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Variation in gluten quality parameters of spring wheat varieties of different origin grown in contrasting environments

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ABSTRACT

The aim of this study was to investigate variation in protein content and gluten viscoelastic properties in wheat genotypes grown in two mega-environments of contrasting climates: the southeast of Norway and Minnesota, USA. Twelve spring wheat varieties, nine from Norway and three HRS from Minnesota, were grown in field experiments at different locations in Norway and Minnesota during 2009–2011. The results showed higher protein content but lower TW and TKW when plants were grown in Minnesota, while the gluten quality measured as Rmax showed large variation between locations in both mega-environments. On average, Rmax of the samples grown in Minnesota was higher than those grown in Norway, but some locations in Norway had similar Rmax values to locations in Minnesota. The data showed inconsistent relationship between the temperature during grain filling and Rmax. Our results suggest that the weakening effect of low temperatures on gluten reported in this study are caused by other environmental factors that relate to low temperatures. The variety Berserk showed higher stability in Rmax as it obtained higher values in the environments in Norway that gave very weak gluten for other varieties.

1. Introduction

Environmental factors that affect grain development in wheat may also have implications for the functionality of the gluten proteins that eventually will affect the end-use quality. Studies have documented that environmental variations in gluten quality can be large, and this represents a great challenge for the milling and baking industry. Comprehensive knowledge exists on the variability of gluten proteins, their inheritance and influence on gluten functional properties. In contrast, the impacts of environmental factors and their interactions with genotype affecting gluten quality are still only scarcely understood.

Gluten quality is determined by the viscoelastic properties of the dough, which are mainly related to the ratio of monomeric to polymeric proteins (Uthayakumaran et al., 2000) and to the proportion of glutenin aggregates above a certain molecular weight (Southan and MacRitchie, 1999). The fraction of large and unextractable glutenin aggregates, known as SDS-unextractable polymeric proteins (UPP), are found to correlate strongly with dough elasticity (Gupta et al., 1993). Large variation in gluten viscoelastic properties is found between varieties. In particular, the genes encoding the HMW glutenin subunits are known to affect the degree of polymerisation of the glutenins, causing differences in baking quality between varieties (see Shewry et al., 1992 for review).

Variation in protein content and gluten quality caused by the environment (E), the genotypes (G) and the G*E interaction have

Abbrevations: ANOVA, Analysis of Variance; Ext, Extensibility measured by the Kieffer Extensibility Rig; FN, Falling Number; GMP, Glutenin MacroPolymers; HMW-GS, High Molecular Weight Glutenin Subunits; HRS, Hard Red Spring; LSD, Least Significant Difference; NIR, Near InfraRed; PC, Principal Component; PCA, Principal Component Analysis; Rmax, Resistance to extension measured by the Kieffer Extensibility Rig; SDS, Sodium Dodecyl Sulphate Sedimentation Volume; TKW, Thousand Kernel Weight; TW, Test Weight; UPP, SDS-Unextractable Polymeric Proteins.

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been reported in many studies (see Finlay et al., 2007 for overview). In most of these studies gluten quality was analysed by rheological methods or by baking tests, and large variation in gluten quality due to both E, G, and G*E have been documented. In several studies, E is shown to be the main cause of variation in wheat quality, whereas the variation caused by G*E was of less importance (Finlay et al., 2007). The temperature during grain filling is among the environmental factors found to affect gluten quality. In Scandinavia, weaker gluten quality is reported in the seasons having cooler and wetter weather (Johansson and Svensson, 1998; Moldestad et al., 2011; Uhlen et al., 2004). Moldestad et al. (2011) found the temperature during grain filling to be the weather parameter that was most strongly associated with gluten quality, and reported lower resistance to stretching of the gluten dough when the mean daily temperature drops below 17–18 °C. Several researchers have performed experiments in controlled climate chambers and analysed gluten quality and composition (Johansson et al., 2005; Malik et al., 2013, 2011; Randall and Moss, 1990; Uhlen et al., 1998). Some of these studies showed effects on gluten polymer structure and found increased UPP with increasing temperature (Malik et al., 2013, 2011; Uhlen et al., 1998), whereas in other studies, no consistent differences were reported (Johansson et al., 2005). Recently, Moldestad et al. (2014) investigated the effects of temperature during grain filling on gluten quality in growth tunnels where a temperature gradient was established in the longitudinal direction, and found increased UPP and gluten strength with increasing temperatures. However, another study performed in tunnels mimicking cool/wet and warm/dry growth conditions (Georget et al., 2008) could not document differences in gluten quality due to these weather conditions. Thus, contrasting results may reflect complex relationships between the growth temperature and the gluten quality. In a recent review, Johansson et al. (2013) suggests how several environmental factors such as temperature, nutrient availability and the duration of grain filling may involve a number of interacting biochemical mechanisms of relevance for the gluten polymer structure. Still, there are needs for further confirmation of the effects on gluten quality of suggested environmental factors as well as an increased understanding of their mechanisms.

