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CHARACTERISATION OF HULLED OAT GRAIN PHYSICAL AND BIOCHEMICAL PARAMETERS SIGNIFICANT FOR DIETARY PRODUCTS

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*The objectives of the study were to investigate the variability of oat (*Avena sativa *L.) grain physical traits and chemical composition and to determine relationships between traits. Field experiments including five hulled oat genotypes were carried out at the State Stende Cereal Breeding Institute for two seasons during 2010–2011. Variation of traits was mainly determined by genotype (ω^2 = 53 – 88%), with the min/max values for 1000 kernel weight 32.4/36.5 g, test weight 470.0/507.9 g·L^{-1}, hull content 215.4/265.6 g·kg^{-1}, crude protein 110.0/124.9 g·kg^{-1}, starch 456.9/483.0 g·kg^{-1}, β-glucans 28.1/36.6 g·kg^{-1} and crude fat 46.2/60.0 g·kg^{-1}. Oat variety 'Arta' had the highest test weight (507 g·L^{-1}) and contents of crude protein (124.9 g·kg^{-1}), β-glucans (36.5 g·kg^{-1}), α-tocopherol (7.8 mg·kg^{-1}), average crude fat (55.5 g·kg^{-1}) and total phenolics (113.9 mg gallic acid equivalents/GAE 100 g^{-1} DM) in the grain. Expression of traits significantly depended on meteorological conditions in the specific year. In both years of investigation there were significant (*$p < 0.05$*) positive correlations between contents of β-glucans and crude fat, and negative correlation of β-glucans with starch content, total phenolics and antiradical scavenging activity.*

Key words: Avena sativa*, physical and chemical traits, α-tocopherol, total phenolic content, scavenging activity.*

INTRODUCTION

Oat (*Avena sativa* L.) grain has been extensively studied due to its specific chemical composition and nutritional and physiological values. Oat grain is valued and assessed by its taste, dietetic properties and its ability to stimulate metabolic activity in the body. All this makes its nutritive value high for both people and animals (Peterson, 2004). Improved oat grain quality benefits the producer as well as the processor, by improving the value of a crop being produced and improving the value of products generated from the grain (Doehlert, 2002). Another variable relevant to the overall quality of grain includes planting a high quality seed of varieties with strong local adaptation, sound cultural practices, and favourable weather conditions. Grain products produced in the oat mill include rolled oats, steel cut groats, different sized flakes from the cut groats, oat flour and oat bran. Oat products are now incorporated into a wide range of foods including breakfast cereals, porridge, and muesli. Oat products are used as ingredients in a wide variety of bread and baked products. These ingredients provide unique flavour and moisture retention characteristics, as well as enhance the nutritional benefits of these products (Welch, 1995). In conventional wheat bread processing, up to 10–20% of wheat flour can be easily replaced with oat flakes. Even higher amounts of oats can be used by adapting by optimised baking technologies (Flander *et al*., 2007). In Latvia, "Rīgas Dzirnavnieks" is the largest manufacturer of oat products, and processes about 8000–10 000 t oat grain per year. The main products from oat are flakes and flour.

Cereal grain physical performance is closely related to the amount of nutrients in the grains, so crop breeders need to realize selection to increase grain weight and size in order to improve the productivity and grain quality of varieties. The oat kernel is normally covered with hull after harvest, which is not edible. The edible portion of the oat kernel is called the groat. Percent hull (or groat) is also an important physical parameter of grain quality in oat (Doehlert *et al*., 1999). Oat grains are valuable for humans and are functional foods. Oats contain optimal raw material beneficial for health and promote the production of foods that contain many natural compounds that are beneficial to health. These include soluble fibres, proteins, lipids, soluble and insoluble fibres, minerals, and phytochemicals such as tocols and phenolics and phytosterols (Peterson, 2004). Oats have a high content of soluble fibre in the form of β-glucans, which is considered to increase the viscosity of the food bolus, leading to slower gastric emptying, enhanced gut fill, and slower absorption of nutrients. Intake of oat β-glucans is linked to two specific physiological responses: a small reduction of serum cholesterol levels in people with elevated cholesterol levels and a promotion of postprandial glycaemic response (Wood, 2007).

