Effect of N:S Ratio on the Breadmaking Quality of Wheat: Preliminary Findings from 1999

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ABSTRACT

Sulphur (S) is an important component of wheat proteins and, therefore, influences the quality of bread wheat. However, information regarding the role of S nutrition in Canadian Western Red Spring (CWRS) wheat cultivars under Western Canadian growing conditions is limited. Field experiments were conducted in Manitoba, Saskatchewan, and Alberta in 1999 and 2000 to examine the effect of S fertilizer application on grain yield, plant nutrient status, and breadmaking quality of AC Barrie wheat (*Triticum aestivum* L.). Plant tissue and soil tests were also evaluated for their suitability in predicting grain yield and grain N:S ratio. Analyses of the 1999 grain samples indicated ranges of 25.3 to 38.7 mg g^{-1} in grain N content (14 to 22% in grain protein content), 1.3 to 2.2 mg g^{-1} in grain S content, and 14:1 to 23:1 in N:S ratio. Preliminary breadmaking quality analyses indicated that high ratios of N to S in grain were associated with lower loaf height, smaller loaf volume, greater dough resistance, and lower dough extensibility. Sulphur fertilization reduced grain N:S ratios at four of five sites. Of the three sites used to examine breadmaking quality, two sites showed significant improvements in loaf height and loaf volume where S fertilizer was applied. Sulphur fertilization also consistently reduced dough resistance and increased dough extensibility. The N:S ratio in grain was strongly correlated with N:S ratio in midseason tissue samples and N:S ratio in soil, calculated with water extractable NO_3-S and SO_4-S plus phosphate-borate extractable N and S. However, grain yield response to S was not well predicted by grain N:S ratio or spring soil test concentrations of sulphate-S.

INTRODUCTION

Sulphur (S) is an essential nutrient required by plants for growth and development. The requirements for S in higher plants have been known for over two centuries (Duke et al. 1986). However, in comparison to the other macronutrients, interest and research has lagged behind because, until recently, S deficiency has not been of great concern.

Deficiencies of S were first identified in Canada in 1927 on gray-wooded Luvisolic soils in the province of Alberta (Doyle and Cowell 1993). In initial research conducted in Western Canada, the majority of S yield responses were limited to legume crops (Cormack et al. 1951). However, in the late 1960s, cereal grains were shown to be sensitive to S, especially when other nutrients were in sufficient supply (Nyborg 1968). Doyle and Cowell (1993) provide an excellent general review of research on the S requirements of crops in Western Canada.

Sulphur is not only important for maximizing grain yields but is an important component of several essential amino acids in wheat grain, including cysteine and methionine (Zhao et al. 1999a). Disulphide bonds that form between the sulphydryl groups of cysteine residues are very important in determining the structure and properties of wheat storage proteins (Shewry and Tatham 1997). When the S supply is limited, the formation of these essential amino acids is depressed, thus, affecting the formation of storage proteins. More specifically, the formation of low molecular weight (LMW) glutenins as well as α-, β-, and γ-gliadins, albumins, and globulins is depressed (Wrigley et al. 1984). In addition, when there is an imbalance between N and S in the grain, there tends to be an imbalance between high molecular weight (HMW) and LMW glutenin subunits (MacRitchie and Gupta 1993). As a result, the breadmaking quality of wheat grain is reduced. During the 1940s, researchers in Alberta found that the largest loaves of best quality bread were obtained when wheat was grown after legumes on plots where S fertilizer had been applied (Newton et al. 1959). Researchers in England (Zhao et al. 1999b) and Australia (MacRitchie and Gupta 1993, Moss et al. 1981, Wrigley et al. 1984) found that low S fertility resulted in tough dough that was not suited to normal breadmaking practices. Further, low S nutrition resulted in small bread loaves of low quality (Zhao et al. 1999b, Byers et al. 1987). These breadmaking quality problems were especially severe when the N fertility was high, causing an imbalance between N and S in the grain. For Australian conditions, Randall et al. (1981) concluded that grain is deficient in S for both yield and quality if the S concentration is below 1.2 mg g^{-1} and the N:S ratio is above 17:1.

Bettany et al. (1982) estimated that of the 36 million ha of cultivated soil in the Prairies, approximately 30% are either S-deficient or potentially S-deficient. This area includes a large portion of the gray Luvisolic soils and spreads into the coarse-textured, well-drained black and brown soil zones. In Manitoba, during the period of 1979 to 1991, an average of 14% of fields sampled and analyzed received a recommendation for S fertilizer (McGill 1991). Sulphur fertility is declining further for several reasons. First, incidental application of S in fertilizers has declined due to increased use of high analysis N and P fertilizers containing little or no S (Zhao et al. 1999a). Second, atmospheric S inputs have declined due to national and international agreements for the reduction of industrial sulphur dioxide emissions (Zhao et al. 1999a). Third, S mineralization in the soil is declining because of widening C:S ratios and less ester-bonded sulphate in soil organic matter (Doyle and Cowell 1993). Fourth, over the last 10-20 years, the production of high S-using crops such as canola has drastically increased resulting in the net removal of S from soil. Finally, in the more humid zones, such as the Gray Luvisolic soils, leaching of soil gypsum and other forms of sulphate from the rooting zone has been substantial (Doyle and Cowell 1993).

