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INFLUENCE OF NITROGEN FERTILISER ON WINTER WHEAT WHOLEMEAL RHEOLOGICAL PROPERTIES

Anda Liniņa*#, Daiga Kunkulberga**, and Antons Ruža*

* Faculty of Agriculture, Latvia University of Agriculture, Lielā iela 2, Jelgava, LV-3001, LATVIA;
anda.linina@llu.lv, antons.ruza@llu.lv

** Faculty of Food Technology, Latvia University of Agriculture, Lielā iela 2, Jelgava, LV-3001, LATVIA;
daiga.kunkulberga@llu.lv

Corresponding author

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The aim of this investigation was to describe the variation of water absorption and mixing properties of wholemeal dough, depending on effects of, different rates of nitrogen (N) application (N60, N90, N120, N150), weather conditions (in 2010 and 2011) and grain storage time (60, 120, and 360 days) for two cultivars of winter wheat (in Triticum aestivum *L.). Trials included winter wheat varieties 'Bussard' and 'Zentos'; both cultivars have high bread-making quality. The farinograph water absorption and wholemeal dough mixing characteristics — dough development time, dough stability time, and degree of softening were tested using a Brabender Farinograph (ICC 115/1). Highly significant effect of cultivars and nitrogen fertiliser were detected on the flour water absorption and dough mixing properties. Grains with higher protein content had better wholemeal dough rheological properties. The wholemeal rheological properties in 2010 and 2011 did not differ significantly. Extended grain storage from 60–360 days resulted in: longer dough development and dough stability time, increased degree of softening, and decreased water absorption. 'Bussard' wholemeal had higher water absorption, longer stability time (sometimes excellent quality) and shorter degree of softening compared with 'Zentos'. According to the farinograph curves, wholemeal dough of 'Bussard' can be classified as having medium/long development time and long/excellent stability. Farinograph curve shapes of 'Zentos' wholemeal dough indicated medium development time and long stability. A very strong a positive correlation was found for protein content between WA and ST.*

Key words: *winter wheat, nitrogen fertiliser, grain storage time, farinogram.*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a dominant cereal crop in the world. Wholesome food ensures health, liveliness and capacity for work. More and more bread wheat whole grain flour is being used. White flour and wholemeal flour are the two main types of wheat flour. In the production of wholemeal flour the whole grain is used. This type of flour has an extraction rate of 100%, which means nothing is removed during milling. White flour is refined. The bran and nutrient-packed germ are separated from the rest of the grain, resulting in loss of many nutrients. These two main types are associated with different types of flour. The commonly called "brown flour" has a higher extraction rate than white flour. It contains more bran and this gives the flour darker colour. Wholemeal flour contains all parts of the grain: fibre-rich bran (outer layer), endosperm (middle layer) and germ (inner layer). The bran provides fibre, B group vitamins, minerals, protein and other phytochemicals. The endosperm contains carbohydrates, proteins and small amounts of B group vitamins. The germ is packed with minerals, B group vitamins, vitamin E and other phytochemicals. Whole grain foods are an important part of the diet, as they provide many nutrients (Kunkulberga *et al.*, 2007b).

Rheological properties of dough play an important role in governing the quality of baked products (Bloksma and Bushuk, 1988). Evaluation of rheological properties of flour by a farinograph is popular among millers, bakers, grain handlers and wheat breeders. The rheological characteristics reflect the dough properties during processing and the quality of the final product (Spies, 1990).

The method is regulated by standards ICC 115/1. On the basis of farinograph data on water absorption, dough development time and dough stability time, wheat flours can be classified as weak, medium, strong and very strong. Strong flours are characterised by a long development time, high stability with a small degree of softening, while poor flours weaken quickly, resulting in high degree of softening. The farinograph curve reflects the common characteristics of flour or grain and the results of changes in grain occurring during grain ripening and storage period. Rheological properties of wheat respond to cultivar diversity and growth conditions. Panozzo (2000) reported that environment-cultivar interactions had significant effect on dough rheological characteristics. For many characters the interaction was of similar magnitude, or greater than the cultivar variance. Temperatures and water stress during grain filling period affects changes in wheat protein aggregation (Triboi, 2003; Karaoglu *et al*., 2010). During ripening wheat needs sunny and warm weather and moderate moisture. These conditions ensure biological maturity and acceptable technological and rheological properties of grain (Krejčirova *et al*., 2006). Nitrogen fertiliser is routinely used to manipulate the relationships between mixing requirements and dough strength to different degrees, depending on the cultivar. The variation in response of cultivars to fertilisation treatment can be explained by genotypic differences in protein composition and interaction of these factors with physical properties (Wooding *et al.,* 2000). Dough is a complex system that presents challenges in product development, and its viscoelastic behaviour is not yet fully understood. Better knowledge of the viscoelastic behaviour of dough is required for modifying baking processes to improve quality (Faubion and Hoseney, 1989).

