# Factors Influencing Yeast Fermentation and the Effect of LMW Sugars and Yeast Fermentation on Hearth Bread Quality

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## ABSTRACT

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The purpose of this study was to investigate how wheat cultivar, growth location, type of mill, LMW sugar composition of wheat flours, mixing time, and type of mixer affected yeast fermentation. Also studied was the effect of yeast fermentation and LMW sugar composition on hearth bread quality. To achieve this, 36 different flours were produced from two different mills using six different wheat cultivars grown at three locations. Yeast fermentation in doughs, measured as gas production, was determined using realtime pressure measurements and GasSmart software. A short mixograph mixing or spatula mixing was not efficient enough to rehydrate instant dry yeast. Compressed yeast and a short mixing time were enough to reach maximum fermentation rate. Maximum pressure after 210 min of fermentation was higher for instant dry yeast than for compressed yeast. Wheat cultivar and growth location had a significant effect on LMW sugar composition. Wheat cultivar, growth location, and type of mill used significantly affected pressure curve parameters. Oligosaccharides and damaged starch were positively correlated, and ash content and flour yield were negatively correlated with pressure curve parameters. Hearth bread characteristic crumb structure was positively correlated with all pressure curve characteristics except fast fermentation rate. Increased levels of mono- and disaccharides in wheat flour gave hearth breads with a more round shape.

The characteristic structure and volume of yeast-fermented products depend on the production of carbon dioxide by the yeast (Eliasson and Larson 1993). A desirable loaf volume is achieved only if the dough provides a favorable environment for yeast growth and gas generation and, at the same time, possesses a gluten matrix capable of maximum gas retention. The latter attribute is most conveniently determined by measuring the volume increase of fermenting dough, whereas gas production can be estimated by any of several available procedures such as the oven rise recorder method (Brabender OHG, Duisburg, Germany), alveograph method (Approved Method 54-30, AACC 2000), and pressure meter methods.

AACC Approved Methods describe a pressure meter method (Approved Method 22-11) and a volumetric method (Approved Method 22-14) for measuring the gas production that is an index of diastatic activity. The former employs the pressure meter described by Sandstedt and Blish (1934) and Malloch (1939) in which the pressure produced in a fermentation vessel is measured by a mercury manometer and by a pressure gauge, respectively. The yeast fermentation was monitored for 5 hr. In the volumetric method first described by Bailey and Johnson (1924) and then modified by Bailey (1939), inversely calibrated burettes were used. In each case, a constant temperature water bath maintained at 30°C (86°F) provides the necessary temperature control. Recently, gas pressure measurement was also approved as a new yeast activity method (Approved Method 89-11). The pressure meter (National Manufacturing Co., Lincoln, NE) is listed as an approved device in this method. Gas pressure is measured for 90 min.

Wheat flour contains monosaccharides (glucose, fructose, and galactose), disaccharides (sucrose and maltose), trisaccharides (glucofructose and raffinose), and oligosaccarides (glucofructans) (Lineback and Rasper 1988). Monosaccarides, disaccharides, trisaccharides, and oligosaccarides in flour are called low molecular weight (LMW) sugars.

The ability of baker's yeast to ferment dough is related to the amount of LMW sugars in the flour (Oura et al 1982). The LMW sugars of greatest importance are sucrose and maltose followed by glucose, fructose, and glucofructans (Magoffin and Hoseney 1974). Because of the potent invertase of yeast, sucrose is converted almost immediately to glucose and fructose. Yeast ferments glucose at a slightly faster rate than it does fructose (Magoffin and Hoseney 1974). If maltose is the only sugar, the rate of gas production drops appreciably after indigenous fructose and glucofructan are exhausted until yeast enzymes adapt to maltose. The fermentation of yeast in bread dough leads to the expansion of the bubbles, which were occluded to the dough during mixing. This creates the open crumb structure of baked products. Therefore, the measurement of yeast activity and content of LMW sugars can be an important factor in the manufacture of consistent products.

In the present study, the mechanical gauge of the pressure meter has been replaced by an electronic sensor (Shelton and Vida 1994) that permits realtime measurement of gas pressure increases generated by a fermenting dough made of flour, water, and yeast. The pressure sensor is a silicon strain gauge with an operating range of 0–30 lb per square inch (PSI). The aim of this study was to investigate how wheat cultivar, growth location, type of mill, LMW sugar composition of wheat flours, mixing time, and type of mixer affected yeast fermentation.

Also studied was the effect of yeast fermentation and LMW sugar composition on hearth bread quality. To test this, 36 different flours were produced from two different mills using six different hard red winter wheat cultivars grown at three locations. Yeast fermentation in doughs was determined using realtime pressure measurements and GasSmart software. A small-scale laboratory method was used to produce hearth bread.

## MATERIALS AND METHODS

### Wheat Samples

The wheat sample set used consisted of six hard red winter wheat genotypes (Abilene, Arapahoe, Cimarron, Karl, Scout 66, TAM 107) that were harvested in 1995 from single replicate trials at North Platte (NE), Hays (KS), and Hemingford (NE).

### Milling of Wheat Samples

Moisture content was determined by AACC Approved Method 44-15A. Two different mills were used.

*Mill 1.* Each wheat sample was conditioned 20–24 hr to 15.2% moisture content. If the moisture content was <11%, the wheat

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sample was conditioned in two steps: 1, <11–12.5% and 2, 12.5–15.2%, total time 40–48 hr. Samples (2,000 g) were milled individually on a laboratory flour mill (Buhler Brothers, Uzwill, Switzerland). Flour collected from the break rolls and the reduction rolls was used in this study.

