Influence of Nitrogen Fertilizer Treatments on Spring Wheat (*Triticum aestivum* L.) Flour Characteristics and Effect on Fresh and Frozen Dough Quality

David J. Boehm,[1] William A. Berzonsky,[1,2] and Monisha Bhattacharya[3]

ABSTRACT

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Growers are targeting hard red spring wheat (*Triticum aestivum* L.) (HRSW) for frozen dough end uses. Consequently, it is important to determine whether increasing nitrogen (N) fertilizer rates and grain protein content (GPC) improve frozen dough quality. Four HRSW cultivars were grown in low-N soils at three locations over two years in North Dakota and fertilized with N rates of 0 kg/ha, 67.2 kg/ha, and 134.4 kg/ha. End use characteristics were analyzed using farinograph, extensigraph, and baking tests. Fresh and frozen doughs were analyzed to determine the effects of N treatments on frozen storage. A cultivar × N treatment interaction existed for extensigram curve area of fresh dough. A significant increase in GPC existed between the 0 and 67.2 kg/ha N treatments. Farinograph water absorption, arrival times, and peak times increased significantly at the 67.2 kg/ha N treatment. Bread loaf volume of fresh dough increased significantly with all treatments, while loaf volume of frozen dough increased significantly only at the 67.2 kg/ha N treatment. Therefore, aside from fresh dough loaf volume, there appears to be no improvement in frozen dough quality with the use of higher than typical N application.

Hard red spring wheat (HRSW) (*Triticum aestivum* L.), grown in the U.S. Northern Plains is uniquely suited for the production of all leavened bread products due to its protein properties. Wheat gluten proteins form cohesive and extensible doughs (Hoseney 1998) that retain gas produced by yeast during oven rise (Bushuk and Wrigley 1974; Hoseney 1998). It is the combination of higher grain protein content (GPC) and gluten quality in wheat, which leads to increased dough strength and loaf volume in bread products (Aitken and Geddes 1934; Mesfin et al 2000).

Although GPC has a heritable component, the environment, including soil fertility and moisture, plays a major role in determining final GPC levels (Davis et al 1961; Lopez-Bellido et al 1998). Therefore, it has been demonstrated that management of nitrogen (N) fertilizer can increase GPC in wheat (Franzen and Goos 1997; Metho et al 1999).

Growers in the U.S. Northern Plains have begun targeting production of HRSW for frozen dough end uses in addition to the traditional fresh baked bread products. This has stimulated research into frozen dough products, which can maintain quality comparable to fresh baked bread products. Doughs made from high-protein flours have increased dough strength, resulting in an increase in loaf volume after baking (Inoue and Bushuk 1992; Wang and Ponte 1994). Therefore, high GPC might also be important for the production of frozen doughs. An understanding of the impact of N fertilizer on GPC may help HRSW growers determine the N level that results in an improvement in frozen dough quality.

MATERIALS AND METHODS

Experimental Design, Treatments, and Grain Yield Determination

The four spring wheats used in the study included ‘Glupro’ (RL4352-1/*T.dicoccoides*//LEN) with very high GPC and good baking quality, ‘Trenton’ (Grandin/Stoa SIB) with average GPC and baking quality, ‘Grandin’ (Len//Butte*2/ND507/3/ND593) with average GPC and good baking quality, and ‘Argent’ (Grandin*5/ND614) with average GPC and good baking quality (Peel 2000). The experiments were conducted in 2000 and 2001 at Carrington, Casselton, and Minot, North Dakota. Three N treatments (0 kg/ha, 67.2 kg/ha, and 134.4 kg/ha) were applied as dry granular urea. The 67.2 kg/ha N treatment is a typical amount of N applied to spring wheat in North Dakota and the 134.4 kg/ha treatment represents twice the typical amount (J. Goos, North Dakota State University, *personal communication*). A granular starter fertilizer, 13.4-26.9-26.9 (N-P-K) kg/ha was added at a rate of 56.0 kg/ha. The fertilizer was incorporated during sowing in addition to existing soil N levels. Therefore, low-N sites were chosen at all locations. The fertilizer treatments were randomly assigned to experimental units using a complete block field design and a split-block arrangement with three replicates (Steel et al 1997). In 2000, each experimental unit consisted of four rows 3.0 m long, spaced 30.5 cm apart. In 2001, the row length was increased to 3.7 m to produce more grain for end use quality evaluation. After harvesting individual plots with a small-plot combine, grain yields were determined by weighing the harvested seed, which had been dried to a standard 13% moisture content.

