IMPACT OF AGROECOLOGICAL CONDITIONS ON THE HAGBERG FALLING NUMBER OF WINTER WHEAT GRAIN

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Abstract
Grain quality adversely affects price and consumer acceptance of finished products. Hagberg falling number (hereinafter falling number) is one of the most important grain quality indices of winter wheat (*Triticum aestivum* L.), especially in humid climate countries (Northern Europe). Field experiments with winter wheat cultivars 'Bussard' and 'Zentos' were conducted at the Latvia University of Agriculture, Study and Research farm 'Peterlauki' during a three year period (from 2009/2010 to 2011/2012). The aim of this investigation was to clarify variation of the falling number (FN) depending on cultivar, weather conditions and different rates of nitrogen (N) fertilizer applied (N 60, N 90, N 120, N 150) on fresh and stored grain (60, 120 and 360 days). During the investigation period, wheat 'Zentos' grain was characterised by a higher falling number compared with 'Bussard' grain. The falling number values for fresh grain for both wheat varieties studied were high: averagely 301 s for 'Bussard' and 359 s for 'Zentos', and reached demands set for grain suitable for bread baking. Differences in the falling number values were noted when freshly harvested winter wheat grain was compared with grain stored for 60 or 120 days and 360 days. During storage (60 – 360 days), α-amylase activity in winter wheat grain reduced and the FN increased on average up from 94 to 110 s. The falling number significantly depended on weather conditions, grain storage period and nitrogen fertilizer. The higher was the falling number of freshly harvested grain, the higher its increase during grain storage of compared to freshly harvested grain with a lower falling number value.
Key words*:* cultivars, nitrogen fertilizer, weather conditions, grain storage.

Introduction

Wheat (*Triticum spp.*) production according to quality food requirements is a relevant problem for wheat growers, grain handlers, millers and bakers. This paper addresses one particular wheat grain quality attribute, the Hagberg falling number, an important test of bread-making quality in wheat because of its negative association with α-amylase activity. Excessive α-amylase activity leads to the production of sticky dough that is difficult to process, and loaves that are poorly structured and discoloured (Mustatea et al., 2006).

The Hagberg falling number (FN) is an indicator of α-amylase activity and a measurement of how far the break-down of starch has progressed in the kernel through enzymatic activities. A high falling number indicates minimal activity, whereas a low falling number indicates more substantial enzyme activity (Hruskova et al., 2004). Alpha-amylase activity depends on weather conditions, especially precipitation (Triboi-Blondel, 2001; Mašauskiene and Cesevičiene, 2005; Skudra and Linina, 2011). E.Johansson (2002) found that the weather conditions during grain ripening of wheat affected the FN in 1998 and 1999 in Sweden. Under rainy conditions, the grains of wheat germinate in the ear either before or at harvest – ripeness, known as sprouting in the ear (Kettlewell, 1999; Ruza et al., 2002; Kondhare et al., 2015). Pre–harvest sprouting or sprouting during storage at a high temperature and humidity increases the level of alpha-amylase enzyme. Sprouted wheat has a low FN and lower values of other quality elements (Ingver et al., 2002; Lan et al., 2005; Krupnova and Svistunov, 2014). Alpha-amylase degrades starch and in excessive amount renders flour unfit for baking (Gooding et al., 1997).

The falling number value depends on the cultivar genetic characteristics (Raza et al., 2010; Liniņa and Ruža, 2012). Analyzing data over 20 years, M.J.Gooding et al. (1997) found that different wheat cultivars planted in the middle of the 1970s had a lower FN value than those cultivars planted in the 1990s, although the climatic conditions and nitrogen fertilizer level were similar. E.Johansson (2002), D.Kunkulberga and co-authours (2007), Ž.Liatukas and his colleagues (2012) also confirmed that the falling number of different cultivars may vary in the same growing conditions.