*Mill 2.* Each wheat sample was conditioned using a two-step process. In the first tempering stage, wheat moisture was raised to 14.5%, followed by a second tempering stage, which raised the moisture content to 15.5%; total time 40–48 hr. Samples (100 lb, 45.3 kg) were milled individually on a Miag pilot mill (Buhler Brothers) as described by Shuey and Gilles (1969).

Of the nine millstreams obtained, composites 1, 2, 3, 4, and 5 were blended as the straight-grade flour and used in this study. Flour yields were calculated from scale weights and expressed as percentage of total products recovered from the mills.

## Flour Composition Analysis

Flour ash content was determined by the muffle furnace method (Approved Method 08-01, AACC 2000) using an ash determinator (TGA-601 Thermo Gravimetric, Leco, St. Joseph, MI). Flour protein was analyzed with the Kjeldahl nitrogen procedure (Approved Method 46-10, AACC 2000) using a nitrogen conversion factor of 5.7. Results were expressed on a 14% moisture basis.

## Flour Quality Evaluation

Falling Number (FN) was determined (model 1800, Falling Number AB, Huddinge, Sweden) as described by Approved Method 56-81B (AACC 2000). Flour (7 g) was analyzed in duplicate and FN value measured in seconds was reported on a 14% moisture basis.

Flour mixing properties were examined using a 10-g mixograph (National Mfg. Co., Lincoln, NE) as described by Approved Method 54-40 (AACC 2000). Mixograph water absorption was calculated using flour moisture content and protein content as described by the manufacturer (Mixograph Instruction Manual, National Mfg. Co., Lincoln, NE). The mixograms were evaluated manually, and parameter peak time was used in quality evaluations. Mixograph analyses were conducted in duplicate and expressed on a 14% moisture basis.

The level of damaged starch of the flours was determined using a starch damage assay kit (Megazyme, Bray, Co., Wicklow, Ireland.)

## Yeast

Two types of commercial yeast were used, Fermipan Red instant dry yeast, moisture content 4.0%, w/w, obtained from American Yeast Sales (Derry, NH) and compressed yeast, moisture content 69.2%, w/w, obtained from Red Star Yeast & Products, Universal Foods Corp. (Milwaukee, WI).

## Measurement of Gas Production

Pressure analyses were conducted using Approved Method 22-11 (AACC 2000). Doughs were prepared by adding 10 g of flour (weighed on 14% moisture basis), water, and instant dry yeast (0.15 g) or compressed yeast (0.45 g). The amount of water added or hydration level was obtained from the mixograph analyses. Dough was mixed to optimum development time (peak time), if not otherwise indicated, in the 10-g mixograph bowl using the mixograph mixer. Mixing was performed at room temperature (24°C).

The dough was weighed on a balance and placed in a pressure vessel (Gasbomb, National Mfg Co., Lincoln, NE) that previously has been warmed to 30°C. The pressure vessel was sealed and placed in a water bath at 30°C. After allowing the pressure vessel to equilibrate for 5 min, the pressure inside was adjusted to zero. Pressure measurements (12 measurements/min) were collected for 300 min using the GasSmart software written by Alan E. Walker (AEW Consulting, Lincoln, NE). The different measurements obtained using the GasSmart software are summarized in Fig. 1. The parameters calculated were fast fermentation rate (PSI/hr), end of fast fermentation (hr), end of fast fermentation (PSI), pressure after 3.5 hr of fermentation (PSI), and the slow fermentation rate (PSI/hr). All the results from the pressure measurements were expressed on a 10-g dough basis. The pressure measurements were performed in duplicate or triplicate.

## LMW Sugar Extraction

Aliquots of flour (5 g) were suspended in 100 mL of boiling 80% (v/v) aqueous ethanol and maintained at 80°C for 30 min to inactivate enzymes and extract sugars (Mercier and Tollier 1984). After centrifugation (15,000 × *g*, 30 min), the supernatant was evaporated to dryness at 80°C. The dry extract was dissolved in water (25 mL) and filtered on a Whatman membrane filter (0.45 µm). A filtrate portion was used for the quantitative separation and determination of sugars by high-performance liquid chromatography (HPLC)

## LMW Sugar Determination

Carbohydrate analysis was performed using a carbohydrate Pb column, 7.8 × 300 mm (Chrompack, Middelburg, The Nether-

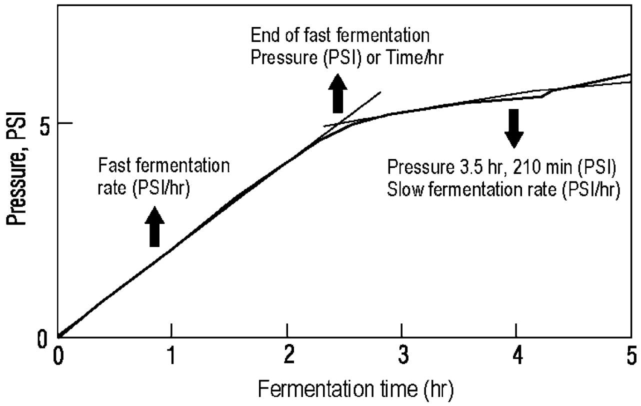

**Fig. 1.** Effect of mixing time on fermentation rate. Pressure measurements (12 measurements/min) were collected for 5 hr (300 min) using GasSmart software. Measurements included fast fermentation rate (PSI/hr 10-g dough), end of fast fermentation time (hr/10-g dough), end of fast fermentation pressure (PSI/10-g dough), pressure 3.5 hr, 210 min of fermentation (PSI/10-g dough), and the slow fermentation rate (PSI/hr 10-g dough) were automatically calculated.