Grain Protein Content

Grains were initially cleaned with an office tester (Clipper Separation Technologies, Bluffton, IN) and followed with a Dockage machine (Carter-Day Co., Minneapolis, MN). Samples (10 g) of whole grain from each experimental unit were milled on a cyclone sampler mill (Udy Corp., Ft. Collins, CO) to determine GPC. Moisture and whole grain protein were determined with an Infra Alyzer 400 near-infrared reflectance (NIR) machine (Technicon Investments Corp., Elmhurst, IL) as in Approved Method 39-10 (AACC 2000) and the GPC (%) was estimated as N × 5.7 and expressed on a 14% moisture basis.

Flour Milling

After grain yield, test weight, and GPC were measured, experimental units consisting of the same cultivar and treatment were bulked at each environment to obtain enough grain to produce the flour needed for all quality tests. The grain moisture was determined using an automatic moisture tester (Motomco moisture meter 919ES, Dickey-John Corp., Auburn, IL) and the grain was scoured with a cyclone grain cleaner (The Forster Manufacturing Co., Wichita, KS) to remove any remaining dirt and hulls. The grain was pretempered to 12.5% moisture for 24 hr, and tempered to 15.5% moisture for an additional 24 hr as described in Approved Method 26-10A (AACC 2000) by use of the table in Approved Method 26-95 (AACC 2000). The grain was milled (Buhler Corp., Minneapolis, MN) as described in Approved Method

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[1] Department of Plant Sciences, North Dakota State University, Fargo, ND 58105.

[2] Corresponding author. Phone: 701-231-8912. Fax: (701)-231-8474. E-mail: Bill.Berzonsky@ndsu.nodak.edu

[3] Department of Cereal and Food Sciences, North Dakota State University, Fargo, ND 58105.

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26-21A (AACC 2000). Resulting flour was sifted with a #84 HRS sieve screen and mixed for 20 min in a flour blender. The flour was stored and rested for one week and moisture content was determined using the NIR as previously described for grain protein content.

Farinographs

The flour quality was evaluated using a farinograph (C.W. Brabender Instrument, South Hakensack, NJ) according to Approved Method 54-21 (AACC 2000). The water absorption (%), arrival time (min), peak time (min), departure time (min), stability (min), and mixing tolerance index (BU) for flour was determined. The farinograph measurements were made in duplicate and the mean of the two measurements was used for statistical analyses. A sample of Grandin HRSW at 14% GPC was evaluated each day as a control.

Fresh Dough Extensigraphs

Using a planimeter and an extensigraph (C.W. Brabender, Instrument), resistance to extension (BU), extensibility (cm), and extensigraph area (cm^2) were measured according to a modified Approved Method 54-10 (AACC 2000). Instead of using the standard 300-g sample of flour, 200 g of flour was used to preserve flour for additional tests. Flour was based on 14% moisture content and was mixed in a 300-g mixing bowl (National Mfg. Co., Lincoln, NE) with 40 mL of a 10% NaCl water buffer. The remaining water was added to reach farinograph absorption less 4 mL. After mixing, the dough piece was scaled into two 150-g pieces. In accordance with a standard method employed in the North Dakota State University Department of Cereal and Food Sciences, both pieces were rounded 16 times and molded with an extensigraph machine. One piece was bagged and placed into a –23°C freezer and held for further testing. The other piece was rested in the extensigraph cradles for 45 min at 30°C and 100% rh and then stretched. This extensigraph procedure was repeated twice for each flour sample, producing two fresh and two frozen extensigraph samples from each cultivar at each treatment and environment. Frozen dough pieces were removed from the –23°C freezer after 90 days, retarded at –2°C for 16 hr, and thawed in a proofing cabinet at 86°C and 85% rh until core temperatures reached 28°C. The samples underwent the same extensigraph procedure as described for the fresh dough extensigraph method.

