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Title: Influence of Nitrogen Fertilization Management on the Bread Making Quality of Different Wheat Genotypes.

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Breadmaking quality is an important criterion in breeding and development of hard wheat (*Triticum aestivum* L.) cultivars. Improvements in N management are needed to produce superior quality grain and satisfy market demands for protein content. Field experiments with three hard red and two hard white spring wheat cultivars were conducted in 1998 and 1999 at Corvallis and Pendleton, Oregon. Nitrogen rates were varied from 0 to 250 kg N ha^{-1}, applied all at planting, or split between planting and stem elongation. Resulting grain was evaluated for protein content, protein quality, dough handling, and bread-making quality. Grain protein content of the five cultivars increased with increasing levels of applied nitrogen. There was a concurrent improvement in bread-making quality, as indicated by increasing protein quality, loaf volume, loaf crumb score. Use of split nitrogen applications contributed to increased grain protein content at both the intermediate and high N

rates. At the higher N rates, a split application had no apparent influence on protein quality. However, at intermediate N rates, a split application contributed to improvements in protein quality and loaf volume. Nitrogen use efficiency and wheat end-use quality can be improved by using split applications of nitrogen during the crop cycle.

INFLUENCE OF NITROGEN FERTLIZATION MANAGEMENT ON THE BREAD MAKING QUALITY OF DIFFERENT WHEAT GENOTYPES

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Marina Castro Derényi, Author

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IN DEDICATION

To

my husband Carlos A.

our children

Manuel, Joaquín and Francisco

my mother Margarita

my grandmother Klára M.

and

to the memory of my father Oscar E.

INFLUENCE OF NITROGEN FERTILIZATION MANAGEMENT ON THE BREAD MAKING QUALITY OF DIFFERENT WHEAT GENOTYPES

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is grown worldwide as a major contributor to human nutrition. Many end products can be obtained from it, depending on the type of wheat utilized. For bread baking purposes, hard red wheats are commonly used. These are noted for superior protein content and protein quality, as needed to satisfy the demands of both processors and consumers for bread products with superior and consistent quality. Breeding and selection for quality traits is the basis for achieving processing quality, but management practices could be optimized to further improve the intrinsic quality of wheat genotypes (López-Bellido et al., 1998). The possibility of using other classes of wheat for bread baking has been already considered. Hard white wheats are being developed in the Pacific Northwest of the USA for the Asian noodle market. If management practices can be used to increase the quality and quantity of protein, these wheats may also meet the needs of domestic and international bread markets. Breeders, farmers and the Industry are interested in order to diversify the production and marketing options for these genotypes.

Changes in nitrogen fertilizer management practices are one of few strategies that growers can use to impact wheat industrial quality. This nutrient is a critical input in the production of wheat and contributes to higher grain yields. It is a challenge for farmers and breeders to use it efficiently, due both to its cost in the production system

and the potential for pollution of ground and surface water (Clarke et al., 1990, Kanampiu et al., 1997).

The purpose of this study was to determine the influence of varying nitrogen management practices on bread making quality of diverse spring wheat genotypes. The cultivars included two hard red wheat entries released by INIA Breeding Program, Uruguay (INIA Mirlo and INIA Boyero); both possessing the translocation 1BL/1RS from rye. A third hard red cultivar is from California (Yecora rojo), and was included in this study as a check due to its well-recognized industrial quality. Two hard white cultivars were evaluated, 377s developed by the University of Idaho and Winsome from Oregon State University. Both hard white wheats have shown potential for dual-purpose end use (noodles and bread making). This broad range of genotypes, which represent genetic variation in bread-making quality, were a useful tool to assess the magnitude of the cultivar x nitrogen treatment interactions, included the response to N fertilization management of cultivars possessing the 1RS translocation, compared to those that do not have it. A specific issue that was considered in this research was the response to N treatments of grain and flour protein content, compared to protein quality, as measured by SDS sedimentation, mixograph parameters and bread-making characteristics.

2. LITERATURE REVIEW

2.1. Bread-wheat quality

Wheat is unique among cereals grains because of gluten proteins (group of insoluble storage proteins), which, due to specific dough elasticity properties, contribute to make a light, palatable, well-risen loaf of bread. There are three basic quality factors that determine bread type, and those are hardness, gluten strength and protein content. Tipples et al., (1994) defined high-quality bread wheat as the one that has the following properties: protein content that it is at least 115 g kg^{-1} on a 13.5% moisture basis; hard grain texture to achieve target starch damage to meet water absorption needs of the baker; desirable balance of gluten strength; sound grain, with no problems of excessive enzyme activity; and consistency in bread quality over a wide range of processing conditions.

The balance among gluten proteins is important in determining wheat flour functional properties. This fraction is composed by two types of proteins: polymeric glutenins and monomeric gliadins. The first group is divided in high molecular weight glutenins subunits (HMW-GS) or HMW prolamins, and low molecular weight glutenin subunits (LMW-GS), which are sulfur-rich prolamins . Glutenin subunits are coded by genes (loci) on the chromosomes from homeologous group 1 in hexaploid wheats. The loci where the HMW-GS genes are located are designed *Glu-A1* (coding for 0 or 1 subunit), *Glu-B1* and *Glu-D1* (both coding for 1 or 2 subunits), and have been mapped to the long arms of chromosomes A1, B1, and D1, respectively

(MacRitchie, 1992). A total of 24 subunits have been described (Payne et al., 1981; Ng and Bushuk, 1989), including 3 encoded at *Glu-A1*, 14 at *Glu-B1*, and 7 at *Glu-D1*. Certain HMW-GS subunits are associated with negative effects on flour properties, whereas others are associated with positive effects. This last fact could be related to the β-spiral conformational structure of their repetitive domain, which might be conferring the elasticity properties of gluten (Schofield, 1994). Examples of allelic variation at the *A1* locus are subunits 1 and 2* (contributing good quality) and the null allele (giving poorer quality). The same can be seen at *B1* locus, where pairs of subunits 17 + 18 are contrasted for better quality with 13 + 16 or 7 + 8; and at *D1* locus (5 + 10 vs. 2 + 12) (MacRitchie, 1992). Low molecular weight glutenin subunits are encoded by genes on the short arms of chromosomes A1, B1, and D1. These loci are designated *Glu-A3, Glu-B3*, and *Glu-D3*. A total of 40 different B and C subunits were detected, ranging in a given cultivar from 7 to 16 (Gupta and Shepherd, 1990). A preliminary approach to ranking LMW-GS alleles in order of quality has been reported by Gupta et al. (1991). Variation in *Glu-3* alleles of glutenin in addition to *Glu-1* alleles was needed to explain the differences in dough handling properties.

Genes coding for the gliadin polypeptides are located on the short arms of chromosomes from homeologous groups 1 (loci *Gli-A1*, *Gli-B1*, and *Gli-D1*) and 6 (loci *Gli-A2*, *Gli-B2*, and *Gli-D2*) in hexaploid wheat, showing multiple allelism (Wrigley and Shepherd, 1973). Metakovski (1991), based on the analysis of 360 wheat cultivars and 45 crosses, reported 111 gliadin alleles mapping to the 6 gliadin loci.

Albumins and globulins are other kind of proteins found in wheat grains, but they are not part of the gluten complex. They are solubilized and washed away into the water-soluble fraction upon gluten isolation. They consist of numerous metabolic enzymes and hydrolytic enzymes synthesized during seeds development to be used to provide nutrients for the future embryo (Wrigley and Bietz, 1988).

2.2. Physical testing of wheat dough.

Rheological properties of dough that are important for the baker industry include water absorption, mixing requirements (time and energy), mixing tolerance, oxidation response and requirement, and physical dough handling properties such as stickiness. Most of these factors can be estimated with small-scale instruments like the mixograph and the farinograph, which record changes in rheological properties of doughs during mixing. Knowledge of these properties of wheat doughs is critical because they have an economic impact in the bake plants, as they determine the dough's handling characteristics and stability in the bakery, and they also impact consistency and quality of the end product. While these small-scale tests are useful indicators of baking quality, they are not the final measure of the bread. Bread baking is the final and ultimate measure of quality. Different variations in procedures and formulas used by bakers means that bakers often do not agree in flour quality assessment. Some bread quality factors, like loaf volume (LVOL), can be objectively measured by seed displacement in a simple volumetric-measuring device. Other factors are highly subjective as determined by trained lab bakers, like crumb structure

and color (Tipples et al., 1994), which are process and formula dependant. Coles and Jian (1997) developed an objective method for determining crumb visual texture by image analysis, but this has not been widely used in the industry.

2.2.1. The mixograph

The mixograph (National Manufacturing Co., Lincoln, Nebraska) is a relatively high-speed recording dough mixer. Many versions have followed the original model described in 1933 by Swanson and Working, but all have the same basic mode of action: the mixing is provided by four vertical planetary pins revolving at constant speed about three stationary pins in the bottom of a mixing bowl. The capacity of this bowl varies from 400 grams of flour in older versions to as little as two grams in newer models. The instrument records resistance of the dough to extension caused by the pull-fold-repull action of the mixing pins, yielding a mixogram curve over time from which several useful parameters on dough properties are estimated. Peak time (in minutes), at which the curve reaches its maximum height, is a measure of time required for optimum dough development. Tolerance to over mixing is a measure of stability during the process, and it is generally assessed by the width of the curve at a specific time after the peak (Martinant et al., 1998), the angle between the ascending and descending portion of the curve, and/or area under the curve. The actual area of the mixograph gives a measure of work done by the instrument (energy input) (Johnson et al., 1943). Curve height measurements, which are strongly influenced by grain hardness (Martinant et al., 1998), water absorption

and flour protein content, give information about dough consistency. An important parameter in this area is peak height (in centimeters) of the center of the curve from the baseline at the time of maximum height, which gives a general indication of dough "strength".

There is significant variation for mixing and dough handling properties among wheat cultivars, depending on their protein quantity, protein quality, starch properties, and water absorption characteristics of the flour. Thus, the mixograph has been widely used as a breeding tool for predicting mixing requirements, mixing tolerance, and water absorption of wheat genotypes (Johnson et al., 1943). The main advantage for breeders is the speed of the analysis and the low flour requirement for each test, especially in the newer versions.

While the mixograph is useful as a general indicator of dough handling properties and gluten strength, mixograph parameters are not necessarily good indicators of loaf volume potential or loaf quality. Johnson et al. (1943) had found that when compared on a common protein level, there was no relationship between loaf volume and mixograph peak height. Baker and Campbell (1971) observed the contrary. Ammar (1997) found a significant positive correlation between these two parameters, though of low magnitude (0.54). Peak time is often poorly correlated with other mixograph parameters (Martinant et al., 1998), and is not a good predictor of LVOL (Ammar, 1997).

2.2.2. The Farinograph.

The Brabender Farinograph (Brabender OHG, Germany) is widely used as a dough-testing instrument by the milling and baking industries. Mixing action is provided by two sigma-type blades rotating in opposite direction from each other, at different speeds. This type of mixing action is gentler than the one found in the mixograph. Also it has a good control of the operating temperature, which can affect dough properties. Several measurements can be obtained, like peak time (or dough development time), water absorption, and indicators of tolerance to over mixing. This instrument requires a larger amount of flour (50 to 300 grams, depending on the version used), which is a disadvantage for using it in early breeding generations. As for the mixograph, different results have been found in relations between farinograph parameters and bread quality parameters. Baker and Campbell (1971) and Baker et al. (1971) reported a positive correlation between farinograph absorption and LVOL. No clear correlation was found between LVOL and dough development time (Baker et al., 1971).

2.3. Genetic variability

2.3.1. Protein content and quality

The relationship between flour protein content and bread loaf volume is often linear. Simple correlation coefficients between these two variables in hard red spring wheats vary from +0.58 to +0.99 (Johnson et al., 1943; Fifield et al., 1950; Baker and

Campbell, 1971; Baker et al., 1971). Protein content accounts for a large part of the variation in LVOL in a variety. The level and slope of the regression of LVOL on protein content differs for different varieties, indicating variations in protein quality (Fifield et al., 1950). Fullington et al. (1983) and Gupta et al. (1992) have found that the increase in flour protein content can also lead to changes in protein composition. This increased protein content improved flour quality parameters (except water absorption), included an increased ratio HMW: LMW glutenin subunits.

Genetic variation for protein quality among seven Canadian wheat cultivars of six different wheat marketing classes and diverse bread-making quality was described by Sapirstein and Fu (1998). They found relatively little variation in the percentage of flour protein corresponding to monomeric proteins, mainly gliadins (48-52%), and residue protein, mainly *Glu-D1* HWM-GS subunits and nongluten polypeptides (14-18%). Both fractions were poorly associated with breadmaking quality. On the other hand, intercultivar variation in glutenin protein was substantial, with contents of 100-280 g kg^{-1} of flour protein. This fraction accounted for 83-95% of the variation of individual dough rheological parameters (except dough extensibility), and approximately 74% of the variation in loaf volume. The concentrations of glutenin in flour protein are therefore mainly genotypic characteristics. Luo et al. (2000), working with 14 New Zealand wheat cultivars or lines, found similar results, reporting that genotypes were the only significant source for the quantity variation of HMW-GS and LMW-GS.

2.3.2. Genotype x Environment interaction.

Protein concentration, as well as other quality related variables, is both influenced by environmental and genetic factors. Fowler et al. (1990) reported that in Saskatchewan soil types, minimum protein concentration of wheat cultivars was maintained until N was no longer the limiting factor, entering then in an increase phase. Any environmental factor like water or time of N availability, or genotypic factor that increases yield potential, also increases the amount of N required to initiate the increase phase of the grain protein concentration N-response curve. Graybosch et al. (1996) reported significant G x E interactions in quality related parameters for hard red wheats in the Great Plains. Flour protein components differed in their response to environmental and genotypic factors. The most sensitive fractions to environmental fluctuations were flour protein concentration and the percentage of protein present as gliadin and non-gluten proteins. The percentage of protein as glutenin was nearly totally genotype dependent.