This research is a continuation of previous work (Liniņa and Ruža, 2012; 2013), in which we investigated the quality of winter wheat grain (protein content, sedimentation value, gluten content and falling number) in relation to different rates of nitrogen fertiliser application, during grain storage (60, 120, and 360 days). The aim of this investigation was to describe the relationships of water absorption and rheological properties of wholemeal dough, depending on different rates of nitrogen fertiliser application, weather conditions and grain storage period (60, 120, and 360 days) for two winter wheat grain cultivars. In Latvia, changes in the mixing properties of whole wheat grain depending on nitrogen fertiliser and grain storage period were studied for the first time.

MATERIAL AND METHODS

Field experiments in 2010 and 2011 were conducted at the Latvia University of Agriculture, Study and Research Farm "Pēterlauki" on silt loam brown lessive soil with close to neutral acidity (pHK_{Cl} 6.9), medium high phosphorus and potassium, and 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 have high bread-making quality (Elite cultivars). These cultivars in Latvian farms nowadays are popular. Phosphorus and potassium fertilisers were applied in autumn: P_20_5 – 72 kg·ha^{-1} and K_20 – 90 kg·ha^{-1}. Nitrogen was applied in spring after resumption of vegetative growth. Nitrogen top-dressing rates were as follows: N60, N90, N120 and N150. All necessary plant protection measures were performed. Grain was harvested at full ripeness; sampling procedure for grain quality evaluation was performed according to standard ICC 101/1 for obtaining an average sample. Freshly harvested grain of each variety was put into separate bags. Grain samples for analyses were taken four times: fresh and stored grain — 60, 120 and 360 days after harvest.

The grain was stored in a storage house in which the indoor temperature depended on the outdoor temperature and relative air humidity was 52–75%.

In 2010 and 2011, the air temperature in spring was close to long-term average observations (norm), which promoted plant growth and development. Mean May temperature was +12.6 ^{o}C in 2010 and +13.9 ^{o}C in 2011, while long-term average was +13.0 ^{o}C. Average daily temperature in June was close to normal in both investigation years. Temperature in the grain filling period (July), which is most decisive for grain quality formation, was similar for both years – 21.2 ^{o}C or by 4.4 ^{o}C warmer than the long-term average in 2010 and 19.9 ^{o}C or by 3.3 ^{o}C warmer in 2011.

Water availability has effect on wheat yield and grain quality (Ruza *et al*., 2002; Povilaitis and Lazauskas, 2010). May in 2010 was wet, when precipitation was 84.6 mm, or 164% higher than the long-term average for this month. In 2011, extremely dry conditions occurred during the third decade in April and first decade in May. Precipitation in June 2010 and 2011 was close to normal; July in 2010 and 2011 was very rainy with total precipitation 298 mm and 179 mm (365% and 219% compared with the long-term averages). Winter wheat was harvested on 4 August in 2010, and on 5 August in 2011.

The rheological properties of wheat wholemeal 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 a Perten Laboratory Mill 3100 with 0.8 mm sieve and then mixed thoroughly. 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 a Brabender Farinograph (Figure) with a mixer for 300 g of flour, slow blade rotation speed 63 min^{-1} and measurement control system software 2.5.17 (Brabender, Germany; ICC 115/1). The guidelines for interpretation of DDT and ST results were used to categorize samples as described by Williams (1997). Flour with dough development time and stability time of ≤ 1 min is categorised as weak, while strong flours — respectively, 3–5 and 8–14 minutes. Medium/strong flours have dough development time of 2–4 min and stability of 4–7 min, and extra strong flours have development time of 4–12 min and stability of 20–32 minutes.

Experimental data evaluation was done using two-factor analysis of variance (ANOVA) by Fisher's criterion and least significant difference ($LSD_{0.05}$). Means, standard errors of the mean and coefficients of variation were determined. Significant differences in wholemeal rheological properties between both investigations years were tested by a t-test: two-sample assuming unequal variance. Correlation analysis between protein content and wholemeal rheological properties was also carried out.

