainly in the region of retention time for rhamnose and xylose, and was similar to the chromatograms of the SRW wheats Fairfield and Titan. The other HRS and HRW wheat flours and the flour from Adder, the strongest of the SRW wheats, showed higher levels of sugars. This observation led us to select wheat flours that showed differences in bromate response

TABLE I
Total Sugar (%) in Osborne Fractions of Hard Red Spring (HRS), Hard Red Winter (HRW), and Soft Red Winter (SRW) Wheats[a]

Class/Cultivar[b]	Albumin	Globulin	Gliadin	Glutenin	Residue
HRS					
Len	3.77	8.79	2.57	4.13	5.34
Butte	5.07	7.30	6.56	0.44	6.00
Coteau	0.21	5.19	2.65	0.19	1.64
Era	4.22	7.41	3.37	5.95	4.41
Marshall	3.11	4.76	1.91	4.60	3.09
HRW					
Eagle	4.05	6.90	5.79	5.69	4.81
Newton	3.60	8.28	3.66	6.05	3.33
Roughrider	2.84	7.15	3.22	5.83	6.05
SRW					
Adder	4.00	9.31	5.64	5.97	5.29
Fairfield	1.84	0.53	0.12	0.29	1.90
Titan	0.00	0.05	0.00	0.51	2.38
LSD at (0.05)[c]	3.34	3.32	3.35	2.18	3.43

[a] Analyzed by gas chromatography of the aldononitrile acetate derivatives.
[b] Each cultivar replicated twice.
[c] Least significant difference at less than 0.05 probability levels.