Nitrogen (N) fertilizer influenced the falling number. Grain of winter wheat without nitrogen fertilizer tended to have a lower falling number (Knapowski and Ralcewics, 2004; Clarke et al., 2004). According to T.Knapowski and M.Ralcewics (2004), the application of N 120 kg ha^{-1} increased the falling number in winter wheat grains significantly, as compared with the control (N0) and the object treated with N 80 kg ha^{-1}. D.R. Kindred and co-authors (2005) have found, that while increased nitrogen leads to lodging and associated sprouting in the ear, applying nitrogen tends to decrease the FN. In the absence of lodging, however, nitrogen application often increases the FN, but this effect varies with year, cultivar and site (Teesalu and Leedu, 2001). B.A.Stewart and G.V.Dyke (1993) and also J.Wang with others (2008) found that nitrogen fertilizer rate may be affected in two ways: increase and decrease the FN of wheat grain. The results obtained in Lithuania (Basinskiene et al., 2011) showed that organically grown wheat had a lower α-amylase activity in comparison with conventionally grown wheat (N 120). However, nitrogen fertilizer influence is lower than the effect of cultivar and climatic conditions (Smith and Gooding, 1996). In general, the FN depends significantly on the interaction between cultivar and the environmental conditions at the corresponding location (Farrell and Kettlewell, 2008).

Changes of the falling number in grain storage period have been reported by several authors. Some scientists have concluded that α-amylase activity decreased over the wheat grain storage duration (Jafri, 2010; Raza et al., 2012; Ruska and Timar, 2012). Other researchers (Lan et al., 2005) found a distinct negative relationship between the activity of α–amylase and the falling number value. Similarly, O.M.Lukow and P.B.E.McVetty (1991), also J. Gonzalez-Torralba and his colleagues (2013) found that the FN values increased significantly during wheat grain storage. M.Hruskova and D.Mackova (2002) observed that the FN increased by 28 s (from 206 to 234 s) in wheat flour over the storage duration of three months. Many other studies conducted by various researchers have shown different results. The conclusion reached by the Hungarian researcher Z.Mezei and co-authors (2007) suggest that the falling number value did not change significantly when the grain of winter wheat was stored for 129 days.

This research is a continuation of previous work (Liniņa and Ruža, 2012) in which we investigated the quality of winter wheat freshly harvested grain (in 2010 and 2011) and during grain storage. The aim of this investigation was to clarify variation in the falling number value depending on cultivar, different rates of nitrogen fertilizer applied, weather conditions and grain storage period. In Latvia, changes in the falling number value during the grain storage were studied for the first time.

Materials and Methods

Field experiments in 2009/2010, 2010/2011 and 2011/2012 were conducted at the Latvia University of Agriculture, Study and Research farm 'Peterlauki' (56° 30.658′ North latitude and 23° 41.580′ East longitude), Endoprotocalcic Chromic Stagnic Luvisol (Clayic Cutanic Hypereutric), silty clay loam/clay, organic mater 20 – 31 g kg^{-1}, pH KCl – 6.6 – 7.0 and medium phosphorus and potassium content easily utilized by plants. Winter wheat (*Triticum aestivum* L.) cultivars 'Bussard' and 'Zentos' (Germany) were sown after black fallow in four replications (rate of 400 germinating seeds per m^2). The sowing was carried out in the second ten-day period of September. These cultivars were grown in four replications with a plot size of 36 m^2, field layout – randomised. Before sowing plots were fertilized with phosphorus and potassium fertilizers at the rate: P 31 kg ha^{-1} and K 108 kg ha^{-1}. Nitrogen (N) fertilizer was applied in spring after renewal of vegetative growth. Nitrogen top–dressing rates were as follows: N 60, N 90, N 120 and N 150.Winter wheat in all investigation years was harvested at optimal time when the growth stage GS 88-91 was reached. On 4 August winter wheat was harvested in 2010, on 5 August in 2011 and in 2012 on 3 August. Sampling procedure for grain quality evaluation was performed according to the standard ICC 101/1 for obtaining average sample. The grain with a moisture content exceeding 14% was dried. Freshly harvested grain of each cultivar and nitrogen top dressing treatment were put into separate cotton bag. Grain was sampled 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%. Initially placed for 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 but never exceeded 14%. Respiration processes became more