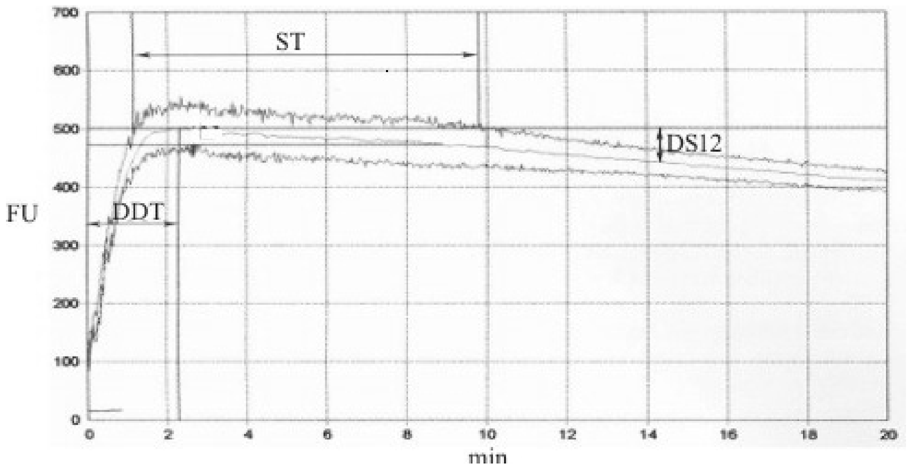

Fig. 1. Brabender farinogram, DDT, dough development time (min); ST, dough stability, (min); DS12, degree of softening, (FU – Farinograph unit).

RESULTS

High quality wheat grain is required for milling and baking industries. Farinographic studies were conducted to determine the rheological properties of whole wheat flour. Water absorption was the only character with a low coefficient of variation CV 3.17–3.66 (Table 1). The wholemeal dough mixing characters were subject to high variation. Wholemeal from 'Bussard' absorbed water on average by 37 $g·kg^{-1}$ more than 'Zentos' (Table2). Cultivar 'Bussard' wholemeal had a 0.95-min lower dough development time and higher CV of these parameters compared with those of 'Zentos'. Wholemeal dough of 'Bussard' was found to be by 2.51 min more stable and to have by 18.0 FU shorter degree of softening compared with those of 'Zentos'.

Water absorption (WA) is indicated as the amount of water need to develop a standard dough of 500 farinograph unit (FU) at the peak of the curve. A critical issue to production is how much water needs to be added for optimum mixing characteristics and how much water can be added to flour to give a higher yield of finished product at a lower cost. Water absorption, which is an important characteristic of wheat flour, ranged from 600–760 $g·kg^{-1}$ (Nurul Islam and Johansen, in Shahzadi *et al.*, 2005) in wheat varieties. Water absorption of weak flours is below 550 $g·kg^{-1}$, of medium flour 540–600 $g·kg^{-1}$, and strong above 580 $g·kg^{-1}$ (William, 2001).

Stronger wheat flours have the ability to absorb and retain more water as compared to weak flours (Mis, 2005). Water

Table 1

THE VARIATION OF WINTER WHEAT WHOLEMEAL WATER ABSORPTION AND DOUGH MIXING PROPERTIES

Assessment	WA	DDT	ST	DS12
	$g·kg^{-1}$	min	min	FU
Cultivar 'Bussard'				
Mean± standard error	707 ± 4.0	5.85 ± 0.17	10.96 ± 0.34	36.04 + 2.37
Range	670–748	4.34–8.50	7.41–15.04	13.2–64.5
CV%	3.17	16.42	17.33	37.15
Cultivar 'Zentos'				
Mean standard error	670 ± 4.3	6.81 ± 0.16	8.45 ± 0.21	54.04 ± 2.61
Range	619–717	5.05–8.6	6.49–11.21	29.95–82.75
CV%	3.66	13.67	13.78	27.35

WA, water absorption; DDT, dough development time; ST, dough stability;

DS12, degree of softening, (FU – Farinograph unit).

Table 2

WHOLEMEAL WATER ABSORPTION ($g·kg^{-1}$) IN WINTER WHEAT DEPENDIG ON NITROGEN FERTILISER RATE, YEAR AND GRAIN STORAGE TYPE

Year	Storage (A)	Nitrogen fertiliser (B) N60	N90	N120	N150	Average
Cultivar 'Bussard'						
2010	Fully ripe	707	717	712	726	715
	60 d	696	707	708	715	706
	120 d	676	675	689	709	687
	360 d.	670	671	679	695	679
	Average	687	692	697	711	697
	$LSD_{0.05}$	A = 5.3	B = 5.3	AB = 10.5		
2011	Fully ripe	721	732	748	737	734
	60 d	706	723	742	730	725
	120 d	688	708	733	726	714
	360 d.	675	677	722	707	695
	Average	697	710	736	725	717
	$LSD_{0.05}$	A = 3.4	B = 3.4	AB = 6.8		
Cultivar 'Zentos'						
2010	Fully ripe	662	664	676	686	670
	60 d	652	658	662	673	661
	120 d	634	644	648	663	647
	360 d.	619	628	643	656	634
	Average	641	648	657	669	641
	$LSD_{0.05}$	A = 3.6	B = 3.6	AB = 7.2		
2011	Fully ripe	705	693	701	717	704
	60 d	701	679	693	708	695
	120 d	684	663	684	694	681
	360 d.	652	654	666	684	664
	Average	685	672	686	701	686
	$LSD_{0.05}$	A = 7.7	B = 7.7	AB = 15.4		