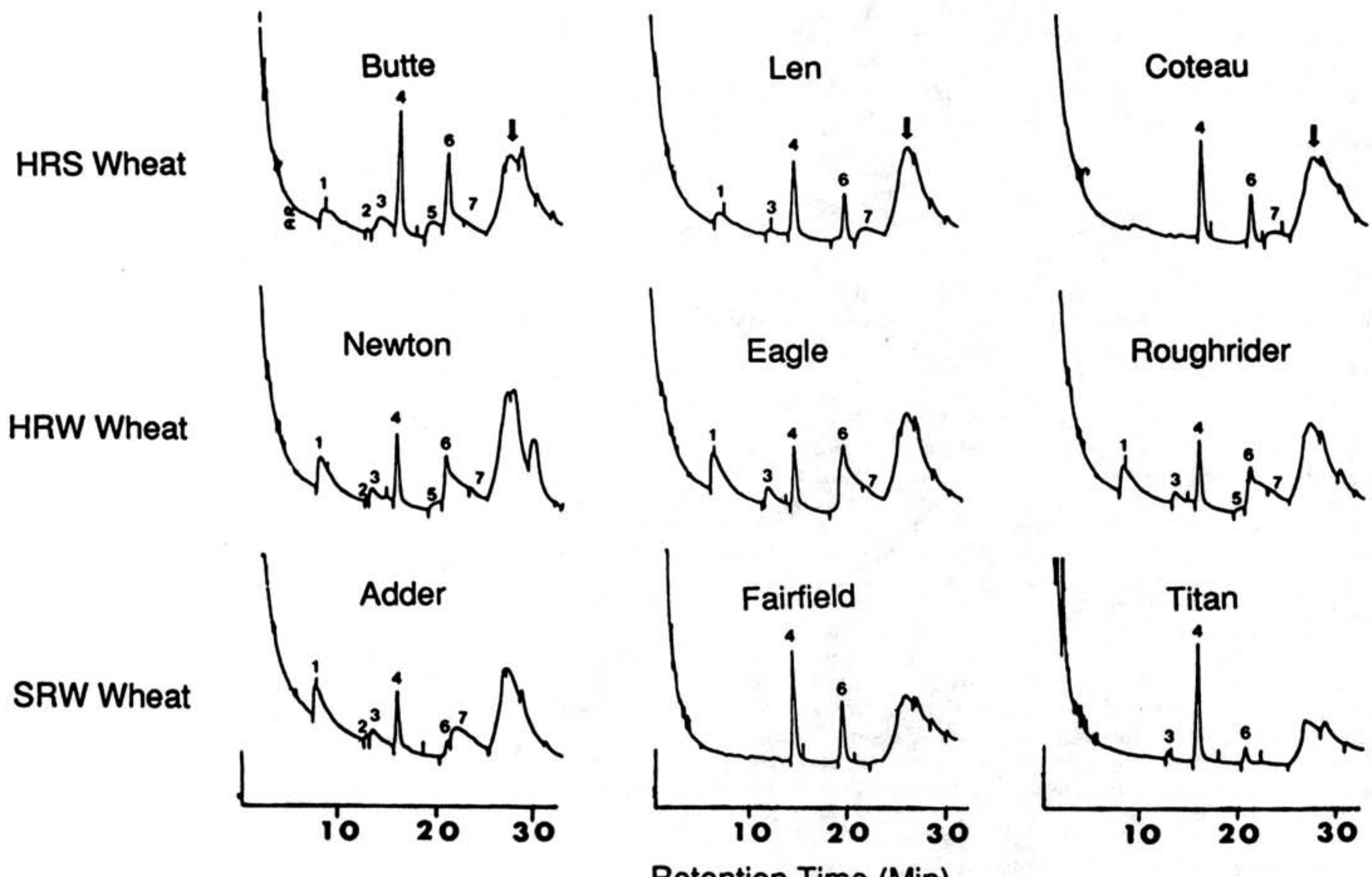

Fig. 2. Gas chromatograms of aldononitrile acetate derivatives of sugars from flour of hard red spring (HRS), hard red winter (HRW), and soft red winter (SRW) wheats. 1, rhamnose; 2, arabinose; 3, xylose; 4, methyl-α-glucopyranoside (internal standard); 5, mannose; 6, glucose; 7, galactose; arrows, solvent peaks.

and to determine the amount of sugars in these flours.

Three flours were selected from each of two locations, Langdon and Minot, in 1987 (wheats grown in Langdon usually require bromate, whereas wheats grown in Minot rarely require it). The cultivar Coteau from both locations required bromate, and the cultivar Tammy required it only from Langdon. Len did not require bromate at all. Chromatograms of the flours (Fig. 3) showed that the cultivars that required bromate also contained very low levels of sugars (especially in the region of retention times of rhamnose and xylose) when compared to cultivars that did not require bromate at all (Tammy from Minot and Len). Although rhamnose seems to be present in wheat flour at levels (0–0.03%) that are very low compared to those of other common sugars in wheat, we are not aware of reports in the literature that associate rhamnose with wheat quality. Also, we observed that within the same wheat class, some cultivars had different levels of total sugars.

We decided to try a simple and more rapid method for analysis of sugars that would be suitable for large numbers of samples. The phenol-sulfuric acid method (Dubois et al 1956) for measuring sugars was investigated.

This method is reproducible if proper extraction is accomplished. We tried extractions with 0.5*M* NaCl or 70% aqueous ethanol, but the replicates varied too much. However, with 0.05*M* acetic acid, the variation was minimal. The 0.05*M* acetic acid solution extracts albumins, globulins, gliadins, soluble glutenin, and other soluble materials, perhaps pentosans and free sugars.

Bromate Requirement and Sugar Levels

Statistical analysis of the data (Table II) shows that flours with bromate requirements have low absorption and short mixing time, arrival time, and stability compared to flours with no bromate requirements for the samples investigated. With respect to the quality parameters (Table III), flours with bromate requirements show high protein, high loaf volume, and low sugar content compared to flours without bromate requirements. The quality of bread was inferior in bromate-requiring flours when no bromate was used in the formula and when bromate was used with flours that did not require bromate. For example, Coteau showed the highest protein, low mixing and arrival times, intermediate mixing tolerance index, and lowest sugar content (Table II). Also, as expected, the bread made from the flour of Coteau without bromate had the lowest loaf volume and poor quality compared to bread made from Len and Tammy flours without bromate (Table III). However, when bread was baked with 10 ppm of potassium bromate, Coteau flour responded to bromate and gave the best loaf volume and bread quality compared to Tammy and Len, which had no-bromate requirements. In both of these, the quality was drastically reduced when bromate was added to their flours.