No-Time Bread Procedure

The bread baking procedure was adapted from McCleary-Bayley (1992). Modifications included changing the sample size from 2,500 g to 150 g of flour, which was mixed with ingredients. The dough formulation consisted of flour (100%), compressed yeast (5%), shortening (4%), sugar, (4%), salt (1.5%), ascorbic acid (100 ppm), potassium bromate (50 ppm), and water (farinograph absorption minus 4%). Flour samples were adjusted to 14% moisture content to make the dough samples, and samples were kept in a proof cabinet overnight at 30°C. A combined sugar and salt solution, a compressed yeast solution, and solutions of ascorbic acid and potassium bromate were made fresh daily and kept in a refrigerator at <5°C. Two mixing bowls were used and stored in a freezer along with all stainless steel bowls and baking pans. These steps were taken to maintain low dough temperatures and prevent yeast activity, as required for a frozen dough study. The doughs were mixed to optimum development in a 100-g mixing bowl (National Mfg. Co., Lincoln, NE). Mix times and dough temperatures were recorded, and available doughs were weighed and divided into six equal portions. Three pieces were baked fresh and three were handled as frozen doughs.

Fresh Bread Samples

Dough pieces were hand-rounded, placed in stainless steel bowls, and rested in a proofing cabinet at 30°C and 85% rh for 10 min. They were sheeted at 4.76 mm, hand molded, placed in lightly greased bread pans suitable for 25-g flour samples, and proofed for an additional 45 min. Proof height was recorded in centimeters and the loaves were baked at 218°C for 20 min. After a 30-min cooling period, loaves were weighed and loaf volume was recorded in cubic centimeters using rapeseed displacement.

Frozen Dough Samples

After mixing, three hand-rounded dough pieces were immediately placed into separate stainless steel bowls and rested in a standard kitchen freezer at –2°C for 10 min. Samples were sheeted to a thickness of 4.76 mm, hand molded, and placed in bread pans

TABLE I
Mean Grain Yields (kg/ha) for Cultivars at Each N Treatment at Six North Dakota Environments in 2000 and 2001[a]

N Treatment	Argent	Glupro	Grandin	Trenton
0	2,105.1	1,582.7	1,966.4	2,185.0
67.2	2,426.3	1,719.8	2,272.1	2,293.0
134.4	2,383.0	1,612.2	2,455.3	2,489.8

[a] Least significant difference ($P < 0.05$) for different N treatments within a cultivar = 490.2; for different cultivars within a N treatment = 536.8; for different cultivars at different N treatments = 537.5.

TABLE II
Mean Grain Protein Content (GPC, %) for Cultivars at Six North Dakota Environments in 2000 and 2001

N Treatment	Argent	Glupro	Grandin	Trenton
0	14.6	18.0	14.3	14.0
67.2	15.4	18.6	15.1	14.9
134.4	15.7	18.8	15.4	15.1
LSD[a]	0.5	0.5	0.5	0.5

[a] Least significant difference ($P < 0.05$).

TABLE III
Mean Farinograph Measurements for N Treatments Averaged over Four Cultivars at Six North Dakota Environments in 2000 and 2001

N Treatment	Water Abs. (%)	Arrival Time (min)	Peak Time (min)	Depart Time (min)	Stability Time (min)
0	68.4	4.1	10.1	24.1	20.0
67.2	69.6	5.2	12.4	25.4	20.2
134.4	70.0	5.1	12.4	25.9	20.8
LSD[a]	0.8	0.8	1.7	1.9	1.8

[a] Least significant difference ($P < 0.05$).

suitable for 25-g flour samples. Pans were placed back into the kitchen freezer for 2 hr until frozen. Samples were removed from the pans, double-bagged, and placed in a freezer at –23°C for 90 days. After frozen storage, the doughs were retarded at –2°C for 16 hr and thawed in a proofing cabinet at 86°C and 85% rh until internal core temperatures reached that of the corresponding fresh sample for the same treatment and cultivar. Samples were panned and proofed to the same height as the corresponding fresh sample. Proof times for each sample were recorded in minutes. Samples were baked and loaf weight and volume were measured as described for fresh bread samples.

Statistical Analyses

An analysis of variance (ANOVA) was used to determine the significance of fertilizer treatments, cultivars, environments, and their interactions. Fertilizer treatments and cultivars were considered fixed effects and environments were considered random effects. Because the farinograph, extensigraph, and baking data were analyzed from samples bulked across replicates, there was no replicate source of variation for quality measurements and the environments themselves were analyzed as replicates. The expected mean squares were used to determine the denominator of each F-test. The F-tests were considered significant at $P < 0.05$, 0.01, and 0.001, and means were separated using Fisher's F-protected least significant difference (LSD) test. Homogeneity of environments was determined by using Bartlett's chi-squared test for homogeneity at $P = 0.005$ in which MS error(c) values were calculated from individual environments (Steele et al 1997). The mean square errors that were not homogeneous were transformed using natural logarithms and recalculated. Analysis of variance diagnostics were computed where a histogram of residuals was used to determine normality of error, and a scatter plot of residual error versus fitted error values tested homogeneity and independence of error (Steele et al 1997). Statistix for Windows (v. 2.0, Analytical Software, Tallahassee, FL) was used for computation of the ANOVA and LSD values.