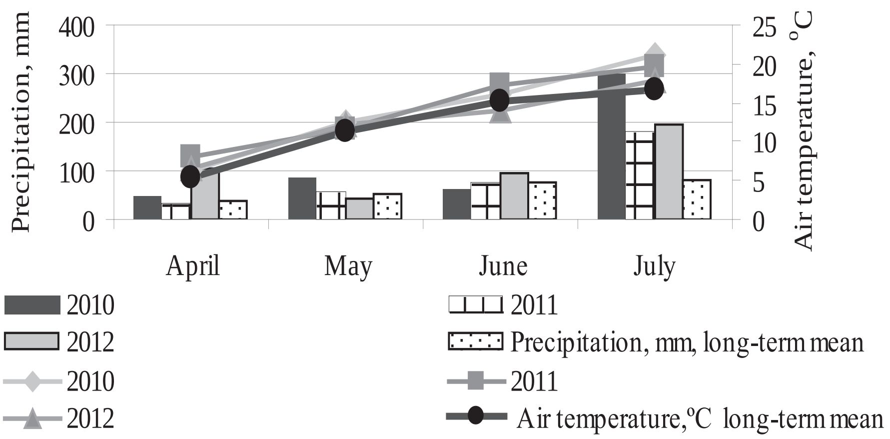

Figure 1. Meteorological conditions in investigation years.

intensive in grain with the moisture content above 14.6%.

Winter wheat sown in 2009, 2010 and 2011 overwintered successfully. In 2010, 2011 and 2012 the air temperature in spring (Figure 1) was close to the long-term average. It promoted plant growth and development. The mean May temperature was close to the long-term mean. The mean daily temperature in June of 2010 and 2011 was higher than the long-term mean, while in 2012 by 1.1 °C lower. Temperatures in grain filling period (July), which is the most decisive for grain quality formation, were 4.7 °C higher in 2010, 3.0 °C higher in 2011 and 2.8 °C higher in 2012 compared to long-term average.

Precipitation in April 2010 and 2011 was close to long-term average, but in 2012 by two times more than long-term mean data. May in 2010 was wet; in 2011 and 2012 precipitation was close to the long-term mean data for this month. Precipitation in June 2010 and 2011 was close to long-term mean; but in 2012 more than long-term mean data. July in 2010, 2011 and 2012 was very rainy; it two to three times exceeded the long-term average data.

Wheat grains were analyzed at the Latvia University of Agriculture in Grain and Seed Research laboratory. A 300 g grain samples were milled to wholemeal flour using 'Perten Laboratory Mill 3100' (Sweden) with 0.8 mm sieve. The Hagberg falling number – α-amylase activity – was measured by the Hagberg-Perten method using a Perten Instruments (Sweden) 'Falling number 1500' was assessed to LVS EN ISO 3093 using 7 g of flour adjusted for moisture content to 15%.

Experimental data evaluation was done using two–factor analysis of variance (ANOVA), the test of statistically significant differences at Fiscer's criterion and impact factors influence (η^2), probability <0.05% were used for the analyses of mean differences. Mean, standard error of the mean, coefficients of variation were determined. Data analyses were done with MS Excel.

Results and Discussion

Falling number is an indication of degree of soundness of wheat in terms of freedom from sprouting (Karaoglu et al., 2010) which causes the production and activation of α–amylase inside the wheat kernel which, in turn, has a very drastic affect on the dough and bread making process. According to the requirements of 'Dobeles Dzirnavnieks' ('Dobele's Miller') (Dobeles Dzirnavnieks, 2012) a grain processing company, wheat grain could be classified by the falling number into five classes. The first class (Elite) and second A class are set with the falling number value above 280 s, the third class with 270 s, respectively, fourth class with 250 s, and the fifth class above 220 s.

The falling number of grain was different for both cultivars. During investigation period, wheat 'Zentos' grain was characterised by a higher falling number compared with 'Bussard' grain. Average data show that the falling number for cultivar 'Zentos' was 395 ± 7.0 s, range min – max 300 – 503 s, for 'Bussard' – 346 ± 9.2 s and 221 – 490 s, respectively. The coefficient of variation of trait was stable for 'Zentos' 12%, while 18% for 'Bussard'.