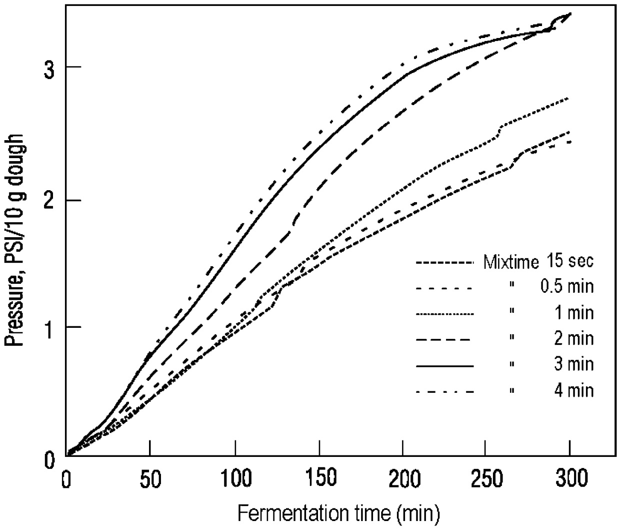

**Fig. 2.** Effect of mixing time on yeast fermentation rate. Effect of using instant dry yeast (0.15 g) without rehydration and using spatula mixing (15 sec, and 0.5, 1.0, 2, 3, and 4 min).

lands), an HP1100 (Hewelett Packard, Amsterdam, The Netherlands) liquid chromatograph equipped with a refractive index detector (Gilson Medical Electronics, Middleton, WI). The sugar content of each sugar was determined using HP Chemstation software (Hewlett Packard, Amsterdam, The Netherlands).

The elution was performed at 70°C and the mobile phase was degassed HPLC-grade water at a flow rate 0.4 mL/min. The sample was injected with a 20-µL sample loop. The concentrations of carbohydrate standards were 0.5–1.5 mg/mL.

### Experimental Baking

The experimental baking was a small-scale baking test using the 50-g farinograph bowl operated at 126 rpm. The baking procedure and measurements of the bread characteristics were as described by Færgestad et al (2000) and Sahlstrøm et al (2003). Only flour produced with the Miag pilot mill was used in the baking trials.

The baking formula consisted of 100% wheat flour (14% moisture basis), 3.3% shortening, 1.3% salt, 1.1% dry yeast (Fermipan Red). The water addition was based on a farinograph test (ISO Method 5530-1). After mixing, the dough was rested in a cabinet for 20 min, scaled to pieces 35 ± 0.5 g, rounded and molded, proofed for 50 min in a proofing cabinet (37°C, 70% rh), and baked at 220°C for 12 min in a rotating oven equipped with a fan. The experimental baking was performed twice.

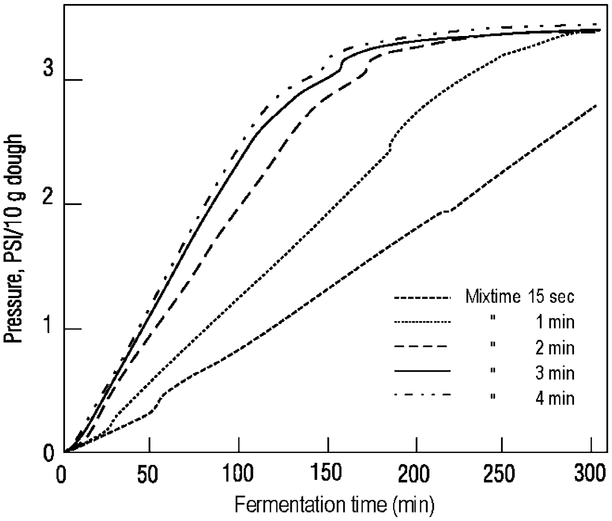

**Fig. 3.** Effect of mixing time on yeast fermentation rate. Effect of using instant dry yeast (0.15 g) without rehydration and using mixograph mixing (15 sec, and 1.0, 2.0, 3.0, and 4.0 min).

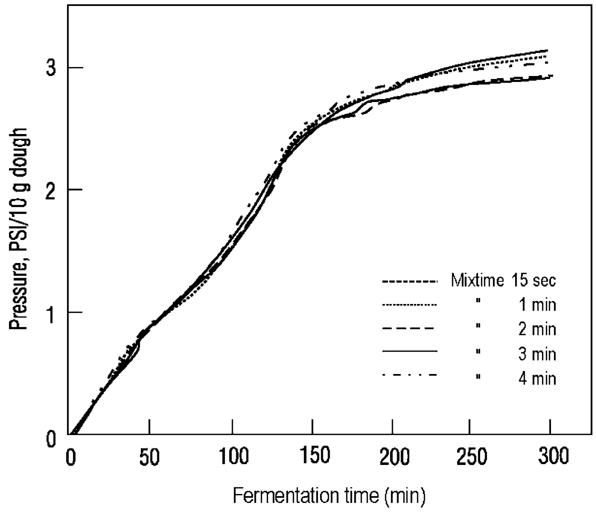

**Fig. 4.** Effect of mixing time on yeast fermentation rate. Effect of using compressed yeast (0.45 g) and using mixograph mixing (15 sec, and 1.0, 2.0, 3.0, and 4.0 min).

After cooling to room temperature for 2 hr, the loaves were weighed, and loaf volumes were measured by rapeseed displacement (Approved Method 10-10B). The height and width were determined (height = maximum height of the loaf lying down, width = maximum height of the loaf lying on the side) and the form ratio was calculated (height/width). Bread score was evaluated subjectively by a skilled baker using a bread score scale (1 = poor, 4 = very good). In addition, loaf grain was scored using a crumb score scale (1 = very open pore structure, 8 = very dense pore structure) according to the pore table of Dallmann (1981).