Oats are a source of many compounds that exhibit antioxidant activity. Among cereals, oat could be a good source of tocopherols and tocotrienols, which are important phytochemical compounds with antioxidant activity providing potential benefits for human health (Colombo, 2010). Most phenolic compounds are bound to cell walls and are mainly found in the bran and germ fraction (Emmons *et al*., 1999; Peterson, 2001). Phenolic compounds are also effective antioxidants with a potential therapeutic value in reducing the risk for cardiovascular disease and cancer (Dykes and Rooney, 2007). Another antioxidant function is to help to maintain the stability of processed oat products. Oats can stabilise oils and fats against rancidity (Lasztity, 1998; Peterson, 2001). There are significant differences among cultivars for antioxidant activities and for total phenolic contents. Growing location can also significantly affect the concentrations of total phenolic contents (Emmons and Peterson, 2001).

In Latvia an aim of oat breeders is to develop varieties with genetic potential capable of ensuring both high productivity level, along with straw strength, disease resistance and grain quality to corresponding to requirements. In 2010, the State Stende Cereal Breeding Institute started implementation of the project “Assessment of Local Cereal Species and Their Potential for Development of Production of Specific Dietary Varieties”. The project was aimed to evaluate the potential of breeding material of different local cereal species and genotypes according to their economic and biochemical parameters associated with dietary value of the grain product. As part of this project, the varieties and breeding lines of hulled and naked oat, mainly of Latvian origin, were studied. The main objectives of this research were to investigate the variability of grain yield, grain physical traits and chemical composition and to determine the relationships between traits.

MATERIALS AND METHODS

The field experiment. The field experiments were carried out at the State Stende Cereal Breeding Institute during 2010 and 2011. The material consisted of five genotypically different hulled oat genotypes (Table 1).

Complex mineral fertiliser was used at the rate 500 kg·ha^{-1} (pure matter N – 80 kg·ha^{-1}, P – 35 kg·ha^{-1}, K – 65 kg·ha^{-1}) in the field trial. Oat was sown in a well-prepared seedbed at a rate of 500 germinating seeds per m². The plot size was 10 m^2, four replicates.

Table 1

DESCRIPTION OF OAT GENOTYPES USED IN THE STUDY

Genotype	Origin	Description
Laima	SSCBI/Latvia	Occupies large areas in Latvia; yield stability; middle early ripening, heightened fat content; average lodging resistance; grain technological quality — test weight, hull content corresponds to requirements of flake production
Arta	SSCBI/Latvia	Early ripening; average yield; low husk content; high test weight, crude protein
Stendes Darta	SSCBI/Latvia	Middle early; average TKW and TW, high husk content, high fat content.
ST Liva, 7.4.	SSCBI/Latvia	Breeding line – selection from variety ‘Stendes Liva’; average yield; tall height, late ripening, high crude protein content
Breton	Danko/Poland	High yield; high TKW, low protein and fat content

SSCBI, State Stende Cereal Breeding Institute

Soil and weather characteristics. The soil type was sod podzolized sandy loam Albeluvisol (Eutric), content of organic substance 21 (2010) – 24 (2011) mg·kg^{-1}, soil pH KCl 5.4 (2010) – 5.8 (2011), available phosphorus P_2O_5 137.0 (2010) – 158.8 (2011) mg·kg^{-1}, and potassium K_2O 211.0 (2010) – 175.7 (2011) mg·kg^{-1}. Pre-crop in both years was pea-wheat intercrops. Soil characteristics met the requirements of oat cultivation.

Overall, the growing seasons of 2010 and 2011 were characterised by average temperature above normal according to long-term data. Some extreme periods of drought were observed at different periods of the vegetation period. In 2011, hot and dry conditions were observed during the third decade of May and in the first decade of June. Moist conditions in July were favourable for plant development. In 2010, high air temperature and low precipitation were observed in the third decade of June and the first decade of July.

Sampling and quality analysis. Yield was estimated at 100% purity and 14% moisture. Samples for estimation of grain quality were taken from each plot. The following grain traits were evaluated: 1000 kernel weight (TKW) (g) by ISTA method (calculated from the average weight of 100 seeds of eight replications), and test weight (TW) (g·L^{-1}) by an automatic grain analyser Infratec Analysis 1241. Hull content (g·kg^{-1}) was evaluated by manual dehulling of 5 g oat grain sample in two replications, weighing dehulled groats and calculating proportion of hulls.

The macronutrients crude protein content (CP) (g·kg^{-1}), starch content (ST) (g·kg^{-1}), and β-glucans content (BGL) (g·kg^{-1}) were determined by an automatic grain analyser Infratec Analysis 1241. All measurements were expressed on a dry matter basis. The content of total insoluble dietary fibre ($g \cdot kg^{-1}$) was evaluated using a Fibertec 1023 system (Foss, Denmark), according to the Van Soest method of analysis for food products LVS EN ISO 16472:2006.