Falling number of fully ripe winter wheat grains

The falling number values for fresh grain for both wheat varieties studied were high (Figure 2): averagely 301 s for 'Bussard' and 350 s for 'Zentos' and reached the standards (Elite) of grain suitable for bread baking exceeding 280 s. The falling number significantly varied depending on the cultivar. High falling number values indicate low α–amylase activity (Lunn et al., 2001b). The falling number was not similar in every year. Weather conditions in investigation years influenced grain α–amylase activity. A higher falling number test for both wheat cultivars was observed in 2010 and 2011 compared to the harvest year of 2012. E.Johansson (2002) found that the higher the sum of active temperatures in summer, the higher the increase in the falling number value in wheat grain. Our results confirmed this conclusion: a higher sum of active temperatures (+10 °C) from the stem elongation (GS 30) until the harvest was in 2010 (1418 °C) and in 2011 (1407 °C) resulted in a higher FN value compared with 2012 (1252 °C). Especially low falling number (241 s) was in 'Bussard' grain – only in the fifth quality class.

The falling number is affected by precipitation during grain maturation. High rainfall in grain maturation period results in higher α–amylase activity and lower falling number (Johansson, 2002). Cereal maturation and harvesting can occur during rainfall period, which can often be a reason for lower grain quality and even grain sprouting in ears (Lunn et al., 2002; Kunkulberga et al., 2007, Skudra and Linina, 2011; Kondhare et al., 2015). Cereal grain is of the highest quality during growth period between wax maturity and full maturity. During this period cereal yield forming is already finished and, in case of unfavourable weather conditions, grains can start sprouting, which would result in a reduced falling number. Under very wet harvesting conditions wheat reaches the limit when α–amylase activity is considered to be too high (Kettlewell, 1999; Lunn et al., 2001a; Gooding et al., 2003). Grain sprouting in the ears may also affect the dormancy period duration. Grain dormancy period is depending on the weather conditions in grain formation and ripening phase (Lan et al., 2005). In our investigation, the rainfall in July 2010, 2011 and 2012 during the grain maturation was high: 298, 179 and 197 mm, respectively, that two to three times exceeded the long-term average data (81.7 mm). In 2010 and 2011 rainy weather in July did not affect the FN of wheat grain because rain alternated with hot (average air temperatures were respectively 21.2 °C and 19.5 °C and sometimes exceeding 30 °C) and sunny weather and grain rapidly dried up. Harvesting of the winter wheat cultivars should not be delayed. Weather conditions in July 2012 were colder, therefore, the FN in wheat grain was lower, however corresponded to the demands set for grain suitable for bread baking > 220 s.

The falling number of wheat fertilized with higher rates of nitrogen was higher than when lower rates were used (Cesevičiene and Mašauskiene; 2007). In our experiment, the average data show that for wheat ‘Zentos’ grain the falling number was significantly higher with higher nitrogen rates N 120 and N 150 compared with crops that received N 60 (Figure 3). Nitrogen fertilizer rate significantly increases the falling number and it is consistent with the conclusions made by T.Teesalu and E.Leedu (2001), T.Knapowski and M.Ralcewics, (2004) and S.Stankovski et al., (2004), who have reported that the falling number is dependent on the rates of nitrogen fertilizer.

According to Fisher’s criteria, the investigation year, nitrogen fertilizer and year×nitrogen fertilizer