### Statistical Analyses

The analyses of flour quality characteristics and measurements of gas production were conducted in duplicate or triplicate. Analysis of LMW sugar contents were made in duplicate using duplicate sugar extractions. The experimental baking was performed twice. The average results were used for analysis of variance (ANOVA), using the general linear model (GLM) procedure of the SAS program (SAS Institute, Cary, NC) to determine the contributions of wheat genotype or cultivar, growing location, and type of mill. Where the ANOVA rejected the hypothesis, the cultivars or the locations, were equal. Tukey's test was used to determine which levels of these effects were significantly different. For obvious reasons, no multiple comparison tests were used on the mill effect. Pearson's correlation analysis examined relationships between LMW sugar content, pressure vessel parameters, and hearth bread characteristics.

## RESULTS AND DISCUSSION

### Effect of Mixing on Gas Production

As shown in Fig. 1, two steps could be observed during yeast fermentation: fast fermentation rate and slow fermentation rate. Total volume of gas production after 3 hr using the Chopin rheofermentometer (Potus et al 1994) or mmHg pressure after 5 hr of fermentation (Approved Method 22-11) does not describe the kinetics of the entire fermentation process and does not give access to the dynamics of yeast fermentation. Therefore, maximum gas pressure after 3.5 hr was only one characteristic providing information about the physiological reactions of yeast. Several other characteristics of the pressure curve were assessed for the ability to describe the effect of wheat cultivar, growth location, type of mill, type of mixer, yeast type, and LMW sugar composition of wheat flours on yeast fermentation (Fig. 1).

In the mixing time experiments presented in Figs. 1–4, wheat flour from cultivar Abeline grown at North Platte and milled on a Buhler mill was used. Approved Method 22-11 recommended using a spatula to mix flour, water, and yeast in suspension to a dough. The effect of using instant dry yeast without rehydration and mixing with a spatula is shown in Fig. 2. The fast fermentation rate increased from 0.53 PSI/hr for doughs mixed for 15 sec to 1.02 PSI/hr for doughs mixed for 4 min.

The three shortest mixing times used (15 sec, 0.5 min, and 1 min) have almost the same fast fermentation rate (0.53, 0.58, and 0.57 PSI/hr, respectively) on a 10-g dough basis. After mixing with a spatula for 4 min, the fast fermentation rate was 67% of the fast fermentation rate obtained using a mixograph (Figs. 2 and 3). Using the mixograph, the fast fermentation rate (10-g dough basis) increased from 0.59 PSI/hr for 15 sec of mixing to 1.55 PSI/hr for 4.0 min of mixing (Fig. 3). Mixing for more than 4.0 min with a spatula and mixing to peak time with a mixograph did not improve the fermentation rate (Figs. 2 and 3). The pressure curve obtained for 4.0 min of spatula mixing was similar to the pressure curve for 1.0 min of mixograph mixing. Increased mixing time with the mixograph produced a pressure curve with two different fermentation steps as described above. This indicates that mixograph mixing was much more efficient in rehydrating instant dry yeast than was spatula mixing. Mixing with a spatula for 2, 3, and 4 min, a maximum pressure level was reached that was comparable to the maximum pressure level obtained with 1, 2, 3, and 4 min of mixograph mixing (Figs. 2 and 3).

### Effect of Yeast Type on Gas Production

The instant dry yeast used in this study contains 4%, w/w, moisture and the dry yeast can be rehydrated during dough mixing or in water before mixing. When instant dry yeast was added without rehydration, the yeast rehydration process or the time to reach full fermentation rate was similar to mixograph development time (3 min) or peak time for the flour (Fig. 3). Increasing mix time to 4 min or overmixing the dough did not improve the fermentation rate. The compressed yeast used in this study had a dry matter content of 30.9%, w/w, which means that the yeast was fully rehydrated. Using a short mixing time was enough to reach maximum fermentation rate; mixing to peak time did not improve the fermentation rate (Fig. 4). Instant dry yeast that was rehydrated before mixing followed the same pattern as compressed yeast; maximum fermentation rate was reached after a short mixing time of 0.5 min (data not shown). Maximum pressure after 210 min of gas production was higher for instant dry yeast than for compressed yeast (3.35 and 2.86 PSI, respectively). The manufacturer of the instant dry yeast used in this study had selected a special strain of *Saccharomyces cerevisiae* with considerably higher fermentation activity than traditional yeast.

### Quantitative Analysis of LMW Sugars in Flours

The means, standard deviation (SD), and ranges of mono- and disaccharide content among the 36 different wheat flours tested were in decreasing order: sucrose mean 2.16 mg/g of flour (SD 0.56, range 1.45–3.30); fructose mean 0.91 mg/g of flour (SD 0.13, range 0.60–1.25); maltose mean 0.53 mg/g of flour (SD 0.09, range 0.34–0.74); glucose mean 0.45 mg/g of flour (SD 0.09, range 0.31–0.66). The total amount of mono- and disaccharides in flour varied between 2.80 mg/g of flour and 5.63 mg/g of flour with a mean of 4.04 mg/g of flour. These values are in agreement with those reported by others (D'Appolonia and MacArthur 1975; Potus et al 1994; Bach Knutsen 1997; Fernandes-Artigas et al 2001) but the order was different. In our study, we used hard red winter wheat cultivars as opposed to Potus et al (1994), who