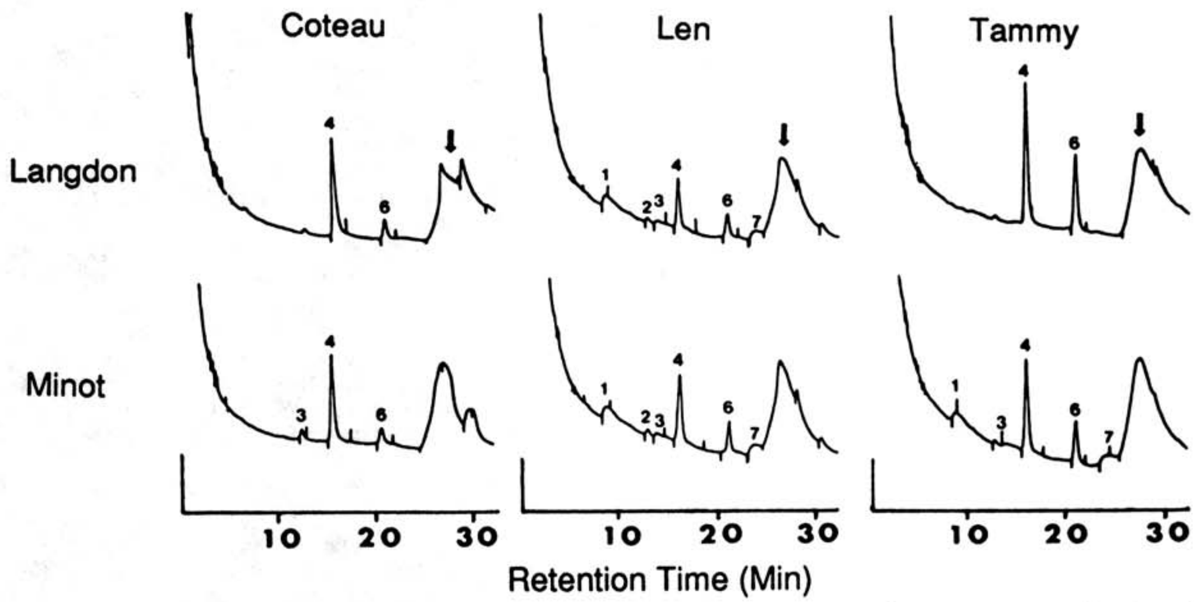

Fig. 3. Gas chromatograms of aldononitrile acetate derivatives of sugars of hard red spring wheat flours grown at two locations, Langdon and Minot, ND. 1, rhamnose; 2, arabinose; 3, xylose; 4, methyl-α-glucopyranoside (internal standard); 5, mannose; 6, glucose; 7, galactose; arrows, solvent peaks.

TABLE II
Duncan's Test on Relationship of Bromate Response to Rheologial Parameters of Hard Red Spring Wheats Grown in 1987 at Two Locations in North Dakota[a]

Cultivar[b] and Bromate Requirement[c]	Location	Absorption[d] (%)	Mixing Time (min)	Arrival Time (min)	MTI[e] (BU)	Stability (min)
Coteau (+)	Langdon	70.1 b	8.3 d	4.8 d	18 c	23.5 b
Coteau (+)	Minot	72.7 a	23.0 b	8.3 c	22 b	16.3 c
Tammy (+)	Langdon	69.5 b	9.0 d	5.0 cd	15 cd	15.0 cd
Tammy (−)	Minot	72.0 a	22.5 b	12.5 b	50 a	13.5 d
Len (−)	Langdon	69.9 b	10.5 c	3.3 d	10 de	28.5 a
Len (−)	Minot	72.4 a	34.5 a	23.5 a	8 e	24.5 b
Flour (−)		71.4 a	22.5 a	13.1 a	23 a	22.2 a
Flour (+)		70.8 b	13.4 b	6.0 b	22 a	18.3 b

[a] Means with the same letter in columns within the same group are not significantly different at the 5% probability level.
[b] Each cultivar replicated twice.
[c] (+) indicates bromate required; (−) indicates no bromate required.
[d] Farinograph absorption at 500 BU consistency.
[e] Mixing tolerance index.