RESULTS AND DISCUSSION

Grain Yield

Table I presents mean grain yields for cultivars at the three levels of N fertilizer. For all cultivars, the 0 kg/ha N treatment produced the lowest grain yields. Grandin and Trenton responded with higher grain yields at each additional N treatment level, while Argent and Glupro produced higher yields, but not significant yield increases with the 67.2 kg/ha N treatment. Trenton was the highest yielding cultivar at the 0 and 134.4 kg/ha N treatment level, while Argent exhibited the highest grain yield at the 67.2 kg/ha N treatment. Glupro exhibited the lowest grain yields at all N treatments. Other research has shown that grain yields for small grains can be improved with N treatments (Finney et al 1957; Bauer 1970; Dubetz 1972).

TABLE IV
Mean Fresh and Frozen Extensigraph Curve Area (cm^2) for N Treatments (kg/ha) Averaged Over Four Cultivars at Six North Dakota Environments in 2000 and 2001

N Treatment	Fresh Curve Area	Frozen Curve Area
0	208.5	201.3
67.2	199.3	190.7
134.4	193.0	193.6
LSD[a]	20.8	28.9

[a] Least significant difference ($P < 0.05$).

Grain Protein Content

Significant differences in GPC existed for all cultivars between the 0 and 67.2 kg/ha N treatment levels (Table II); however, there was no difference between the typical and high N treatments. This suggests there is no significant increase in GPC with a higher than typical N treatment. Glupro however was significantly higher than the other cultivars in GPC at all N treatments, and Argent was significantly higher than Trenton at the 0 and 134.4 kg/ha N treatments.

Farinograph

Water absorption increased significantly with the application of 67.2 kg/ha N, whereas, no significant difference in mean water absorption was observed with an increase in N to 134.4 kg/ha (Table III). Farinograph arrival and peak times were significantly shorter at the 0 kg/ha N treatment level, but there was no significant difference between mean arrival and peak times measured at the 67.2 kg/ha and 134.4 kg/ha N levels. Departure and stability times were not significantly affected by N fertilizer treatments. These results demonstrate that typical N fertilization produces increased water absorption and longer arrival and peak times. Higher N treatments most likely will not have additional significant effects on dough characteristics. While higher water absorption is an indication of increased GPC and is beneficial for bread baking, shorter arrival and peak times are desired to speed up the dough mixing process. Balancing these quality parameters may be possible at typical N application rates.

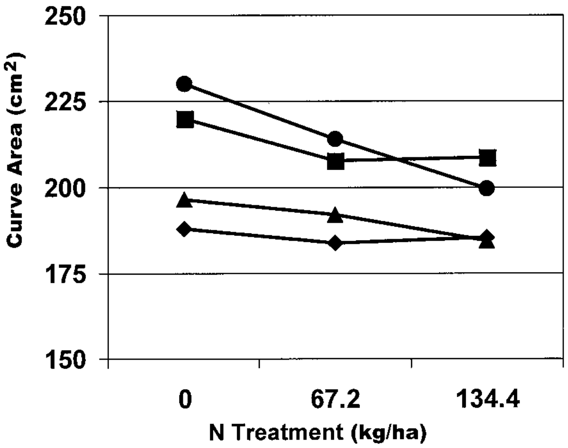

Fig. 1. Cultivar by nitrogen treatment interaction for extensigram curve area of fresh dough averaged over four cultivars at six North Dakota environments for 2000 and 2001: Argent (◆); Glupro (●); Grandin (▲); Trenton (■). LSD (0.05) = 21.1.

TABLE V
Mean Fresh and Frozen Dough Baking Quality for N Treatments Averaged Over Cultivars at Six North Dakota Environments in 2000 and 2001

	Fresh Dough				Frozen Dough		
N Treatment	Mix Time (min)	Proof Height (cm)	Loaf Volume (cm^3)	Loaf Weight (g)	Proof Time (min)	Loaf Volume (cm^3)	Loaf Weight (g)
0	3.1	6.5	215.7	31.3	123.8	178.8	31.1
67.2	3.2	6.5	222.0	31.5	109.1	192.4	31.1
134.4	3.2	6.6	229.5	31.7	111.6	191.7	31.4
LSD[a]	0.1	0.1	7.7	0.5	15.8	9.7	0.5

[a] Least significant difference ($P < 0.05$).