Predicting S deficiency in the field is especially difficult for cereals because these crops have a relatively low requirement for S. Visual diagnosis of S deficiency is difficult because S deficiency symptoms in the plant can be easily confused with deficiency of N (Havlin et al. 1999). In addition, visual diagnosis of S deficiency may be too late; therefore, yield and quality may have already been adversely affected. However, soil testing provides an earlier diagnosis that may allow producers to correct deficiencies before they affect the crop. The conventional soil test that measures soluble SO_4-S provides an estimate of soil available S but has problems due to the variability of SO_4-S concentrations within a field and variability in mineralization of organic S from soil organic matter. Zhao et al. (1999a) concluded that soil testing is only reliable in predicting non-responsive soils when they contain high amounts of available S. These researchers also concluded that in situations where soils contain low or marginal amounts of available S, soil tests are not reliable for the prediction of S responses. Analysis of plant tissue may be a more reliable tool for diagnostic purposes. However, of the many diagnostic indices proposed, there is no general consensus as to which index is the best (Zhao et al. 1999a).

The Canadian Wheat Board currently sells Canadian grain and pays producers on the basis of grade and grain N content (protein) only. Premiums are paid for high protein grain to ensure that the market demand for guaranteed minimum protein levels is met. However, grain S content is not considered in determining the market value of wheat because little is known about the impact of S nutrition on breadmaking quality of Canadian Western Red Spring (CWRS) wheat grown in Western Canada.

The first objective of our project is to understand the influence of grain S content and grain N:S ratio on the breadmaking quality of CWRS wheat grown under Western Canadian conditions. The second objective is to evaluate and further develop practical tools (e.g. soil and tissue tests) which will help predict S and N concentrations in wheat grain, thereby, creating the opportunity for producers and agronomists to manage the S and N fertilization of wheat to meet certain breadmaking quality criteria. The following paper examines the relationship between grain N:S ratio and grain yield and quality. It also evaluates plant tissue and soil analyses for their suitability in predicting grain N:S ratios.

MATERIALS AND METHODS

Field experiments were conducted in 1999 and 2000. In 1999, field sites were located at Erickson, MB; Brandon, MB; Melfort, SK; Kelvington, SK; and Athabasca, AB. All sites, except Kelvington, were regarded as low to medium with respect to S fertility for wheat production (Table 1). The variety used in all experiments was AC Barrie, a CWRS wheat (*Triticum aestivum* L.) of high breadmaking potential. There were 4 treatments, consisting of factorial combinations of two N rates (26 and 100 kg/ha) and two S rates (0 and 20 kg/ha). All treatments were replicated four times at each site in a randomized block design. Nitrogen was applied as urea and S was applied as ammonium sulphate. Forty kg P_2O_5/ha as monoammonium phosphate was also applied to all plots at each site. All fertilizers were applied prior to seeding. Herbicides, fungicides, and insecticides were applied according to standard recommended practices.

Soil samples were collected from each subplot at each site in early spring, immediately prior to fertilization, from 0-15, 15-30, 30-60, and 60-90 cm depths. The samples were air dried and ground to pass through a 2 mm screen. Extractable SO_4-S and NO_3-N were extracted using a 0.001M calcium chloride solution. The SO_4-S was analyzed using the automated methylthymol blue method and NO_3-N was analyzed using the automated cadmium reduction method (Greenberg et al. 1992). Mineralizable N was estimated using the phosphate-borate method (Gianello and Bremner 1986). Total S was determined in the phosphate-borate extraction using inductively-coupled plasma atomic emission spectrometry. Mineralizable S was then estimated as the difference between total S and SO_4-S, and is termed phospate-borate sulphur in the paper.

Table 1. Concentrations of SO_4-S and NO_3-N in Soil Prior to Fertilization

Site	SO_4-S to 60 cm		NO_3-N to 60 cm	
	kg/ha*	Rating**	kg/ha*	Rating**
Brandon	26	L-M	20	VL
Erickson	26	L-M	19	VL
Melfort	32	M	144	VH+
Kelvington	61	H	91	VH
Athabasca	26	L-M	60	M-H

*estimated assuming a soil bulk density of 1.33 g cm^{-3}
**ratings for wheat production according to the Manitoba Soil Fertility Guide (L = low; M = medium; H = high)

Plant tissue from each site was sampled and analyzed. Whole plant tissue samples were collected from each subplot at the 50% heading stage (Feekes 10.3 stage). The plant samples were dried and ground to pass through a 2 mm screen; then analyzed for total N and S concentrations by combustion using a Leco CNS 2000 Analyzer (Leco Corporation 1996).

At maturity, grain yields were determined using plot combines. Straw samples were also collected and used to determine total dry matter yield. Grain and straw samples were ground to pass through a 2 mm screen and analyzed for total N and S by combustion using a Leco Analyzer. Total N and S uptake was determined using total dry matter yield and nutrient concentration values. Grain protein was determined using a conversion factor of 5.7 x %N for human food protein. Soil samples were also taken from the check treatments (0 kg S/ha and 26 kg N/ha) after harvest and NO_3-N and SO_4-S were measured.