TABLE III
Duncan's Test on Relationship of Bromate Response to Quality Parameters of Hard Red Spring Wheats Grown in 1987 at Two Locations in North Dakota[a]

Cultivar[b] and Bromate Requirement[c]	Location	Bread Without Bromate[d] Protein (14% mb)	Sugar[e] (%)	Loaf Volume (cm)	Grain and Texture	Symmetry[f]	Bread with 10 ppm Bromate[d] Loaf Volume (cm)	Grain and Texture	Symmetry[f]
Coteau (+)	Langdon	15.54 a	2.46 c	888 cd	7.5 c	9.0 b	1,025 a	10.0 a	10.0 a
Coteau (+)	Minot	15.42 a	2.72 a	855 d	9.0 ab	9.5 ab	915 b	10.0 a	9.5 ab
Tammy (+)	Langdon	14.63 c	2.99 b	975 a	9.0 ab	10.0 a	1,020 a	9.5 ab	10.0 a
Tammy (−)	Minot	13.61 e	3.76 a	910 bc	9.0 ab	10.0 a	830 c	8.5 cb	6.5 c
Len (−)	Langdon	14.81 b	3.12 b	945 ab	8.5 b	10.0 a	785 c	6.5 d	6.0 c
Len (−)	Minot	14.35 d	3.58 a	920 bc	10.0 a	10.0 a	770 c	8.0 c	7.0 bc
Flour (−)		14.24 b	3.49 a	925 a	9.2 a	10.0 a	795 b	7.7 b	6.5 b
Flour (+)		15.19 a	2.72 b	906 a	8.5 b	9.5 b	987 a	9.8 a	9.8 a

[a] Means with the same letter in columns within the same group are not significantly different at the 5% probability level.
[b] Each cultivar replicated twice.
[c] (+) indicates bromate required; (−) indicates no bromate required.
[d] Grain and texture and symmetry are expressed by a score from 1 to 10, with the high score more desirable.
[e] Extracted with 0.05M acetic acid and measured by the phenol-sulfuric acid method.
[f] Symmetry indicates the general shape of the loaf, with attention to "old" and "young" appearance.

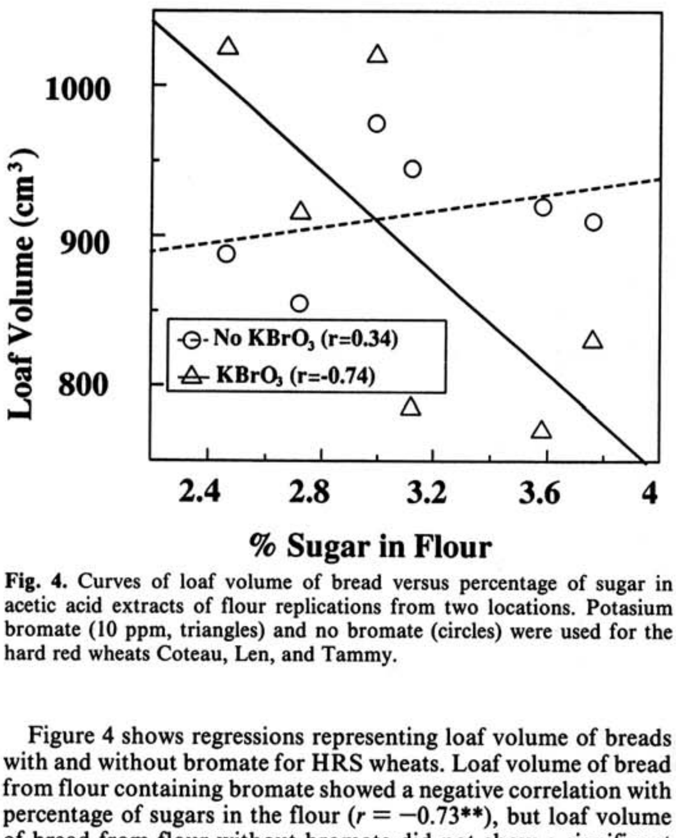

Fig. 4. Curves of loaf volume of bread versus percentage of sugar in acetic acid extracts of flour replications from two locations. Potasium bromate (10 ppm, triangles) and no bromate (circles) were used for the hard red wheats Coteau, Len, and Tammy.