**TABLE I**
**Effect of Wheat Cultivar on Flour Quality Characteristics, LMW Sugar Content, and Gas Bomb Parameters[a]**

| | Wheat Cultivar | | | | | |
|---|---|---|---|---|---|---|
| | **Abilene** | **Arapahoe** | **Cimarron** | **Karl** | **Scout 66** | **Tam107** |
| Protein content (%)[b] | 11.18c | 10.73e | 10.88d | 12.07a | 11.88b | 11.27c |
| Ash content (%)[b] | 0.39c | 0.41b | 0.42a | 0.37e | 0.38d | 0.37f |
| Sucrose (mg/g of flour) | 1.88d | 2.15bc | 2.22b | 2.46a | 2.18b | 2.02cd |
| Maltose (mg/g of flour) | 0.46c | 0.48c | 0.63a | 0.59ab | 0.57b | 0.44c |
| Glucose (mg/g of flour) | 0.40b | 0.44b | 0.50a | 0.50a | 0.44b | 0.42b |
| Fructose (mg/g of flour) | 0.86b | 0.88b | 1.04a | 1.02a | 0.87b | 0.79c |
| Total amount of sugar (mg/g of flour) | 3.61c | 3.94b | 4.39a | 4.57a | 4.07b | 3.67c |
| Oligosaccarides (mg/g of flour) | 4.89b | 3.62d | 6.01a | 3.39de | 3.28e | 4.63c |
| Mixograph absorption (%) | 60.7b | 58.5c | 60.3b | 62.7a | 62.3a | 61.5ab |
| Mixograph peak time (min) | 3.77bc | 4.27ab | 4.32ab | 4.53a | 3.40c | 3.33c |
| Falling number (sec) | 455.3bc | 509.3a | 430.0c | 435.7bc | 460.3bc | 470.5b |
| Flour yield (%) | 71.8bc | 72.5a–c | 71.6c | 73.0ab | 73.4a | 71.3c |
| Fast fermentation rate (PSI/hr) | 1.66a | 1.54b | 1.65a | 1.52b | 1.55b | 1.64a |
| End of fast fermentaion (hr) | 1.31b | 1.37b | 1.51a | 1.49a | 1.39b | 1.49a |
| End of fast fermentaion (PSI) | 2.76d | 2.80d | 3.34a | 2.91c | 2.71d | 3.06b |
| Pressure after 3.5 hr (PSI) | 3.16c | 3.19c | 3.69a | 3.22c | 3.15c | 3.51b |
| Slow fermentation rate (PSI/hr) | 0.10bc | 0.10b | 0.14a | 0.08c | 0.14a | 0.14ab |
| Damaged starch (%) | 4.66d | 4.80cd | 5.29a | 5.06b | 4.91c | 5.43a |

[a] Values in the same row followed by different letters are significantly different ($P < 0.05$).
[b] 14% moisture basis.

**TABLE II**
**Effect of Growth Location on Flour Quality Characteristics, LMW Sugar Content, and Gas Bomb Parameters[a]**

| | **North Platte, NE** | **Hays, KA** | **Hemingford, NE** |
|---|---|---|---|
| Protein content (%)[b] | 11.23c | 11.47a | 11.30b |
| Ash content (%)[b] | 0.39b | 0.41a | 0.37c |
| Sucrose (mg/g of flour) | 2.86a | 1.69c | 1.91b |
| Maltose (mg/g of flour) | 0.57a | 0.52b | 0.50b |
| Glucose (mg/g of flour) | 0.56a | 0.38c | 0.42b |
| Fructose (mg/g of flour) | 0.99a | 0.80c | 0.94b |
| Total amount of sugar (mg/g of flour) | 4.98a | 3.39c | 3.76b |
| Oligosaccarides (mg/g of flour) | 2.74c | 3.97b | 6.19a |
| Mixograph absorption (%) | 60.3b | 61.1ab | 61.6a |
| Mixograph peak time (min) | 4.30a | 4.01a | 3.50b |
| Falling number (sec) | 448.9b | 476.7a | 455.0b |
| Flour yield (%) | 72.4a | 72.9a | 71.5b |
| Fast fermentation rate (PSI/hr) | 1.57b | 1.57b | 1.65a |
| End of fast fermentation (hr) | 1.30b | 1.30b | 1.68a |
| End of fast fermentation (PSI) | 2.65c | 2.72b | 3.43a |
| Pressure after 3.5 hr (PSI) | 3.00c | 3.09b | 3.87a |
| Slow fermentation rate (PSI/hr) | 0.09b | 0.09b | 0.17a |
| Damaged starch (%) | 5.15b | 4.52c | 5.40a |

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).
[b] 14% moisture basis.

analyzed a French patent white flour and flours milled from two French wheat cultivars (Sossions and Recital). D'Appolonia and MacArthur (1975) analyzed sugar content in flours from eight hard red spring wheat cultivars. Bach Knudsen (1997) and Fernandez-Artigas et al (2001) analyzed commercial wheat flours from Europe.

Also extracted with 80% ethanol were trisaccharides (glucodifructose and raffinose) and other oligosaccharides (glucofructans) (Lineback and Rasper 1988). The amount of these oligosaccharides was determined as 1.78–8.55 mg/g of flour with a mean of 4.3 mg/g of flour. Results presented by Lineback and Rasper (1988) showed that the content of trisaccharides and oligosaccharides in the wheat kernel was 9.4–11.4 mg/g for glucofructans, 1.9–6.8 mg/g for raffinose, and 2.6–4.1 mg/g for glucodifructose. Wheat flour analyzed by Bach Knutsen (1997) contained 3 mg/g for raffinose and 3 mg/g for stachyose.