Other environmental factors can affect the dough properties of a given wheat genotype, and heat stress even for a few days during grain filling has been found by many authors to be one of them. Randall and Moss (1990) reported that temperature during grain filling is an important source of variation in dough properties, based mainly on glasshouse experiments. They concluded that dough strength increased with increasing temperatures up to about 30°C, and that high temperatures (e.g. short episodes of a few days at > 35°C) produced grain with weaker-than-expected dough properties. Blumenthal et al. (1991a, 1993) have provided evidence from field and

glasshouse experiments that supports the view that episodes of high temperature can be expected to cause weaker dough due to a higher ratio gliadin:glutenin, because gliadin synthesis continues at a greater rate than glutenin synthesis as part as the heat shock response. This change in the normal balance of gluten polypeptides is shown immediately after the heat shock, as well as in the mature grain (Blumenthal et al., 1994). Also heat stress correlated negatively with loaf volume (Blumenthal et al., 1991b). Protein quality, as measured by SDS sedimentation volumes and size-exclusion high-performance liquid chromatography, is highly influenced by the frequency of high temperatures during grain filling and by the relative humidity (Graybosch et al., 1995).

Stone et al. (1997) reported that moderately high temperatures (20-32°C) during grain filling of a heat sensitive wheat genotype, increased flour protein percentage; but significantly decreased dough strength, measured as mixing time and resistance breakdown. A short exposure to very high temperatures (> 32°C) also increased flour protein percentage and reduced dough strength. The effects of moderately high and very high temperatures on dough strength tended to be additive.

Wrigley et al. (1994) reported that a glasshouse experiment involving 45 genotypes of wheat has indicated that there is some variation in the response to heat stress, with a few genotypes being promising sources of tolerance. Blumenthal et al. (1994) working with 45 genotypes have found that the overall mean values for the glutenin:gliadin ratio for all these varieties were 0.74 for the control samples and 0.69 for the heat stressed samples. Though, they have identified a group of genotypes that showed either a very small change or an increase in the glutenin:gliadin ratio. Such

lines indicate a likely source of parental lines for further examination as genetic sources for heat tolerance.

2.3.3. Genetic translocations.

Modern bread wheat originated from a series of natural hybridizations between wild diploids possessing A, B, and D genomes. There are a series of wild relatives of wheat that possess useful genes, and some spontaneous and induced wheat-alien genetic transfers have occurred. One such transfer that has had a worldwide impact on wheat production is the replacement of the short arm of chromosome 1B of wheat by the short arm of chromosome 1R from rye (*Secale cereale* L.) (1BL/1RS) to introduce genes for disease resistance, wide adaptation, abiotic stress tolerance, and improve yield. Unfortunately, hard wheats possessing this translocation have also shown lower SDS-sedimentation values, suggesting decreased protein quality and a decrease in dough development time, thus evidencing a weaker dough, compared with common wheat (Dhaliwal et al., 1987). Other authors (Graybosch et al., 1993), while obtaining the same results for SDS sedimentation values, have found that 1BL/1RS cultivars have lower mixing tolerance than normal lines at comparable mixing time. Also, the doughs made from them tend to be sticky when exposed to over mixing (Friebe et al., 1996). This deterioration in industrial quality is due to loss of several loci encoding the gluten fraction of the storage proteins, which are located in the short arms of chromosomes Group 1 of wheat (Payne, 1987), and their replacement by secalins. Graybosch et al. (1993) quantified this effect, showing that the flour protein

composition of 1BL/1RS lines used in their research had 31.14% glutenins and 27.85% gliadins compared with common wheat lines, which had 45.45% and 31.21%, respectively. The 1RS arm carries locus *Sec-1,* encoding secalins, which do not belong to the gluten fraction (Shewry et al., 1985), and do not adequately compensate for the loss of gluten proteins in bread-making.

Selection of the most favorable alleles for quality at glutenin loci not involved in the translocation (both HMW and LMW-GS) is a potential strategy to compensate the detrimental effects of this translocation (Rosa, 1997). Crosses involving high yielding 1BL/1RS wheats and good bread making genotypes can produce new lines with favorable agronomic and quality characteristics (Peña et al., 1990). Lee et al. (1995) suggested potential for improvement by combining 1RS lines with parents possessing higher levels of glutenins and gliadins, and non-1RS lines with strong gluten type. Recently, genetic modifications by induced homoeologous recombination have been proposed to overcome the quality defects associated with the 1BL/1RS translocation. Manipulations on the 1RS arm adding two intercalary segments of 1BS have the effect of introducing the *Gli-1/Glu-3* loci, and removing the *Sec-1* locus, while leaving the disease resistance loci of interest (Lukaszewski, 2000).

2.4. Nitrogen fertilizer management.

2.4.1. Effects on grain yield and plant development.

2.4.1.*1. Levels of nitrogen*

Nitrogen (N) is one of the six macronutrients essential for plant development (Havlin et al., 1999b). Nitrogen deficiencies may lead to stunting, scleromorphism, shoot/root ratio shifted towards roots, and premature yellowing of old leaves (Wallace, 1951 cited by Larcher, 1995). Wheat grain yields generally respond to increasing levels of N, up to the point were this nutrient is no longer the limiting factor (Terman et al., 1969). N levels above this point contribute to increase grain protein content (Fowler and Brydon, 1989; Gauer et al., 1992; López-Bellido et al., 1998). However, when maximum grain yield is achieved, utilization efficiency (N uptake per unit N applied, NUE) decreases, so applying high rates of N fertilizer to increase grain protein content, may not be efficient from both the biological and economical point of view (Gauer et al., 1992).

2.4.1.*2. Timing of nitrogen application.*

Management strategies that could be used to improve the use efficiency of N fertilizer include different timing of application throughout the wheat-growing season (Havlin et al., 1999a). Alcoz et al. (1993), working in south-central Texas with hard red winter wheat, reported that more total recovery of added N (measured as total N concentration in plant tissue and grain samples), and thus lower surface soil NO_3^-

concentrations, were found when N is split between preplant and GS 10 (Feekes' scale), rather when all N is applied preplant.

Stark and Tindall (1992) suggested that little information is available on N fertilizer timing effects on yield and quality of spring wheat varieties adapted to the Pacific Northwest (PNW) of the United States of America (USA). Research on this topic from other regions is not directly transferable, because of the type of soils and humidity particular conditions of the PNW. The results of the work of these researchers indicate that, for irrigated hard red spring wheat, maximum grain yield, test weight (TWT) and grain protein content can be obtained by applying the bulk of seasonal N requirement at planting (60 to 120 kg N ha^{-1}) combined with split applications (30 kg N ha^{-1}), either at anthesis (Feekes stage 10.5) alone, or stem elongation (Feekes stage 7) and anthesis. If there is an initial N deficit and N is applied only at ear emergence, grain yield may decrease, as yield components are impacted (Mellado, 1990; 1993). Application of supplemental N at early double ridge stage has been shown to increase the number of grains per ear (Langer and Liew, 1973), thus increasing grain yield (Peltonen, 1992). Similar increases in grain yield have been shown when 50% of the N fertilizer is applied at planting and the other half at the end of tillering (Mellado, 1996). Other researchers (Ayoub et al., 1994b) reported that splitting N application 60% at planting and 40% at heading, had little effect on grain yield, but decreased the risk of lodging while decreasing number of tillers m^{-2} and spikes m^{-2}, and increases kernel weight as well as TWT (Randall et al, 1990).

2.4.2. Effects on grain protein content.

2.4.2.*1.* *Levels of nitrogen.*

A major concern in the PNW of the USA for growing hard wheat cultivars is achieving acceptable grain protein levels (135 g kg^{-1}) for marketing, while maintaining grain yield levels comparable to that of the predominant soft white wheat classes (Altman et al., 1983). Some times, a negative correlation can be seen between grain yield and grain protein content (Bhatia, 1975; Loffler et al., 1985). Miezan et al. (1977) concluded that genetic effects influence grain protein as effectively as the environment. Thus, increments in grain protein content in wheat can be obtained by breeding without sacrificing grain yield. It has been reported that wheat genotypes with a given harvest index (HI) and a relatively high nitrogen harvest index (NHI), tend to have a higher grain protein content. Lines possessing this characteristic could be used as parents in designed crosses (Loffler et al., 1985) to increase genetic potential for higher grain protein content.

2.4.2.*2.* *Timing of nitrogen application.*

Split application of N fertilizer in some regions has shown to be an effective way of increasing grain protein content in hard red wheats. Strong (1986); working with spring wheat in Australia, and Zebarth and Sheard (1992), working with hard red winter wheat in Ontario, found that supplemental N applications at tillering, stem elongation, and booting, increased grain protein content. Dubetz (1977), in southern

Alberta, and Miezan et al. (1977), in Kansas, found similar results when supplemental N was applied at flowering. Even additions of supplemental N to spring wheat as late as pollination stage in Finland, seems to stimulate the synthesis of protein and storage proteins in the endosperm (Peltonen, 1992). One of the few researches done in the PNW utilizing hard red winter wheat, reported that N applied at flowering increases grain protein content (Altman et al., 1983). Substantial information for this kind of management for hard red spring wheat in this region is lacking.

2.4.3. Effects on bread making quality.

2.4.3.*1. Levels of nitrogen.*

N fertilizer may have as much, or more, marked effect on wheat quality parameters than on grain yield (López-Bellido et al., 1998). Increasing N rates in hard red spring wheats contributed to increased flour protein concentration and flour water absorption (Ayoub et al., 1994a). In a long term wheat trial established in Italy, Borghi et al. (1995) have found that much higher levels of N fertilizer (200 kg N ha^{-1}) are required to achieve high protein concentration and optimize bread making quality, than the one needed to obtain maximum grain yield (100 kg N ha^{-1}). However, very high protein contents (over 170 g kg^{-1} at a 13.5% moisture basis) is some times associated with deterioration in baking quality: decrease in mixing times evidencing weaker dough, increase in flour color, and opening of the crumb structure (Tipples et al., 1977). Also, Bushuk et al (1978) found that, for Neepawa hard red spring wheat

flour samples with a protein content range of 93 to 164 g kg^{-1} at a 14% m.b., LVOL decreased with increased N fertility in the top protein range. Under some environmental conditions as high nitrogen availability, the rates of the synthesis of different protein components are affected differently. The increase in the ratio of soluble glutenin to insoluble glutenin (residue protein) found in this study at the high protein level, seems to explain the major portion of the decrease in bread-making quality per unit of protein.

2.4.3.2. *Timing of nitrogen application.*

Split application of N fertilizer between planting and heading to Australian wheat cv. Matong has been shown to increase water absorption, LVOL, dough development time and extensibility (Randall et al., 1990). Also, splitting N at flowering stage in hard red spring wheat in Eastern Canada has shown an improvement in quality by means of an increase in flour protein concentration, LVOL, and improved dough mixing tolerance compare to a single application (Ayoub et al., 1994a). This demonstrates that extra protein synthesized late in the wheat growing season can be functional protein contributing to the baking characteristics in an additive manner (Randall et al., 1990). However, as was seen in the previous section, there are reports of baking quality declining at very high protein levels, which can be achieved with the split management of the N fertilizer, under certain environmental conditions, and in certain regions. Thus, more investigation should be done to adjust this kind of management to obtain the desired results.

No information exists regarding the response in industrial quality of bread type hard red and hard white spring wheats to N fertilizer management in the Pacific Northwest of USA, a region with particular growing conditions. There is interest among breeders, farmers and the Industry to explore genetic resources and management practices that can diversify the production and marketing options for wheat in the region.

3. MATERIALS AND METHODS

3.1 Genotypes

Five spring wheat (*Triticum aestivum* L.) cultivars were chosen for evaluation in this study to represent a broad range of genotypes and genetic variation in bread-making quality. INIA Mirlo and INIA Boyero are hard red spring cultivars, released in 1995 and 1998 respectively, by the National Institute for Agriculture Research (INIA) Wheat Breeding Program, Uruguay. I. Mirlo is a high grain yielding cultivar, and based in industry acceptability parameters, it has adequate, but not remarkable, French bread baking quality. Its pedigree is: Car853/Coc//Vees/3/Ures, and in 1999 it accounted for 30% of the wheat production area in Uruguay. I. Boyero is a medium grain yielding cultivar, but recognized for outstanding and stable bread baking quality. Its pedigree is: Mn72131/Bobwhite, and in 1999 it represented 2% of the wheat production area in Uruguay. Both cultivars have the 1BL/1RS translocation. Yecora Rojo, a hard red cultivar released in 1975 by the California Agricultural Experiment Station, is a selection from the Bluebird family of cultivars having the parentage Ciano 67 /2/ Sonora 64 / Klein Rendidor /5/ (II-8156, (Frontana /2/ Kenya 58 / Newthatch /3/ Norin 10 / Brevor, II-7078) /4/ Gabo 55) (Qualset et al., 1985). It was included as an adapted check variety, known for its good bread baking quality. The remaining two cultivars are hard white spring wheats. Idaho 377s was released by the Idaho Agricultural Experiment Station in cooperation with the USDA-ARS. It was derived from the cross Chova/59Ab10293-5, where the later experimental line has the

pedigree Norin 10/Brevor//Baart/Onas (Souza et al., 1997). In 1999, 50,000 ha of this cultivar were sown in the United States (Montana, Idaho, Washington, Oregon, and Utah). Winsome was released by the Oregon State University Wheat Breeding and Genetics Program in February 2000, and its pedigree is Hork's'/Yamhill//Kalyansona/Bluebird. Both cultivars have acceptable bread quality, and have shown promise for use in Asian noodle products.

3.2 Field experiments

Experiments I and II were conducted at Oregon State University Crop Science Field Laboratory at Hyslop Farm (Corvallis, OR) during the spring-summers of 1998 and 1999 respectively. Experiment III was carried out at the Barnett-Rugg Farm (Northwest of Pendleton, OR) during 1999. The soil type at Hyslop Field Laboratory corresponds to the Woodburn Series (fine-silty, mixed, superactive, Aquultic Argixerolls) (Knezevich, 1975). The Barnett-Rugg Farm (Pendleton) has a soil type corresponding to the Walla Walla Series (coarse-silty, mixed, superactive, mesic Typic Haploxerolls) (Johnson and Makinson, 1988), and it is representative of the primary wheat-producing region in Oregon. The previous crops were: spring wheat (Exp. I), winter red clover for green manure (Exp. II) and green peas (Exp. III). Based on soil tests of the 0 – 30 cm zone of the profile, the initial Nitrogen (N) levels prior to planting for Exp. I were 10.4 kg N ha^{-1}, and for Exp. II, 26.0 kg N ha^{-1} (Table 1). Thus, both were expected to be N response sites. Ninety kg N ha^{-1} (as Aqua ammonia) and 17 kg Sulfur (S) ha^{-1} (as Thiosul) were applied prior to planting at the Barnett-

Table 1. Soil test results prior to planting.