All grain samples were graded and only samples meeting #1 or #2 grading standards were examined to determine milling and breadmaking characteristics. Grain samples from Brandon and Kelvington were eliminated due to fusarium and frost damage, respectively. Milling was conducted on a Buhler experimental mill. The flour was analyzed for S and N by combustion using a Leco Analyzer. Flour protein was determined using a conversion factor of 5.7 x %N for human food protein. Sedimentation tests were conducted on 2.5 g samples of whole meal (Modified version of the Approved Method 56-7, AACC, 1995). Farinograph tests were conducted using a Brabender Farinograph (Approved Method 54-21, AACC, 1995). A 2-g micromixograph (National Mfg. Div. TMCO, Lincoln, NE) measured mixing characteristics of flour and dough (Ingelin and Lukow 1998). Extensograph tests were conducted using a Texture Analyzer (Suchy et al. 1999). Baking tests (Approved Method 10-10B, AACC, 1995) with 100 g flour samples were used to measure bread loaf characteristics. Subsamples of grain were selected and analyzed for their composition of amino acids using a modification of the glucosamine method (Mills et al. 1989).

Results and Discussion

All results presented in this paper are preliminary and based on 1999 field experiments only.

I. Grain Nutrient Content and Yield

Overall growing conditions were excellent at Melfort; good at Brandon, Kelvington, and Erickson; and poor at Athabasca. Significant, positive yield responses to S fertilizer application occurred at two out of five sites (Table 2). There were yield increases of 142 kg/ha (2 bu/ac) and 515 kg/ha (8 bu/ac) in Athabasca and Melfort, respectively. However, Athabasca was the only responsive site where soil tests showed low to moderate levels of available SO_4-S according to the Manitoba Soil Fertility Guide (Table 1). In Melfort, the soil tests showed moderate levels of SO_4-S, with an average SO_4-S concentration of 32 kg/ha, and a yield response was not expected. Kelvington, with an average soil SO_4-S concentration of 61 kg/ha, did not show a yield response due to adequate SO_4-S levels. These data support the conclusion of Zhao et al. (1999a) that soil testing may not be reliable in predicting responsive soils when they contain low to marginal amounts of available S.

Responses to N fertilization were only observed at Erickson and Kelvington. The yield response was positive at Erickson because the soil NO_3-N concentrations were very low. A yield reduction was observed at Kelvington because of ammonia toxicity effects in the high N treatments. Nitrogen fertilizer did not increase grain yield at Melfort because the site was previously cropped with alfalfa and had sufficient N supplies.

Table 2. Effect of S and N fertilizer on grain yield in 1999

Treatment		Grain Yield (kg/ha) – Dry Matter Basis				
S Applied (kg/ha)	N Applied (kg/ha)	Athabasca	Erickson	Kelvington†	Brandon	Melfort
Treatment Means						
0	26	1038	1772	3488	2182	2831
20	26	1107	1976	3392	2372	3280
0	100	978	2479	2730	2342	3013
20	100	1192	2360	2583	2450	3645
Group Means						
0		1008	2126	3109	2262	2922
20		1150	2168	2987	2411	3437
LSD (P=0.05)		124	NS	NS	NS	440
	26	1072	1874	3440	2277	3056
	100	1085	2419	2656	2396	3284
	LSD (P=0.05)	NS	391	206	NS	NS
ANOVA	df			Pr>F		
Sulphur (S)	1	0.029*	0.80	0.21	0.49	0.014*
Nitrogen (N)	1	0.82	0.014*	0.0001**	0.58	0.12
S*N	1	0.22	0.35	0.78	0.85	0.44

† unadjusted for moisture
*, ** Significant at the 0.05 and 0.01 levels, respectively

Analyses of the grain samples indicated a range of 1.2 to 2.3 mg g^{-1} in grain S content. Grain N concentrations ranged from 25.3 to 38.7 mg g^{-1} (protein range of 14 to 23%); all of which would be regarded as high for CWRS wheat. Ratios of N:S in grain ranged from 14:1 to 23:1 (Table 3). Athabasca tended to have the highest grain N:S ratios due to drought and subsequent low yields and extremely high grain protein concentrations (Table 2 & 3). Across all sites, the average grain N:S ratio was approximately 18:1 where no S fertilizer was applied and dropped to approximately 16:1 as a result of S fertilization. Kelvington was the only site at which S fertilization did not cause a significant decline in grain N:S ratio; at this site S fertilizer application did not significantly increase the S concentration in grain.

Across all sites, the application of N fertilizer increased the overall average grain N:S ratio from approximately 17:1 to approximately 18:1. A significant increase in grain N:S ratio was seen at three out of five sites. However, the grain N:S ratio at Kelvington declined significantly as a result of N fertilization, probably due to ammonia toxicity damage in the treatments where N fertilizer was applied. Grain N:S ratios at Athabasca did not respond to N fertilizer due to the depressed yields and high protein concentrations under the 26 kg N/ha treatment.