Mean samples of hulled whole grains from all replications were taken and milled for assessment of micronutirents: total phenol compounds and 2.2-diphenyl-1-picrylhydrazyl/ DPPH radical scavenging activity. Oat grain flour was defatted with n-hexane: about 3 g dry flour was extracted with 40 ml n-hexane for 3 h with stirring at room temperature and then was filtered through a paper filter and air-dried at room temperature. Samples of 1 g of dry defatted grains flour was extracted in 30 mL of 50% (v/v) ethanol for 2 h with continuous stirring at room temperature. Extracts were filtered through a paper filter. The filtrates were stored in dark at 4 °C.

The method reported by Vaher *et al.* (2010) was slightly modified to determine the total content of phenolic compounds (TPC) in the extracts. 1 mL of extract was mixed with 5 ml of 10% Folin-Ciocalteu reagent in distilled water and 4 mL of 7.5% sodium carbonate solution. After incubation of samples with reagent at room temperature for 30 min with periodical mixing, the absorbance at 765 nm was measured using a spectrophotometer UVIKON 930 (Kontron Instruments, Italy). The calibration curve was constructed within the concentration range 0.0075–0.09 $mg \cdot mL^{-1}$ (R^2 = 0.9994). Mean values were calculated from three parallel analyses. Results were calculated as gallic acid equivalents (GAE) in mg GAE 100 g^{-1} of dry grain material using equation (1):

$$C = \gamma \times (V/m) \times 100, \quad (1)$$

where: C – total amount of phenolic compounds, mg GAE 100 g^{-1} grain; γ – concentration obtained from calibration curve, mg mL^{-1}; V – volume of aqueous ethanol used for extraction; m – weight of dry grain material, g.

The method reported by Zhu *et al.* (2011) was modified for spectrophotometric DPPH radical scavenging assay. 0.66 mL of oat grain flour extract (mixed with ethanol) or ethanol (blank) were added to 3.6 mL of a 0.1 mM DPPH solution in ethanol. The reaction mixture was shaken and incubated in the dark at room temperature. After 20 min, absorbance at 517 nm was measured using a spectrophotometer UVIKON 930 (Kontron Instruments, Italy). The DPPH radical scavenging activity/RSA (%) was calculated using equation (2):

$$RSA (\%) = (A_{control}-A_{sample})/ A_{control}\times 100 \% \quad (2)$$

where: $A_{control}$ is the absorbance of blank, A_{sample} is the absorbance of the sample.

Determination of α-tocopherol (α-T) was conducted in the Laboratory of Food and Environmental Investigations Institute of Food Safety, Animal Health and Environment "BIOR" using the high-performance liquid-chromatography method for detection of α-tocopherol in diet samples (Commission Directive 2000/45/EC). Chromatographical distribution was carried out on a C_{18} column using methanol/water (98/2 v/v). Fluorometric detection of all peaks was performed at an excitation wavelength of 292 nm.

Statistical analysis. Analysis of variance (ANOVA) was used for statistical data analysis. The obtained results were statistically processed using methods of descriptive statistics. The variance omega squared (ω^2) was calculated to estimate the relative effect of factors (genotype/A and year/B) (Grissom and Kim, 2012). Characteristics of soil, pre-crop and agro-technical measures in both years were identical. The significance of the effect of factors was determined at probability level of 0.05. Variability for trait values within genotypes was determined and expressed by coefficient of variation (V, %) values. To test for differences among the grand means of the two years, the t-test for paired samples was used. Pearson correlation coefficients between the two year phenotypic means were calculated.

RESULTS

Grain yield. ANOVA showed that the grain yield for the tested oat varieties was significantly ($p < 0.05$) determined by genotype (ω^2 = 46%). According to the means of two years, significantly higher grain yield was obtained for oat variety 'Breton' (5.57 $t \cdot ha^{-1}$). The variation in yield for this variety was very low, as indicated the absolute difference between years (0.1 $t \cdot ha^{-1}$). The yield for early ripening variety 'Arta' was significantly lower and was the most variable in this trait, compared with other varieties.

Grain physical traits. Variation of 1000-kernel weight, test weight and hull content were influenced significantly and mainly by genotype (ω^2 = 69, 57 and 80%, respectively, ANOVA). 1000-kernel weight of oat varieties varied significantly from 32.4 to 36.5 g (Table 2). Oat variety 'Breton' had maximum value of 1000-kernel weight. Test weight of oat varieties varied from 470.0 to 507.9 $g \cdot L^{-1}$. Among varieties, 'Breton' and 'Arta' appeared to have minimum and maximum values of test weight (470.0 and 507.9, respectively). Significant differences ($p < 0.05$) between varieties were observed in hull contents. Significantly lower proportion of hulls in the grain yield was indicated for oat variety 'Arta' (215.4 $g \cdot kg^{-1}$). For other oat varieties of Latvian origin, the hull content exceeded 250 $g \cdot kg^{-1}$ (Table 2).

