THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON WINTER WHEAT WHOLEMEAL PROTEIN CONTENT AND RHEOLOGICAL PROPERTIES

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Abstract

The aim of this investigation was to clarify variation of protein content on winter wheat (*Triticum aestivum* L.) grain, water absorption and mixing properties of wholemeal dough, depending on harvest year weather conditions (2010–2012) and cultivar. Trial included winter wheat cultivars 'Bussard' and 'Zentos'. The farinograph water absorption (WA) and wholemeal dough mixing characteristics – dough development time (DDT), dough stability time (ST) and degree of softening (DS12) were tested by Brabender Farinograph (ICC 115/1). The data show that experimental year and cultivar significantly ($p<0.05$) affected protein content, farinograph water absorption and mixing properties of winter wheat wholemeal dough**.** The influence of year was confirmed on higher level for grain protein content and wholemeal dough stability time, compared with the cultivar effect. Cultivar had a much stronger effect on wholemeal dough water absorption, dough development time and degree of softening than year. Cultivar 'Bussard' wholemeal had higher protein content, water absorption, longer stability time and shorter degree of softening compared with 'Zentos'. The results demonstrate that the quality of the studied varieties meets the requirements for high-grade wheat for food consumption, and are suitable for wholegrain flour production and baking. The positive correlation ($r=0.972$) existed between protein content and dough stability. Protein content correlated negative ($r=-0.893$) with dough degree of softening. Dough stability time had negative correlation ($r=-0.878$) with degree of softening.

Keywords: winter wheat, protein, rheological properties, Farinograph.

Introduction

Wheat (*Triticum aestivum* L.) is a dominant cereal crop in the Latvia, and more and more is used in the preparation of bread made from whole wheat grain flour. Whole grain foods are an important part of the diet because they provide many nutrients (Kunkulberga et al., 2007b). The wheat kernels contain a germ, pericarp layers (outer and inner), seed coat, aleurone layer and starchy endosperm. The objective of milling is to separate the starchy endosperm from the kernel, and to ground it into flour. The aleurone layer, pericarp layer and seed coat form the bran. When white flour is produced, many important nutrients including dietary fibres are removed, because these components are mainly located in bran and germ (Dewettinck et al., 2008).

Quality parameters of winter wheat are not stable between production years because of the inconsistency of the variables, such as initiation of the growing season, distribution of rainfall and heat units available for crop growth during corresponding phases of plant growth and development (Linina, Ruza, 2004).

Protein content is commonly used as predictor of baking quality (Koppel, Ingver, 2010). The temperatures and water stress occurring during grain filling period affects changes in wheat protein aggregation (Daniel, Triboi, 2002). Grain protein content significantly varied depending on the differences among cultivars (Linina, Ruza, 2012). During ripening wheat needs sunny and warm weather and moderate moisture. These conditions secure biological maturity and acceptable technological and rheological properties of grain (Krejčirova et al., 2006).

Evaluation of rheological properties of flour by farinograph is popular among the millers, bakers, grain handlers and wheat breeders. The rheological characteristics reflect the dough properties during processing and the quality of the final product. Strong flours are characterized by a long dough development time, high stability with a small degree of softening, while poor flours weaken quickly, resulting in high degree of softening (Shahzadi et al., 2005).

Rheological properties of wheat mainly depend from cultivars diversity and the growth conditions. Panozzo (2000) reported that year meteorological conditions and cultivar interactions were significant for the dough rheological characteristics.

In Latvia there were no made investigations about winter wheat wholemeal rheological properties depending on weather conditions and cultivar till now.

Therefore, the aim of the present research was to investigate the influence of weather conditions in three harvesting years and two different cultivars on the content of wholemeal protein, and the farinograph water absorption, dough development time, stability time and degree of softening.

Materials and Methods

Study fields. Field experiments in years 2010, 2011 and 2012 were conducted at the Latvia University of Agriculture, Study and Research farm "Peterlauki" on silt loam brown lessive soil with close to neutral acidity (pH_{KCl} 6.9), medium high phosphorus and potassium, humus content 2.7 g kg^{-1}. Registered winter wheat (*Triticum aestivum* L.) bread cultivars from Germany 'Bussard' and 'Zentos' were sown after black fallow. Both cultivars are with high bread – making quality. Phosphorus and potassium fertilizers were applied in autumn $P_2 0_5$ – 72 kg ha^{-1} and $K_2 0$ – 90 kg ha^{-1}. Nitrogen (N), was applied N60 – 150 kg ha^{-1} in spring after resumption of vegetative growth. Grain was harvested at full ripeness; sampling procedure for grain quality evaluation was performed according to the standard ICC 101/1 for obtaining average sample.