Table 3. Effect of S and N fertilizer on grain N:S ratio in 1999

Treatment		Grain N:S Ratio				
S Applied (kg/ha)	N Applied (kg/ha)	Athabasca	Erickson	Kelvington	Brandon	Melfort
Treatment Means						
0	26	21.4	15.8	14.6	16.7	19.3
20	26	18.1	14.7	14.5	16.5	16.0
0	100	22.8	17.9	14.0	17.5	22.4
20	100	18.2	15.4	13.8	16.6	16.9
Group Means						
0		22.1	16.8	14.3	17.1	20.8
20		18.1	15.0	14.1	16.6	16.4
LSD (P=0.05)		1.00	1.17	NS	0.45	1.71
	26	19.7	15.2	14.5	16.6	17.6
	100	20.5	16.7	13.9	17.1	20.0
	LSD (P=0.05)	NS	1.17	0.38	0.45	1.71
ANOVA	df			Pr>F		
Sulphur (S)	1	0.0001**	0.0069**	0.27	0.021*	0.0004**
Nitrogen (N)	1	0.13	0.019*	0.0035**	0.032*	0.032*
S*N	1	0.18	0.21	0.65	0.10	0.16

*, ** Significant at the 0.05 and 0.01 levels, respectively

In Figure 1a, absolute grain yield was plotted against grain N:S ratio. The relationship between the two variables was significant, but weak. This weak relationship was originally believed to be a result of the variability in yield potential between field sites, obscuring the effect of grain N:S ratio on yield. For example, high grain N:S ratios were observed in Athabasca where the yield potential was low due to the lack of precipitation in 1999; whereas, high N:S ratios were also observed in Melfort even though growing conditions were excellent and the yield potential was high. In an attempt to reduce this variability due to yield potential across sites, grain yield was calculated relative to the highest-yielding treatment at each N level at each site. The relationship between relative grain yield and grain N:S ratio shows that relative yield tended to increase as grain N:S ratio narrowed (Figure 1b). However, this relationship was still quite weak, indicating that grain N:S ratio was a poor indicator of grain yield in 1999.

Randall et al. (1981) concluded that grain is deficient in S for yield if the S concentration is below 1.2 mg g^{-1} and the N:S ratio is above 17:1, when they used a critical yield threshold of

90% of maximum yield. In Figure 1b, the grain N:S threshold of 17:1 corresponded to a relative yield of 80 to 85%, indicating that this threshold may not be applicable to AC Barrie wheat.

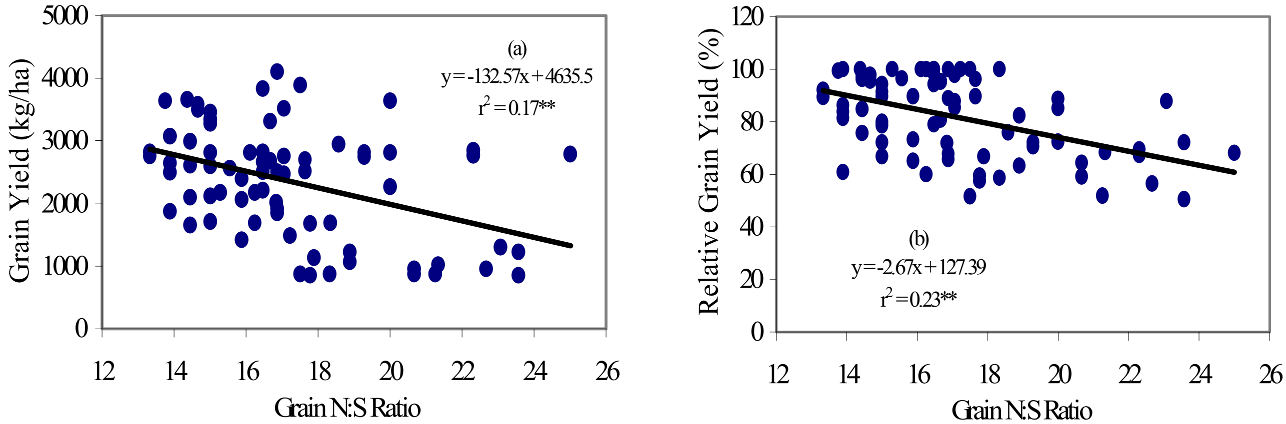

Figure 1. Effect of grain N:S ratio on absolute grain yield and relative grain yield in 1999
**Indicates significant at $P<0.01$

II. Grain Quality

a. Baking Characteristics

Bread loaf volume is of commercial importance because consumers tend to find large, light loaves more appealing than small, dense loaves. Therefore, agronomic management practices that improve loaf volume are valuable to the baking industry. Grain N:S ratio was plotted against loaf volume and loaf height (Figure 2). Loaf volume was negatively correlated with grain N:S ratio. In addition, grain N:S ratio, alone, accounted for 33% of the variation in loaf volume. The correlation between loaf height and grain N:S ratio was also strong, negative, and significant. Grain N:S ratio, alone, accounted for 55% of the variation in loaf height. The negative relationships between grain N:S ratio and loaf volume and loaf height indicate that a balance between grain N and S concentrations is important for quality bread production.

Application of S fertilizer improved loaf volume and loaf height at all three sites; however, the improvements were only significant at Athabasca and Melfort, which are also the only two sites that showed yield responses where S fertilizer was applied (Table 4). At these two sites, there was an average improvement in loaf volume of 92 cm^3 and in loaf height of 6.8 mm in response to S fertilizer application. Application of N fertilizer had no effect on loaf volume and loaf height at any of the sites.

Other technical baking measurements were also recorded and their correlation coefficients were calculated with grain N:S ratio. Dough mixing time was the only parameter that correlated positively with grain N:S ratio. Loaf fineness and oven spring correlated negatively with grain N:S ratio. Elongation, proof height, F1AVG, and F2AVG were not correlated with grain N:S ratio.