absorption ranged from 707–748 g·kg^{-1} for cultivar 'Bussard' and from 662–717 g·kg^{-1} for 'Zentos'. Mašauskiene and Cesevičiene (2006) reported that water absorption of white bread flour Type-550 was 601–649 g kg^{-1} for cultivar 'Ada' and 591–631 g·kg^{-1} for 'Zentos'. Previous studies reported a higher need for water (range 704–825 g·kg^{-1}) by wholemeal flour (Rao *et al*., 1989).

Higher absorption indicates that more water is required to reach a desired consistency in the dough mixing process. In trials in Germany, water absorption of winter wheat 'Batis' grain flour was 588 g·kg $^{-1}$ in 2000 and 641 g·kg^{-1} in 2001, whereas in both crop years the grain was similar in protein content: 128 and 131 g·kg^{-1}, respectively (Meyer and Lindhauer, 2001; Meyer and Brummer, 2002). With increase of the dose of N fertiliser, protein content is higher and water absorption significantly increases. Intensified wheat fertilisation with nitrogen resulted in better flour properties estimated by a farinograph through increased grain protein content (Pushman and Bingham, McNeal *et al.* in Varga *et al*., 2003). Matz (1972) reported that an increase in protein content increased water absorption. Cesevičiene *et al*. (2012) observed that water absorption was lower when grain had higher protein concentrations. In our experiment protein content in 'Bussard' grain in both years was in the range 144–159 g·kg $^{-1}$, while 'Zentos', respectively, 120–143 g·kg^{-1} (Linina and Ruža, 2012; 2013). Other researchers have found that both quantity and quality of protein have effect on water absorption (Holas and Tipples, 1978; Finney, 1984; MacRitchie, 1984). Grain protein content significantly varies depending on the cultivars (Juodeikiene *et al.,* 2002; Ruza *et al*., 2002; Mezei *et al*., 2007; Kunkulberga *et al.,* 2007b; Skudra and Linina, 2011).

Wholemeal from the grain ripened and stored for 60 to 360 days absorbed less water, compared with freshly harvested grain in both experiment years. During grain storage wholemeal from cultivar 'Bussard' absorbed by 37–46 g·kg^{-1} less water, while 'Zentos', respectively, 30–53 g·kg^{-1}. This result is consistent with previous studies of Shahzadi *et al*. (2005) who observed that grain stored for 60 days resulted in lower water absorption in wholemeal wheat. Mašauskiene and Cesevičiene (2006) observed that white bread flour water absorption increased for cultivar 'Ada' after grain storage for 60–90 days, but for cultivar 'Zentos' it fluctuated.

In our investigation, according to Fisher's criteria, nitrogen fertiliser, storage time and nitrogen fertilizer storage time interaction had significant ($p < 0.05$) effect on dough development time, stability and degree of softening for both cultivars.

Dough development time (DDT) indicates the relative strength of wheat/flour and can also reflect the level of water absorption in the test. Dough development time of both cultivars was high, on average 5.49–6.21 min for 'Bussard' wholemeal and 6.65–6.97 for 'Zentos' (Table 3). Mašauskiene and Cesevičiene (2005) found what wheat dough development time for cultivar 'Zentos' white flour was 2.25–3.43 minutes. The excessively high dough development time may be due to the presence of a higher moisture content of the bran particles in wholemeal, which may interfere in the quicker development of gluten (Haridas Rao *et al.*, 1989). Dough development time is affected by protein content (Dabkevičius *et al*., 2006). When higher doses of nitrogen were applied on wheat, dough development time for wholemeal was significantly increased, as previously described by Mašauskiene and Cesevičiene (2006) and also Kučerova (2005). Dough development time significantly increased for both cultivar grains stored for 60–360 days by 0.64–0.82 min, compared with fresh grain. This is in agreement with earlier reports of Shahzadi *et al.* (2005), who found that storage of grain for 60 days increased wholemeal wheat dough development time by 1.9 minutes. Similarly, Rao *et al.* (1989) observed that storing grain for four months decreased wholemeal wheat water absorption by 1.6 minutes.