Exp.	Depth (cm)	pH	P	NH_4_N	NO_3_N	SO_4_S	Incub.N	NO_3_N
			----------(ppm)----------				(mg N kg^{-1})	(kg ha^{-1})
I	0 – 15	6.4	157	3.1	2.7	7.2	18.5	5.4
	15 – 30	6.3	160	2.6	2.5	5.1	15.9	5.0
II	0 – 15	6.5	129	12.0	5.1	27.9	22.3	10.2
	15 – 30	6.6	117	10.0	7.9	28.5	15.3	15.8
III	0 – 15	6.0	37	6.9	13.1	37.5	33.3	26.2
	15 – 30	6.2	27	3.4	15.2	58.2	9.6	30.4

Rugg site, for Experiment III. However, N levels at planting were 56.6 kg N ha^{-1}, higher than in the other two. Phosphorus (P) and S were not limiting nutrients at any of the experimental sites (Table 1).

The experimental design used for Exp. I was a Randomized Complete Block design (RCBD) with three replications. Wheat cultivars received N application of 0, 150 or 250 kg N ha^{-1} in the form of Urea. In the 150 and 250 N levels, the fertilizer was applied all at seeding or 50 kg N ha^{-1} at stem elongation (Feekes stage 6 to 7; Large, 1954) and the rest at seeding. Experiment II had a Split-split plot design with four replications. The treatments were: the cultivars (sub-sub-plots) received nitrogen range applications of 50, 150, 200 or 250 kg N ha^{-1} (total N: main plots) in the form of Urea, either applied all at seeding or 50 kg N ha^{-1} at stem elongation and the rest at seeding (timing: sub-plot). Experiment III had a Split-plot design with four replications. Nitrogen range applied to wheat cultivars was 50, 100, 150 or 200 kg N ha^{-1} in the form of Ammonium nitrate, either applied all at seeding or 50 kg N ha^{-1} at stem elongation and the rest at seeding. The fertilizer was broadcasted by hand in all cases.

The plots had six rows spaced 25 cm apart, trimmed to uniform length at harvest. Plots dimensions in Exp. I were 150 by 410 cm; in Exp II, 150 by 450 cm; and in Exp. III, 150 by 430 cm. The plots in Hyslop Farm (Exp. I and II) were sown at 388 seeds m^{-2}, and in the Barnett-Rugg Farm (Exp. III), at 288 seeds m^{-2}, according to the recommended rate for each location. Planting was conducted on 16th and 15th April for Exp. I and II respectively. Exp. III was sown on 24th March.

In order to avoid stripe rust (*Puccinia striiformis*) and leaf rust (*Puccinia recondita*), Exp. I received three fungicide applications. Propiconazole (0.148 kg a.i.ha^{-1}) was used twice and Bayleton® (0.56 kg ha^{-1}), once. The other two experiments did not required fungicide application, as growing conditions were not favorable for disease development. In Exp. I and III, weed control was maintained by the application of Harmony Extra® (0.028 kg ha^{-1}). Exp. III also received an application of Bronate® (1.17 l ha^{-1}). Weed control in Exp. II was further maintained by hoeing.

Irrigation was used in all experiments to avoid water stress.

3.3 Collection of data

Agronomic data, grain protein content, and SDS sedimentation values were collected from all replications of each experiment to provide the following measures:

Plant height (H): Distance (in cm) from soil surface to the tip of the tallest spikes, including awns.

Grain yield (Y): Weight of the grain harvested in the plot area with a combine machine, and reported as kg ha^{-1}. Moisture content was determined with an Infratec Grain Analyzer (Near Infrared Transmit, Techator). Yield data was adjusted to a 10% moisture level.

Thousand-kernel weight (TKW): A clean sample of 400 random kernels from each plot was weighed and this result multiplied by 2.5. Results were reported in grams.

Test weight (TWT): Weight of one liter of clean grain from each plot. Results were reported in kg hl^{-1}.

Biomass per unit area, harvest index (HI), and yield components (spikes m^{-2}, grains m^{-2}, grains $spike^{-1}$), were derived from the data obtained for aerial biomass and grain weight of 50 tillers, modified from Sayre et al., 1997. These tillers were sampled at random before harvest, and air-dried. The dry samples were weighed, threshed, and the resulting grain weight recorded.

Grain samples from each plot were ground in an UDY-Cyclone mill equipped with a 1 mm opening size screen. These ground samples were used to determine total grain protein content and to perform the SDS-sedimentation test.

Total grain protein content (GPROT): Was determined at the Pendleton Flour Mill's Laboratory, using a LECO FP-528 Combustion Nitrogen Analyzer, with a Nitrogen: Protein factor of 5.7. Results were given at 12% moisture basis, and reported on a dry weight basis (dwb) in g kg^{-1}.

SDS-sedimentation test (SDS): Gluten strength was evaluated by measuring the height (in mm) of the sediment resulting from performing a Sodium Dodecyl Sulfate – sedimentation test on 1 gram of ground wheat.

3.3.1. Milling conditions

Samples from two replications of each experiment were used for milling and baking analysis.

Prior to milling, 500 g of wheat samples were tempered to 15 – 16 % moisture for 24 hours. Tempering was performed in one liter bottles containing 500 gram of grain and inverted with a mechanical rotor for three hours upon addition of the

appropriate amount of water to reach the desired 15-16 % moisture level, calculated after measuring the moisture content of the grain. For this purpose, a Dickey John moisture meter or an Infratec Grain Analyzer (Near Infrared Transmit, Techator) was used.

Tempered grain was milled in a Quadrumat Senior mill (Brabender Gmbh. Duisburg, Germany). The bran and "shorts" fractions were discarded after weighing, and the reduction and break flours were collected and weighed separately. Afterwards, they were mixed thoroughly to yield a straight flour on which all further quality analysis were performed. Subsequent evaluations were conducted at the USDA-ARS Western Wheat Quality Laboratory (WWQL). Flour samples were stored in moisture-proof containers.

3.3.2 Flour yield

Flour yield was estimated as the proportion of the total flour fractions that correspond to reduction plus break flours, expressed in percentage.

3.3.3 Flour protein content

Flour protein content was determined using a LECO Combustion Nitrogen Analyzer according to A.A.C.C. method 46-30 (A.A.C.C. Approved methods, 9th edition, 1995). Results were given on a 14 % moisture basis, and reported in a dry weight basis, in g kg^{-1}.

3.3.4. Mixing properties

Mixing properties were evaluated using a National 10 g mixograph according to A.A.C.C. method 54-40A (A.A.C.C. Approved methods, 1992). Several parameters were measured from the mixograph curve: optimum mixograph water absorption at 14 % moisture (MABS, in ml), time to peak dough development (P, in minutes), peak at optimal development height (PHT, in mm), angle of the trace's medium line after the peak (A), and width of the trace two minutes after the peak (W, in mm). The latter two variables are considered as measures of tolerance to over-mixing.

3.3.5. Baking performance evaluation

Baking performance was evaluated by performing a bake test according to the straight-dough method used at the WWQL. Optimum mixing time (MT, in minutes), and bake water absorption at 14 % moisture basis (BABS, in ml) correspond to those resulting in a dough with optimum handling characteristics, as judged by an experienced baker. Loaf volume (LVOL, in cc) was determined by rapeseed displacement on fresh loaves. A subjective crumb score (1 for excellent to 9 for very poor) was assigned to each loaf to describe the suitability of the crumb structure.

3.4 Statistical analysis

Statistical analysis were performed using the SAS computer software (The SAS Institute, Cary, NC). Analysis of variance for all traits was performed with the

General Linear Model (GLM) procedure, using first data for each experiment separately. Cultivars, total N and timing were considered as fixed effects; and replications as random effects. A combined analysis was performed using experiments I and II because of their similar initial fertility level in the soil (Table 1). Nitrogen rates of both experiments were combined in low (0 kg N ha^{-1} Exp. I, and 50 kg N ha^{-1} Exp. II), intermediate (150 kg N ha^{-1}, both experiments) and high (250 kg N ha^{-1}, both experiments) levels of N, assuming a RCBD for the analysis of variance. Experiment III was not included in this combined analysis, because the initial nitrate levels of the soil were much higher than in Exp. I and II, thus being expected a different response pattern.

Associations between traits of interest were further investigated by computing Pearson's correlation coefficients for least square means from each experiment separately.

4. RESULTS AND DISCUSSION

Analysis of variance, least square means, and simple correlation coefficients between selected traits are presented in the following sections. A combined Analysis of Exp. I and II was performed to show the consistency of the results. Exp. III was not included in the Combined Analysis because the initial fertility of the soil in this case was much higher than in Exp. I and II (Table 1), thus being expected a more limited response pattern.

4.1. Experiment I, Corvallis 1998.

4.1.1. Response to nitrogen treatments

The different levels of nitrogen (N) applied in this Experiment (0, 150 and 250 kg N ha^{-1}) affected in different ways agronomic and industrial quality indicators wheat variables, as shown in the analysis of variance Tables 2a, 2b and 2c.

Significant differences between all N levels were observed for test weight (TWT) and grain protein content (dry weight basis) (GPROT) (Table 2a). Grain characteristics such as TWT, thousand-kernel weight (TKW), and, more indirectly, GPROT, are believed to influence milling performance. TWT was higher in the low level of N and decreased with increasing N (Table 3a). These results coincide with those found by López-Bellido et al (1998), under rainfed Mediterranean conditions. One possible reason for this decrease is that the tillering ability of the plants was affected by N availability. At the low N level, plants had fewer tillers and the main

Table 2a. Analysis of variance for grain yield (Y), test weight (TWT), thousand-kernel weight (TKW), grain protein content (dry weight basis) (GPROT), and sedimentation value (SDS), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Randomized Complete Block Design at Hyslop Farm, near Corvallis-Oregon, in 1998.

Source of variation	df	Mean squares				
		Y	TWT	TKW	GPROT	SDS
Rep	2	332361**	0.05	2.89	46*	38.64*
Control	1	72859053**	52.04**	140.69**	13639**	2206.33**
S	1	17781	4.76**	2.35	860**	14.93
N	1	132593	5.22**	0.59	915**	1.52
S x N	1	98647	0.33	0.26	096*	51.51*
C	4	1191647**	4.06**	143.01**	2015**	921.27**
C x Control	4	566752**	0.71*	23.96**	82**	55.40**
S x C	4	44832	0.46	0.94	6	3.22
N x C	4	26639	0.40	4.67	61**	17.47
S x N x C	4	71920	0.06	0.38	7	15.14
Error	47	54464	0.25	3.03	14	10.44
Total	73					

Rep = replications; N = total N; S = N splitting; C = cultivars.
Control : comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 2b. Analysis of variance for flour yield (FYIELD), flour protein content, dry weight basis, (FPROT) and mixograph parameters [water absorption (MABS), time to peak (P), peak height (PHT), angle of the trace's medium line after the peak (A), and width of the trace two minutes after the peak (W)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Randomized Complete Block Design at Hyslop Farm, near Corvallis-Oregon, in 1998.

		Mean squares						
Source of variation	**df**	**FYIELD**	**FPROT**	**MABS**	**P**	**PHT**	**A**	**W**
Rep	1	1.96	23	3.33*	0.20	50.00*	3.38	2.00
Control	1	48.22**	6741**	39.78**	0.0002	796.01**	136.13**	1.81
S	1	8.65**	740**	1.09	0.08	60.03*	75.63**	4.23
N	1	3.48	470**	10.40**	0.23	105.63**	99.23**	1.23
S x N	1	4.76*	044	0.23	0.17	50.63*	5.63	0.03
C	4	59.99**	1322**	2.47**	11.93**	121.01**	208.01**	47.47**
C x Control	4	1.29	60**	0.74	0.35	35.41**	11.54	3.32
S x C	4	0.71	20	1.55*	0.24	3.40	15.19	1.66
N x C	4	2.62	35	0.53	0.18	6.75	12.04	1.66
S x N x C	4	1.31	6	0.65	0.06	13.63	26.69*	1.59
Error	24	1.09	13	0.50	0.23	8.00	8.09	2.25
Total	49							

Rep = replications; N = total N; S = N splitting; C = cultivars.
Control = comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 2c. Analysis of variance for bread-making quality parameters [bake water absorption (BABS), optimum mixing time (MT), loaf volume (LVOL), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Randomized Complete Block Design at Hyslop Farm, near Corvallis-Oregon, in 1998.

		Mean squares			
Source of variation	**df**	**BABS**	**MT**	**LVOL**	**BCRGR**
Rep	1	1.25	0.10	13945*	0.32
Control	1	30.97**	0.56	281625**	85.81**
S	1	1.26	0.63**	12426*	5.63**
N	1	2.97	0.12	9456*	4.23*
S x N	1	0.16	0.44*	2326	0.23
C	4	6.15**	13.88**	31422**	13.88**
C x Control	4	1.63	0.35**	3881	1.77*
S x C	4	1.85	0.03	732	1.19
N x C	4	3.55	0.08	1490	0.54
S x N x C	4	3.02	0.17	710	0.54
Error	24	1.31	0.08	1810	0.57
Total	49				

Rep = replications; N = total N; S = N splitting; C = cultivars.
Control = comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 3a. Observed least square means for grain yield (Y) (kg ha^{-1}), test weight (TWT) (kg hl^{-1}), thousand-kernel weight (TKW) (grams), grain protein content (dry weight basis) (GPROT) (g kg^{-1}), and sedimentation value (SDS) (mm), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in randomized complete block design at Hyslop Farm, near Corvallis-Oregon, in 1998.

N levels (Kg N ha^{-1})		Y	TWT	TKW	GPROT	SDS
0		2986	83.1	50	114.7	51
150 - 0	**P**	5388	81.6	46	139.5	63
100 – 50	**S**	5433	81.1	46	149.6	66
	(P-value)	*(0.6184)*	*(0.0302)**	*(0.6169)*	*(<0.0001)***	*(0.0081)***
	Mean	5411	81.4	46	144.6	65
250 - 0	**P**	5563	81.1	46	149.9	65
200 - 50	**S**	5446	80.4	46	155.0	64
	(P-value)	*(0.2604)*	*(0.0014)***	*(0.4003)*	*(<0.0001)***	*(0.5083)*
	Mean	5505	80.8	46	152.5	65
General Mean		4960	81.5	47	141.6	62
C.V. (%)		*4.71*	*0.62*	*3.72*	*2.65*	*5.23*

P = N applied at planting
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

shoots developed bigger spikes than in the intermediate and high level of N. These spikes did not have much interplant competition, yielding more grains per spike (data not shown) and heavier grains than in the other N treatments. Increasing amounts of N also delayed maturity in some cultivars, especially the hard red ones. Thus, the grain filling period took place during hotter and drier days, reducing kernel size and test weight.