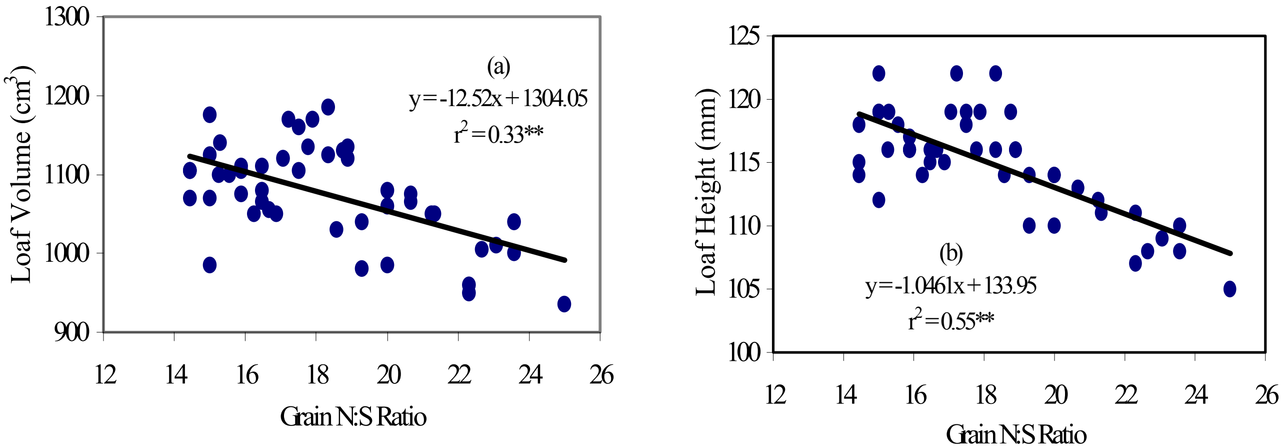

Figure 2. Effect of grain N:S ratio on loaf volume and loaf height in 1999
**Indicates significant a P<0.01

Table 4. Effect of S and N fertilizer on loaf height and loaf volume in 1999

Treatment		Loaf Height (mm)			Loaf Volume (cm^3)		
S Applied (kg/ha)	N Applied (kg/ha)	Athabasca	Erickson	Melfort	Athabasca	Erickson	Melfort
Treatment Means							
0	26	111.5	116.3	112.0	1050.0	1088.8	1008.8
20	26	119.0	116.5	116.5	1156.3	1105.0	1056.3
0	100	109.5	116.0	109.3	1023.8	1100.0	976.3
20	100	117.3	118.3	116.7	1143.8	1121.3	1075.0
Group Means							
0		110.5	116.1	110.6	1036.9	1094.4	992.5
20		118.1	117.4	116.6	1150.0	1113.1	1064.3
LSD (P=0.05)		2.84	NS	3.26	29.24	NS	44.07
	26	115.3	116.4	114.3	1103.1	1096.9	1032.5
	100	113.4	117.1	112.4	1083.8	1110.6	1018.6
	LSD (P=0.05)	NS	NS	NS	NS	NS	NS
ANOVA	df			Pr>F			
Sulphur (S)	1	0.0002**	0.36	0.002**	0.0001**	0.27	0.003**
Nitrogen (N)	1	0.17	0.58	0.60	0.17	0.41	0.91
S*N	1	0.92	0.46	0.21	0.61	0.88	0.11

*, ** Significant at the 0.05 and 0.01 levels, respectively

b. Milling, Flour, and Dough Characteristics

Correlations were calculated between grain N:S ratio and flour yield, sedimentation volume, mixograph parameters, farinograph parameters, and extensograph parameters. Flour yield and sedimentation volume both correlated negatively with grain N:S ratio. For the mixograph parameters, peak time and energy to peak correlated positively with grain N:S ratio; whereas, peak height, peak width, and total energy did not correlate significantly with grain N:S ratio. For the farinograph parameters, farinograph absorption, stability, and time to dough breakdown correlated positively with grain N:S ratio. Mixing tolerance index showed a negative correlation and dough development time was not significantly correlated with grain N:S ratio.

Of the flour and dough quality measurements recorded, the extensograph measurements of dough resistance to extension and dough extensibility are regarded as very good indicators of breadmaking quality. Dough resistance to extension is an indicator of dough strength or elasticity. Dough extensibility is an indicator of dough viscosity. A balance between dough strength and extensibility is required for breadmaking purposes. Grain N:S ratio showed a positive relationship with dough resistance to extension. On the contrary, dough extensibility showed a negative relationship with grain N:S ratio. All other extensograph parameters including extensograph area to peak, total area, and maximum resistance/dough extensibility correlated positively with grain N:S ratio.