The means, standard deviation, and ranges of pressure curve characteristics among the 36 different wheat flours (10-g dough basis) tested were fast fermentation rate (mean 1.58 PSI/hr, SD 0.12, range 1.06–1.76); end of fast fermentation time (mean 1.42 hr, SD 0.22, range 1.11–1.98); end of fast fermentation pressure (mean 2.93 PSI, SD 0.47, range 2.24–4.02); pressure after 3.5 hr (mean 3.31 PSI, SD 0.50, range 2.42–4.35); and slow fermentation rate (mean 0.11 PSI/hr, SD 0.05, range 0.05–0.27).

### Effect of Wheat Cultivar, Growth Location, and Type of Mill on LMW Sugar Composition

The differences in LMW sugars among the six wheat cultivars were significant (Table I). Flour from wheat cultivars Karl and Cimarron had the highest levels of mono- and disaccharides and TAM 107 had the lowest. Also, flour from wheat cultivar Cimarron had the highest content of oligosaccharides (trisaccharides and oligosaccharides). Flour from wheat cultivar Scout 66 had the lowest level of oligosaccharides.

Wheat flours produced from wheat grown at different locations also showed a significant difference in LMW sugars (Table II). Wheat flour produced from wheat grown at North Platte, NE, and Hays, KA, had the highest and lowest content of LMW sugars, respectively. Contradictory results were found for wheat flour from Hemingford, NE, which contained the highest levels of oligosaccharides.

In this study, flours were produced using two different mills, a laboratory Buhler mill and a Miag pilot mill. Flour produced with the Miag pilot mill contained significantly higher levels of oligosaccharides (Table III)

### Effect of Wheat Cultivar, Growth Location, and Type of Mill on Gas Production

The differences in pressure curve characteristics among flours from the six wheat cultivars were significant (Table I). Flour from wheat cultivar Cimarron had the highest values for fast fermentation rate, end of fast fermentation time, end of fast fermentation pressure, pressure after 3.5 hr, and slow fermentation rate. Flour from wheat cultivar Karl had the lowest values for fast fermentation rate and slow fermentation rate. Flour from wheat cultivar Scout 66 had the lowest pressure at end of fast fermentation and pressure after 3.5 hr. Flour from wheat cultivar Abilene had the lowest value for end of fast fermentation time.

There was a significant difference in pressure curve characteristics among wheat flours produced from wheat grown at different locations (Table II). Wheat flour produced from wheat grown at Hemingford, NE, and North Platte, NE, had the highest and lowest pressure curve characteristics, respectively.

**TABLE III**
**Effect of Type of Mill on Flour Quality Characteristics, LMW Sugar Content, and Gas Bomb Parameters**

| | Buhler Mill, Lincoln, NE | Pilot Mill, Miag, Fargo, ND | *P* Value[a] |
|---|---|---|---|
| Protein content (%)[b] | 11.53 | 11.14 | <0.0001 |
| Ash content (%)[b] | 0.38 | 0.40 | <0.0001 |
| Sucrose (mg/g of flour) | 2.15 | 2.16 | 0.638 |
| Maltose (mg/g of flour) | 0.52 | 0.54 | 0.1850 |
| Glucose (mg/g of flour) | 0.45 | 0.45 | 0.5054 |
| Fructose (mg/g of flour) | 0.90 | 0.91 | 0.4892 |
| Total amount of sugar (mg/g of flour) | 4.02 | 4.06 | 0.3883 |
| Oligosaccarides (mg/g of flour) | 4.22 | 4.39 | 0.001 |
| Mixograph absorption (%)[b] | 61.2 | 60.8 | 0.001 |
| Mixograph peak time (min) | 3.97 | 3.89 | 0.2432 |
| Falling number (sec) | 459.7 | 460.1 | 0.8613 |
| Flour yield (%) | 72.5 | 72.0 | 0.001 |
| Fast fermentation rate (PSI/hr) | 1.62 | 1.57 | <0.0001 |
| End of fast fermentation (hr) | 1.51 | 1.34 | <0.0001 |
| End of fast fermentation (PSI) | 3.10 | 2.76 | <0.0001 |
| Pressure after 3.5 hr (PSI) | 3.50 | 3.15 | 0.0882 |
| Slow fermentation rate (PSI/hr) | 0.12 | 0.11 | 0.3525 |
| Damaged starch (%) | 5.49 | 4.56 | <0.0001 |

[a] *P* value <0.05 indicates a significant difference between mills.
[b] 14% moisture basis.

**TABLE IV**
**Effect of Wheat Cultivar on Bread Quality Characteristics[a]**

| | Wheat Cultivar | | | | | |
|---|---|---|---|---|---|---|
| | Abilene | Arapahoe | Cimarron | Karl | Scout 66 | Tam107 |
| Bread volume (mL) | 121.9a | 105.5c | 112.3b | 120.8a | 113.4b | 113.6b |
| Weight (g) | 30.2bc | 30.3ab | 30.4a | 30.3ab | 30.1c | 30.1bc |
| Height (mm) | 42.0b | 39.3d | 45.2a | 44.5a | 38.9d | 40.9c |
| Width (mm) | 71.6ab | 70.0c | 68.8d | 71.1b | 72.1a | 70.9bc |
| Bread score | 3.21bc | 3.01cd | 3.38ab | 3.48a | 2.90d | 3.04cd |
| Crumb score | 7.96a | 7.93ab | 7.96a | 8.00a | 7.83bc | 7.80c |
| Specific volume (mL/g) | 4.03a | 3.47c | 3.68bc | 3.98a | 3.77b | 3.76b |
| Form ratio | 0.58c | 0.56d | 0.65a | 0.62b | 0.53e | 0.57cd |

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

A significant effect of type of mill used was observed for pressure curve characteristics fast fermentation rate, end of fast fermentation time, and end of fast fermentation pressure (Table III). All flours produced using the Buhler mill had significantly higher pressure curve values.