Figure 4 shows regressions representing loaf volume of breads with and without bromate for HRS wheats. Loaf volume of bread from flour containing bromate showed a negative correlation with percentage of sugars in the flour ($r = -0.73$**), but loaf volume of bread from flour without bromate did not show a significant correlation with sugars.

The bread without bromate had a "young" appearance (low volume, sharp edges, tight grain, tough and rubbery crust), indicating underoxidized bread, when the level of sugar in the flour was less than 3% (e.g., the flour of Coteau). At higher sugar levels in the flour, the bread without bromate showed good characteristics (e.g., the flour of Len). Bread with 10 ppm of potassium bromate in the flour showed a positive bromate response at less than 3% sugar in flour (e.g., the flour of Coteau) and a negative bromate response (an "old" appearance—low volume, large holes, rough break and shred, coarse grain, and tough texture), indicating overoxidized bread, at more than 3% sugar (e.g., bread from Len). This overoxidation effect observed in bread from some flours may be due to a double contribution of sugars and bromate in the oxidation reaction in doughs.

The low levels of sugars, especially those at the region of retention time for rhamnose and xylose, and the negative correlation coefficient of xylose ($r = -0.65$**) with bromate response, from the data of Fig. 3, seem to indicate that xylose may play an important role in the oxidation reaction.

The coefficient of determination (r^2) from the regression analysis (Fig. 4) for loaf volume (with bromate) showed that sugar in flour can explain 54% of the variability of loaf volume (with bromate). The model with two independent variables (namely, protein and sugar in flour or percentage of xylose and sugar in flour) can explain 76 and 80% of the variability of loaf volume (with bromate), respectively.

Assuming that sugars affect the bromate response, then the data for sugars from the Osborne fractions (Table I) are in accord with earlier data indicating that gluten protein (Sullivan et al 1940), water solubles (Finney 1943), as well as gluten and water solubles (Baker et al 1942, Hoseney et al 1969, Marais and D'Appolonia, 1981) are responsible for oxidation response. The Osborne fractions (Table I) of the HRS wheat Coteau, which usually requires bromate for good loaf volume, showed low levels of sugars in the albumin, glutenin, and residue fractions—levels similar to sugar levels of SRW wheats (except Adder)—as compared to the levels of the other HRS wheats that normally do not require bromate.

Finney (1943) studied the water-soluble materials from HRS and HRW wheats at different breadmaking bromate levels and suggested that "poor quality" varieties required more bromate than good quality varieties. In addition, Patil et al (1976), showed that water-soluble pentosans and bromate had an additive effect on overoxidation and reduced loaf volume. The same kind of overoxidation behavior was observed in the present study when bromate was added to the flours (Len from both locations and Tammy from Minot) that contained sugars higher than 3%.

Testing the Model of Sugar Content vs Bromate Requirements with Respect to Rheological and Quality Characteristics

The extension of the bromate experiment to include a larger population of cultivars and locations was needed, to estimate the levels of sugar and to confirm the behavior of flour from different cultivars with respect to quality characteristics with and without bromate in the baking procedure.

Breadmaking quality data was obtained from the 1988 Hard Red Spring Wheat Variety Trial Report, Department of Cereal Science and Food Technology, North Dakota State University. Total sugar determination and statistical analysis were done on 70 HRS flours, that is, 10 HRS wheat cultivars grown at seven locations (Carrington, Williston, Minot, Dickinson, Fargo, Hettinger, and Langdon) in North Dakota.