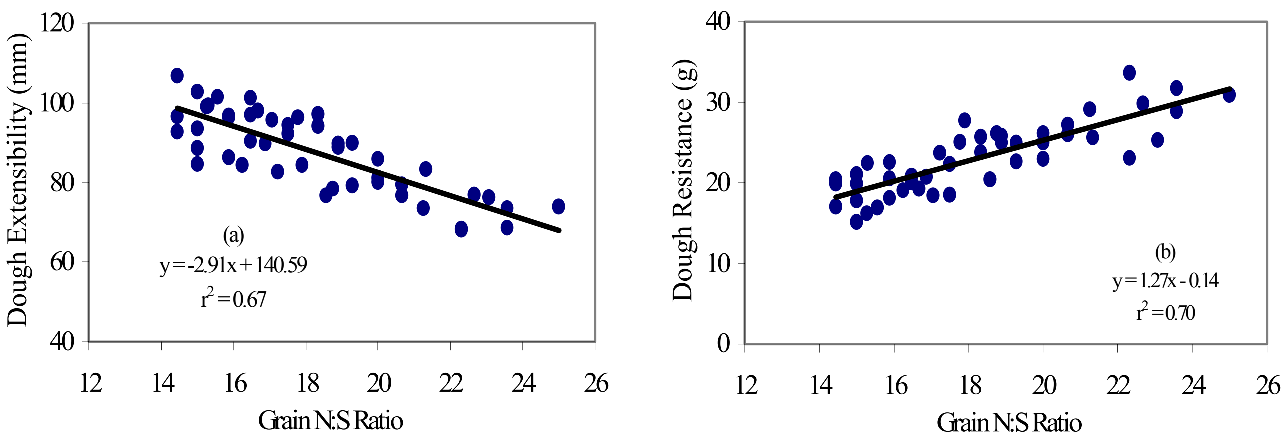

Figure 3. Effect of grain N:S ratio on dough extensibility and dough resistance in 1999
** Indicates significant at P<0.01

In order to explain these results, a few subsamples of grain were selected and analyzed for their amino acid composition. Grain samples with high ratios of N to S tended to have low concentrations of cysteine. The low cysteine concentration in grain with a high N:S ratio may have resulted in an imbalance between low-S polypeptides and high-S polypeptides, causing dough extensibility to decline (Wrigley et al. 1984). The former include ω-gliadins and HMW glutenin subunits and the latter include α-, β-, and γ-gliadins, and albumins. Dough resistance increased as grain N:S ratio increased, probably due to an increase in the ratio of HMW/LMW glutenin subunits (Zhao et al. 1999a). When there is an imbalance between low-S polypeptides and high-S polypeptides or an increase in the ratio of HMW/LMW glutenin subunits, there may be a decline in the number of potential disulfide links that are important for protein structure, thus producing tough, inelastic dough (Yoshino and McCalla 1965).

Across all sites, the overall average dough extensibility was approximately 81 mm without S fertilization and increased to approximately 95 mm with S fertilizer application (Table 5). The improvement in dough extensibility was significant at all sites, even Erickson where grain yield was not improved with S fertilization. Fertilizer N had no impact on dough extensibility.

At all sites, dough resistance declined significantly when S fertilizer was applied (Table 5). Sulphur fertilizer caused the overall average dough resistance to decline from 25.1 g to 20.8 g. In Athabasca, however, there was a significant interaction effect between N and S fertilizer and the drop in dough resistance was mostly seen at the high N rate. Nitrogen fertilizer, alone, significantly increased dough resistance at Melfort.

Table 5. Effect of S and N fertilizer on dough resistance and dough extensibility in 1999

Treatment		Dough Resistance (g)			Dough Extensibility (mm)		
S Applied (kg/ha)	N Applied (kg/ha)	Athabasca	Erickson	Melfort	Athabasca	Erickson	Melfort
Treatment Means							
0	26	26.0	20.8	23.2	78.9	89.0	81.8
20	26	24.6	19.9	18.0	90.5	98.8	93.0
0	100	29.9	22.5	28.4	73.2	87.9	72.6
20	100	25.2	17.8	19.5	91.4	99.9	94.5
Group Means							
0		27.9	21.6	25.8	76.0	88.5	77.2
20		24.9	18.9	18.6	90.9	99.4	93.6
LSD (P=0.05)		1.60[1]	2.64	2.84	5.70	7.03	7.81
	26	25.3	20.4	20.6	84.7	93.9	87.4
	100	27.5	20.1	24.6	82.3	93.9	82.0
	LSD (P=0.05)	1.60[1]	NS	2.84	NS	NS	NS
ANOVA	df	Pr>F					
Sulphur (S)	1	0.0021**	0.041*	0.0004**	0.0002**	0.0067**	0.0013**
Nitrogen (N)	1	0.012*	0.86	0.036*	0.36	0.99	0.32
S*N	1	0.048*	0.13	0.14	0.22	0.73	0.14

[1]Interaction effect between N and S fertilizers – most of S response occurred at high N rate (refer to treatment means)

*, ** Significant at the 0.05 and 0.01 levels, respectively

III. Prediction of N:S Ratio in Grain

Based on the preliminary data from 1999, grain N:S ratio is an important parameter that may be used to predict breadmaking quality and, to a lesser extent, grain yield of wheat. Prediction of grain N:S ratio early in the growing season might allow producers to adjust their soil fertility program to improve both the quality and yield of wheat.

A number of prediction tools were evaluated throughout the growing season at the five field sites. Midseason tissue analysis appears to be valuable in predicting N:S ratio in grain. The strong correlation between midseason N:S ratio and grain N:S ratio (r= 0.88; r^2 = 0.77) indicates that even though the absolute concentrations of N and S in the plant may change during the period between 50% heading and maturity, the N:S ratio may remain relatively stable and provide a good estimate of N:S ratio in grain. The midseason sampling period, however, may not provide enough time for producers to apply an S fertilizer rescue treatment.