Grain chemical traits. ANOVA indicated that variation of various macronutirents of grain were influenced significantly by genotype (ω^2 = 53–88%) (Table 3). The highest amount of crude protein ($p < 0.05$) in two years of investigation was for variety 'Arta' (124.9 $g \cdot kg^{-1}$), while other varieties had crude protein content from 110.2 to 114.6 $g \cdot kg^{-1}$. Significant differences were observed in starch content of oat varieties, which varied from 456.9 to 483.0 with maximum value for variety. The oat variety 'Breton' had significantly lower β-glucan content in the grain. Varieties 'Laima' (36.6 $g \cdot kg^{-1}$) and 'Arta' (36.5 $g \cdot kg^{-1}$) contained significantly ($p < 0.05$) higher amounts of β-glucans in the two years of investigation. The difference between these va-

Table 2

MEAN VALUES OF GRAIN YIELD AND PHYSICAL TRAITS FOR OAT GENOTYPES, 2010–2011

Genotype	Grain yield, $t \cdot ha^{-1}$		1000-kernel weight, g		Test weight, $g \cdot L^{-1}$		Hull content, $g \cdot kg^{-1}$	
	Mean	D[1]	Mean	D	Mean	D	Mean	D
Laima	5.02b[2]	0.9	34.1c	1.1	503.4a	28.1	254.8b	6.0
Arta	3.99e	1.3	32.4d	0.5	507.9a	16.3	215.4c	7.7
Stendes Darta	4.81c	0.8	32.6d	0.8	483.9b	39.3	265.6a	17.1
ST Liva 7.4.	4.57d	1.7	35.2b	3.5	470.3c	17.9	252.4b	14.1
Breton	5.57a	0.1	36.5a	1.7	470.0c	19.4	248.6b	1.9
$LSDs_{0.05A}$	0.166	-	0.795	-	8.900	-	11.050	-
ω^2_A, %	46*	-	69*	-	57*	-	80*	-

[1] Difference between years (absolute value); [2] means within column with different letters are significantly different ($p < 0.05$); *relative contribution of factors for oat grain quality traits are significant ($p < 0.05$).

Table 3

MEAN VALUES OF GRAIN CHEMICAL TRAITS FOR OAT GENOTYPES, 2010–2011

Genotypes	Crude protein, $g \cdot kg^{-1}$		Starch $g \cdot kg^{-1}$		β-glucans, $g \cdot kg^{-1}$		Crude fat, $g \cdot kg^{-1}$	
	Mean	D[1]	Mean	D	Mean	D	Mean	D
Laima	110.2b[2]	3.0	459.6c	0.8	36.6a	0.3	60.0a	36.3
Arta	124.9a	8.4	458.6c	12.2	36.5a	5.6	55.5b	39.3
Stendes Darta	113.8b	3.5	456.9c	9.3	34.8b	3.0	59.4a	52.5
ST Liva 7.4.	114.6b	5.3	471.1b	3.3	31.0c	0.5	50.2c	20.0
Breton	112.3b	3.1	483.0a	4.0	28.1d	0.3	46.2d	0.5
$LSDs_{0.05A}$	4.794	-	4.437	-	1.606	-	1.132	-
ω^2_A, %	74*	-	53*	-	74*	-	88*	-

[1] Difference between years (absolute value); [2] mean within column with different letter are significantly different ($p < 0.05$); * relative contribution of factors for oat grain quality traits are significant ($p < 0.05$).

rieties was in range of this trait between both years of investigation. The varieties 'Laima' and 'Breton' had very insignificant differences in this trait between years (0.3 $g \cdot kg^{-1}$). There was rather high variation in crude fat content among varieties; 'Laima' and 'Breton' had maximum and minimum values of crude fat (60.0 and 46.2 $g \cdot kg^{-1}$, respectively). Oat variety 'Stendes Darta' had a high amount of average crude fat in the two years of investigation.

