THE IMPACT OF HYDROTHERMAL CONDITIONS DURING VEGETATION PERIOD ON GRAIN QUALITY TRAITS OF OAT

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Metrology is one of the main conditions influencing oat (*Avena sativa* L.) plant growing and development and grain quality as well. The objective of this study was to evaluate grain quality and its dependence of various metrological factors for 12 oat genotypes of Stende collection in five year period (2009-2013). The genotypes were evaluated according to the following grain quality traits: crude fat content (CF), crude protein content (CP) and β-glucan (β-GLU) content (g kg^{-1}). Hydrothermal coefficient (HTC) was calculated for each year in two phases – growing stages 10 – 69 (HTC 1) and growing stages 70 – 90 (HTC 2). Cultivars were arranged in two groups: the first block included genotypes with relatively high values of analysing trait and the second block of genotypes with lower values of trait. Significant differences among genotypes by years were found for CF and CP content, but for β-GLU significant was only year impact of lower trait group. The lowest CP and CF variability was observed in 2011, but β-GLU in 2009. Significant ($p<0.05$) correlative connection was observed only between CP and HTC 2 for lower CP group.

Key words: oat, hydrothermal coefficient, crude protein, crude fat, β-glucan.

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INTRODUCTION

Common oat *Avena sativa* L. is one of the major crops grown in temperate climate zone and is used for human and animal nutrition as well. Grain yield, test weight and 1000 kernel weight are the most important economic traits mentioned by the oat consumers. Oat breeders through hybridization and selection have improved yielding ability potential of oat varieties, but lower standards are set forward regarding biochemical composition of grain: protein, lipids, β-glucan, starch amount in grain, though dietetic value of oats is just due to these traits (Wood 1997). There is a lack of information available describing the effects of environment and genotype on oat grain quality. Protein is the most important nutrient for humans and animals nutrition. The average protein content of oat grains covers a relatively narrow range from 8 – 13 % (Butt *et al.* 2008). Protein content can be influenced by nitrogen treatment, sowing date, meteorology (Biel *et al.*, 2009, Givens *et al.* 2004). Oat contains relatively higher amounts of lipids about 7.5 %, comparing with other cereal grains. Among the main compounds associated with health-promoting effects in cereals is dietary fiber that is found only in plant foods. Water-soluble fiber in cereals is composed of non-starchy polysaccharides such as β-glucan (Brindzova et al. 2008). It is described that β-glucan depends on genotypes, meteorology and growing technologies (Doehlert *et al.* 2001). Most literature studied describes significant environmental effect on quality parameters, but there is a lack of literature investigating what conditions exactly increases or decreases protein, lipid and β-glucan contents in oat grains.

Climate – precipitation and mean daily temperature; is a primary importance factor influencing oat growth and development. Researchers emphasize that weather conditions can disturb the development of wheat plants and influence their chemical composition further grain quality (Dupont & Altenbach 2003). Selyaninov's hydrothermal coefficient (HTC) is frequently used in many studies (Melkonyan & Asadoorian, 2014, Evarte-Bundere & Evarts-Bunders 2012). This index, which is a coefficient of the sum of the temperature and the sum of the precipitation, is known in the literature as the coefficient of the hydration needs of plants.

The aim of this trial was to determine the influence of hydrothermal conditions in specific plant development stages on grain quality traits (represented by their chemical composition).

MATERIAL AND METHODS

The field trials were carried out at the State Stende Cereal Breeding Institute during the years 2009 – 2013 that differed much in meteorological conditions. The trials were established in seed farming crop rotation field. The soil in all five trial years was sod-podzolic sandy loam, with pH KCl 5.0-6.0, content of organic substance 22-26 g kg^{-1}, the content of available for plants phosphorus P_2O_5 191-254 mg kg^{-1} and potassium K_2O 151-199 mg kg^{-1}. Varieties were laid out in four replications. Recorded plot area was 10 m^2. 12 oat cultivars of varieties list recommended for growing in Latvia were included in field trial for clarifying climatic impact. Uniform oat management practice were performed in all studied years. Prior to sowing fields received mineral fertilizer Kemira NPK 18:9:9, calculated in nitrogen 58-63 kg ha^{-1} N. Sowing date in the 2nd or 3rd decade of April considering soil readiness for sowing in a specific year. Grain yield was harvested in full ripeness – in the 2nd or 3rd decade of August.

For description of growing conditions of oat hydrothermal coefficient (HTC) has been used, it is correlation between amount of precipitation in the time period, when average day temperature exceeds +10 °C, and sum of temperature in degrees in that same period. Hydrothermal coefficient has been calculated by applying formula of G. Selyaninov (Selyaninov 1928):

$$HTC = \Sigma x / \Sigma t \times 10$$

where Σ x and Σ t – accordingly sum of precipitations and temperatures in the period, when the temperature has not been lower than 10^{o} C.