As shown in Tables IV and V, the percentage of sugar and protein was higher than the values found for the six samples of the first experiment. It is also interesting to note that, compared to the material from 1987 used in this study, the 1988 crop contained a greater number of cultivars with bromate requirements at some locations in North Dakota, a result, perhaps, of the severe drought conditions of the 1988 growing season. However, the overall results were basically similar to those of the six samples discussed in the last section. The *t*-test (Table IV) indicated that flours with bromate requirements had higher protein, higher loaf volume, and lower sugar content than flours without bromate requirement, which is similar to the results of the first (Table III) experiment. Rheological characteristics were not significantly different between flours requiring bromate and those not requiring it, perhaps due to the low sensitivity of the *t*-test (used with no repetitions) compared with the analysis of variance using two repetitions (Duncan's test). However the trend of short mixing and low mixing tolerance index was found in both experiments.

Table V shows that 30% of the population required bromate. Locations such as Williston, Langdon, and Carrington were very susceptible to bromate requirements. In some locations such as Fargo and Minot, where bromate was not required, the level of sugar (3.82 and 3.88%, respectively) seemed to be higher than that in the majority of cultivars at locations requiring bromate, except Carrington.

The cultivars that required bromate from some locations also showed low levels of sugar compared to the cultivars that did not require bromate. Amidon, however, contained high sugar content only at the locations without bromate requirement, such as Fargo, Dickinson, and Minot. The level of sugar within the same location was usually lower in bromate-required than in no-bromate-required flours except for Carrington. Variations in sugar content were also observed among locations. The average sugar content in the bromate and non-bromate cultivars and locations selected in 1988 is also listed in Table V. Since some cultivars contained low sugar levels (Minnpro and Laura) or high sugar levels (Leif and Kenyon), even at different locations, and also since the variation of sugar seems to be related directly to oxidation need, it is possible that the biochemical components affecting bromate requirement are genetically controlled and are affected also by environmental factors.

Figure 5 shows the plot, similar to that of the earlier experiment (Fig. 4), of loaf volume of the 10 flours treated with 10 ppm potassium bromate. Data from the HRS Wheat Variety Trial Report, Department of Cereal Science and Food Technology, North Dakota State University, was available for only 36 samples (Fig. 5) baked both with and without bromate. The correlation coefficient of loaf volume with bromate vs percent of sugar in flour was −0.73**, similar to that of the earlier experiment.

TABLE IV
Means of the Quality Characteristics of Hard Red Spring Wheat Cultivars Grown at Different Locations in North Dakota in 1988

Quality Parameters	Samples: Requiring Bromate (n = 21)	Samples: Not Requiring Bromate (n = 49)	Standard Error	*t* Test[a]
Sugar in flour,[b] %	3.61	3.83	0.05	*
Protein (14% mb)	17.60	16.60	0.18	**
Absorption,[c] %	69.2	69.8	0.5	NS
Mixing time, min	2.4	2.5	0.1	NS
MTI,[d] BU	14.0	16.9	1.4	NS
Loaf volume, cm^3	964	996	13	NS
Loaf volume BR,[e] cm^3	1,042	903	22	**

[a] *, ** = Significant at less than 0.05 and 0.01 probability levels, respectively. NS = Not significant.
[b] Extracted with 0.05*M* acetic acid and measured by the phenol-sulfuric acid method.
[c] Farinograph absorption at 500 BU consistency.
[d] Mixing tolerance index.
[e] Loaf volume of bread baked with 10 ppm potassium bromate ($KBrO_3$).

CONCLUSION

The present investigation shows a possible relationship between the amount and kind of sugars in wheat flour and the requirements for oxidizing agents such as bromate. Although there are reports (Sullivan et al 1940, Baker et al 1942) of no involvement of sugars in the bromate response, our current data, obtained by using