Total insoluble fibre in dry mater had rather high variation among oat varieties, with minimum value 251.5 $g \cdot kg^{-1}$ for 'Arta' and maximum value 312.5 $g \cdot kg^{-1}$ for variety 'Breton' (Table 4). These both varieties showed the highest variation for this trait during the two years of investigation. Among varieties, 'Arta' had maximum values of α-tocopherol (7.8 $mg \cdot kg^{-1}$). The oat variety 'Breton' had high average α-tocopherol content with low variation of this trait between the two years (7.0 $mg \cdot kg^{-1}$). The difference in total phenolic content between oat genotypes was also relatively high, from 102.7 mg GAE 100 g^{-1} DM for variety 'Stendes Darta' to 134.0 mg GAE 100 g^{1} DM for variety 'Breton'.

Table 4

MEAN VALUES OF TOTAL INSOLUBLE FIBRE AND MICRONUTRIENT CONTENT FOR OAT GENOTYPES, 2010–2011

Genotype	Total insoluble fibre, $g \cdot kg^{-1}$		α-tocopherol, $mg \cdot kg^{-1}$		Total phenolic content, mg GAE 100 g^{-1} DM		Radical scavenging activity, %	
	Mean	D[1]	Mean	D	Mean	D	Mean	D
Laima	292.0	4.0	6.9	3.4	105.6	14.2	14.1	2.2
Arta	251.5	23.0	7.8	4.0	113.9	13.1	16.3	1.5
Stendes Darta	301.0	4.0	5.0	3.3	102.7	16.2	17.1	2.1
ST Liva 7.4.	276.5	3.0	6.8	2.3	121.4	25.3	23.4	5.5
Breton	312.5	31.0	7.0	0.7	134.0	19.7	21.9	6.6
Average	286.7	-	6.7	-	115.5	-	18.6	-
V%	8.3	-	15.7	-	10.9	-	21.1	-

[1]Difference between years (absolute value).

Oat varieties 'ST Liva 7.4.' (23.4%) and 'Breton' (21.9%) had considerably higher radical scavenging activity than the other oat genotypes (Table 4). Both these varieties showed the highest variation in this trait between years.

ANOVA showed that yield and grain quality traits depended not only on genotype as a factor but also on growing conditions of a specific year (ω^2_B = 2–39%) (Table 4). There was significant difference in between the two years of investigation. The mean values of macronutrients characterising dietary quality of grain harvest, such us crude protein, crude fat, β-glucan content, were significantly higher in 2010 than in 2011. Higher test weight and total insoluble fibre content, total phenolic content and radical scavenging activity were also obtained in 2010. In 2011, the meteorological conditions were more favourable for grain yield and 1000-kernel weight (Table 5).

Table 5

VARIATION OF GRAIN YIELD AND GRAIN QUALITY TRAITS, 2010–2011

Trait	2010	2011	$LSDs_{0.05 B}$	D[1]	ω^2_B, %
Yield, $t \cdot ha^{-1}$	4.31b[2]	5.28a	0.100	15.4	39
1000-kernel weight, g	33.9b	34.5a	0.360	0.5	2
Test weight, $g \cdot L^{-1}$	495.3a	478.9b	4.020	16.5	15
Hull content, $g \cdot kg^{-1}$	243.9b	250.9a	4.910	7.0	3
Crude protein, $g \cdot kg^{-1}$	117.5a	112.9b	3.020	4.6	4
Crude fat, g·kg-1	55.8a	52.8b	0.710	3.0	4
Starch, g·kg-1	462.9b	468.8a	2.830	5.9	11
β-glucans content, g·kg-1	34.2a	32.6b	1.010	1.6	7
Total insoluble fibre, $g \cdot kg^{-1}$	291.0	282.4	-	8.6	-
α-tocopherol, $mg \cdot kg^{-1}$	4.9	8.4	-	3.5	-
TPC, mg GAE 100 g^{-1} DM	124.4	106.7	-	17.7	-
RSA, %	19.6	17.5	-	2.1	-

[1] Difference between years (absolute value); [2] estimates of means with different letters between years are significantly different ($p < 0.05$); TPC, mg GAE 100 g^{-1}DM – total content of phenolic compounds; GAE, Gallic acid equivalents; RSA, radical scavenging activity.