Weather data collection. The air temperature in investigation years (Table 1) in April was by 0.8–2.5 °C higher compared with long-term average observations; also May was by 0.3–1.3 °C warmer, which promoted plant growth and development. Average daily temperature in June 2010 and 2011 was warmer by 0.9–2.0 °C which contributed to the accumulation of protein. In 2012 air temperature was lower than 1.1 °C, compared to long-term average data. Temperature in the grain filling period (July), which is most decisive for grain quality formation, was in 2010 by 4.4 °C warmer and by 2.7 °C warmer in 2011, while in 2012 only by 1.2 °C higher than the long-term average mean data.

Table 1

Weather conditions during the field experiment

Month	Average temperature °C			
	2010	2011	2012	LTM*
April	6.2	7.9	6.4	5.4
May	12.6	11.6	12.2	11.3
June	16.1	17.2	14.1	15.2
July	21.2	19.5	18.0	16.8
Average	14.0	14.1	12.7	12.2
	Sum of precipitation, mm			
April	48	32	106	40
May	85	56	45	51
June	60	78	95	75
July	298	179	197	82
Average	122	86	111	62

*LTM–long-term mean

Water availability has effect on wheat grain quality. Precipitation in April 2010 and 2011 was close to long-term average, but in 2012 by 265% more than long-term means data.

May in 2010 was wet, when precipitation was 164% higher than the long-term average for this month, in 2011 and 2012 precipitation was close long-term mean data for this month.

Precipitation in June 2010 and 2011 was close to long-term mean; but in 2012 by 126% more than long-term means data. July in 2010, 2011 and 2012 was very rainy, respectively by 365%, 219% and 241% exceeded the long-term averages data.

Technological properties of wheat. The protein content and rheological properties of wholemeal wheat were determined at the Latvia University of Agriculture, in the Grain and Seed Research Laboratory and Laboratory of Food analysis. Grains were milled to wholemeal using Laboratory Mill 3100 (Perten Instruments, Sweden) at a particle size of 0.8 mm. Wheat technological properties were analyzed in duplicate. Grain protein content (PC) was calculated multiplying total nitrogen content by factor 5.7 determined by Kjeldahl method (ICC 105/2; Kjeltec system 1002, Foss Tecator AB, Sweden). The farinograph water absorption (WA, 14%) and dough mixing characteristics–dough development time (DDT), dough stability time (ST) and degree of softening (DS12) were tested by Brabender Farinograph with a mixer using 300 g of flour, with slow blade rotation speed 63 rpm and measurement control system software 2.5.17 (Brabender, Germany; ICC 115/1).

Statistical analysis. Experimental data evaluation was done using two – factor analysis of variance by Fisher's criteria and least significant difference ($LSD_{0.05}$) were applied to estimate the effects of year (weather conditions) and cultivars. Component of variance ANOVA for each quality characteristic were expressed as percentage to illustrate the relative impact of each source to the total variance. Correlation analysis between protein content and wholemeal rheological properties was also carried out.

Results and Discussion

Protein content (PC) is one of more important indicators of grain quality for the bread making industry (Ruzgas, Liatukas, 2008). Grains with protein content 12–13% are suitable for bread making; however, grains with higher protein content traditionally are used for improving the properties of lower quality grains. Grain processing companies in Latvia are limited requirements for A quality class wheat is protein contents >145 g kg^{-1}, first class > 140 g kg^{-1}, second class >130 g kg^{-1} and third class – > 120 g kg^{-1}.

Average data in our experiment (3 years) suggest (Table 2) that protein content in cultivar 'Bussard' grains was 143.4 g kg^{-1}, it was statistically significantly higher compared to 'Zentos' (122.6 g kg^{-1}). Grain protein content significantly varied depending on the cultivars and meteorological conditions (Ruza et al., 2002; Kunkulberga et al., 2007a; Skudra, Linina, 2011).