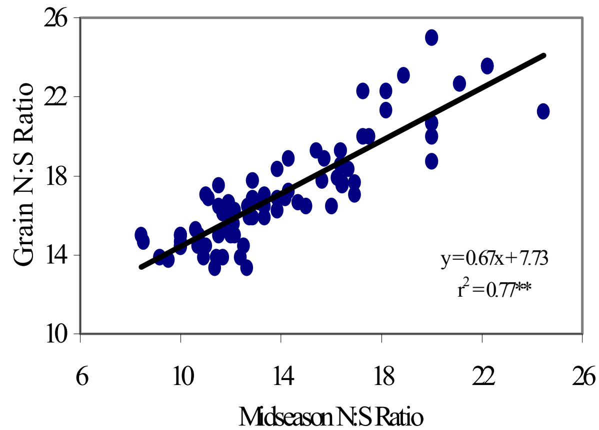

Figure 4. Relationship between midseason N:S ratio and grain N:S ratio in 1999
**Indicates significant at P<0.01

A number of soil analyses were also evaluated for their suitability in predicting grain N:S ratio. Soil N:S ratio indices were calculated for each type of soil analysis. Correlation coefficients were then calculated for the relationship between grain N:S ratio and each soil N:S ratio index (Table 6). The soil N:S ratio calculated with the water soluble NO_3-N and SO_4-S values from the check treatments correlated significantly with grain N:S ratio (r = 0.55). This correlation was improved when the fertilizer treatments were included in the calculation of soil N:S ratio (r = 0.65). The soil N:S ratio calculated with the phosphate-borate estimates of mineralizable N and S from the check treatments was superior (r = 0.72) to the soil N:S ratio calculated with water soluble NO_3^- and SO_4^{2-} in indicating N:S ratio in grain. However, when the fertilizer treatments were included in the correlation, this relationship declined (r = 0.53). Summing the estimates for soil N and S from the water soluble and phosphate-borate extractable analyses for the check treatments resulted in the strongest correlation with grain N:S ratio (r = 0.87). However, this correlation also declined when the fertilizer treatments were included in the calculation of soil N:S ratio (r = 0.66).

These correlation values imply that it is necessary to consider the labile organic fractions of N and S in the calculation of soil N:S ratio when predicting grain N:S ratios. These organic N and S fractions contribute significantly to plant nutrition through mineralization during the growing season. The soil N:S ratio calculated with the estimates of water soluble NO_3-N and SO_4-S only, may be less reliable. The inconsistency between grain N:S ratio and soil N:S ratio when fertilizer N and S are simply added to the soil test values indicates that more work is required to determine the relative bioavailability of soil inorganic, soil organic, and fertilizer sources of N and S.

Table 6. Correlation coefficients between measured soil N:S ratio indices and grain N:S ratio in 1999

Soil N:S Ratio Index†	Treatments Included	Correlation Coefficient
Nitrate:Sulphate	Checks‡	0.55*
Nitrate & Fertilizer N:Sulphate & Fertilizer S	All Treatments	0.65**
P-B Nitrogen:P-B Sulphur	Checks‡	0.72**
P-B Nitrogen & Fertilizer N:P-B Sulphur & Fertilizer S	All Treatments	0.53**
Nitrate & P-B Nitrogen:Sulphate & P-B Sulphur	Checks‡	0.87**
Nitrate & P-B Nitrogen & Fertilizer N:Sulphate & P-B Sulphur & Fertilizer S	All Treatments	0.66**

†P-B refers to Phosphate-Borate mineralizable N or S
‡Check treatments have 0 kg S/ha and 26 kg N/ha applied
*, ** Significant at the 0.05 and 0.01 levels, respectively

Summary

In conclusion, based on preliminary data from 1999, grain N:S ratio is an important factor influencing the breadmaking performance of wheat. High ratios of N to S in grain might be associated with lower loaf height, smaller loaf volume, greater dough resistance, and lower dough extensibility.

Application of S fertilizer is likely to benefit the breadmaking quality of CWRS wheat grown in Western Canada wherever soil S is marginal to deficient for wheat yield. Sulphur fertilization significantly reduced grain N:S ratios at four out of five locations. Loaf volume and loaf height were significantly improved at Athabasca and Melfort where S fertilizer was applied. Sulphur fertilization also caused dough resistance to decline and dough extensibility to increase at all three sites. In addition, S fertilization may result in occasional increases in grain yield for CWRS wheat where S concentrations in conventional SO_4-S tests indicate adequate supplies of soil S.

Agronomic management practices that improve the breadmaking quality of wheat are valuable to the baking industry. Prediction of grain N:S ratio would provide producers with the opportunity to make adjustments to their fertilizer programs in order to improve the quality of wheat. Midseason tissue analysis appears to be valuable in predicting grain N:S ratio at plant maturity. The N:S ratio in soil, calculated with water extractable NO_3-S and SO_4-S plus phosphate-borate extractable N and S also appears to be valuable for predicting grain N:S ratios. However, more work is required to determine the relative bioavailability of soil inorganic, soil organic, and fertilizer sources of N and S.

Acknowledgements

We thank Agrium Inc., United Grain Growers Ltd., and the Agri-food Research and Development Initiative for the financial and technical support to make this project possible. In particular, we appreciate the efforts of Dr. Adrian Johnston and Dr. Sukhdev Malhi of Agriculture and Agri-food Canada Melfort Research Station, Lenz Haderlein of Agrium Inc., and Kevin McCallum of Proven Seed for establishing and maintaining the field sites. We also thank Pat Greer and the rest of the quality control personnel at United Grain Growers Ltd. for their aid in grading our grain samples.