Grain protein and flour protein content (FPROT) increased with increasing N levels (Tables 3a, 3b), coinciding with the results reported for six spring wheat cultivars by Gauer et al. (1992). Grain protein content was increased on average 26 % with the addition of 150 kg N ha^{-1}, and an additional 5 % increment was obtained with 250 kg N ha^{-1}. Similar situation was found for FPROT, where the increment obtained with 150 kg N ha^{-1} applied was 24 %, and an additional 5 %, with 250 kg N ha^{-1}. Nitrogen applications also impacted end-use quality as evidenced by differences observed in dough-handling and bread-making variables (Tables 2b and 2c). Mixograph parameters like optimum water absorption (MABS) and peak height (PHT) increased with increasing N levels, while angle of the trace's medium line after the peak (A), decreased. Width of the trace two minutes after the peak (W), which is considered a measure of tolerance to over-mixing (quality indicator), was not affected by the different levels of N. Changes in MABS, PHT, and A, without changes in W (Table 3b), suggest changes in mixing properties were primarily related to enhanced protein quantity rather than protein quality.

Crumb score (BCRGR) and loaf volume (LVOL), an important measure of the bread (end product in this case), were the only bread-making variables that showed an

Table 3b. Observed least square means for flour yield (FYIELD) (%), flour protein content, dry weight basis (FPROT) (g kg^{-1}), and mixograph parameters [water absorption (MABS) (ml), time to peak (P) (minutes), peak height (PHT) (mm), angle of the trace's medium line after peak (A) (degrees), and width of the trace two minutes after the peah (W) (mm)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a randomized complete block design at Hyslop Farm, near Corvallis-Oregon, in 1998.

N levels (Kg N ha^{-1})	FYIELD	FPROT	MABS	P	PHT	A	W
0	56.9	106.9	57.4	4.3	51	82	13
150- 0 P	58.3	127.1	58.8	4.4	57	81	14
100-50 S	59.9	137.8	59.3	4.3	61	78	13
(P-value)	(0.0054)**	(<0.0001)**	(0.2794)	(0.8542)	(0.0004)**	(<0.0001)**	(0.2033)
Mean	59.1	132.5	59.1	4.4	59	80	14
250- 0 P	59.6	136.1	60.0	4.1	62	77	14
200-50 S	59.8	142.6	60.2	4.3	62	75	13
(P-value)	(0.5542)	(0.0004)**	(0.4629)	(0.2500)	(0.8928)	(0.3233)	(0.3680)
Mean	59.7	139.4	60.1	4.2	62	76	14
General mean	58.9	130.1	59.1	4.3	59	79	13
C.V (%)	1.78	2.82	1.20	11.16	4.82	3.62	11.30

P = N applied at planting.
S = N split between planting and stem elongation.
** - Significant at 1 % level.

improvement with levels of N. From zero to 150 kg N ha^{-1} applied to the experiment, LVOL was increased on average 26 %. An additional 4 % increment in LVOL was obtained with the application of 250 kg N ha^{-1} (Table 3c). Sedimentation volume (SDS), a reliable predictor of loaf volume (Lorenzo and Kronstad, 1987) and an indicator of protein quality, showed a significant increase from zero to 150 kg N ha^{-1} applied, but there was no additional increase when N was increased to 250 kg N ha^{-1}.

Significant increases in GPROT, FPROT and LVOL without concurrent increases in SDS, and mixograph tolerance (W), suggest that the N levels affected the protein of the cultivars by increasing its quantity more than impacting its quality. However, the significant increases in LVOL with increasing N levels, show that protein quantity also impacts in a positive way the end-product of bread wheat.

4.1.2. Response to timing of nitrogen application.

The timing when the N fertilizer was applied, either all at planting or split between 50 kg N ha^{-1} at stem elongation and the rest at planting, influenced GPROT, FPROT and TWT (Tables 3a and 3b). Grain and flour protein content increased on average 6 % with split application at both N levels of N. However, TWT decreased 1%. Miezan et al. (1997) found similar responses for GPROT in winter x spring wheat lines in Kansas, and Ayoub et al. (1994a) also showed improvement in FPROT with split N application in Eastern Canada. In the first study, the split application of N was done at blooming stage, and in the second one, at anthesis. However, Ayoub et al. (1994b) and Randall et al. (1990) found an increase in TWT with a split application of

Table 3c. Observed least square means for bread-making quality parameters [bake water absorption (BABS) (ml), optimum mixing time (MT) (minutes), loaf volume (LVOL) (cc), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a randomized complete block design at Hyslop Farm, near Corvallis-Oregon, in 1998.

N levels (Kg N ha^{-1})	BABS	MT	LVOL	BCRGR
0	61.7	4.8	665	9
150- 0 P	63.3	4.8	812	6
100-50 S	63.5	4.4	863	5
(P-value)	*(0.6426)*	*(0.0033)***	*(0.0111)**	*(0.0370)**
Mean	63.4	4.6	838	6
250- 0 P	63.7	4.5	858	5
200-50 S	64.2	4.5	878	5
(P-value)	*(0.4549)*	*(0.7270)*	*(0.2394)*	*(0.1501)*
Mean	64.0	4.5	868	5
General mean	63	4.6	815	6
C.V (%)	*1.81*	*6.02*	*5.22*	*12.42*

P = N applied at planting.
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

N at heading stage. There was no response of grain yield to timing of N application. There was adequate N to express the yield potential of the wheat cultivars at both N levels. The TWT decrease with late N application could be related to changes in maturity. The split application delayed a few days the maturity of the plots, but less than with the increasing levels of N.

A significant interaction between N levels and timing of the N applications was seen for some variables (Table 2a, 2b, 2c). Within the first level of N applied (150 kg N ha^{-1}), the application of N at stem elongation showed a significant improvement in SDS (Table 3a), flour yield (FYIELD), PHT (Table 3b), LVOL, BCRGR (Table 3c), and a decrease in A (Table 3b) and optimum bake mixing time (MT) values (Table 3c). Split application at the higher N level (250 kg N ha^{-1}) did not have any influence on these variables as compared with the single application at planting.

The response of SDS, LVOL and BCRGR to splitting at the intermediate level of N suggests a concurrent improvement in GPROT quality, and quantity.

4.1.3. Response of cultivars to nitrogen treatments

Wheat cultivars used in this study were genetically diverse for agronomic and end-use quality traits. Two of them were spring hard white (Winsome and Idaho 377s), and the other three were spring hard red (I. Mirlo, I. Boyero, and Yecora Rojo). I. Mirlo and I. Boyero had the chromosomal rye translocation 1BL/1RS. On average in this experiment, Winsome had 16 % superiority in grain yield compared to Idaho 377s, which yielded the lowest of the five cultivars. Winsome had the lowest GPROT,

and I. Mirlo had the highest GPROT (23 % superiority compared to Winsome) (Table 4a). However, I. Mirlo showed the lowest SDS value, 47 % less than Yecora Rojo, the standard variety for end-use quality (Table 4b). This apparent inconsistency between GPROT and SDS values in I. Mirlo, is probably the result of the genetic background of this variety, where the 1BL/1RS translocation might be affecting protein quality, as reported by Dhaliwal et al. (1987). This effect was not seen in I. Boyero, the other variety possessing the 1BL/1RS translocation, suggesting that the translocation per se is not always a quality detrimental factor. Yecora Rojo had the highest LVOL, being 20 % superior than Winsome, the variety with the lowest LVOL.

I. Boyero showed a significant increase in grain yield with the timing treatment in the intermediate level of N. The same occurred with Winsome and Idaho 377s for GPROT. This last cultivar also showed a significant increase in SDS with the split application of N at the intermediate N level.

The only two cultivars that had a significant increment in LVOL through all the N levels with the timing treatment were Idaho 377s and Yecora Rojo.

4.1.4. Cultivar x timing interactions

The interaction of cultivar x timing was significant only for MABS. For all the other quality variables, but A (the three way interaction was significant also), the cultivars used in this study responded similarly to the split application of N.

Table 4a. Observed least square means for grain yield (Y) (kg ha^{-1}), and grain protein content (dry weight basis) (GPROT) (g kg^{-1}), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments in randomized complete block design at Hyslop Farm, near Corvallis-Oregon, in 1998.

N levels (kg N ha^{-1})	Y					GPROT				
	Id377s	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**	**Id377s**	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**
0	3423	3386	2640	2608	3055	100.0	107.9	135.3	123.9	106.4
150 – 0 P	4927	5839	5463	5202	5517	132.2	126.6	159.0	149.2	129.5
100 – 50 S	4666	6103	5496	5328	5571	141.3	137.3	167.7	158.8	143.1
(P-value)	*(0.0635)*	*(0.5237)*	*(0.8629)*	*(0.0419)**	*(0.8127)*	*(0.0003)***	*(0.0423)**	*(0.3337)*	*(0.3930)*	*(0.1000)*
Mean	4797	5971	5480	5265	5544	136.8	132.0	163.4	154.0	136.3
250 - 0 P	4998	6009	5664	5508	5636	144.4	138.6	165.6	154.4	146.4
200 – 50 S	4904	5832	5474	5172	5848	153.1	142.0	169.2	159.1	151.5
(P-value)	*(0.7455)*	*(0.6046)*	*(0.2536)*	*(0.1459)*	*(0.2311)*	*(0.1000)*	*(0.1166)*	*(0.2874)*	*(0.0554)*	*(0.1119)*
Mean	4951	5921	5569	5340	5742	148.8	140.3	167.4	156.8	149.0
General mean	4391	5093	4563	4404	4780	128.5	126.7	155.4	144.9	130.6

P = N applied at planting
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 4b. Observed least square means for sedimentation value (SDS) (mm), and loaf volume (LVOL) (cc), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments in randomized complete block design at Hyslop Farm, near Corvallis-Oregon, in 1998.

N levels (Kg N ha $^{-1}$)	SDS					LVOL				
	Id377s	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**	**Id377s**	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**
0	43	58	40	53	60	603	603	670	680	770
150 – 0 P	63	68	51	65	71	783	765	803	780	930
100 – 50 S	70	70	49	69	72	860	815	848	808	983
(P-value)	*(0.0310)**	*(0.1917)*	*(0.3828)*	*(0.4208)*	*(0.6035)*	*(0.0205)**	*(0.0635)*	*(0.0704)*	*(0.2716)*	*(0.0303)**
Mean	67	69	50	67	72	822	790	826	794	957
250 - 0 P	64	68	50	68	74	870	840	850	788	943
200 – 50 S	61	67	50	66	75	908	843	820	840	980
(P-value)	*(0.2863)*	*(0.6784)*	*(1.0000)*	*(0.5254)*	*(0.6595)*	*(0.0424)**	*(0.9511)*	*(0.5903)*	*(0.1488)*	*(0.0424)**
Mean	63	68	50	67	75	889	842	835	814	962
General mean	58	65	47	62	69	771	745	777	763	896

P = N applied at planting
S = N split between planting and stem elongation.
* - Significant at 5 % level.

4.2. Experiment II, Corvallis 1999.

4.2.1. Response to nitrogen treatments

The treatments of the split-split plot design of experiment II consisted on 50 (low), 150, 200 (intermediate to high), and 250 kg N ha^{-1} (high) levels of N (main plots) applied to the cultivars (sub-sub plots), either applied all at seeding or 50 kg N ha^{-1} at stem elongation and the rest at seeding (timing: sub-plot).

A significant improvement in Y, GPROT, SDS (Tables 5a, 6a), FPROT, FYIELD (Tables 5b, 6b), LVOL and BCRGR (Tables 5c, 6c), was related to increasing levels of N, while TWT, TKW (Tables 5a, 6a), and A (Tables 5b, 6b) showed a corresponding decrease. There was 12% increment in GPROT from adding 50 to 150 kg N ha^{-1}, 4% more when adding 200 kg N ha^{-1}, and an additional 3% increment at 250 kg N ha^{-1}. LVOL had a similar response, with 13% increment from the first to the second N level, 3% from the second to the third, and only 1% with the high N level. However, for most quality traits, there was no difference related to increasing levels of N rates. Wheat plants were not able to use further more the excess of N that was being applied.

Table 5a. Analysis of variance for grain yield (Y), test weight (TWT), thousand-kernel weight (TKW), grain protein content (dry weight basis) (GPROT), and sedimentation value (SDS), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

		Mean squares				
Source of variation	**df**	**Y**	**TWT**	**TKW**	**GPROT**	**SDS**
Rep	3	2346022*	0.59	1.37	57	19.17
N	3	29900034**	4.58**	32.02*	4804**	1353.96**
Error 1	9	391938	0.42	5.65	86	13.57
S	1	2979249**	0.12	0.96	3506**	322.06**
N x S	3	1086048*	0.44	0.32	1585**	298.81**
Error 2	12	196773	0.51	1.86	20	14.97
C	4	12820210**	34.68**	1005.91**	7340**	2184.60**
N x C	12	173038**	0.86*	5.15**	44*	30.65**
S x C	4	125565*	0.19	1.44	193**	2.48
N x S x C	12	110824**	0.31	1.87	79**	15.96
Error 3	96	42948	0.40	1.71	21	9.17
Total	159					

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively

Table 5b. Analysis of variance for flour yield (FYIELD), flour protein content, dry weight basis, (FPROT) and mixograph parameters [water absorption (MABS), time to peak (P), peak height (PHT), angle of the trace's medium line after the peak (A), and width of the trace two minutes after the peak (W)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

		Mean squares						
Source of variation	**df**	**FYIELD**	**FPROT**	**MABS**	**P**	**PHT**	**A**	**W**
Rep	1	24.60 **	285	0.86	0.41	5.51	42.05	26.45*
N	3	8.38 **	1980 *	23.90	0.76	150.08	55.68 *	10.70
Error 1	3	0.18	125	5.86	0.22	18.15	4.88	2.55
S	1	0.56	1225 **	7.87 **	1.65 *	227.81 **	45.00	5.00
N x S	3	0.52	535 **	6.95 **	0.59	158.11 **	81.90	1.63
Error 2	4	1.02	15	0.18	0.11	8.79	33.68	3.68
C	4	72.18 **	4427 **	37.07 **	17.19 **	283.79 **	833.77 **	112.78 **
N x C	12	0.41	12	0.81	0.21 *	10.03 *	27.74	1.65
S x C	4	0.10	79 **	1.85 *	0.52 **	17.97 **	22.09	2.16
N x S x C	12	0.29	31 *	1.08	0.23 *	7.27	16.91	0.96
Error 3	32	0.39	12	0.53	0.10	4.42	23.18	2.01
Total	79							

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively

Table 5c. Analysis of variance for bread-making quality parameters [bake water absorption (BABS), optimum mixing time (MT), loaf volume (LVOL), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

		Mean squares			
Source of variation	**df**	**BABS**	**MT**	**LVOL**	**BCRGR**
Rep	1	0.85	0.04	2311.25	0.31
N	3	9.15	0.55	84068 *	24.85 *
Error 1	3	3.75	0.10	4311.25	1.05
S	1	7.56 **	2.35 *	28880 *	5.51 *
N x S	3	4.04 **	0.55	15648 *	7.18 *
Error 2	4	0.24	0.13	2256.25	0.66
C	4	28.69 **	17.87 **	127023 **	24.26 **
N x C	12	1.66	0.43	800.73	1.22 **
S x C	4	0.50	0.31	1336.25	0.33
N x S x C	12	0.76	0.19	1484.79	0.20
Error 3	32	0.82	0.30	1042.34	0.36
Total	79				

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively.