- HTC from 1.0 till 2.0 – humidity is sufficient;
- HTC> 2.0 – immoderately humid;
- HTC< 1.0 – insufficient humidity;
- HTC from 1.0 till 0.7 – dry;
- HTC from 0.7 till 0.4 – very dry

(Čirkovs 1978).

The development of oat plants were divided into two phases: till anthesis – productive tillers, sprouts of spikes and flowers is formed; and anthesis till post anthesis – the grain and its quality characterizing indices are being formed (Peltonen-Sainio *et al*. 2008). HTC in seedling growth (DC 10) – anthesis (DC 69) period and HTC in anthesis (DC 69) – dough (DC 85-87) development period were determined.

The cultivars were evaluated according to the following grain quality traits: crude fat content, crude protein content and β-glucans content by Infratec Analyser 1241 performed in the laboratory of the State Stende Cereals Breeding Institute. Phase setting dates of plant development were stated in the vegetation period.

ANOVA procedures were used for data analyses. The significance of the differences between the averages (LSD, $p<0.05$), variation and correlation coefficients were calculated.

RESULTS

Crude protein

GROUP A. Crude protein content of group A varied from 101.0 to 119.0 g kg^{-1} (Fig.1). In this group, where all selected cultivars were with high protein content, there were observed significant ($p<0.05$) influence of genotype (49.6%) and environment or growing year (46.2%). Interaction of these factors was only 4.3%. Coefficient of variation (CV) of group A in protein content is 12.4-19.0%. The highest CV was observed for cultivar 'St.Liva', but the most stabile cultivar was 'Laima'. The highest CV was fixed in 2013 – 22.3%, but the lowest in 2011 – 11.1%.

Comparing protein contents of group A cultivars with HTC values, there were found out that metrological conditions significantly influences protein content for all cultivars except 'Arta'. The analysis of correlation showed that higher HTC 1 values decreases crude protein content, while higher HTC 2 values increases crude protein content in oat grains.

GROUP B. Crude protein content of group B cultivars varied from 95.3 - 100.8 g kg^{-1} (Fig. 2) and significant differences in crude protein content were observed among tested cultivars ($p<0.05$) and growing season ($p<0.01$). The impact of metrological conditions on protein content was significantly higher (83.1%), while genotypic influence were only 8.5%. CV of group B cultivars were from 14.0-19.4%, the highest CV was determined for cultivar 'Duffy', but the lowest – 'Ingeborg'. The highest CV was observed in 2009 – 12.4%, but the lowest in 2011 – 5.7%.

There were observed correlation between crude protein content of group B and metrological conditions. Significant correlation was observed between HTC values and crude protein content for cultivars 'Corona', 'Kerstin' (HTC1 and HTC2), 'Scorpion', 'Duffy' (HTC1). Also in this group higher HTC 1 values decreases crude protein content, but higher HTC 2 values increases, as it was observed in group A.

Crude fat

GROUP A. In the group A, the crude fat content was in the limits of 48.9-62.6 g kg^{-1} (Fig.3) and was significantly ($p<0.01$) influenced by genotype and growing years. The genotype (62.9%) and environmental (29.0%) impact on crude fat content was significant ($p<0.01$).

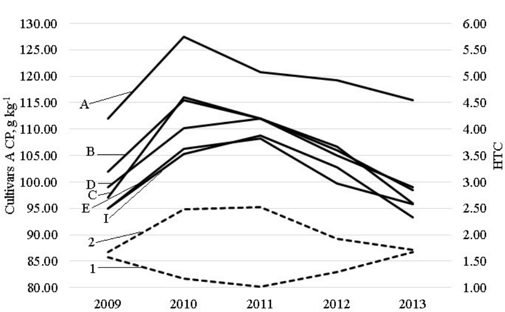

Fig. 1. Crude protein content and hydrothermal coefficient of phase 1 and 2 for cultivars A: A – 'Arta', B – 'St.Darta', D – 'Laima', C – 'St.Liva', E – 'Cwal', I – 'Vendela', 1 – HTC1, 2 – HTC2.

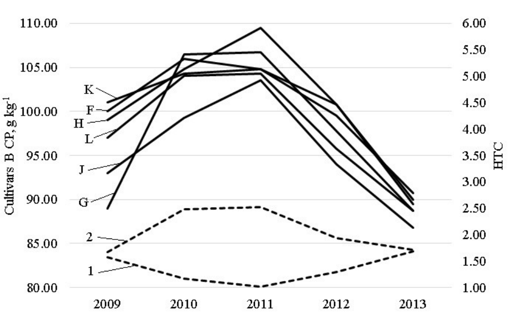

Fig. 2. Crude protein content and hydrothermal coefficient of phase 1 and 2 for cultivars B: K – 'Ingeborg', F – 'Pergamon', H – 'Duffy', L – 'Scorpion', J – 'Kerstin', G – 'Corona', 1 – HTC1, 2 – HTC2.