References

American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 54-21, Method 10-10B, Method 56-7. The Association: St. Paul, MN.

Bettany, J.R., H.H. Janzen, and J.W.B. Stewart. 1982. Sulphur deficiency in the Prairie Provinces of Canada. p. 573 In Proc. of Sulphur 1982. An International Symposium on Sulphur, Nov. 1982, London, England.

Byers, M., J. Franklin, and S.J. Smith. 1987. The nitrogen and sulphur nutrition of wheat and its effect on the composition and baking quality of the grain. Asp. App. Bio. 15:337-344.

Cormack, D.V., C.F. Bentley, and D.B. Scott. 1951. Fertilizer studies with radioactive sulphur. I. Sci. Agric. 31:41-51.

Doyle, P.J. and L.E. Cowell. 1993. Sulphur. p.202-250. In D.A. Rennie, C.A. Campbell, and T.L. Roberts (Eds.) A Review of the Impact of Macronutrients on crop responses and environmental sustainability on the Canadian Prairies. Canadian Society of Soil Science, Ottawa, Ont.

Duke, S.H. and H.M. Reisenauer. 1986. Roles and requirements of sulfur in plant nutrition.p.123-168. In M.A. Tabatabai (Ed.) Sulfur in Agriculture. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.

Gianello, C. and J. M. Bremner. 1986. Comparison of chemical methods of assessing potentially available organic nitrogen in soil. Commun. Soil Sci. Plant Anal. 17:215-236.

Greenberg, A.E., L.S. Clesceri, and A.D. Eaton. 1992a. Standard Methods for Examination of Water and Wastewater, 18th ed. 4500 - SO_4^{2-} (Automated Methylthymol Blue Method) and 4500 – NO_3^- (Automated Cadmium Reduction Method).

Havlin, J.A., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. p.217-235 In Soil Fertility and Fertilizers. An Introduction to Nutrient Management, 6th ed. Prentice Hall. NJ.

Ingelin, M.E. and O.M. Lukow. 1998. A two-gram test for extensibility and resistance to extension. p.207-213. In D.B Fowler, W.E. Gedes, A.M. Johnston, and K.R.Preston (eds.) Wheat Protein Production and Marketing. University of Saskatchewan, Saskatoon, SK.

Leco Corporation. 1996. Leco CNS 2000 Elemental Analyzer Instruction Manual. Version 4.0.

Manitoba Agriculture and Manitoba Agricultural Sustainability Initiative. Soil Fertility Guide.

MacRitchie, F. and R. B. Gupta. 1993. Functionality-composition relationships of wheat flour as a result of variation in sulphur availability. Aust. J. Agric. Res. 44:1767-1774.

McGill, K.S. 1991. Trends in nutrient levels in Manitoba soils. p.115-136 In 34th Ann. Man. Soil Sc. Soc. Proc., Winnipeg, MB.

Mills, P.A., R.G. Rotter, and R.R. Marquardt. 1989. Modification of the glucosamine method for the quantification of fungal contamination. Can. J. Anim. Sc. 69:1105-1106.

Moss, H. J., C. W. Wrigley, F. MacRitchie, and Randall, P. J. 1981. Sulphur and nitrogen fertilizer effects on wheat. II Influence on grain quality. Aust. J. Agric. Res. 32:213-226.

Newton, J.D., C.F. Bentley, J.A. Toogood, and J.A. Robertson. 1959 (Rev.). Grey-wooded Soils and Their Management. Univ. of Alberta. Fac. of Agric. Bul. No. 21.

Nyborg, M. 1968. Sulphur deficiency in cereal grains. Can. J. Soil. Sci. 48:37-41.

Randall, P. J., K. Spencer, and Freney, J. R. 1981. Sulphur and nitrogen fertilizer effects on wheat. I Concentrations of sulphur and nitrogen and the nitrogen to sulphur ratio in grain in relation to the yield response. Aust. J. Agric. Res. 32:203-212.

Shewry, P.R. and A.S. Tatham. 1997. Disulphide bonds in wheat gluten proteins. J. Cer. Sci. 25:207-227.

Suchy, J., O.M. Lukow, and M.E. Ingelin. 2000. Dough microextensibility method using a 2-g mixograph and a texture analyzer. Cereal Chem. 77:39-43.

Wrigley, C.W., D.L. Du Cros, J.G. Fullington., and D.D. Kasarda. 1984. Changes in polypeptide composition and grain quality due to sulfur deficiency in wheat. J. Cer. Sci. 2:15-24.

Yoshino, D. and A.G. McCalla. 1965. The effects of sulphur content on the properties of wheat gluten. Can. J. Biochem. 44:339-346.

Zhao, F.J., M.J. Hawkesford, and S.P. McGrath. 1999a. Sulphur assimilation and effects on yield and quality of wheat. J. Cer. Sci. 30:1-17.

Zhao, F.J., S.E. Salmon, P.J.A. Withers, J.M. Monaghan, E.J. Evans, P.R. Shewry, and S.P. McGrath. 1999b. Variation in the breadmaking quality and rheological properties of wheat in relation to sulphur under field conditions. J. Cer. Sci. 30:19-31.