Table 6a. Observed least square means for grain yield (Y) (kg ha^{-1}), test weight (TWT) (kg hl^{-1}), thousand-kernel weight (TKW) (grams), grain protein content (dry weight basis) (GPROT) (g kg^{-1}), and sedimentation value (SDS) (mm), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

N levels (kg N ha^{-1})	Y	TWT	TKW	GPROT	SDS
50 - 0 P	5269	82.5	45	110.4	56
0 - 50 S+	4338	82.8	45	137.6	67
(P-value)	*(<0.0001)***	*(0.1163)*	*(0.4134)*	*(<0.0001)***	*(<0.0001)***
Mean	4804	82.7	45	124.0	62
150 - 0 P	6997	82.4	44	135.0	71
100 - 50 S	6773	82.1	44	143.7	71
(P-value)	*(0.0120)**	*(0.2886)*	*(0.9834)*	*(<0.0001)***	*(0.8317)*
Mean	6885	82.2	44	139.3	71
200 - 0 P	7040	81.9	43	145.7	74
150 - 50 S	7068	82.0	43	144.8	75
(P-value)	*(0.7518)*	*(0.6265)*	*(0.4969)*	*(0.2865)*	*(0.3633)*
Mean	7054	81.9	43	145.2	75
250 - 0 P	7062	82.0	43	147.7	73
200 - 50 S	6824	82.0	43	150.0	73
(P-value)	*(0.0181)**	*(0.8606)*	*(0.9776)*	*(0.1628)*	*(0.7572)*
Mean	6943	82.0	43	148.8	73
General mean	5137	82.2	44	139.4	70
C.V. (%)	*4.03*	*0.77*	*2.99*	*3.32*	*4.32*

P = N applied at planting; S = N split between planting and stem elongation; S+ = all N at stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 6b. Observed least square means for flour yield (FYIELD) (%), flour protein content (dry weight basis) (FPROT) (g kg^{-1}), and mixograph parameters [water absorption (MABS) (ml), time to peak (P) (minutes), peak height (PHT) (mm), angle of the trace's medium line after peak (A) (degrees), and width of the trace two minutes after the peak (W) (mm)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

N levels (kg N ha^{-1})	FYIELD	FPROT	MABS	P	PHT	A	W
50 - 0 P	71.1	105.1	60.1	4.6	52	79	14
0 - 50 S +	71.6	128.1	62.5	3.8	64	72	14
(P-value)	*(0.1331)*	*(<0.0001)***	*(0.0001)***	*(0.0087)***	*(<0.0001)***	*(0.0183)**	*(1.0000)*
Mean	71.3	116.6	61.3	4.2	58	75	14
150 - 0 P	72.2	127.8	61.9	4.2	62	75	13
100 - 50 S	72.7	133.5	61.8	4.0	64	74	14
(P-value)	*(0.0110)**	*(0.0007)***	*(0.8179)*	*(0.3226)*	*(0.0301)**	*(0.6289)*	*(0.0425)**
Mean	72.4	130.7	61.8	4.1	63	74	14
200 - 0 P	73.00	137.2	63.7	3.9	64	72	13
150 - 50 S	72.9	137.7	63.8	3.7	64	74	13
(P-value)	*(0.7259)*	*(0.6855)*	*(0.7937)*	*(0.1090)*	*(0.7194)*	*(0.4749)*	*(0.7707)*
Mean	73.0	137.5	63.7	3.8	64	73	13
250 - 0 P	72.7	136.9	62.9	4.1	64	71	12
200 - 50 S	72.6	139.0	63.0	4.1	63	72	12
(P-value)	*(0.7136)*	*(0.2875)*	*(0.7770)*	*(0.9004)*	*(0.5530)*	*(0.6991)*	*(0.3535)*
Mean	72.7	138.0	62.9	4.1	63	71	12
General mean	72.4	130.7	62.4	4.1	62	73	13
C.V. (%)	*0.87*	*2.64*	*1.17*	*7.62*	*3.40*	*6.55*	*10.90*

P = N applied at planting; S = N split between planting and stem elongation; S+ = all N at stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 6c. Observed least square means for bread-making quality parameters [bake water absorption (BABS) (ml), optimum mixing time (MT) (minutes), loaf volume (LVOL) (cc), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

N levels (Kg N ha $^{-1}$)	**BABS**	**MT**	**LVOL**	**BCRGR**
50 - 0 P	65.3	5.0	712	7
0 - 50 S +	67.2	4.1	832	5
(P-value)	*(0.0026)***	*(0.0706)*	*(<0.0001)***	*(<0.0001)***
Mean	66.2	4.5	772	6
150 - 0 P	66.5	4.4	862	5
100 - 50 S	67.1	4.2	886	4
(P-value)	*(0.1766)*	*(0.2754)*	*(0.0876)*	*(0.3887)*
Mean	66.8	4.3	874	5
200 - 0 P	67.7	4.3	904	4
150 - 50 S	67.5	4.1	903	4
(P-value)	*(0.6244)*	*(0.1147)*	*(0.8844)*	*(0.3465)*
Mean	67.6	4.2	903	4
250 - 0 P	67.5	4.3	909	4
200 - 50 S	67.7	4.1	919	4
(P-value)	*(0.3919)*	*(0.0526)*	*(0.6275)*	*(0.5137)*
Mean	67.6	4.2	914	4
General mean	67.1	4.3	866	5
C.V. (%)	*1.35*	*12.69*	*3.73*	*12.87*

P = N applied at planting

S = N split between planting and stem elongation; S+ = all N at stem elongation.

*, ** - Significant at 5 and 1 % level respectively.

4.2.2. Response to timing of nitrogen application.

In the experiment, a split application of N resulted in a decrease in grain yield at all N levels except 200 kg N ha^{-1}. The yield reduction was most pronounced at the 50 kg N ha^{-1} rate, with over 900 kg ha^{-1} less grain compared to a single N application (Table 6a). When part of that nutrient was delayed toward the stem elongation stage, grain yields decrease. Grain protein content showed a significant increase in the two first levels of N with split N treatment (25 and 6%, respectively) (Table 6a). Higher N levels had already reached high GPROT with single N application, so the split treatment was not effective in increasing this variable.

At the 50 kg N ha^{-1} level, a split application of N contributed to improvements in SDS (Table 6a), MABS (Table 6b), BABS, LVOL, and BCRGR (Table 6c). In this same level, mixing time, as estimated from the mixograph curve (P), and A, decreased. Randall et al. (1990) reported an increase in LVOL of wheat with the addition of 50 kg N ha^{-1} at heading stage, coinciding with the results found in this Experiment at the low N level. At the 150 kg N ha^{-1} rate, there was a significant increase in FYIELD and mixograph W (Table 6b) with the split application of N at stem elongation. However, a split application of N at the 200 and 250 kg N ha^{-1} level had little effect on protein quality, mixing properties or loaf volume.

A split application of N resulted in a general improvement in protein quantity and quality at the lower N levels. At the higher N levels, where this nutrient was not limiting during plant development, a split application of N was not beneficial for improving either protein content or end-use quality.

4.2.3. Response of cultivars to nitrogen treatments

As in experiment I, Winsome was the cultivar that had on average the highest grain yield (5882 kg ha^{-1}), and the lowest grain protein content (122.3 g kg^{-1}) (Table 7a). An opposite situation was seen for I. Mirlo, which had the lowest grain yield (4471 kg ha^{-1}), the highest GPROT (157.0 g kg^{-1}), and the lowest SDS value (58 mm) (Table 7b), confirming that I. Mirlo does not have good intrinsic quality characteristics. Yecora Rojo again showed the best values for quality parameters: 1006 cc LVOL, and 81 mm SDS. Almost the same ranking of cultivars as in experiment I was seen in experiment II for Y, GPROT, SDS, and LVOL variables. The cultivars all responded similarly in terms of increasing GPROT with increasing N levels.

Cultivars response to N and timing are presented in Table 7a. Winsome was the only cultivar that did not show any significant decrease in Y with split applications of N. All other cultivars showed decrease in this variable at the first level of N, and Yecora Rojo also showed this response in the second level. I. Boyero was unique in that its Y increased when N was applied at stem elongation in the 200 kg N ha^{-1} level.

With the exception of Yecora Rojo, the cultivars showed similar significant increases in protein quality, or SDS, with split application at the low N level, but not at the higher N levels.

For all the cultivars, LVOL improved with increasing levels of N. When the timing factor was taken in account, only in INIA Mirlo (hard red) was there observed a significant response, and then only at the low N level (Table 7b). The few degrees of freedom available for the experimental error could be yielding weak tests that are not

Table 7a. Observed least square means for grain yield (Y) (kg ha^{-1}), and grain protein content (dry weight basis) (GPROT) (g kg^{-1}), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

N levels (kg N ha^{-1})	Y					GPROT				
	Id377s	Winsome	I.Mirlo	I.Boyero	Yecora Rojo	Id377s	Winsome	I.Mirlo	I.Boyero	Yecora Rojo
50 - 0 P	4865	4598	3741	3922	3952	96.8	106.5	123.3	111.1	114.2
0 - 50 S+	4032	4230	3188	3256	2646	124.6	113.3	148.8	142.5	159.0
(P-value)	*(0.0267)**	*(0.0918)*	*(0.0381)**	*(0.0418)**	*(<0.0001)***	*(0.0017)***	*(0.3607)*	*(0.0018)***	*(0.0163)**	*(0.0006)***
Mean	4448	4414	3465	3589	3299	110.7	109.9	136.1	126.8	136.6
150 - 0 P	6180	6310	4933	5335	5230	122.1	118.6	152.4	138.6	143.0
100 - 50 S	6086	6174	4862	5061	4908	127.5	125.4	164.2	145.4	156.0
(P-value)	*(0.5166)*	*(0.5887)*	*(0.6397)*	*(0.1529)*	*(0.0060)***	*(0.1122)*	*(0.0349)**	*(0.0254)**	*(0.0630)*	*(0.0231)**
Mean	6133	6242	4898	5198	5069	124.8	122.0	158.3	142.0	149.5
200 - 0 P	6503	6442	4740	5200	5274	131.7	127.7	167.5	145.2	156.3
150 - 50 S	6096	6527	4824	5431	5396	131.4	126.2	163.2	145.4	157.9
(P-value)	*(0.3350)*	*(0.6799)*	*(0.6890)*	*(0.0473)**	*(0.5254)*	*(0.6237)*	*(0.5418)*	*(0.1174)*	*(0.8946)*	*(0.4242)*
Mean	6299	6485	4782	5315	5335	131.6	127.0	165.4	145.3	157.1
250 - 0 P	6080	6435	4935	5324	5473	135.6	129.6	167.6	150.5	155.1
200 - 50 S	6096	6340	4542	5168	5151	136.9	130.6	168.9	149.9	163.8
(P-value)	*(0.8712)*	*(0.6081)*	*(0.2062)*	*(0.0831)*	*(0.4380)*	*(0.7459)*	*(0.1755)*	*(0.7856)*	*(0.7892)*	*(0.2690)*
Mean	6088	6388	4738	5246	5312	136.3	130.1	168.3	150.2	159.5
General mean	5742	5882	4471	4837	4754	125.9	122.3	157.0	141.1	150.7

P = N applied at planting

S = N split between planting and stem elongation; S+ = all N at stem elongation.

*, ** - Significant at 5 and 1 % level respectively .

Table 7b. Observed least square means for sedimentation values (SDS) (mm), and loaf volume (LVOL) (cc), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments in a split-split plot design at Hyslop Farm, near Corvallis-Oregon, in 1999.

N levels	SDS					LVOL				
(Kg N ha $^{-1}$)	Id377s	Winsome	I.Mirlo	I.Boyero	Yecora Rojo	Id377s	Winsome	I.Mirlo	I.Boyero	Yecora Rojo
50 - 0 P	53	56	45	55	73	645	648	725	735	805
0 - 50 S +	67	68	55	68	79	750	712	838	850	1010
(P-value)	*(0.0084)***	*(0.0321)**	*(0.0001)***	*(0.0012)***	*(0.1247)*	*(1.0000)*	*(0.1900)*	*(0.0141)**	*(0.0826)*	*(0.1227)*
Mean	60	62	50	62	76	698	680	781	793	908
150 - 0 P	69	75	60	71	81	793	803	873	858	985
100 - 50 S	69	74	58	73	80	790	817	923	878	1020
(P-value)	*(0.9444)*	*(0.7199)*	*0.3672)*	*(0.6897)*	*(0.7688)*	*(0.9097)*	*(0.8440)*	*(0.6257)*	*(0.5704)*	*(0.2578)*
Mean	69	75	59	72	81	791	810	898	868	1003
200 - 0 P	75	77	60	78	81	790	835	948	898	1050
150 - 50 S	73	78	62	76	86	843	805	926	883	1055
(P-value)	*(0.1354)*	*(0.7244)*	*(0.2007)*	*(0.1027)*	*(0.1041)*	*(0.3949)*	*(0.6560)*	*(0.4097)*	*(0.6560)*	*(1.0000)*
Mean	74	78	61	77	84	816	820	938	890	1053
250 - 0 P	73	77	60	76	81	818	835	940	893	1060
200 - 50 S	76	76	60	73	81	870	860	885	920	1058
(P-value)	*(0.0938)*	*(0.6500)*	*(1.0000)*	*(0.2504)*	*(0.3910)*	*(0.5000)*	*(0.5577)*	*(0.3179)*	*(0.5000)*	*(0.9423)*
Mean	75	77	60	75	81	844	848	913	906	1059
General mean	70	73	58	72	81	787	790	883	864	1006

P = N applied at planting. S = N split between planting and stem elongation. S+ = all N at stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

"picking" up potential real differences in cultivar response.