Table 3

WHOLEMEAL DOUGH DEVELOPMENT TIME (min) IN WINTER WHEAT DEPENDING ON NITROGEN FERTILISER RATE, YEAR AND GRAIN STORAGE TYPE

Year	Storage (A)	Nitrogen fertiliser (B) N60	N90	N120	N150	Average
Cultivar 'Bussard'						
2010	Fully ripe	5.12	5.41	5.53	6.12	5.55
	60 d	5.24	5.56	5.48	6.13	5.60
	120 d	5.82	6.09	6.28	6.27	6.12
	360 d.	6.88	7.27	7.70	8.50	7.59
	Average	5.77	6.08	6.25	6.76	6.21
	$LSD_{0.05}$	A = 0.06	B = 0.06	AB = 0.12		
2011	Fully ripe	4.34	4.48	5.14	4.72	4.67
	60 d	4.58	4.85	5.83	5.23	5.12
	120 d	4.99	5.39	6.60	5.87	5.71
	360 d.	6.15	5.92	7.33	6.41	6.45
	Average	5.01	5.16	5.55	6.22	5.49
	$LSD_{0.05}$	A = 0.18	B = 0.18	AB = 0.36		
Cultivar 'Zentos'						
2010	Fully ripe	5.05	5.97	6.13	6.82	5.99
	60 d	5.18	6.51	6.60	7.26	6.39
	120 d	5.75	6.73	6.99	8.11	6.89
	360 d.	6.15	7.22	7.41	8.56	7.33
	Average	5.53	6.60	6.78	7.69	6.65
	$LSD_{0.05}$	A = 0.05	B = 0.05	AB = 0.11		
2011	Fully ripe	5.49	6.33	6.81	6.70	6.33
	60 d	5.73	6.24	7.04	6.83	6.46
	120 d	6.18	7.11	8.29	7.20	7.19
	360 d.	6.96	7.90	8.60	8.22	7.92
	Average	6.09	6.89	7.24	7.68	6.97
	$LSD_{0.05}$	A = 0.11	B = 0.11	AB = 0.23		

Stability (ST) of dough is very important relative to the type of fermentation and mechanical stress to which the dough can be subjected. Mixing time is critical to fit high speed production facilities. Excellent quality flour has a stability time of greater than 10 minutes. Poor quality flours have a stability time of not less than 3 minutes (Flour, 2004, in Mašauskiene and Cesevičiene, 2005). Flour stability is related with features of cultivars (Cesevičiene *et al.,* 2012). Cultivar 'Bussard' wholemeal can be referred as good to excellent (with N 120 and N 150) quality, and 'Zentos' — as having good quality (Table 4). The same grades remained in the both years of experiment. Average stability of 'Bussard' wholemeal dough in both years was 10.77–11.15 min, while for cultivar 'Zentos', respectively, 7.67–9.23 minutes. Dough stability is an important indicator for flour strength, which is based on the quality and quantity of dough protein (Kučerova, 2005). More frequent nitrogen fertilisation increased dough stability time. In our study, in plots with N120 and N150, when grain accumulated higher protein content, dough stability for cultivar 'Bussard' wholemeal was excellent quality (exceed 10 min) while 'Zentos' wholemeal was strong. Dough stability significantly increased for wholemeal milled from grain stored 60–360 days, compared with freshly harvested grain. During grain storage, dough stability time significantly increased for cultivar 'Bussard' by 0.82–1.16 min and 'Zentos' by 0.73–0.75 min, compared with fresh grain. Similar results with wheat wholemeal were reported by Leelavathi *et al.* (1986) and Shahzadi *et al*. (2005), while Mašauskiene and Cesevičiene (2005) reported what white flour dough stability declined during grain storage for 30–90 days.

Table 4

WHOLEMEAL DOUGH STABILITY TIME (min) IN WINTER WHEAT DEPENDING ON NITROGEN FERTILISER RATE, YEAR AND GRAIN STORAGE TYPE

Year	Storage	Nitrogen fertiliser (B)				Average
	(A)	N60	N90	N120	N150	
Cultivar 'Bussard'						
2010	Fully ripe	7.41	9.41	10.44	12.54	9.95
	60 d	7.99	10.10	10.72	12.89	10.42
	120 d	8.10	10.41	11.32	13.19	10.75
	360 d.	9.03	11.36	12.34	15.04	11.94
	Average	8.13	10.32	11.20	13.41	10.77
	LSD $_{0.05}$	A = 0.11	B = 0.11	AB = 0.22		
2011	Fully ripe	9.12	9.38	10.08	11.37	9.99
	60 d	9.09	9.50	10.35	11.32	10.06
	120 d	10.23	10.92	11.56	13.30	11.50
	360 d.	11.14	12.45	13.60	14.97	13.04
	Average	9.89	10.56	11.40	12.74	11.15
	LSD $_{0.05}$	A = 0.15	B = 0.15	AB = 0.29		
Cultivar 'Zentos'						
2010	Fully ripe	6.82	6.75	6.92	7.29	6.94
	60 d	7.02	6.49	7.28	7.91	7.17
	120 d	7.65	7.54	7.41	8.54	7.78
	360 d.	8.51	8.39	8.75	9.56	8.80
	Average	7.50	7.29	7.59	8.32	7.67
	LSD $_{0.05}$	A = 0.06	B = 0.06	AB = 0.13		
2011	Fully ripe	8.40	8.36	8.57	8.85	8.5
	60 d	8.58	8.34	8.70	9.03	8.7
	120 d	8.82	8.95	9.43	10.40	9.4
	360 d.	9.55	10.19	10.40	11.21	10.3
	Average	8.83	8.96	9.27	9.87	9.23
	LSD $_{0.05}$	A = 0.05	B = 0.05	AB = 0.09		