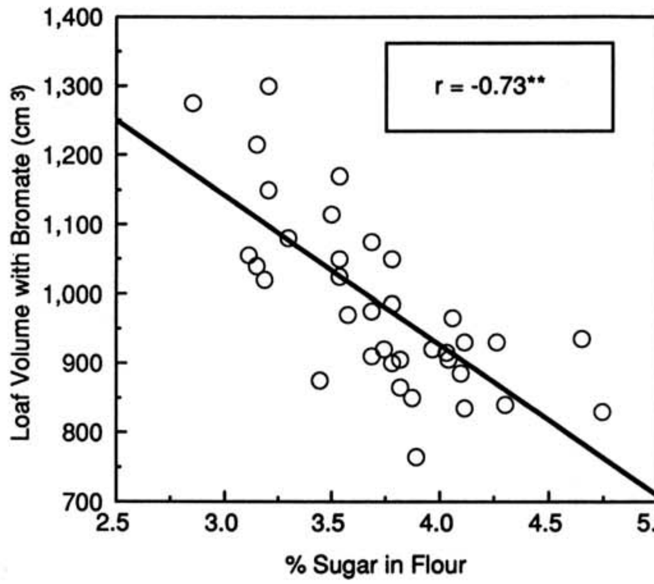

Fig. 5. Relationship between loaf volume baked with 10 ppm potassium bromate and percentage of sugar in acetic acid extracts of flours of hard red spring wheat cultivars grown at several locations in North Dakota in 1988.

TABLE V
Total Sugar (%) and Bromate Requirements in Hard Red Spring Wheat Flour of Several Cultivars Grown in North Dakota in 1988

Cultivar	Location: Williston	Hettinger	Fargo	Dickinson	Minot	Langdon	Carrington	Mean (+)[a]	Mean (−)[a]
Minnpro	2.85 (+)	3.21 (+)	3.39 (−)	3.30 (−)	3.30 (−)	3.21 (+)	3.54 (+)	3.20	3.33
Marshall	3.11 (+)	3.47 (−)	3.30 (−)	3.45 (−)	3.60 (−)	4.09 (−)	3.82 (+)	3.47	3.58
Butte	3.15 (+)	3.52 (−)	3.86 (−)	3.58 (−)	3.78 (−)	4.04 (+)	4.11 (+)	3.77	3.69
Columbus	3.54 (+)	3.47 (−)	3.82 (−)	3.78 (+)	3.91 (−)	4.11 (−)	3.69 (+)	3.67	3.83
Amidon	3.15 (+)	3.50 (+)	4.02 (−)	4.52 (−)	4.26 (−)	3.20 (+)	3.97 (+)	3.45	4.27
Celtic	3.69 (−)	3.78 (−)	3.78 (−)	3.80 (−)	3.87 (−)	3.89 (−)	3.45 (−)[b]	...	3.75
Laura	3.19 (−)	3.35 (−)	3.61 (−)	3.41 (−)	3.56 (−)	3.82 (−)	3.65 (−)	...	3.51
Kenyon	3.69 (+)	3.99 (−)	4.12 (−)	4.26 (−)	3.71 (−)	4.30 (−)	4.06 (+)	3.87	4.07
Len	3.54 (−)	4.04 (−)	4.28 (−)	4.12 (−)	4.41 (−)	4.65 (−)	3.58 (+)	3.58	4.17
Leif	3.79 (+)	3.61 (−)	4.12 (−)	3.82 (−)	4.39 (−)	4.75 (−)	4.30 (+)	4.04	4.14
Mean Br	3.32	3.35	...	3.78	...	3.66	3.87		
Mean No-Br	3.47	3.65	3.82	3.81	3.88	4.23	3.55		

[a] (+) indicates bromate requirements; (−) indicates no-bromate requirements.
[b] The quality of the bread (bread score) improved with bromate (Br), but the loaf volume decreased when bromate was used.

a different approach for extracting sugars, appears to be consistent with the majority of the research done in this area and therefore, may help to clarify some of the controversies.

ACKNOWLEDGMENTS

The technical assistance of T. Olson and G. Matthiensen in this study is appreciated. Also, thanks to Patrick L. Finney of the USDA-ARS Soft Wheat Laboratory, Wooster, OH, for the soft wheat samples.

LITERATURE CITED

ALI, M. R., and D'APPOLONIA, B. L. 1979. Einfluss von roggenpentosanen auf die teig- und broteigenschaften. Getreide Mehl Brot 33:334-339.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Method 46-11A, approved October 1976, revised September 1985; Method 54-21, approved April 1961, reviewed 1982. The Association: St Paul, MN.