In this experiment, many variables showed a significant interaction cultivar x timing of N application, like Y, GPROT, FPROT, MABS, P, and PHT (Tables 5a, and 5b). The initial diverse quality potential of the five cultivars used in this study could be the base of these interactions.

4.3. Combined analysis of Experiments I and II.

In order to identify consistent, major effects contributing to variation in protein and end-use quality, data from Experiments I and II were combined and analyzed as a Randomized Complete Block design. The treatments consisted in low (without splitting), intermediate and high N levels, applied to the different cultivars all at planting, or for the intermediate and high levels, split between planting and stem elongation.

4.3.1. Response to nitrogen treatments

The levels of N had a significant positive effect on GPROT, SDS (Tables 8a and 9a), FYIELD, FPROT, mixograph variables (MABS, PHT, and W; Tables 8b and 9b), and baking related variables (BABS, LVOL, and BCRGR; Tables 8c and 9c). Grain protein content increased on average 26% (112.2 g kg^{-1} to 141.5 g kg^{-1}) from the low to the intermediate N level, and 6% (141.5 g kg^{-1} to 150.4 g kg^{-1}) from the intermediate to the high N level. In a similar way, LVOL increased on average 24% from the low to the intermediate N level, and 4% from the latter to the high N level.

Table 8a. Analysis of variance from a Combined Analysis (Randomized Complete Block Design) of two experiments for grain yield (Y), test weight (TWT), thousand-kernel weight (TKW), grain protein content (dry weight basis) (GPROT), and sedimentation value (SDS), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999.

		Mean squares				
Source of variation	**df**	**Y**	**TWT**	**TKW**	**GPROT**	**SDS**
Year	1	3979904	22.59**	425.97**	812*	2144.23**
Error [Rep(Year)]	5	730989	0.30	3.01	51	26.62
Control	1	91817701**	35.71**	136.05**	31869**	6180.57**
N	1	156981	5.48**	20.37**	2747**	50.40*
S	1	511467*	3.06**	1.03	1467**	3.46
S x N	1	50464	0.002	0.14	307**	24.03
C	4	5443352**	20.69**	686.34**	5631**	2390.26**
C x Control	4	336662**	0.88*	21.02**	212**	83.19**
N x C	4	69142	0.22	4.06	43	1.28
S x C	4	17511	0.07	0.10	32	6.98
S x N x C	4	51835	0.09	1.79	8	14.48
Year x Control	1	9154795**	19.32**	31.72**	0.02	34.97
Year x N	1	19701	1.06	8.32	20	56.47*
Year x S	1	190486	1.97*	1.37	42	14.86
Year x S x N	1	49281	0.65	0.13	3	32.04
Year x C	4	3733390**	5.80**	59.96**	689**	23.38
Year x Control x C	4	414806**	1.24**	8.18**	96**	48.25**
Year x N x C	4	56502	0.51	1.72	26	33.84**
Year x S x C	4	76260	0.67	1.28	15	2.38
Year x S x N x C	4	54029	0.08	0.78	6	11.93
Error	120	77520	0.34	2.30	25	9.71
Total	174					

Rep = replications; N = total N; S = N splitting; C = cultivars.
Control = comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 8b. Analysis of variance from a Combined Analysis (Randomized Complete Block Design) of two experiments for flour yield (FYIELD), flour protein content, dry weight basis, (FPROT) and mixograph parameters [water absorption (MABS), time to peak (P), peak height (PHT), angle of the trace's medium line after the peak (A), and width of the trace two minutes after the peak (W)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998 and 1999.

		Mean square						
Source of variation	**df**	**FYIELD**	**FPROT**	**MABS**	**P**	**PHT**	**A**	**W**
Year	1	4494.36**	65	194.60**	0.14	108.16	497.29*	2.56
Error [Rep(Year)]	2	11.67	102	1.68	0.49	25.04	26.69	6.76
Control	1	53.51**	13562**	82.26**	1.12*	1751.42**	416.16**	0.42
N	1	3.57*	1002**	22.05**	0.03	66.61**	186.05**	17.11*
S	1	6.22**	782**	0.58	0.0005	52.81**	39.20	0.31
S x N	1	4.75*	76*	0.01	0.26	70.31**	11.25	0.61
C	4	95.66**	3584**	9.79**	24.93**	212.37**	757.12**	110.99**
C x Control	4	1.96*	62**	1.44	0.06	28.46**	15.09	5.25
N x C	4	1.72	13	0.75	0.07	3.05	12.93	1.36
S x C	4	0.19	15	1.01	0.19	0.50	7.58	1.94
S x N x C	4	1.04	10	0.21	0.16	10.13	25.38	0.99
Year x Control	1	6.27**	0.1	0.02	1.08*	3.80	15.21	6.50
Year x N	1	0.56	1	0.02	0.24	40.61*	0.20	6.61
Year x S	1	2.78	111*	0.51	0.14	13.61	36.45	12.01*
Year x S x N	1	0.82	0.4	0.31	0.005	2.81	0.00	1.01
Year x C	4	20.83**	312**	10.20**	1.12**	17.49*	48.27**	2.41
Year x Control x C	4	0.87	47*	0.18	0.461*	10.67	33.24	0.53
Year x N x C	4	1.20	27	1.24	0.17	12.30	15.70	0.61
Year x S x C	4	0.78	17	2.70*	0.32	10.05	28.83	1.89
Year x S x N x C	4	0.44	3	0.62	0.06	7.00	6.50	0.89
Error	48	0.75	16	0.78	0.18	6.71	12.88	2.39
Total	99							

Rep = replications; N = total N; S = N splitting; C = cultivars. Control = comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 8c. Analysis of variance from a Combined Analysis (Randomized Complete Block Design) of two experiments for bread-making quality parameters [bake water absorption (BABS), optimum mixing time (MT), loaf volume (LVOL), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998 and 1999.

Source of variation	df	Mean squares			
		BABS	MT	LVOL	BCRGR
Year	1	313.29**	0.94	44521	40.96**
Error [Rep(Year)]	2	0.70	0.19	4.90	0.20
Control	1	60.37**	3.78**	547230**	170.30**
N	1	9.11**	0.30	25028**	9.11**
S	1	2.74	0.95*	13390**	2.81*
S x N	1	0.00	0.17	2475	0.61
C	4	12.67**	26.44**	93537**	31.36**
C x Control	4	0.99	1.28**	3079	1.58*
N x C	4	3.53*	0.13	1269	0.08
S x C	4	0.57	0.09	849	1.28
S x N x C	4	1.47	0.20	1746	0.64
Year x Control	1	0.01	0.78	116	0.003
Year x N	1	0.34	0.003	428	0.01
Year x S	1	0.005	0.02	1758	2.81*
Year x S x N	1	0.31	0.28	340	0.01
Year x C	4	6.50**	0.53	8932**	2.06**
Year x Control x C	4	1.36	0.54	1964	2.12**
Year x N x C	4	1.42	0.10	747	0.79
Year x S x C	4	2.15	0.04	132	0.22
Year x S x N x C	4	1.58	0.03	793	0.11
Error	48	1.12	0.23	1624	0.51
Total	99				

Rep = replications; N = total N; S = N splitting; C = cultivars.
Control = comparison between no N applied and some N applied.
*, ** - significant at 5% and 1% level respectively.

Table 9a. Observed least square means from a Combined Analysis (Randomized Complete Block Design) for grain yield (Y) (kg ha^{-1}), test weight (TWT) (kg hl^{-1}), thousand-kernel weight (TKW) (grams), grain protein content (dry weight basis) (GPROT) (g kg^{-1}), and sedimentation value (SDS) (mm), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999.

N levels		Y	TWT	TKW	GPROT	SDS
Low		3689	82.8	47	112.2	54
Intermediate	**P**	5500	82.0	45	137.2	67
	S	5417	81.6	45	146.6	68
	(P-value)	*(0.4327)*	*(0.0706)*	*(0.8325)*	*(<0.0001)***	*(0.1886)*
	Mean	5466	81.9	45	141.5	68
High	**P**	5609	81.5	45	148.9	69
	S	5450	81.2	44	152.4	69
	(P-value)	*(0.1539)*	*(0.1554)*	*(0.6161)*	*(0.0208)**	*(0.4874)*
	Mean	5533	81.4	44	150.4	69
General Mean		5137	81.9	45	139.2	66
C.V. (%)		*5.42*	*0.71*	*3.37*	*3.56*	*4.73*

P = N applied at planting
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 9b. Observed least square means from a Combined Analysis (Randomized Complete Block Design) of two experiments for flour yield (FYIELD) (%), flour protein content, dry weight basis (FPROT) (g kg^{-1}), and mixograph parameters [water absorption (MABS) (ml), time to peak (P) (minutes), peak height (PHT) (mm), angle of the trace's medium line after peak (A) (degrees), and width of the trace two minutes after the peah (W) (mm)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999.

N levels	FYIELD	FPROT	MABS	P	PHT	A	W
Low	6.41	106.0	58.7	4.5	51	80	13
Intermediate							
P	65.2	127.5	60.4	4.3	59	78	13
S	66.3	135.7	60.6	4.2	63	76	14
(P-value)	*(0.0281)**	*(0.0001)***	*(0.5561)*	*(0.5029)*	*(<0.0001)***	*(0.0764)*	*(0.4884)*
Mean	65.7	131.6	60.5	4.2	61	77	14
High							
P	66.1	136.5	61.4	4.1	63	74	13
S	66.2	140.8	61.6	4.2	63	73	13
(P-value)	*(0.8499)*	*(0.0298)**	*(0.6875)*	*(0.3700)*	*(0.7893)*	*(0.6523)*	*(0.9125)*
Mean	66.2	138.6	61.5	4.2	63	74	13
General mean	65.6	129.3	60.5	4.2	58	76	13
C.V. (%)	*1.32*	*3.09*	*1.46*	*9.90*	*4.34*	*4.71*	*11.77*

P = N applied at planting.
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 9c. Observed least square means from a Combined Analysis (Randomized Complete Block Design) of two experiments for bread-making quality parameters [bake water absorption (BABS) (ml), optimum mixing time (MT) (minutes), loaf volume (LVOL) (cc), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999..

N levels	BABS	MT	LVOL	BCRGR
Low	63.5	4.9	688	8
Intermediate				
P	64.9	4.6	837	5
S	65.3	4.3	874	4
(P-value)	*(0.2547)*	*(0.0070)***	*(0.0059)***	*(0.0263)**
Mean	65.1	4.5	856	5
High				
P	65.6	4.4	884	5
S	66.0	4.3	898	4
(P-value)	*(0.3837)*	*(0.2064)*	*(0.3435)*	*(0.5147)*
Mean	65.8	4.3	891	5
General mean	65.0	4.5	836	5
C.V (%)	*1.63*	*10.63*	*4.82*	*13.16*

P = N applied at planting. S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

However, grain characteristics such as TWT and TKW (Table 8a and 9a), as well as A of the mixograph (Table 8b and 9b), decreased with increasing levels of N. The combined analysis shows the same general trend as the individual experiments, where the addition of more N resulted in more GPROT with better overall end-use quality, particularly as denoted by SDS and baking related variables.

4.3.2. Response to timing of nitrogen application.

A significant difference between timing treatments was observed for GPROT and FPROT at both the intermediate and high N levels (Tables 8a, 8b, 9a, and 9b), increasing on average 4.5% protein content with the split N application. At the intermediate level of N, quality variables like FYIELD, PHT (Table 9b), LVOL and BCRGR showed an improvement with split application of N, while MT decreased significantly. At the high N level, split application had little effect on mixing and baking parameters.

The effect on protein quality seen in Experiment II with the application of N at stem elongation stage, was not evident in this combined analysis. Even though important baking-related variables like LVOL and BCRGR showed an increase with split applications at the intermediate N level, SDS and most mixograph parameters were unaffected, suggesting changes primarily in protein quantity rather than quality.

The principal effect found with split applications of N was the improvement obtained in nitrogen use efficiency. Comparable grain protein levels and LVOL values were achieved at intermediate levels of N split applications as compared with higher N rates single applications (Figures 1, 2). The decrease in grain yield with split

applications at this N level was minimal (83 kg ha^{-1}), while the increase in GPROT (9.4 g kg^{-1}) (Table 9a) and LVOL (4%) (Table 9c) was significant.

4.3.3. Response of cultivars to nitrogen treatments.

The interactions of cultivars with N rates or timing of the N applications were significant (Tables 8a, 8b and 8c) for many traits in the combined analysis. Tables 10a and 10b report least square means for each cultivar, either with the N applied at planting or split between planting and stem elongation, within each level of total N.

Even though only I. Boyero showed a significant difference in Y with the timing treatment at the high level of N, the general trend for all the cultivars was a decrease in grain yield. All cultivars had a significant GPROT increase in the intermediate level of N with the split application of N between planting and stem elongation. Grain protein content for Winsome showed a similar response in the high level of N, but no other cultivar showed a response for GPROT in this N level to split N application. None of the cultivars expressed a significant change in SDS in response to the timing treatment at either N rate.

Only Yecora Rojo showed a statically significant increase in LVOL at the intermediate level of N, when this nutrient was split. However, the general trend for all cultivars was to improve LVOL with the timing treatment. No significant interaction was observed between cultivars and timing treatment. Thus, the results discussed in section 4.3.2., apply to all the cultivars in the same way. Also, section

Table 10a. Observed least square means from a Combined Analysis (Randomized Complete Block Design) of two experiments, for grain yield (Y) (kg ha^{-1}), and grain protein content (dry weight basis) (GPROT) (g kg^{-1}), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999.