Table 6

PHENOTYPIC CORRELATION COEFFICIENTS BETWEEN TEST WEIGHT, β-GLUCAN AND TOTAL PHENOLIC CONTENT AND OTHER PHYSICAL AND BIOCHEMICAL TRAITS OF OAT

Trait	Test weight		β-glucan		Total phenolic content	
	2010	2011	2010	2011	2010	2011
Yield	-0.558	-0.511	-0.613	-0.352	0.280	0.369
1000 kernel weight	-0.580	-0.400	-0.689	-0.746	0.764	0.541
Test weight	-	-	0.965*	0.366	0.109	-0.911*
Hull content	-0.216	-0.868*	-0.391	-0.087	-0.341	-0.119
Crude protein	0.334	0.487	0.523	0.040	0.049	-0.062
Crude fat	0.916*	0.219	0.858*	0.934*	-0.929*	-0.999*
Starch	-0.918*	-0.187	-0.954*	-0.943*	0.952*	0.922*
β-glucans content	0.965*	0.366	-	-	-0.841*	-0.864*
Total insoluble fibre	-0.637	-0.585	-0.650	-0.148	-0.107	0.409
α-tocopherol	-0.498	0.629	-0.392	0.532	-0.083	0.760
Total phenolic content	-0.911*	0.109	-0.864*	-0.841*	-	-
RSA	-0.938*	-0.472	-0.892*	-0.728	0.861*	0.634

RSA, Radical scavenging activity; *significant at 0.05 probability level.

Results of phenotypic correlation between test weight, β-glucan and total phenolic content, which are traits indicating high value for food oat, are summarised in Table 6. There was no significant correlation between test weight and other traits in both years. There was a significant positive correlation ($p < 0.05$) between β-glucan and crude fat, and negative correlation β-glucan with both starch content and total phenolic content in both years of investigation (Table 6). In hulled oat grains, total phenolic content was significantly related to starch and crude fat content.

Correlation analysis indicated a positive relationship between total phenolics content and radical scavenging activity.

DISCUSSION

The assessment of the potential of hulled oats of local origin for the production of dietary foods is desirable in oat breeding programmes. The aim of these products is to acquire the benefits of gut microbial composition (Charalampopoulos *et al*., 2002). The important parameters that have to be considered in applying oats to functional foods are the composition and processing of the grain as well as organoleptic properties and nutritional value of the final product.

The hull of the oat grain of the normal covered or hulled oat protects the groat. Oat milling involves the removal of the hull to produce clean, sound oat groat. High groat content (or low hull content) and low screenings are particularly important for the achievement of high milling yield, which is an important criteria for hulled food oat (Cowan and Valentine, 2004). High broad-sense heritability has been observed for hull percentage, which indicates the potential for selecting for reduced hull content (Ronald *et al*., 1999). Groat proportion, usually determined by hand dehusking, is used to provide the ceiling value for groat percentage (Doehlert *et al*., 1999). This method was used for estimation of hull content also in our study. According to results of the current study, the great proportion for varieties varied from 735 $g \cdot kg^{-1}$ for variety ‘Stendes Darta’ to 785 $g \cdot kg^{-1}$ for early maturity variety ‘Arta’, calculating as hull content (Table 2). Early maturing oats are considered to be superior regarding groat percentage (Doehlert, 2002).

“Rīgas Dzirnavnieks”, the biggest grain processor in Latvia, has basic requirements for weight and hull content of oat grain; however, this company does not take into account the interests of those consumers who are concerned about the chemical composition or dietary value when purchasing the grain. The popularity of test weight as the main criterion of the value of the grain is largely due to the ease of the measurement, the effectiveness of the test in predicting groat percentage and milling yield (Doehlert *et al*., 1999; 2002). Several studies have indicated positive correlations between test weight and groat percentage (Pomeranz *et al*., 1979; Doehlert *et al*., 1999). Therefore, grain physical characteristics such as high test weights and high groat percentage (or low hull content) will continue to be priorities for hulled oat varieties and are used as a selection criterion in our oat breeding tests.

Quality specification for grain biochemical quality requirements can also vary widely among applications of oat. Feed applications favour higher protein and fat concentrations, and lower fibre (Doehlert, 2002). Food applications favour lower fat concentrations, provided that there is no effect on oat flavour, and higher β-glucans in order to fully benefit from health claims related to the soluble fibre content in oats (Lasztity, 1998; Cowan and Valentine, 2004). Additional desirable qualities of milling oat varieties are high groat protein, low kernel breakage, high grain yield, and superior yield stability (Yan *et al*., 2007).