Extensigraph

An interaction existed between cultivar and N treatment for curve area for fresh dough (Fig. 1). Cultivar rank changes at the 134.4 kg/ha N fertilizer treatment illustrate this interaction. In the case of Glupro, the 0 kg/ha treatment produced a curve area significantly larger than the 134.4 kg/ha N fertilizer treatment. Argent and Trenton had their lowest curve areas at the 67.2 kg/ha N fertilizer treatment, and Glupro and Grandin had their lowest curve areas at the 134.4 kg/ha N fertilizer treatment, although the change was nonsignificant for Argent, Grandin, and Trenton. Therefore, N responses were not consistent across all four cultivars, and cultivars did not exhibit similar extensigram responses at all N fertilizer treatments. Glupro was significantly larger in curve area than Argent and Grandin at the 0 and 67.2 kg/ha N treatments, whereas Trenton was larger than Argent and Grandin at the 134.4 kg/ha N treatment. Nitrogen treatments had no significant effect on extensigram curve area for fresh and frozen dough samples (Table IV), and fresh and frozen dough qualities remained unchanged with an increase in N fertilization.

Bread Quality

Loaf volumes for breads made from both fresh and frozen doughs were the only trait affected by N treatments (Table V). Mean loaf volumes for bread made from fresh doughs increased with N treatments, and these increases were significant between the 0 and 134.4 kg/ha N treatments, but not the 0 and 67.2 kg/ha N levels. This suggests that to increase the loaf volume of fresh dough, higher than typical rates of N need to be used. Metho et al (1999) determined that the highest fresh dough loaf volume was achieved by N application, while Ayoub et al (1994) reported significant increases in loaf volume for each additional 60 kg/ha N fertilizer application from 0 to 180 kg/ha. In our study, for breads made from frozen doughs, the 0 kg/ha N treatment produced the lowest loaf volume. The 67.2 kg/ha and 134.4 kg/ha N treatments produced significantly larger loaf volumes, but the mean loaf volumes at these treatments were not significantly different from one another. We suggest loaf volumes for frozen dough can be increased with typical N treatments in North Dakota, but no additional increase would likely be realized with above typical fertilizer treatments. Typical fertilizer treatments may be adequate for bread quality of frozen dough, as defined by loaf volume. Mean loaf volumes for frozen dough was lower compared with fresh dough. A significant reduction in loaf volume was also reported by Berglund et al (1991) and Lu and Grant (1999) when frozen doughs were compared with fresh doughs. Nitrogen treatments did not significantly affect mix time or loaf weight for bread made from fresh dough. One possibility was that higher water absorption and dough strength could have led to increased retention of moisture through baking and resulted in heavier loaf weights. However, this was not observed.

CONCLUSIONS

Under North Dakota growing conditions, adding N fertilizer resulted in higher GPC, farinograph water absorption, and longer farinograph arrival and peak times for these genotypes tested. Nonsignificant increases in grain yield were observed for two cultivars for all N treatments and between zero and typical N treatments for the other two cultivars. Loaf volumes increased with N fertilizer treatments for both fresh dough and breads made from frozen dough. Aside from loaf volume of fresh dough, all these effects were evident only between the low and typical N application rates. No other quality traits evaluated in the present study for either fresh or frozen dough were significantly affected by changes in N fertilization. An indication of cultivar × treatment interaction existed for fresh extensigram curve area. Although some of the quality traits evaluated in the study can be increased by additional N fertilization, there was little improvement in these quality traits at higher than typical N application rates and there was no improvement in frozen dough quality. Spring wheat growers in North Dakota should not necessarily need to change N fertilization practices to target improved fresh or frozen dough quality.

Although all cultivars in this study traditionally had above adequate quality for breadbaking, Glupro had the greatest affect on GPC and extensigram curve area for fresh dough. Glupro may be a preferred genotype for fresh and frozen end use quality; however, it also has significantly lower grain yield compared with the other cultivars. This will likely mean that Glupro is not a sound economical choice for growers, even considering that it is more desirable for quality compared with the other cultivars tested.

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