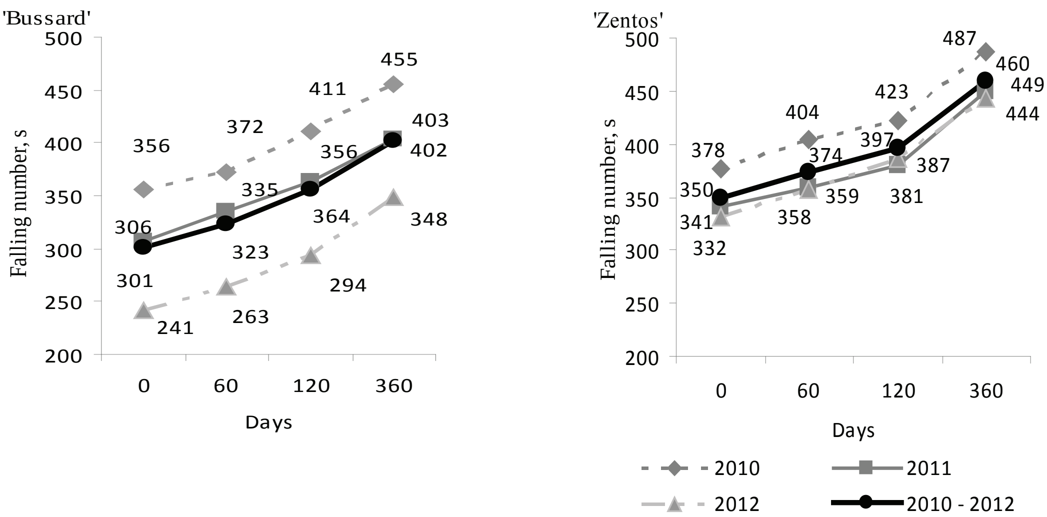

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Figure 2. Winter wheat cultivars ‘Bussard’(a) and ‘Zentos’ (b) grain falling number (s) during grain storage (days), depending on investigation years.

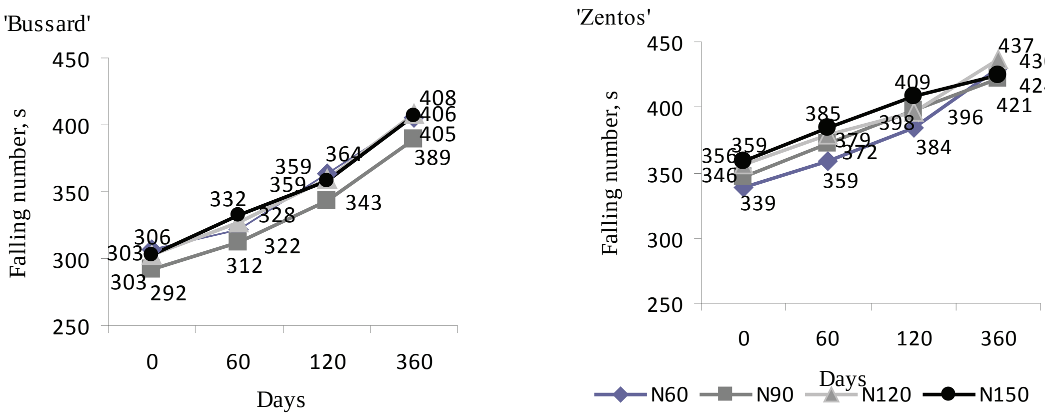

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Figure 3. Winter wheat cultivars ‘Bussar’(a) and ‘Zentos’ (b) grain falling number (s) during grain storage (days), depending on nitrogen fertilizer.

interaction had a significant ($p<0.05$) impact on the both cultivars grain falling number.

In cultivar 'Bussard' grain this tendency was not observed. B.Varga and co-authors in Croatia (2003) also found that some cultivars failed to significantly improve the falling number under more intensive nitrogen fertilization.

The analysis of variance for two cultivars in 3 experiment years suggest that winter wheat 'Bussard' and 'Zentos' grain falling number (impact factors influence – $ŋ^2$, probability < 0.05%) recpectively by 87% and 65% depended on weather conditions (year), year×nitrogen fertilizer interaction was also remarkable – 10% and 19%, while the influence of nitrogen fertilizer was 1% and 10% respectively. Similar results obtained in England (Smith, Gooding, 1996), suggest that the falling number by 67% depends on the rainfall in grain ripening period, and the temperatures from June to winter wheat harvest. Influence of the year was most remarkable also in the investigation with 15 winter wheat cultivars in the years 2004 – 2007 in Estonia (Koppel and Ingver, 2008).