Interaction of these factors was – 8.1%. The CV of group A in crude fat content varied from 11.9-30.7%, the highest CV was observed for cultivar ‘St.Liva’, but the lowest for cultivar ‘Arta’. The highest CV was determined in 2009 – 36.9%, but the lowest in 2011 – 15%.

For group A correlation between crude fat content and HTC values were not significant.

GROUP B. In the group B the crude fat content varied from 45.0 to 48.8 g kg^{-1} (Fig. 4). Crude fat content was significantly influenced by growing year and genotype ($p<0.01$). The highest impact on crude fat content was observed for environmental factors – 86.9%, genotypic impact was only 7.6%, but interaction of these factors – 5.5%.

Also for group B significant correlation was not observed between crude fat content and HTC values.

β-glucan content

GROUP A. For group A the β-glucan content varied from 31.0-35.8 g kg^{-1} (Fig. 5). Significant differences in β-glucan content were observed among tested cultivars and growing years ($p<0.01$). Influence of genotype was 49.6%, bet of growing year – 46.2%. CV of group A for β-glucan content was from 30.76-13.97%, the

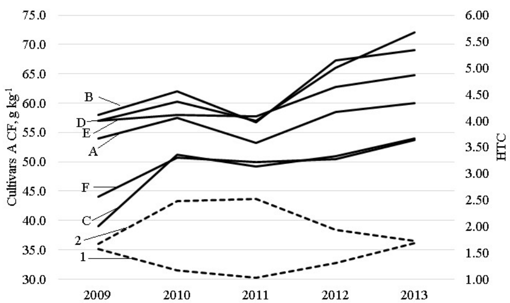

Fig. 3. Crude fat content and hydrothermal coefficient of phase 1 and 2 for cultivars A: B – ‘St.Darta’, D – ‘Laima’, E – ‘Cwal’, A – ‘Arta’, F – ‘Pergamon’, C – ‘St.Liva’, 1 – HTC1, 2 – HTC2.

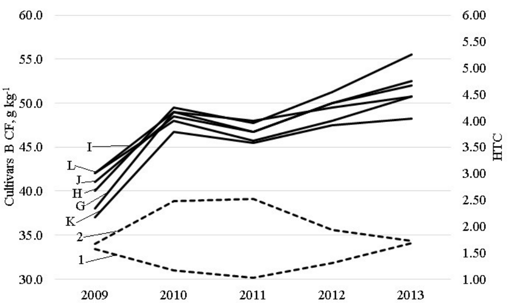

Fig. 4. Crude fat content and hydrothermal coefficient of phase 1 and 2 for cultivars B: I – ‘Vendela’, L – ‘Scorpion’, J – ‘Kerstin’, H – ‘Duffy’, G – ‘Corona’, K – ‘Ingeborg’, 1 – HTC1, 2 – HTC2.

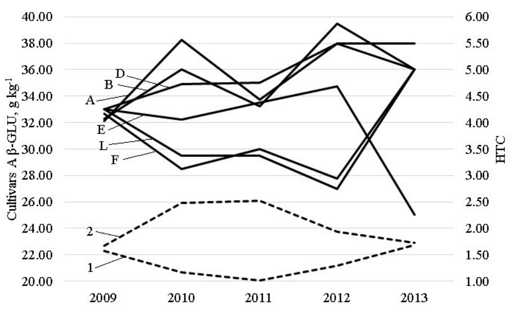

Fig. 5. β-glucan content and hydrothermal coefficient of phase 1 and 2 for cultivars A: D – ‘Laima’, B – ‘St.Darta’, A – ‘Arta’, E – ‘Cwal’, L – ‘Scorpion’, F – ‘Pergamon’, 1 – HTC1, 2 – HTC2.

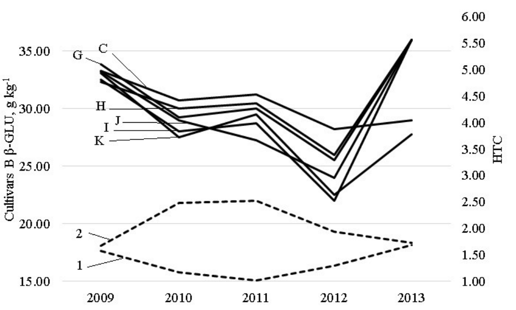

Fig. 6. β-glucan content and hydrothermal coefficient of phase 1 and 2 for cultivars B: C – ‘St. Liva’, G – ‘Corona’, H – ‘Duffy’, J – ‘Kerstin’, I – ‘Vendela’, K – ‘Ingeborg’, 1 – HTC1, 2 – HTC2.

highest CV was observed for cultivar 'Cwal', but the lowest for 'Laima'. From tested years the highest CV was in 2012 and 2012 – respectively 37.7% and 36.6%, but the lowest in 2009 – 2.75%.