### Effect of Wheat Cultivar and Growth Location on Hearth Bread Characteristics

Only flours produced with the Miag mill were used in the baking test. The differences in bread characteristics among the six wheat cultivar flours were significant (Table IV). Flour from wheat cultivars Karl and Abilene gave the highest loaf volume and Arapahoe gave the lowest. Only small differences in loaf weight were observed, however significant and highest loaf weight was obtained using flour from Cimarron. Hearth bread produced from Cimarron wheat flour had the roundest shape (a high form ratio value). A skilled baker gave hearth bread produced from wheat cultivar Karl the highest bread score and crumb score. Flour from wheat cultivar Scout 66 produced breads with a low value for bread score, form ratio, crumb score, and height.

There were significant differences in hearth bread characteristics among wheat flours produced from wheat grown at different locations (Table V). Wheat flour grown at North Platte, NE, had high volume, height, bread score, crumb score, and form ratio values.

### Statistical Relationships

*Pressure vessel parameters affected by LMW sugar content, ash content, flour yield, and damaged starch.* The amount of oligosaccarides and damaged starch was positively correlated to pressure curve values for fast fermentation rate, end of fast fermentation, pressure after 3.5 hr, and slow fermentation rate (Table VI).

The sugars of greatest importance in breadmaking are the disaccharides (sucrose and maltose) and the monosaccharides (glucose, fructose, and glucofructans) (Magoffin and Hoseney 1974). Because of yeast's potent invertase enzyme, sucrose is converted almost immediately to glucose and fructose. Yeast ferments glucose at a slightly faster rate than it does fructose (Magoffin and Hoseney 1974). Yeast enzymes, constitutive for glucose and fructose, must adapt if maltose is to be fermented. If maltose is the only sugar, the rate of gas production drops appreciably after indigenous fructose and glucofructans are exhausted, until yeast enzymes adapt to maltose. The oligosaccaride fraction contains trisaccharides, (glucodifructose and raffinose) and oligosaccharides (glucofructans) (Lineback and Rasper 1988). Increased amounts of these sugars increased the yeast fermentation rate measured by the pressure vessel parameters. No correlation was obtained between mono- and disaccharides and pressure vessel parameters.

The enzyme β-amylase is an exoenzyme (which is abundant in flour) that hydrolyzes available glucose chains (oligosaccarides) or damaged starch to maltose (Lineback and Rasper 1988). Increased amounts of damaged starch will therefore be positive for yeast fermentation. However, high levels of damaged starch will be diametrical to bread quality. The endoenzyme α-amylase facilitates the break down of hydrated starch granules to shorter chained, unbranched molecules known as dextrins. This action creates β-amylase to convert starch to maltose (Hoseney 1998). Wheat flour usually contains sufficient β-amylase, but levels of α-amylase will vary and, in many cases, may be so low that the starch-to-maltose conversion is limited. A low FN is an indication of α-amylase activity in flour, and none of the flours used had a low FN (Table I).

Ash content and flour yield were significantly correlated with pressure curve characteristics (Table VI). The ash content was negatively correlated to pressure curve measurements for end of fast fermentation, pressure after 3.5 hr, and slow fermentation rate. Wheat flour that contains more bran has a higher ash content. Bran contains bacteria, different types of enzymes, and a greater amount of carbohydrates than the endosperm portion of the kernel (MacArthur and D'Appolonia 1976). The negative correlations obtained indicate that components in the bran reduce the amount of $CO_2$ produced by the yeast and also reduce the slow fermentation rate.

The flour yield or extraction rate was negatively correlated to pressure curve measurements for fast fermentation rate and end of fast fermentation (Table VI). An increase in flour yield gives a

**TABLE V**
**Effect of Growth Location on Bread Quality Characteristics[a]**

| | North Platte, NE | Hays, KA | Hemingford, NE |
|---|---|---|---|
| Bread volume (mL) | 116.1a | 111.0b | 116.7a |
| Weight (g) | 30.3a | 30.3a | 30.2b |
| Height (mm) | 43.4a | 41.0b | 41.0b |
| Width (mm) | 70.1b | 70.6b | 71.5a |
| Bread score | 3.27a | 3.06b | 3.20a |
| Crumb score | 7.94a | 7.95a | 7.85b |
| Specific volume (mL/g) | 3.83a | 3.66b | 3.86a |
| Form ratio | 0.61a | 0.58b | 0.57b |

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

**TABLE VI**
**Statistically Significant Correlations Between Gas Bomb Parameters and LMW Sugar Content and Flour Quality Characteristics[a]**

| | Pressure Vessel Parameters | | | | |
|---|---|---|---|---|---|
| | Fast Fermentation Rate (PSI/hr) | End of Fast Fermentation (hr) | End of Fast Fermentation (PSI) | Pressure After 3.5 hr (PSI) | Slow Fermentation Rate (PSI/hr) |
| Ash content (%)[b] | ns | –0.62*** | –0.49** | –0.48** | –0.42* |
| Flour yield (%) | –0.55* | ns | –0.48* | ns | ns |
| Sucrose (mg/g of flour) | ns | ns | ns | ns | ns |
| Maltose (mg/g of flour) | ns | ns | ns | ns | ns |
| Glucose (mg/g of flour) | ns | ns | ns | ns | ns |
| Fructose (mg/g of flour) | ns | ns | ns | ns | ns |
| Total amount of sugar (mg/g of flour) | ns | ns | ns | ns | ns |
| Oligosaccarides (mg/g of flour) | 0.65*** | 0.64*** | 0.81*** | 0.82*** | 0.55*** |
| Damaged starch (%) | 0.51** | 0.78*** | 0.82*** | 0.81*** | 0.55*** |

[a] *, **, *** = significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively; ns = not significant.