Changes falling number during winter wheat grain storage

The activity of α-amylase reduced during the grain storage (Figure 2) and FN increased. Averaged data show that the falling number for cultivar 'Bussard' for 60 days stored wheat grain was 16 – 22 s higher if compared to freshly harvested grain, 71 – 86 s higher for 120 days stored grain, while after 360 days of grain storage it increased 97 – 101 s. For 'Zentos' grain we observed a similar tendency: after 60 days stored wheat grain was 18 – 27 s higher, 40 – 55 s higher for 120 days stored grain, after one year of grain storage it increased for 109 – 112 s. Winter wheat grains 'Zentos' before storage had a higher falling number, it grew by 12 s more, in comparison with the variety of 'Bussard'grains.

Similar results were found by H. Kibar (2015) who stored wheat grain for 6 months and reported that the FN increase was 65 s (from 230 to 295 s), while M.M.Karaoglu with co-authors (2010) stored wheat grain for 9 months and concluded that the FN was 86 s higher compared to freshly harvested grain. A.M.Buchanon and E.M. Nicholas (1980) reported that the FN increase was 100 s (from 250 to 350 s) after a year of wheat grain storage. The same tendency was also observed in trials performed by M.Hruskova and D.Machova (2002) and J.Cesevičiene (2007). The reason for the increase in the falling number, as indicated in references, could be a reduction in the activity of pericarp α-amylase which occurs during storage (Lunn et al., 2001a; Ruska and Timar, 2012), while M.M.Karaogly with co-authors (2010) reported that the increase in the falling number may be attributed to degradation of amylase enzyme and the variation of starch gelatinization properties during storage period.

More rapid increase in the falling number value was found when the grain was stored for 120 to 360 days. Similar results were reported by J.Cesevičiene (2007), who stored wheat grain for one year. Biochemical changes in grain were going on during storage (Rehman and Shah, 1999). Winter wheat grains 'Zentos' before storage had a higher falling number, after one year grain storage it grew by 12 s more, in comparison with the variety of 'Bussard' grains. Our experimental results support the conclusion made by J.Cesevičiene (2007) that the higher the falling number of freshly harvested grain, the higher its increase during grain storage compared to freshly harvested grain with a lower falling number value.

Variation in the falling number values during grain storage was related to nitrogen fertilizer rates used. There was a tendency, - if given a higher fertilizer rate (N 120 and N 150), the falling number in grain stored for 360 days increased more, than when given lower nitrogen rates (N 60 and N 90), compared with freshly harvested grain. After a year of grain storage, for cultivar 'Zentos' grain the FN increase averaged 75 s if given fertilizer rates N 60 and N 90, at N 120 and N 150 – 113 s, the difference was less for 'Bussard' grain – respectively 98 and 105 s.

The analysis of variance for each cultivar in every experimental year suggest that storage time and nitrogen fertilizer had a significant ($p < 0.05$) impact on the both cultivars grain falling number, while storage time×nitrogen fertilizer interraction this indicator affected significantly only in the harvest year of 2012. In the harvest years of 2010, 2011 and 2012, for cultivar 'Bussard' grain the falling number depended on 77%, 75 and 78% on grain storage time, respectively; on nitrogen fertilizer – 21%, 21 and 20%, while grain storage time×nitrogen fertilizer interraction impact factor ($ŋ^2$) was significant only in 2012 and it was low – 1%. For 'Zentos' grain the falling number by 94% (2010), 95% (2011) and 74% (2012) depended on grain storage time but the influence of nitrogen fertilizer was, respectively – 2%, 3% and 24%, while storage time×nitrogen fertilizer impact factor was significant only in the harvest year of 2012 – 2%.

Conclusions

1. During three trial years, the falling number of the studied winter wheat grain showed a low activity of α-amylase and corresponded to demands of grain suitable for bread baking. Wheat 'Zentos' had averagely higher falling number values compared to wheat 'Bussard'.

2. The falling number depended on precipitation, the sum of active temperatures and cultivar. Nitrogen fertilizer influence on the falling number was smaller.
3. Differences in the falling number values were noted when freshly harvested winter wheat grain was compared with grain stored for 60 or 120 days and 360 days. Within 360 days of storage, α-amylase activity in winter wheat grain reduced and the increase in the falling number values on average was 94 – 110 s. The higher was the falling number of freshly harvested grain, the higher its increase during grain storage, compared to freshly harvested grain with a lower falling number value.

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