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 and Cesevičiene, 2005). Average degree of softening of 'Bussard' wholemeal was identified to be 35.3–36.8 FU and that of 'Zentos' to be 53.2–54.9 FU (Table 5). Dough softening depends on genetic characteristics, as confirmed in the present experiment. We observed that nitrogen application tended to decrease degree of softening, in contrast to other studies (Kučerova, 2005) in which an increase of protein content was associated with longer DDT and DS12. Average degree of softening was slightly higher for the

Table 5

WHOLEMEAL DOUGH DEGREE OF SOFTENING (FU*) IN WINTER WHEAT DEPENDING ON NITROGEN FERTILISER RATE, YEAR AND GRAIN STORAGE TYPE

Year	Storage	Nitrogen fertiliser (B)				Average
	(A)	N60	N90	N120	N150	
Cultivar 'Bussard'						
2010	Fully ripe	23.6	18.2	13.2	14.7	17.4
	60 d	37.3	30.0	27.8	34.4	32.4
	120 d	44.3	31.1	31.5	41.0	37.0
	360 d.	64.5	57.0	43.7	53.0	54.5
		42.4	34.1	29.0	35.8	35.3
	LSD $_{0.05}$	A = 1.8	B = 1.8	AB = 3.6		
2011	Fully ripe	29.5	24.4	22.5	19.7	24.0
	60 d	37.3	30.0	34.4	27.8	32.4
	120 d	44.3	31.1	41.0	31.5	37.0
	360 d.	60.7	45.1	54.9	54.6	53.8
		42.9	32.6	38.2	33.4	36.8
	LSD $_{0.05}$	A = 1.8	B = 1.8	AB = 3.5		
Cultivar 'Zentos'						
2010	Fully ripe	47.5	32.2	37.5	30.0	36.8
	60 d	56.9	41.6	52.5	39.6	47.6
	120 d	62.4	63.2	49.5	45.7	55.2
	360 d.	82.1	74.5	68.9	67.1	73.1
		62.2	52.9	52.1	45.6	53.2
	LSD $_{0.05}$	A = 4.4	B = 4.4	AB = 8.8		
2011	Fully ripe	41.2	51.05	32.7	31.15	39.0
	60 d	52.05	45.85	43.65	52.3	48.5
	120 d	64.45	70.3	54.25	51.15	60.0
	360 d.	71.25	82.75	68	66.2	72.1
		57.2	62.5	49.7	50.2	54.9
	LSD $_{0.05}$	A = 3.3	B = 3.3	AB = 6.7		

FU, farinograph unit

grain stored for 60–360 days; this is in agreement with earlier reports (Mašauskiene and Cesevičiene, 2006). Degree of softening is a measure of dough tolerance to mixing. During grain storage, degree of softening significant increased for cultivar 'Bussard' by 12.8–17.9 min and 'Zentos' 15.4 by 15.9 min, compare with freshly harvested grain. However, another study (Karaoglu, 2011) observed a decrease of DS12 during grain storage for nine months.

DISCUSSION

Dough quality is one of the most important features enabling one to predict the final bread-making value of the winter wheat cultivar (Ruzgas and Liatukas, 2008). The elasticity of the dough was measured by a Brabender's farinograph, the operation of which is based on physical methods. In general, during the first few weeks or months after harvest, rheological properties of wheat improve. However, adverse storage conditions, such as under high temperature, excessive moisture content and long storage period, cause a dramatic reduction in quality of wheat (Iconomou, 2006). In our experiment, at time of storage, the grain moisture content was 13.5–13.8% for 'Bussard' and 13.0–13.8% for 'Zentos'. During storage, the grain moisture content changed significantly but never exceeded 14%. Respiration rate increases in grain with moisture content above 14.6% (Linina and Ruža, 2012).