Evaluation of basic biochemical parameters showed that in conditions of Latvia, there is a possibility to obtain grains that differ in biochemical composition. The choice of the variety is equally important. For example, the difference between oat varieties in crude fat content were from 46.2 to 60.0 $g \cdot kg^{-1}$, which demonstrates the possibility to select oat genotypes with suitable values of these traits. The Latvian hulled oat varieties were characterised with high crude fat content, which was not desirable according to recommendations of oat processors. Large manufacturers usually pay more attention to safety and quality stability of products. The kernel grinding, germ seperation, moisturising, heat treatment of flakes and high fat content could promote the development of oxidative and hydrolytic rancidity during handling, storage and processing (Ranhotra and Gelroth, 1995). Nevertheless, a valuable property of lipids is their ability to provide more than twice as much dietary energy than carbohydrates or protein, and oat lipids provide dietary essential fatty acids (Welch, 1995). In addition, many applications for oats and oat products have the potential in processing for non-traditional products. Special cultivars with high crude fat content can be developed especially for specific value-added applications, where oat lipids could be purified for pharmaceutical and food applications (Doehlert, 2002). For oats, fat and fibre content are the major causes of variation in nutritional value (Ranhotra and Gelroth, 1995). Both insoluble and soluble fibres are present in oat. Previous studies (Bach-Knudsen *et al*., 2001) of hulled oats reproted high fibre grain with 290 $g{\cdot}kg^{-1}$ insoluble fibre, which corresponds to the average value in the current study, compared with barley at 140 $g{\cdot}kg^{-1}$ and wheat at 110 $g{\cdot}kg^{-1}$. The average value of total insoluble fibre content in Swedish hulled oats was reported to be 323 $g{\cdot}kg^{-1}$ (Aman, 1987).

Due to the considerable amount of hulls in oats, the content of components like starch and protein is relatively low, when compared to other cereals (Ranhotra and Gelroth, 1995). The early maturing variety 'Arta' had the highest crude protein content. Unfortunately, increase in groat protein concentration is usually associated with decrease in grain yield, as it was confirmed in our study. In contrast, oat variety 'Arta' also had a high level of soluble fibre β-glucans. Also, another study (Zute *et al*., 2011) on hulled breeding material of Latvian origin found the highest variable β-glucan content in oat variety 'Arta' (mean value 34.2 $g{\cdot}kg^{-1}$).

Differences between oat genotypes in grain micronutrients that exhibit antioxidant activity, such as α-tocopherols and total phenolic compounds, were also found. The difference between five varieties included in this research for α-tocopherols was 2.8 $g{\cdot}kg^{-1}$. In another study in Latvia, in which 52 hulled oat genotypes were included from the working collection, the content of α-tocopherols was found to vary more widely (3.2 to 8.4 $g{\cdot}kg^{-1}$) (Berga and Zute, 2012), similar to the results reported elsewhere (Lasztity, 1998). Phenolic compounds in oat, regarding their distribution, content and health benefits for humans, have extensively been reviewed by D. M. Peterson (2001). The first results obtained in the present research on hulled oat suggest that it could be a good source of phenolic compounds. The total content of phenolic compounds and antioxidant activity estimated in the present study, correspond to values specified in literature for whole-grain flours of the hulled oat varieties from other European countries, obtained by the same spectrophotometric method using the reagent DPPH (Peterson *et al*., 2001; Serea and Barna, 2011). It was found that the total phenolic content in the black hulled oats was significantly higher than in the yellow and naked oat varieties (Brindzova *et al*., 2008). New cultivars may be developed with especially high antioxidant activities to supply natural alternatives for the food ingredient industry. It has to be taken into account that there is a decreasing concentration of total phenolics as more material is pearled from the groats (Peterson *et al*., 2001) and as a higher amount of phenolics has been reported in the outer layer of oat (Emmons *et al*., 1999; Peterson, 2001).

The results showed that expression of grain physical traits also depended significantly on the growing conditions of a specific year. In 2010, the weather conditions were not favourable for yield, because there were limited amounts of precipitation during the grain filling period. In that year, less hull proportion, higher test weight, crude protein, crude fat, β-glucans, total phenolic content and radical scavenging activity were observed. Also, other studies showed that growing conditions affect quantitatively inherited traits and the quality of food grain indices in naked oats such as hull proportion (Doehlert *et al*., 1999; Ronald *et al*., 1999), crude protein and β-glucans (Aman, 1987; Biel *et al*., 2009; Zute *et al*., 2011), fat content (Brindzova *et al*., 2008), α-tocopherols (Colombo, 2010), antioxidant activity and phenolic content (Emmons and Peterson, 2001). Significant environmental effect on variation of these oat quality traits was indicated also in a review (Doehlert, 2002). Environment also affects nutritive value. This means that the environment will continue to add a significant level of uncertainty to the production of quality oat grain.