It is generally experienced that higher protein content as well as stronger gluten quality is obtained for spring wheat from the USA compared to wheat grown in Western Europe. The different weather conditions in these regions are believed to be a main factor causing these quality differences. However, few investigations have tried to compare the impacts of different weather conditions in such mega-environments to gluten quality parameters. The present study characterizes gluten from a set of twelve wheat varieties from Norway and Minnesota, USA grown in field trials at different locations in both countries. The aim was to 1) reveal the effects of different climates on gluten quality, 2) compare the gluten quality potential of the Norwegian varieties with the expected superior North American Hard Red Spring (HRS) wheat varieties, and 3) explore the possibility of using varieties of genetically strong gluten to obtain satisfactory quality in regions with a cooler and wetter climate.

2. Materials and methods

2.1. Field experiments

Twelve spring wheat varieties, including nine varieties adapted to Norwegian/Scandinavian growth conditions and three HRS varieties from Minnesota, USA (Supplementary Table 1), were grown in field trials at several locations during the seasons 2009–2011. All varieties possessed strong gluten and the high molecular weight glutenin subunits (HMW-GS) 5 + 10 encoded by *Glu-D1*. The varieties from Minnesota were selected to be representatives for the HRS quality. The field trials were located at four research farms in the southeast of Norway and were run from 2009 to 2011, at Vollebekk (59.660468, 10.781989), Bjørke (60.80276, 11.20403), Rød (59.34387, 10.89505) and Apelsvoll (60.70024, 10.86952), and at three locations in Minnesota, USA in 2011, at St. Paul (44.98958, 93.17923), Crookston (47.818558, 96.613451) and Morris (45.592758, 95.873911). A replicated complete block design with two replicates was used. The amount of fertiliser used at sowing was optimised for each location. The varieties from Minnesota were very susceptible to lodging when grown in Norway, and they were supported by nylon nettings stretched across the plots to avoid this. The experiments in Norway were treated with fungicides sufficient to control diseases with the potential to destroy grain quality.

The phenological development stages heading (Zadoks 49) and yellow ripeness were recorded for each plot at Vollebekk and Apelsvoll, whereas the phenological data was estimated based on calculations of day-degrees for the locations Bjørke and Rød. Heading (Zadoks 49) was recorded in the experiments in Minnesota. Weather data was collected from weather stations located close to the fields. Mean daily temperatures and sum of precipitation during the grain filling period was calculated for each location. Supplementary Table 2 summarises sowing dates, dates for heading and yellow ripening and the weather parameters for all environments.

The experiments were harvested plot-wise with an experimental plot combine. Samples were dried below 15% moisture and cleaned. The experiments at Rød, Bjørke and Apelsvoll in 2011 suffered from severe sprouting, and were excluded from further analyses.

2.2. Physical grain analyses and milling

Thousand kernel weight (TKW) and test weight (TW) were determined for all samples. Wholemeal flour was milled on a Laboratory Mill 3100 (Perten Instruments AB, Huddinge, Sweden) using a screen of 0.8 mm. Samples of 50 g were milled from each variety and replicated for all locations.

2.3. Analyses of whole-meal flour

Falling Number (FN) was determined for all samples using a Falling Number 1800 (Perten Instruments AB, Huddinge, Sweden). Sodium dodecyl sulphate sedimentation volume (SDS) was determined according to the AACC method 56–70 (AACC 2000). Protein content was determined by near infrared (NIR) reflectance spectroscopy using a Perten Inframatic 9200 (Perten Instruments AB, Huddinge, Sweden).

2.4. Gluten micro-extension test

Gluten micro-extension tests were performed as described by Moldestad et al. (2011) using the SMS/Kieffer Dough and Gluten Extensibility Rig (Kieffer et al., 1998) for the TA.XT *plus* Texture Analyser (Stable Micro Systems, Godalming, UK). Gluten was prepared from wholemeal in a Glutomatic 2100 (Perten Instruments AB, Huddinge, Sweden) by using a 2% NaCl solution to remove salt soluble components. The dough was mixed for 1 min before 10 min of washing. To remove starch and bran particles, two different filters were used in the process. An 88 μm sieve was changed after 2 min and replaced by an 840 μm sieve. To remove excess water, the gluten dough was centrifuged in a custom-made centrifuge mould at 3000 g for 10 min at 20 °C (Beckmann TJ-25 (Rotor TS-5.1–500). Subsequently, it was pressed in the standard Teflon mould and