Table 2

Winter wheat wholemeal protein content, g kg^{-1}

Cultivar, factor A	Year, factor B			Average
	2010	2011	2012	$LSD_{0.05\ A}$=1.1
Bussard	150.1	155.3	124.9	143.4
Zentos	131.5	133.8	102.5	122.6
Average B	140.8	144.5	113.7	×
$LSD_{0.05\ B}$ = 1.4				
$LSD_{0.05\ AB}$ = 2.0				

The protein content of both wheat cultivars in years 2010 and 2011 was consistent with the requirements of food wheat, while protein content in variety 'Bussard' grains was significantly higher than mentioned in A class requirements. The average temperature from

April to July during the years 2010 and 2011 exceeded 14 °C and this was favourable for protein synthesis, therefore, in cultivar 'Bussard' grain average protein content was 153.6 g kg^{-1}, while in 'Zentos'– 132.7 g kg^{-1}. Similar scientific results were obtained in the trial Dotnuva (Lithuania) Cesevičiene and co-authors (2009), they conclude, that warmer weather with more sunny days is more favourable for the accumulation of protein content in wheat grains.

The lowest protein content was identified in both analysed cultivars in year 2012. Grain quality mainly was affected by the weather conditions during the ripening period (Cesevičiene, 2012). Cool (average air temperature in growing season 12.7 °C) and rainy weather in 2012 during grain filling – ripening stage was adverse for protein accumulation. In cultivar 'Bussard' grain average protein content was 124.9 g kg^{-1} and corresponded to third class, especially low protein content accumulated in the cultivar 'Zentos' grain – 102.5 g kg^{-1}.

In our experiment, according to Fisher's criteria, the weather conditions and cultivar had a significant ($p<0.05$) impact on the grain protein content. Grain protein content did not significantly depend either on the year–cultivar interaction.

Similarly, the analysis of variance for two cultivars and 3 experiment years suggest that winter wheat grain protein content by 63.3% depended on weather conditions (year), but the influence cultivar was also remarkable – 36.4% (Table 3). Influence of the year was most remarkable also in the investigation with 15 winter and 14 spring wheat cultivars in the years 2004–2007 in Estonia (Koppel, Ingver, 2008).

Table 3

Impact factors of winter wheat wholemeal quality indices, %

Source of variation	PC	WA	DDT	ST	DS12
Year	63.3	28.1	37.4	59.1	28.1
Cultivar	36.4	66.4	51.8	37.8	68.9
Year/cultivar interraction	0.2 ns.	3.1 ns.	10.6	3.0	2.1

PC–protein content, WA–water absorption; DDT–dough development time; ST–dough stability; DS12–degree of softening, ns–not significant.

Dough quality is one of the most important features enabling one to predict the final bread making value of the winter wheat cultivar (Liatukas et al., 2012). The elasticity of the dough was measures by Brabender's farinograph, whose operations are based on physical methods. The diagram (farinogram) shoved direct indexes: water absorption, dough development time, stability and degree of softening.

Water absorption (WA) is the most important parameter measured by farinograph, it indicated as the amount of water need to develop the standard dough of 500 farinograph unit (FU) at the peak of the curve. Stronger wheat flours have the ability to absorb and retain more water as compared to weak flours (Mis, 2005).

Average data suggest (Table 4), that wholemeal made from 'Bussard' absorbed water (721 g kg^{-1}) on average by 34 g kg^{-1} more than 'Zentos' (687 g kg^{-1}) and this is statistically significantly higher. In reports of Mašauskiene and Cesevičiene (2006) with winter wheat a white bread flour Type-550 water absorption for cultivar 'Zentos' was 591–631 g kg^{-1}, however according to Koppel and Ingver (2010) 550–650 g kg^{-1} WA is appropriate for yeast bread. Wholemeal flour need larger water content as compared to white flours, in experiment of Haridas Rao and other (1989) it was 704–825 g kg^{-1}, similar results we obtained in our experiment too.

It has been shown that water absorption increased with increasing of PC content (Zaidul et al., 2002; Shahzadi et al., 2005, Constantinescu et al., 2011). In our experiment the average PC in wheat grain cultivars 'Bussard' and 'Zentos' was higher in year 2011, (respectively 155.3 and 133.8 g kg^{-1}) as a result WA was higher too, respectively 704–734 g kg^{-1}, similar results also found by Varga with colleges (2003).