[b] 14 % moisture basis.

TABLE VII
Statistically Significant Correlations Between Gas Bomb Parameters and Bread Quality Characteristics[a]

| | Bread Quality Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bread Vol. (mL) | Weight (g) | Height (mm) | Width (mm) | Form Ratio | Specific Vol. | Bread Score | Crumb Score |
| Fast fermentation rate (PSI/hr) | ns | ns | ns | ns | ns | ns | ns | ns |
| End of fast fermentation (hr) | ns | –0.39* | ns | 0.35* | ns | ns | ns | –0.64*** |
| End of fast fermentation (PSI) | ns | ns | ns | ns | ns | ns | ns | –0.58*** |
| Pressure after 3.5 hr (PSI) | ns | ns | ns. | ns | ns | ns | ns | –0.58*** |
| Slow fermentation rate (PSI/hr) | ns | –0.38* | ns | 0.36* | ns | ns | ns | –0.60*** |

[a] *, **, *** = significant at $P< 0.05$, $P < 0.01$, $P < 0.001$, respectively; ns = not significant.

TABLE VIII
Statistically Significant Correlations Between LMW Sugar Content and Bread Quality Characteristics in Hard Red Wheat Samples[a]

| | Bread Quality Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bread Vol (mL) | Weight (g) | Height (mm) | Width (mm) | Form Ratio | Specific Vol (g/mL) | Bread Score | Crumb Score |
| Sucrose (mg/g of flour) | ns | ns | 0.44** | –0.37* | 0.47** | ns | ns | ns |
| Maltose (mg/g of flour) | ns | ns | 0.52** | ns | 0.52** | ns | ns | ns |
| Glucose (mg/g of flour) | ns | ns | 0.51** | –0.35* | 0.53** | ns | ns | 0.33* |
| Fructose (mg/g of flour) | 0.35* | ns | 0.65*** | ns | 0.60*** | ns | 0.38* | ns |
| Total amount of sugar (mg/g of flour) | ns | ns | 0.54*** | –0.37* | 0.56*** | ns | ns | ns |
| Oligosaccarides (mg/g of flour) | ns | ns | ns | ns | ns | ns | ns | ns |

[a] *, **, *** = significant at $P< 0.05$, $P < 0.01$, $P < 0.001$, respectively; ns = not significant.

flour with more bran material, thus an increase in flour yield has the same effect as increased ash content: it reduces the rate and amount of $CO_2$ produced by the yeast.

*Hearth bread quality characteristics affected by pressure vessel parameters.* There was a strong negative correlation between crumb score and pressure vessel measurements for end of fast fermentation, pressure after 3.5 hr, and slow fermentation rate (Table VII). This indicates that low $CO_2$ production by yeast gives a very dense bread crumb pore structure.

The hearth bread weights were also negatively correlated with pressure vessel measurements for end of fast fermentation and slow fermentation slope. A high $CO_2$ production by the yeast is necessary to obtain hearth bread with a low weight. Normally, hearth bread with a high volume usually has a low weight.

Both end of fast fermentation and slow fermentation rate correlate positively with hearth bread width. This indicates that a high $CO_2$ production and a high-yeast slow fermentation produce flat hearth bread.

*Hearth bread quality characteristics affected by LMW sugar content.* The amount of mono- and disaccharides in wheat flour was positively correlated with hearth bread form ratio. In addition, the amount of sucrose and fructose, respectively, was positively correlated with crumb score and bread score (Table VIII). Therefore, to obtain a hearth bread with a high form ratio, a dense bread crumb, and a high bread score, the flour must contain high levels of mono- and disaccharides. Jiménez and Martínez-Anaya (2001) found that maltose increased specific volume. In this study, increased fructose positively correlated to hearth bread volume.

Jiménez and Martínez-Anaya (2001) found that the amount of dextrins DP5 and DP6 negatively influenced loaf volume, while maltose increased specific volume. In this study, no correlation was obtained between oligosaccharides and hearth bread characteristics.

## CONCLUSIONS

Data from the improved, computerized pressure meter from National shows that realtime measurements have many advantages compared with the old manual pressure meter. Significant differences in pressure meter data indicate that yeast ferments wheat flours differently and that these differences in gas production depend on wheat cultivar, growth location, and type of mill used. If instant dry yeast is used, it is important to mix the dough properly to obtain maximum yeast fermentation.

Increased amounts of oligosaccharides in wheat flour improves the yeast fermentation rate measured with the pressure meter. To obtain a hearth bread with a high form ratio value, the wheat flour must contain high levels of mono- and disaccharides. Monosaccharide content alone is important for production of hearth bread with a large volume, a dense bread crumb, and good overall bread quality judged by a baker. A more open crumb structure is obtained when the pressure meter values are high, indicating that the yeast ferments available sugars rapidly.

Therefore, a combination of two different flour analyses, LMW sugar content and yeast fermentation, with the pressure meter can be used to predict hearth bread quality. LMW sugar analysis and pressure meter measurements provide additional information about flour quality and, together with other flour quality analyses, makes it possible to choose the right flour for hearth bread production.

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