Water absorption is considered to be an important characteristic of wheat (Cesevičiene *et al*., 2009). Higher water absorption is required for bread that remains soft for a longer time. Average water absorption of 'Bussard' wholemeal was 707 $g \cdot kg^{-1}$, and that of 'Zentos' was 670 $g \cdot kg^{-1}$ in both investigation years (Table 2), indicating that both varieties gave strong flour. In plots with N120 and N150, grain had higher protein content (Linina and Ruža, 2012; 2013), which increased water absorption, as previously reported (Zaidul *et al.,* 2002; Constantinescu *et al.*, 2011). Prabhasankar *et al.* (2002) tested wholemeal dough of nine wheat varieties by farinograph, and determined that water absorption was in the range 725 to 810 $g \cdot kg^{-1}$, dough development time in the range 5.0–7.5 min, dough stability 2.5–5.5 min and degree of softening 20–60 FU. He also found out that wholemeal dough development required a longer time, because it contained bran and stability was higher than for white flour.

A cultivar depends not only on its genetic potential for particular characters but also on its ability to realise this potential in actual production and under different environmental conditions (Linina and Ruza, 2004). Weather conditions during the grain ripening period, nitrogen fertiliser rates and grain storage period had effect on winter wheat wholemeal mixing qualities (Mis, 2005). In both experiment years, temperature and precipitation were similar. Rainy weather in July in both investigation years did not affect the grain quality of wheat grain, as the cultivars were not yet ripe. Rain alternated with hot (sometime exceeding 30 ^{o}C) and sunny weather and grain was able to rapidly dry. Wheat varieties 'Bussard' and 'Zentos' differed significantly in grain yield and quality. The grain of cultivar 'Bussard' had higher protein content, sedimentation value and gluten content and lower grain yield than 'Zentos'. The average range for fresh and stored grain (2010 and 2011) of protein content in 'Bussard' was 152 $g \cdot kg^{-1}$, protein quality — sedimentation value was 59 units, wet gluten content 299 $g \cdot kg^{-1}$, gluten index 82, while in 'Zentos', respectively, 132 $g \cdot kg^{-1}$, 46 unit, 250 $g \cdot kg^{-1}$ and 62. The falling number values for fresh and stored grain for both wheat varieties studied were high: average 357 s for 'Bussard' and 380 s for 'Zentos', and reached the standards (Elite) of food grain quality of > 280 s. A high falling number value indicate low α–amylase activity in the grains (Linina and Ruza, 2012). The quality indices show that the quality of the studied varieties meet the requirement for high-grade wheat grains for food consumption, and wholemeal rheological properties also are good. There were no significant differences between wholemeal rheological properties in 2010 and 2011. Cultivar had a much stronger effect on grain quality indices and farinograph dough strength properties, and dough development time and stability, than the environment, as previously observed Preston *et al.* (2001).

This is consistent with the well-known strong influence of protein content on gluten content, sedimentation value and farinograph rheological properties in flour (Tipples *et al.,* 1978; Koppel and Ingver, 2008; Cesevičiene *et al*., 2009). In our experiment a significant high positive correlation for cultivar 'Zentos' between protein content and wet gluten was found (r = 0.82), also between protein content and sedimentation value (r = 0.91). Significant high positive correlation was observed between wet gluten and sedimentation value for both cultivars 'Bussard' (r = 0.80) and 'Zentos' (r = 0.74) (Linina and Ruza, 2012). Protein is often used as indirect indicator of baking quality. A higher protein content is associated with better baking quality (Koppel and Ingver, 2008). Therefore we examined correlation between wholemeal rheological properties and protein content for fresh and stored (60, 120, and 360 days) winter wheat grain (Table 6). A very strong relationship for both cultivar was evident between protein content (P) and WA (r = 0.746–0.931); a much weaker relationship between these parameters (r = 0.51) was reported previously (Preston, 2001). ST and P were closely correlate for both cultivars in all cases, except only for 'Zentos' on 60 days after harvest and these results are in accordance with Cesevičiene *et al.* (2012). A positive correlation was found also between WA and ST for cultivar 'Bussard' at all experiment times, while for 'Zentos' 120 and 360 days after grain harvest.

In conclusion, winter wheat cultivars 'Bussard' and 'Zentos' differed in their farinograph curve shapes. Cultivar 'Bussard' wholemeal had higher water absorption, longer stability time (sometime excellent quality) and shorter degree of softening, compared with 'Zentos'. According to the farinograph curves wholemeal dough, of 'Bussard' and 'Zentos' was characterised with a medium/long development time, long stability and satisfactory softening. The dif-