N levels	Y					GPROT				
	Id377s	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**	**Id377s**	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**
Low	4054	3992	3190	3265	3503	98.4	107.2	129.3	117.5	110.3
Intermediate										
P	5547	6089	5202	5277	5387	127.3	122.7	155.6	144.0	136.3
S	5382	6125	5175	5180	5226	134.3	131.2	166.1	152.0	149.5
(P-value)	*(0.0860)*	*(0.8608)*	*(0.7991)*	*(0.4255)*	*(0.1934)*	*(0.0034)***	*(0.0015)***	*(0.0146)**	*(0.0076)***	*(0.0015)***
Mean	5465	6107	5189	5229	5307	130.8	127.0	160.9	148.0	142.9
High										
P	5535	6219	5307	5410	5573	140.3	134.2	166.7	152.6	150.6
S	5504	6089	5000	5176	5480	144.7	136.2	169.0	154.3	157.8
(P-value)	*(0.7855)*	*(0.3959)*	*(0.0781)*	*(0.0189)**	*(0.6953)*	*(0.1470)*	*(0.0373)**	*(0.4091)*	*(0.3372)*	*(0.0915)*
Mean	5520	6154	5154	5293	5527	142.5	135.2	167.9	152.8	154.2
General mean	5013	5418	4511	4596	4779	123.9	123.1	152.7	139.4	135.8

P = N applied at planting
S = N split between planting and stem elongation.
*, ** - Significant at 5 and 1 % level respectively.

Table 10b. Observed least square means from a Combined Analysis (Randomized Complete Block Design) of two experiments, for sedimentation value (SDS) (mm), and loaf volume (LVOL) (cc), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I.Mirlo, I.Boyero and Yecora Rojo) grown under different N fertilization treatments at Hyslop Farm, near Corvallis-Oregon, in 1998, 1999.

N levels	SDS					LVOL				
	Id377s	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**	**Id377s**	**Winsome**	**I.Mirlo**	**I.Boyero**	**Yecora Rojo**
Low	48	57	42	54	67	624	625	698	708	788
Intermediate										
P	66	71	55	68	76	788	784	838	819	958
S	69	72	54	71	76	825	816	885	843	1001
(P-value)	*(0.2283)*	*(0.8853)*	*(0.1659)*	*(0.2324)*	*(0.7690)*	*(0.2189)*	*(0.3087)*	*(0.2198)*	*(0.1334)*	*(0.0120)**
Mean	68	72	55	70	76	807	800	861	831	979
High										
P	68	72	55	72	78	844	838	895	840	1001
S	69	72	55	69	78	889	851	853	880	1019
(P-value)	*(0.6914)*	*(0.4738)*	*(1.0000)*	*(0.1394)*	*(0.9046)*	*(0.1320)*	*(0.5254)*	*(0.1444)*	*(0.0679)*	*(0.3575)*
Mean	69	72	55	71	78	866	844	874	860	1010
General mean	62	67	51	65	74	766	756	811	800	926

P = N applied at planting
S = N split between planting and stem elongation.
* - Significant at 5 % level.

Figure 1. Response of grain yield (Y) (kg/ha) and grain protein content (GPROT) (g/kg) of five spring hard wheats grown in Corvallis 1998, 1999 (Combined Analysis) to different nitrogen rates and timing of N application (kg N/ha). p = N all applied at planting. s = 50 kg N/ha applied at stem elongation and the rest at planting.

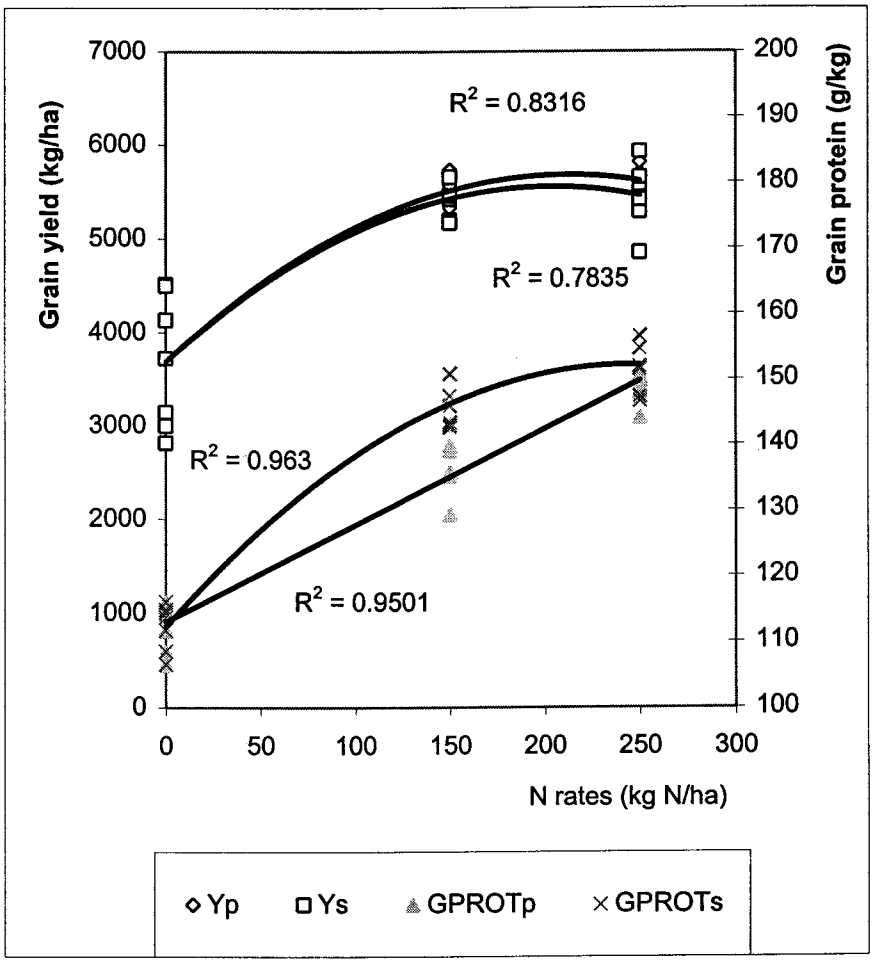
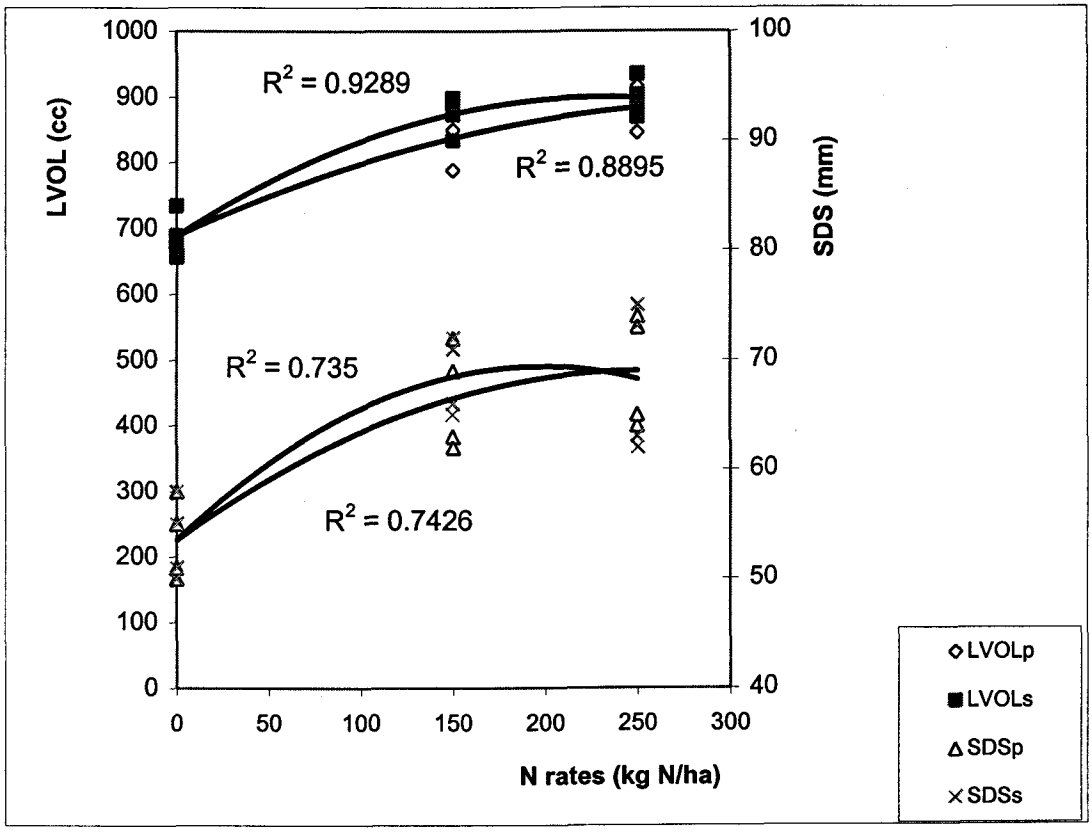


Figure 2. Response of bread loaf volume (LVOL) (cc), and sedimentation value (SDS) (mm) of five spring hard wheats grown in Corvallis 1998, 1999 (Combined Analysis) to different nitrogen rates and timing of N application (kg N/ha). p = N all applied at planting. s = 50 kg N/ha applied at stem elongation and the rest at planting.



4.3.3. shows specifically for Y, GPROT, SDS, and LVOL, the general trends followed by all the cultivars.

4.4. Experiment III, Pendleton 1999.

Experiment III was planned and planted before the results from the soil tests were obtained. As shown in Table 1, nitrates levels were much higher in the soil at this site than in experiments I and II. As such, limited response to the N treatments was expected. N levels did increase GPROT and FPROT in a significant way, but the increase was relatively small (Tables 11a, 12a). The timing treatment also increased GPROT slightly, but this difference was significant only in the low N level. No other variable showed a significant response to either the N treatment level or split application of N (Tables 11a, 11b, 11c, 11 a, 12b, 12c, 13a, and 13b).

4.5.Correlations between selected agronomic and quality traits.

The association among different traits measured in this study was investigated using Pearson's correlation coefficients on the parameters means over replications for the five spring wheat cultivars included in the different experiments (Tables 14a, 14b and 14c). TWT was moderately negatively correlated with GPROT in all experiments (Table 14a). This tendency of TWT to decrease with increasing GPROT, was discussed in previous sections. Strong evidence for the independence of gluten quality, or gluten strength, from protein quantity is shown by the consistent non-significant

Table 11a. Analysis of variance for grain yield (Y), test weight (TWT), thousand-kernel weight (TKW), grain protein content (dry weight basis) (GPROT), and sedimentation value (SDS), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

Source of variation	df	Mean squares				
		Y	TWT	TKW	GPROT	SDS
Rep	3	206421	24.62	12.92	406**	45.31
N	2	140828	16.01	8.43	694**	48.16
S	1	60962	1.79	7.01	677**	53.33
N x S	2	382317	5.61	16.51	488**	8.66
Error 1	15	268894	7.77	18.18	54	14.33
C	4	432445**	8.90**	433.69**	1079**	3710.37**
N x C	8	133804	1.51	1.61	119**	14.84
S x C	4	118855	1.26	2.90	47	9.67
N x S x C	8	68093	0.41	3.84	30	20.84
Error 2	72	74668	1.00	5.18	43	14.33
Total	119					

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively

Table 11b. Analysis of variance for flour yield (FYIELD), flour protein content, dry weight basis, (FPROT) and mixograph parameters [water absorption (MABS), time to peak (P), peak height (PHT), angle of the trace's medium line after the peak (A), and width of the trace two minutes after the peak (W)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

		Mean squares						
Source of variation	**df**	**FYIELD**	**FPROT**	**MABS**	**P**	**PHT**	**A**	**W**
Rep	1	1.23	101	2.20	0.20	10.42	303.75*	1.35
N	2	0.10	373**	0.42	1.49*	12.82	9.27	0.52
S	1	7.87*	11	0.43	0.004	25.35	0.82	0.02
N x S	2	6.22*	97	3.99	0.04	30.65	57.87	3.62
Error 1	5	0.57	24	1.97	0.22	10.22	39.71	8.99
C	4	87.49**	828**	14.25**	6.77**	77.44**	1117.53**	56.04**
N x C	8	3.70**	32	0.94	0.29	6.07	56.04	7.20*
S x C	4	1.64	19	0.58	0.23	1.31	19.19	1.81
N x S x C	8	1.03	27	0.38	0.27	6.36	71.55	4.60
Error 2	24	0.81	17	1.51	0.19	3.58	35.22	2.84
Total	59							

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively

Table 11c. Analysis of variance for bread-making quality parameters [bake water absorption (BABS), optimum mixing time (MT), loaf volume (LVOL), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

Source of variation	df	Mean squares			
		BABS	MT	LVOL	BCRGR
Rep	1	0.15	0.02	11900*	2.40
N	2	4.14	1.01	2912.92	0.35
S	1	1.23	0.18	633.75	0.07
N x S	2	2.95	0.34	9083.75*	5.72
Error 1	5	2.04	0.74	1277.42	3.08
C	4	18.06**	7.76**	43895**	35.90**
N x C	8	1.22	0.56	1413.96	1.41
S x C	4	0.70	0.37	1824.38	0.32
N x S x C	8	0.29	0.38	2383.75	1.02
Error 2	24	1.97	0.29	1241.67	1.47
Total	59				

Rep = replications; N = total N; S = N splitting; C = cultivars.
*, ** - significant at 5% and 1% level respectively.

Table 12a. Observed least square means for grain yield (Y) (kg ha^{-1}), test weight (TWT) (kg hl^{-1}), thousand-kernel weight (TKW) (grams), grain protein content (dry weight basis) (GPROT) (g kg^{-1}), and sedimentation value (SDS) (mm), computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

N levels (kg N ha^{-1})		Y	TWT	TKW	GPROT	SDS
50 - 0	**P**	4712	80.1	36	153.8	73
50 -50	**S**	4725	79.5	35	166.1	72
	(P-value)	*(0.8878)*	*(0.1137)*	*(0.5075)*	*(0.0296)**	*(0.3247)*
	Mean	4719	79.8	36	160.0	73
100 - 0	**P**	4689	78.6	34	165.9	73
100 - 50	**S**	4943	78.9	35	164.9	72
	(P-value)	*(0.0603)*	*(0.7997)*	*(0.8681)*	*(0.6857)*	*(0.7601)*
	Mean	4816	78.8	35	165.4	73
150 - 0	**P**	4895	78.1	34	166.6	72
150 - 50	**S**	4760	79.1	36	169.4	69
	(P-value)	*(0.5530)*	*(0.2787)*	*(0.2043)*	*(0.2957)*	*(0.2100)*
	Mean	4828	78.6	35	168.0	71
General Mean		4788	79.0	35	166.8	72
C.V. (%)		*5.71*	*1.27*	*6.52*	*3.92*	*4.81*

P = N applied at planting; S = N split between planting and stem elongation. * - Significant at 5 % level.