BAKER, J. C., PARKER, H. K., and MIZE, M. D. 1942. The action of an oxidizing agent in bread dough made from patent flours. Cereal Chem. 19:334-346.

CHEN, C. H., and BUSHUK, W. 1970. Nature of proteins in triticale and its parental species. I. Solubility characteristics and amino acid composition of endosperm proteins. Can. J. Plant Sci. 50:9-14.

D'APPOLONIA, B. L., GILLES, K. A., and MEDCALF, D. G. 1970. Effect of water-soluble pentosans on gluten-starch loaves. Cereal Chem. 47:194-204.

DE STEFANIS, V. A., RANUM, P. M., and ERICKSON, R. W. 1988. The effect of metal ions on bromate oxidation during breadmaking. Cereal Chem. 65:257-261.

DUBOIS, M., GILLES, K. A., HAMILTON, J. K., REBERS, P. A., and FRED, S. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350-356.

FINNEY, K. F. 1943. Fractionating and reconstituting techniques as tools in wheat flour research. Cereal Chem. 20:381-396.

FITCHETT, C. S., and FRAZIER, P. J. 1986. Action of oxidants and other improvers. Pages 179-198 in: Chemistry and Physics of Baking: Materials, Processes and Products. J. M. V. Blanshard, P. J. Frazier, and T. Galliard, eds. R. Soc. Chem.: London.

HOSENEY, R. C., FINNEY, K. F., SHOGREN, M. D., and POMERANZ, Y. 1969. Functional (breadmaking) and biochemical properties of wheat components. III. Characterization of gluten protein fractions obtained by ultracentrifugation. Cereal Chem. 46:126-135.

HOSENEY, R. C., FINNEY, K. F., and SHOGREN, M. D. 1972. Functional (breadmaking) and biochemical properties of wheat flour components. X. Fractions involved in the bromate reactions. Cereal Chem. 49:372-378.

JOINER, R. R., VIDAL, F. D., and MARKS, H. C. 1963. A new powdered agent for flour maturing. Cereal Chem. 40:539-553.

JORGENSEN, H. 1936. On the existence of powerful but latent proteolytic enzymes in wheat flour. Cereal Chem. 13:346-355.

KAMMAN, P. W. 1984. Oxidation. The do's and don'ts. Baker's Dig. 58:18-20.

KOHMAN, H. A., HOFFMAN, C., GODFREY, T. M., ASHE, L. H., and BLAKE, A. E. 1916. On the use of yeast nutrients in bread-making. J. Ind. Eng. Chem. 8:781-789.

MARAIS, G. G., and D'APPOLONIA, B. L. 1981. Factors contributing to baking quality differences in hard red spring wheat. I. Bases for different loaf volume potentials. Cereal Chem. 50:444-447.

McGINNIS, G. D. 1982. Preparation of aldononitrile acetates using *N*-methylimidazole as catalyst and solvent. Carbohydr. Res. 108:284-292.

McMASTER, G. J., and BUSHUK, W. 1983. Protein-carbohydrate complexes in gluten: Fractionation and proximate composition. J. Cereal Sci. 1:171-184.

PATIL, S. K., FINNEY, K. F., SHOGREN, M. D., and TSEN, C. C. 1976. Water-soluble pentosans of wheat flour. III. Effect of water-soluble pentosans on loaf volume of reconstituted gluten and starch doughs. Cereal Chem. 53:347-354.

READ, J. W., and HAAS, L. E. 1937. Studies on the baking quality of flour as affected by certain enzymes actions. IV. Potassium bromate and enzyme activity. Cereal Chem. 14:752-766.

SULLIVAN, B., HOWE, M., SCHMALZ, F. D., and ASTLEFORD, G. R. 1940. The action of oxidizing and reducing agents on flour. Cereal Chem. 5:507-528.

THEWLIS, B. H. 1974. The fate of potassium bromate when used as a breadmaking improver. J. Sci. Food Agric. 25:1471-1475.

[Received January 22, 1990. Accepted January 2, 1991.]