Understanding the relationships between the breeding objectives and their responses to the environment (years and/or locations) is important for improving the efficiency of oat breeding. Correlation analysis conducted for the five genotypes there showed many strong significant correlation relationships among the analysed traits. Some of these, such as between target traits (test weight, β-glucan and total phenolics) and the other traits did not remain stable through both years of investigation, as was the case between test weight and other grain quality traits. Significant and consistent relationships in boths years of investigation were found between starch vs. β-glucan content (negative) and total phenolic content (positive). Comprehensive study of agronomic and quality trait-association by environment interaction including oat genotypes of different origin in a diverse set of 21 environments was conducted previously (Yan *et al*., 2007). In all environments, positive relationship between β-glucan and crude fat content was observed, which was consistent with our results. This sugests that it could be difficult to develop an oat variety characterised simultanously by high β-glucan and low crude fat content, which is more desired for food application. A positive correlation between the content of β-glucans in covered oat grains and the radical scavenging activity was observed (Brindzova *et al*., 2008). In the current study a significant negative correlation was found between β-glucan and phenolic compound content, as well as DPPH radical scavenging activity. These two latter mentioned traits were positively correlated, as found in several other studies with oat (Emmons and Peterson, 2001; Peterson, 2001; Serea and Barna, 2011) and also for other cereals such as wheat (Zhu *et al*., 2011), and barley (Zhao *et al*., 2008).

In summary, it was possible to select hulled oat genotypes with considerable variability of grain physical traits and grain biochemical composition in hulled oat varieties of

Latvian origin. The variation of all traits was significantly affected by genotype as a factor. Of the tested oat varieties of Latvian origin, the variety 'Arta' showed the best results, as it had high test weight, crude protein, β-glucans and α-tocopherol content in grains and medium crude fat and total phenolic content in grains. Expression of traits significantly depended on growing conditions of the specific year. Hulled oat genotypes with high crude fat content showed high β-glucan content, but lower starch, total phenolic content and antiradical activity. Due to a lack of stable correlation between overall productivity and physical traits of hulled oat genotypes, the evaluation needed to be made in consideration of biochemical composition. Grain processors have to provide options for consumers to acquire products with specific dietary properties. It is necessary to use the raw material to produce oat products with high dietary value, using grains obtained from varieties with the best biochemical composition.

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PLĒKŠŅAINO AUZU GRAUDU RAKSTUROJUMS PĒC DIĒTISKU PRODUKTU RAŽOŠANAI NOZĪMĪGĀM FIZIKĀLĀM UN ĶĪMISKĀM PAZĪMĒM

Nozīmīgs raksturlielums, kas jāņem vērā, izmantojot auzas (*Avena sativa* L.) specifisku diētisku pārtikas produktu ražošanai, ir atbilstoša graudu kvalitāte. Pētījuma mērķis bija izpētīt plēkšņaino auzu (*Avena sativa* L.) graudu fizikālo pazīmju un ķīmiskā sastāva mainību un analizēt korelatīvās sakarības starp pazīmēm. Lauka izmēģinājumi ar pieciem plēkšņainajiem auzu paraugiem tika iekārtoti Valsts Stendes graudaugu selekcijas institūtā 2010. un 2011. gadā. 1000 graudu masas (32.4–36.5 g), tilpummasas (470.0–507.9 $g \cdot L^{-1}$) un plēkšņainības (215.4–265.6 $g \cdot kg^{-1}$), kopproteīna (110.0–124.9 $g \cdot kg^{-1}$), cietes (456.9–483.0 $g \cdot kg^{-1}$), β-glikānu (28.1–36.6 $g \cdot kg^{-1}$), koptauku (46.2–90.0 $g \cdot kg^{-1}$) mainība bija būtiska ($p < 0.05$), kuru galvenokārt ietekmēja genotips (ω^2 = 53–88%). Pazīmju mainību būtiski ietekmēja arī gada (meteoroloģisko apstākļu) kā faktora ietekme. Auzu šķirnei 'Arta' bija augstākā tilpummasa (507.9 $g \cdot L^{-1}$), kopproteīns (124.9 $g \cdot kg^{-1}$), α-tokoferola saturs (7.8 $mg \cdot kg^{-1}$), paaugstināts β-glikānu (36.5 $g \cdot kg^{-1}$) un vidējs koptauku saturs (55.5 $g \cdot kg^{-1}$) un kopējais fenolu saturs (113.9 mg GAE (gallijskābes ekvivalents) 100 g^{-1}) graudos. Abos pētījuma gados β-glikāniem konstatēja pozitīvu un būtisku ($p < 0.05$) sakarību ar koptauku saturu, bet negatīvu korelāciju ar cieti, kopējo fenolu saturu un antiradikālo aktivitāti.