Table 12b. Observed least square means for flour yield (FYIELD) (%), flour protein content, dry weight basis (FPROT) (g kg^{-1}), and mixograph parameters [water absorption (MABS) (ml), time to peak (P) (minutes), peak height (PHT) (mm), angle of the trace's medium line after peak (A) (degrees), and width of the trace two minutes after the peak (W) (mm)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Split plot Design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

N levels (kg N ha^{-1})	FYIELD	FPROT	MABS	P	PHT	A	W
50 - 0 P	69.1	150.1	61.2	3.0	65	69	10
50 -50 S	68.6	154.3	62.0	3.1	66	68	11
(P-value)	*(0.1900)*	*(0.1638)*	*(0.1103)*	*(0.7422)*	*(0.2780)*	*(0.0577)*	*(0.6560)*
Mean	68.8	152.2	61.6	3.1	65	68	10
100 - 0 P	68.0	156.9	61.9	3.1	66	67	10
100 - 50 S	69.7	154.2	61.6	3.1	63	71	11
(P-value)	*(0.0634)*	*(0.3760)*	*(0.6684)*	*(0.9296)*	*(0.2220)*	*(0.5922)*	*(0.8145)*
Mean	68.9	155.5	61.7	3.1	65	69	11
150 - 0 P	68.4	162.8	62.4	2.6	68	69	11
150 - 50 S	69.5	158.8	61.4	2.6	65	66	10
(P-value)	*(0.0122)**	*(0.4807)*	*(0.3743)*	*(0.2952)*	*(0.2625)*	*(0.1881)*	*(0.2422)*
Mean	69.0	160.8	61.9	2.6	66	67	10
General mean	68.9	156.2	61.7	2.9	65	68	10
C.V. (%)	*4.04*	*2.61*	*1.99*	*14.94*	*2.90*	*8.70*	*16.18*

P = N applied at planting; S = N split between planting and stem elongation. * - Significant at 5 % level.

Table 12c. Observed least square means for bread-making quality parameters [bake water absorption (BABS) (ml), optimum mixing time (MT) (minutes), loaf volume (LVOL) (cc), and crumb score (BCRGR)], computed for five spring wheat cultivars (two hard white and three hard red types) grown under different N fertilization treatments in a Split plot Design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

N levels (kg N ha^{-1})	BABS	MT	LVOL	BCRGR
50 - 0 P	64.9	3.5	909	5
50 -50 S	65.4	3.7	951	4
(P-value)	*(0.5223)*	*(0.4626)*	*(0.1488)*	*(0.4296)*
Mean	65.1	3.6	930	4
100 - 0 P	66.2	3.8	970	4
100 - 50 S	65.7	3.6	932	4
(P-value)	*(0.6772)*	*(0.8556)*	*(0.3933)*	*(0.8305)*
Mean	65.9	3.7	951	4
150 - 0 P	66.4	3.4	962	4
150 - 50 S	65.4	3.1	938	5
(P-value)	*(0.3743)*	*(0.1331)*	*(0.4409)*	*(0.0577)*
Mean	65.9	3.3	950	4
General mean	65.7	3.5	943	4
C.V. (%)	*2.14*	*15.30*	*3.74*	*28.83*

P = N applied at planting
S = N split between planting and stem elongation

Table 13b. Observed least square means for sedimentation values (SDS) (mm), and loaf volume (LVOL) (cc), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I. Mirlo, I. Boyero and Yecora Rojo) grown under different N fertilization treatments in a Split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

N levels (kg N ha^{-1})		SDS					LVOL				
		Id. 377s	Winsome	I. Mirlo	I. Boyero	Yecora Rojo	Id. 377s	Winsome	I. Mirlo	I. Boyero	Yecora Rojo
50 - 0	P	79	79	53	73	83	913	923	878	805	1025
50 -50	S	78	80	45	75	80	928	995	883	890	1058
(P-value)		*(0.9293)*	*(0.3101)*	*(0.0964)*	*(0.4058)*	*(0.6120)*	*(0.3743)*	*(0.2308)*	*(0.9097)*	*(0.2800)*	*(0.1444)*
Mean		78	79	49	74	81	920	959	880	848	1041
100 - 0	P	79	78	50	75	81	955	1028	890	928	1050
100 - 50	S	78	80	52	71	82	923	970	905	918	1045
(P-value)		*(0.3910)*	*(0.4119)*	*(0.4502)*	*(0.1739)*	*(0.7177)*	*(0.6725)*	*(0.3813)*	*(0.8305)*	*(0.8743)*	*(0.9097)*
Mean		78	79	51	73	82	939	949	898	923	1048
150 - 0	P	78	77	54	70	80	978	955	918	915	1043
150 - 50	S	76	74	49	70	79	915	935	890	918	1033
(P-value)		*(0.3730)*	*(0.3938)*	*(0.1170)*	*(0.9501)*	*(0.5636)*	*(0.1257)*	*(0.4097)*	*(0.5529)*	*(0.9576)*	*(0.7578)*
Mean		77	75	51	70	79	946	945	904	916	1038
General mean		78	78	50	72	81	935	951	894	896	1042

P = N applied at planting; S = N split between planting and stem elongation.

Table 13b. Observed least square means for sedimentation values (SDS) (mm), and loaf volume (LVOL) (cc), computed for five spring wheat cultivars (two hard white: Id377s and Winsome, and three hard red types: I. Mirlo, I. Boyero and Yecora Rojo) grown under different N fertilization treatments in a Split plot design at Barnett-Rugg Farm, near Pendleton-Oregon, in 1999.

N levels (kg N ha^{-1})	SDS					LVOL				
	Id. 377s	**Winsome**	**I. Mirlo**	**I. Boyero**	**Yecora Rojo**	**Id. 377s**	**Winsome**	**I. Mirlo**	**I. Boyero**	**Yecora Rojo**
50 - 0 P	79	79	53	73	83	913	923	878	805	1025
50 -50 S	78	80	45	75	80	928	995	883	890	1058
(P-value)	*(0.9293)*	*(0.3101)*	*(0.0964)*	*(0.4058)*	*(0.6120)*	*(0.3743)*	*(0.2308)*	*(0.9097)*	*(0.2800)*	*(0.1444)*
Mean	78	79	49	74	81	920	959	880	848	1041
100 - 0 P	79	78	50	75	81	955	1028	890	928	1050
100 - 50 S	78	80	52	71	82	923	970	905	918	1045
(P-value)	*(0.3910)*	*(0.4119)*	*(0.4502)*	*(0.1739)*	*(0.7177)*	*(0.6725)*	*(0.3813)*	*(0.8305)*	*(0.8743)*	*(0.9097)*
Mean	78	79	51	73	82	939	949	898	923	1048
150 - 0 P	78	77	54	70	80	978	955	918	915	1043
150 - 50 S	76	74	49	70	79	915	935	890	918	1033
(P-value)	*(0.3730)*	*(0.3938)*	*(0.1170)*	*(0.9501)*	*(0.5636)*	*(0.1257)*	*(0.4097)*	*(0.5529)*	*(0.9576)*	*(0.7578)*
Mean	77	75	51	70	79	946	945	904	916	1038
General mean	78	78	50	72	81	935	951	894	896	1042

P = N applied at planting; S = N split between planting and stem elongation.

Table 14a. Phenotypic correlation coefficients between means of grain yield (Y) and grain protein content (GPROT), and means of test weight (TWT), thousand kernel weight, sedimentation values (SDS) and grain protein content (GPROT), for five spring wheat cultivars (two hard white and three hard red), grown at Hyslop Farm, near Corvallis-Oregon in 1998, 1999 (Exp. I and II), and Barnett-Rugg Farm, near Pendleton-Oregon, 1999 (Exp.III).

	Y			GPROT			SDS		
	Exp. I	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**
SDS	0.58**	0.47**	0.41*	n.s	n.s.	n.s.			
GPROT	0.63**	n.s.	n.s.						
TWT	-0.83**	n.s	n.s.	-0.57**	-0.54**	-0.38*	0.50*	n.s.	n.s.
TKW	n.s	n.s	0.47**	-0.66**	n.s.	n.s.	n.s.	0.54**	0.48**

*, ** - Significant at 5 and 1 % level of probability, respectively.
n.s. - Non significant.

Table 14b. Phenotypic correlation coefficients between means of baking parameters and means of mixograph parameters [mixing time (MT), water absorption (MABS), time to peak (P), peak height (PHT), angle of the trace after the peak (A), and width of the trace two minutes after the peak (W)], and crumb score (BCRGR), loaf volume (LVOL), for five spring wheat cultivars (two hard white and three hard red), grown at Hyslop Farm, near Corvallis-Oregon in 1998, 1999 (Exp. I and II), and Barnett-Rugg Farm, near Pendleton-Oregon, 1999 (Exp.III).

	BABS			MT			LVOL			BCRGR		
	Exp. I	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**
BCRGR	-0.58**	-0.81**	-0.81**		n.s.	-0.63**	-0.91**	-0.89**	-0.78**			
LVOL	0.56**	0.87**	0.76**	n.s.	n.s.	n.s.						
MT	n.s.	n.s.	0.59**									
MABS	0.81**	0.94**	0.92**	n.s.	n.s.	0.54**	0.63**	0.89**	0.80**	-0.59**	-0.81**	-0.87**
P	0.45*	n.s.	0.43*	0.92**	0.93**	0.95**	n.s	n.s	n.s.	n.s.	n.s.	-0.51**
PHT	n.s.	0.78**	0.37*	-0.45*	-0.50**	n.s.	0.69**	0.88**	0.61**	-0.54**	-0.78**	n.s.
A	n.s.	n.s.	0.61**	0.82**	0.88**	0.86**	n.s	n.s	n.s	n.s.	n.s.	-0.73**
W	0.40*	n.s.	0.70**	0.91**	0.62**	0.75**	n.s	n.s	0.64**	n.s.	n.s.	-0.83**

*, ** - Significant at 5 and 1 % level of probability, respectively.
n.s. - Non significant.

Table 14c. Phenotypic correlation coefficients between means of grain yield (Y), grain protein content (GPROT) and sedimentation values (SDS), and means of mixograph parameters and baking parameters, for five spring wheat cultivars (two hard white and three hard red), grown at Hyslop Farm, near Corvallis-Oregon in 1998, 1999 (Exp. I and II), and Barnett-Rugg Farm, near Pendleton-Oregon, 1999 (Exp.III).

	Y			GPROT			SDS		
	Exp. I	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**	**Exp. I**	**Exp. II**	**Exp. III**
MABS	0.79**	n.s.	n.s.	0.57**	0.75**	n.s.	0.47*	0.53**	0.74**
P	n.s.	0.34*	n.s.	-0.48*	-0.67**	-0.45**	0.78**	0.44**	0.75**
PHT	0.67**	n.s	n.s.	0.86**	0.87**	n.s	n.s	0.44**	n.s
A	n.s	0.32*	0.41*	-0.70**	-0.72**	n.s	0.42*	0.35*	0.85**
W	n.s	n.s	0.58**	-0.43*	-0.36*	n.s	0.72**	0.41**	0.76**
BABS	0.60**	n.s	n.s	n.s	0.70**	n.s	0.64**	0.56**	0.76**
MT	n.s	0.35*	n.s	-0.62**	0.70**	n.s	0.67**	0.43**	0.82**
LVOL	0.72**	n.s	0.47**	0.57**	0.85**	n.s	0.64**	0.57**	0.54**
BCRGR	-0.61**	n.s	-0.61**	n.s	-0.65**	n.s	-0.71**	-0.80**	-0.85**

*, ** - Significant at 5 and 1 % level of probability, respectively.
n.s. - Non significant.

correlation found between SDS and GPROT. These results agree with those found by Ammar (1997), working with durum wheats and common wheats in Pendleton, Oregon.

In Table 14b, association between baking parameters and mixograph parameters can be seen. LVOL was significantly correlated with MABS, and PHT of the mixograph, in all the experiments. However, in exp. III, LVOL showed a relatively high correlation with W, which is a measure of tolerance of the dough to over mixing, and an indicator of protein quality. The fact that neither exp. I nor exp. II showed this association, and that PHT and MABS were also significantly correlated with GPROT in these two experiments, but not in the third one (Table 14c), indicates a different pattern of associations in the experiments. As discussed in previous sections, responses to N identified in Exp. I and II, were related mainly to protein quantity. The only consistent source of variation for Experiment III were the cultivars, and the association of W with LVOL could be due to the genetic difference found among cultivars, especially contrasting those with 1BL/1RS translocation and those that lack it. Dough development time was positively associated with gluten strength, as indicated by the highly significant correlation coefficient between SDS and either bake mixing time (MT), or mixograph time to peak (P).

The mixograph parameters, with the exception of MABS and PHT for all experiments, and W for Exp. III, tended not to show association with LVOL. The only consistent association with LVOL through all experiments, though of moderate magnitude, was with SDS values. This variable, which showed to be independent of

protein content, could be considered a good predictor of LVOL, and has been widely used in wheat breeding programs for that reason.

5. CONCLUSIONS

1. Increasing nitrogen levels resulted in increased grain protein content of hard spring wheat cultivars. A concurrent increase in bread making quality was shown, as denoted by increase in sedimentation values, loaf volume and bread crumb score.

2. Grain protein content was influenced by the timing of N fertilizer application. Split application of nitrogen increased grain protein content in both intermediate and high N treatments. An improvement in protein quality and also in baking quality was suggested with a split N application at the intermediate or lower N level.

3. Nitrogen use efficiency was improved with split application of N. Comparable grain protein levels were achieved with intermediate levels of N split applications as compared with higher N rates single applications.

This research on influence of N fertilizer management on bread making quality of a broad range of wheat genotypes with genetic variation in these traits, has shown that it is possible to optimize management practices to further improve the intrinsic quality of different wheat genotypes. Improvement in nitrogen use efficiency (NUE) in terms of grain protein content and baking-related variables is one of the key results of this research, which was not commonly reported in the literature reviewed here. Further understanding of this subject should involve molecular studies describing possible changes in wheat grain components with this kind of management practices.

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