The correlation between β-glucan content HTC values for different cultivars were different, but not significant. For example, correlation between β-glucan content and HTC 1 of cultivars 'Pergamon' and 'Scorpion' is positive, but with HTC2 – negative, while for cultivar 'Cwal' situation is opposite.

GROUP B. β-glucan content of group B varied from 28.1-31.0 g kg^{-1} (Fig. 6). Among cultivars ($p<0.05$) and tested years ($p<0.01$) differences in β-glucan content were significant. On β-glucan content changes significant influence is to growing year (83.1%) and genotype (8.5%). CV of group B varied from 47.5-16.6%, the highest CV was determined for cultivar 'Vendela', but the lowest – 'St.Liva'. In this group the highest CV were in 2012 and 2013 (respectively 25.3% and 24.7%), but the lowest in 2009. (4.8%).

Correlation between HTC1 and HTC2 with β-glucan content was not significant.

DISCUSSION

Analysing mean values in 5 year period there were observed variation in traits during studied period (CV- coefficient of variation) from 11.9% to 47.5%. The highest variation was recorded to content of β-glucan. There were observed genotypic impact to trait dependence from HTC characterized growing conditions. Impact of growing year to crude fat and β-glucan content for group B (lower values of traits) was more pronounced comparing with group with higher trait values (group A). But for impact of growing conditions to crude protein content to both groups was not observed differences. It means that cultivars, potentially having higher ability to adapt to metrological conditions (group A), are characterizing with higher crude fat and β-glucan contents.

In this study has been stated that grain quality varies a lot and depends on meteorological conditions in various years. Based on five years experiment data, all traits were significantly different ($p<0.05$) for growing years except β-glucan content. Some genotypes were more stable across environmental conditions; others responded differently in different conditions. Group B (value of quality traits were relative lower) was more sensitive to environmental conditions, except crude protein content.

Most of the variance was associated with genotype for all traits except crude protein content, generally influenced by HTC characterized metrological conditions.

Analysis of the combined data for all environments showed significant ($p<0.05$) genotypic differences for all traits, except β-glucan content. Researchers have reported that the effect of cultivars on β-glucan content of oats is significant (Doehlert et al. 2001, Andersson & Börjesdotter 2011) and cultivar selection is the most important input parameter compared to other inputs in determining the β-glucan level (Tiwari & Cummins 2009). These studies show that genetic background has a greater influence of β-glucan level compared to environmental factors although environmental stresses (higher precipitation during grain ripening) may reduce the β-glucan content in oats (Brunner & Freed 1994). Similar observations were also in this study when HTC2 was higher in 2011, but β-glucan content was relatively lower.

The genotype × trial interaction was significant ($p<0.05$) only for β-glucan content, besides this interaction were more pronounced for cultivars of group A.

Correlation analysis showed several close associations among traits and HTC values: protein content in the first stage of growth was positively correlated with HTC, but negatively – in the second stage of growth. There were observed positive correlation between β-glucan and crude protein content during this trial according to information found in scientific literature (Fan *et.al.* 2009, Redaelli *et al.* 2003). Summarized results of correlation analysis indicated difference of metrological factors impacting level of grain quality traits in both growing stages. Weak positive correlation was observed between crude fat and HTC values in first growing stage for three cultivars from group A, but convincing correlation among cultivars from group B was not detected in both growing stages. There was positive correlation for both groups at first growing stage between crude protein content and HTC values, but at second stage correlation was negative. In group B medium-close positive correlation between β-glucan and HTC was detected for number of cultivars except 'Ingeborg' and 'St.Liva', but in group A such connection was observed only for two cultivars – 'Pergamon' and 'Scorpion', therefore for cultivar 'Cwal' correlation was negative.

Knowledge found in this research about interactions of quality traits and metrological conditions could help for oat breeders to understand what traits could be obtained by genotype and what traits are strongly influenced by metrology.

CONCLUSIONS

In this study has been stated that oat grain quality varies a lot and depends on meteorological conditions in various years. Based on five years experiment data, all traits were significantly different ($p<0.05$) by years except β-glucan that was more affected by genotype. β-glucan content varied the most among growing years – from 29.4 g kg^{-1} till 34.0 g kg^{-1}. The most stable quality trait in the reporting period was protein content. That varied from 94.4 g kg^{-1} till 108.9 g kg^{-1}. Correlation analysis showed several close associations among traits and HTC: protein content in the first stage of growth was positively correlated with HTC, but negatively – in the second stage of growth. Influence of metrological conditions to oat grain quality traits was different in each group. In group B influence of metrological conditions to crude fat and β-glucan content was pronounced comparing with group A.

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