Table 4

Winter wheat wholemeal water absorption, g kg^{-1}

Cultivar, factor A	Year, factor B			Average
	2010	2011	2012	$LSD_{0.05\,A}$=6.4
Bussard	715	734	712	721
Zentos	672	704	686	687
Average B	694	719	699	×
$LSD_{0.05\,B}$ = 7.9				
$LSD_{0.05\,AB}$ = 11.2				

The cultivar and weather conditions (harvesting year) had a significant ($p<0.05$) impact on the wholemeal WA, while cultivar–year interaction does not affect WA significantly (Table 3). WA was mostly affected by the cultivar (66.4%) however; the year factor was also remarkable (28.1%). In Koppel and Ingver (2010) experiments with 11 winter wheat cultivars in the years 2005-2009, WA dependency on year complete to 63.6% but the influence of cultivar – 24.3%.

Dough development time (DDT) indicates the relative strength of the wheat flour and can also reflect the level of water absorption in the test. Therefore, if the dough development time is shorter, the less time is needed to mix the dough (Sabovics, Straumite, 2012). In the present experiments, the dough development time of both analyzed cultivars was high (Table 5).

A dough development time of wholemeal from 'Bussard' was 4.75 min in average, and this is by 1.11 min lower compared with 'Zentos' (5.86 min). Sabovics and Straumite (2012) found similar results in Latvia: they tested wholemeal triticale properties by farinograph and determined dough development time as 5.95 min, while Mašauskiene and Cesevičiene (2006) found that wheat dough development time for cultivar 'Zentos' white flour was 2.25–3.43 min.

Table 5

Winter wheat wholemeal dough development time, min

Cultivar, factor A	Year, factor B			Average
	2010	2011	2012	$LSD_{0.05\,A}$=0.05
Bussard	5.55	4.67	4.05	4.75
Zentos	5.99	6.33	5.27	5.86
Average B	5.77	5.50	4.66	×
$LSD_{0.05\,B}$ = 0.06				
$LSD_{0.05\,AB}$ = 0.09				

Prabhasankar et al., (2002) and Shahzadi et al., (2005) found that wholemeal dough require a longer development time compared to white flour because it contains bran.

The weather conditions in the investigations years, cultivars and year–cultivar interaction had a significant ($p<0.05$) impact on the wholemeal DDT. DDT was more affected by the cultivar (51.8%) than by the year (37.4%) and lowest impact belonged to interaction cultivar-year (10.6%).

Dough Stability (ST) indicates the time when the dough maintains maximum consistency and a good indication of dough strength (Karaoglu, 2011). ST is measure that is expected by baking industry for producing yeast bread. Good quality dough could be stable for 4–12 min. Satisfactory ST is about 6 min.

Average dough stability (Table 6) of cultivar 'Bussard' wholemeal dough was 9.01 min, while it for 'Zentos' was 6.77. The dough stability should relate with the cultivars peculiarities mainly (Cesevičiene et. al., 2012).

Table 6

Winter wheat wholemeal dough stability time, min

Cultivar, factor A	Year, factor B			Average
	2010	2011	2012	$LSD_{0.05\,A}$=0.07
Bussard	9.95	9.99	7.11	9.01
Zentos	6.94	8.54	4.82	6.77
Average B	8.45	9.26	5.96	×
$LSD_{0.05\,B}$ = 0.08				
$LSD_{0.05\,AB}$ = 0.12				

Dough stability is an important indicator for flour strength which is based on the quantity and quality of dough protein (Kučerova, 2005). In our experiment it was determined that if the protein content in grain was higher (year 2011), the dough stability made from both cultivars 'Bussard' and 'Zentos' wholemeal was longer – 9.99 and 8.54 min respectively, similar results Varga et. al., (2003) was found.

The weather conditions in the investigations years, cultivars and year–cultivar interaction had a significant ($p<0.05$) impact on the wholemeal ST (Table 3). ST was most markedly affected by the year (59.1%) but influence of a cultivar was also reliable (37.8%), while the influence year–cultivar interaction was small 3.0%, this is agreement with earlier reports of Kopel and Ingver (2010).

Degree of softening (DS12) is the difference between the centre of the curve at the end of the dough development time and the centre of the curve 12 minutes after this point. Dough mixing qualities are considered satisfactory when the degree of softening is below 70 FU. When this value exceeds 110 FU, the dough is considered to be weak (Mašauskiene, Cesevičiene, 2006). Average degree of softening of 'Bussard' wholemeal was 23.8 FU where the degree of softening 'Zentos' was 43.0 FU (Table 7). Therefore the dough softening depends on the cultivar genetic characteristics (Mašauskiene, Cesevičiene, 2006) which were confirmed in the present experiment.