Table 6

CORRELATION BETWEEN WINTER WHEAT PROTEIN CONTENT AND REOLOGICAL PROPERTIES IN RELATION TO STORAGE TIME

Quality indices	Grain storage time			
	Fully rape	60	120	360
	'Bussard'			
P/WA	0.931**	0.872**	0.832**	0.746*
P/DDT	0.325	0.188	0.220	0.900**
P/ST	0.984**	0.889**	0.813*	0.567
P/DS12	0.016	0.026	0.324	-0.803*
WA/DDT	0.523	0.286	0.441	0.795*
WA/ST	0.953**	0.935**	0.916**	0.950**
WA/DS12	-0.211	0.028	-0.193	-0.622
DDT/ST	0.437	0.291	0.432	0.704
DS12/ST	-0.015	0.040	-0.134	-0.373
DS12/DDT	-0.606	-0.705	-0.582	-0.601
	'Zentos'			
P/WA	0.769*	0.806*	0.840**	0.735*
P/DDT	0.021	0.262	0.400	0.162
P/ST	0.742*	0.651	0.841**	0.898**
P/DS12	-0.294	-0.602	-0.388	-0.669
WA/DDT	-0.213	0.26	0.316	0.217
WA/ST	0.447	0.417	0.720*	0.746*
WA/DS12	0.153	-0.295	-0.076	-0.104
DDT/ST	0.483	0.676	0.344	0.319
DS12/ST	-0.612	-0.399	-0.360	-0.465
DS12/DDT	-0.839**	-0.087	-0.130	-0.127

P, protein content; WA, water absorbtion; DDT, dough development time; DS, dough stability; DS12, degree of softening . Coefficients of linear correlation r at significance level $\alpha_{0,05}$=0.707*; $\alpha_{0.01}$=0.834** (n = 8).

ferences on the wholemeal rheological properties in the two investigations years were not significant. Grain storage for 60–360 days changed wholemeal dough mixing properties as follows: longer dough development and dough stability time and increased degree of softening. The farinograph water absorption significant increased at 120–360 days. A very strong relationship for both cultivars was evident between WA and ST. A positive correlation was found between WA and ST. The observed correlation between traits depends on genetic factors.

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SLĀPEKĻA MĒSLOJUMA IETEKME UZ ZIEMAS KVIEŠU PILGRAUDU MILTU REOLOĢISKAJĀM ĪPAŠĪBĀM

Izmēģinājuma mērķis bija analizēt ziemas kviešu pilngraudu miltu ūdens uzņemšanas spēju un mīklas fizikālo īpašību izmaiņas atkarībā no šķirnes, slāpekļa (N) papildmēslojuma (N60, N90, N120, N150) un laika apstākļiem (2010. un 2011. gadā) tikko nokultiem graudiem un tos uzglabājot (60, 120 un 360 dienas). Izmēģinājumā iekļautas ziemas kviešu šķirnes 'Bussard' un 'Zentos', kuras raksturojas ar augstas kvalitātes pārtikas kviešu graudiem. Ar Brabendera farinogrāfu (ICC 115/1) noteikta pilngraudu miltu ūdens uzņemšanas spēja un mīklas fizikālās īpašības: mīklas veidošanās laiks, mīklas stabilitātes laiks un mīklas izplūstamības pakāpe. Izmēģinājumā noskaidrots, ka pilngraudu miltu ūdens absorbcijas spēju un mīklas fizikālās īpašības būtiski ietekmē šķirne, slāpekļa mēslojums un graudu uzglabāšanas laiks. Graudiem ar augstāku proteīna saturu ir labākas pilngraudu mīklas fizikālās īpašības. Būtiskas atšķirības starp abu izmēģinājuma gadu meteoroloģisko apstākļu ietekmi uz ziemas kviešu pilngraudu mīklas fizikālajiem rādītājiem netika konstatētas. Graudus uzglabājot 60–360 dienas, būtiski palielinājās pilngraudu mīklas veidošanās un stabilitātes laiks, kā arī palielinājās mīklas izplūstamības pakāpe, bet ūdens absorbcijas spēja būtiski samazinājās. Šķirnes 'Bussard' pilngraudu miltiem bija augstāka ūdens absorbcijas spēja, garāka mīklas stabilitāte un īsāka mīklas izplūstamības pakāpe. Farinogrāfa līknes liecina, ka šķirnes 'Bussard' pilngraudu miltiem mīklas veidošanās laiks ir vidējs/ilgs, mīklas stabilitāte ilga/teicama. Savukārt 'Zentos' pilngraudu miltiem mīklas veidošanās laiks ir vidējs, bet stabilitāte ilga. Vērtējot abu šķirņu pilgraudu miltus pēc ūdens absorbcijas spējas, tie ir stipri. Abām izmēģinājumā iekļautajām šķirnēm proteīna saturs pilngraudu miltos būtiski pozitīvi korelē ar ūdens absorbcijas spēju un mīklas stabilitāti. Cieša pozitīva sakarība noteikta arī starp pilngraudu miltu ūdens absorbcijas spēju un mīklas stabilitāti.