Table 7

Winter wheat wholemeal dough degree of softening, FU*

Cultivar, factor A	Year, factor B			Average
	2010	2011	2012	$LSD_{0.05\,A}$=2.34
Bussard	17.4	24.0	30.1	23.8
Zentos	36.8	39.0	53.3	43.0
Average B	27.1	31.5	41.7	×
$LSD_{0.05\,B}$ = 2.87				
$LSD_{0.05\,AB}$ = 4.05				

***FU**–farinograph units

In 2012, when the protein content in grain was lower (compared with 2010 and 2011), the dough softening of analyzed wholemeal made from both cultivars 'Bussard' and 'Zentos' was higher–30.1 and 53.3 FU respectively, acquired results agree with report of Varga et al., (2003). The year, cultivar and year – cultivar interaction had a significant ($p<0.05$) impact on the wholemeal DS12 (Table 3). DS12 mostly depending on cultivars (68.9%), influence of a year was 28.1% while both factors influence was only 2.1%. Protein content is often used as indirect indicator of baking quality–higher protein content means that the dough stability is higher, compare with lower protein content (Kopel, Ingver, 2010).

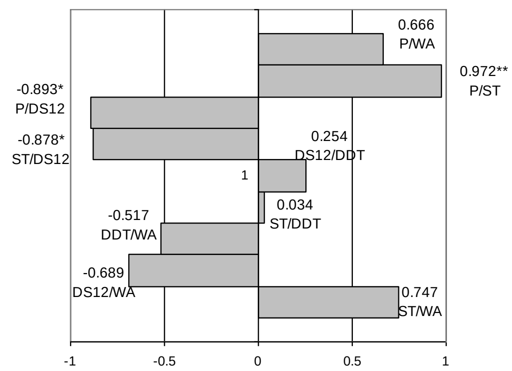

Figure 1. Correlation coefficient (r) **between quality indices**

r**–is significant at 99%; r*–at 95% level of probability. PC–protein content, WA–water absorption; DDT–dough development time; ST–dough stability; DS12–degree of softening.

In our investigation a tendency was found, namely, if the grain protein content is higher the dough formation time is longer, the dough stability is higher, and the dough softening is lower.
The wheat wholemeal quality parameters were assed by correlation analysis too (Figure 1).
A statistically significant positive correlation was found between PC and ST r=0.972**, R^2=0.945, a regression equation y=9.192x+60.48, these results are in accordance with studies made by Kopel and Ingver (2010), and Ceseviciene et al., (2012).
Preston (2001) found that the correlation between PC and WA was statistically significant (r=0.51), however in our investigation relationship between PC and WA was higher (r=0.66), but not significant.
PC showed high negative relationship between DS12 described by the regression equation y=–1.341x+177.83, and correlation coefficient r=0.893*, R^2=0.798.
Mikos and Podolska (2012) found that higher degree of softening indicated lower dough stability. Our results are in agreement with this as a strong negative relationship was evident between DS12 and ST r=–0.878*, R^2=0.771, y=–0.139x+12.55.

Conclusions

In the present research it was found that wheat cultivars with differences in their genetic as well as weather conditions significantly influence protein formation in grains. Higher protein content was found in the wheat samples in harvest years with warmer growing conditions (2010 and 2011).
Winter wheat rheological properties demonstrate that the quality of the studied varieties correspond to the requirements for high-grade wheat for food consumption, and are suitable for wholegrain flour production and bread baking.
Winter wheat cultivars 'Bussard' and 'Zentos' are different in their farinograph curve shapes. 'Bussard' wholemeal had higher water absorption, longer stability time and shorter degree of softening, compared with 'Zentos'.
Cultivar had a much stronger effect on wholemeal dough water absorption, dough development time and degree of softening than weather conditions in investigations years. The influence of environmental conditions on higher content of protein in winter wheat grain was confirmed as well as wholemeal dough stability time, compared with the cultivar effect.
The strong correlation was found between protein content and dough stability time. Degree of softening had negative correlation with protein content. Dough stability correlated negatively with degree of softening.

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