ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 104, No. 4 (2017), p. 291–298
DOI 10.13080/z-a.2017.104.037

The new winter wheat cultivars 'Kena DS', 'Gaja DS', 'Sedula DS' and 'Herkus DS' for increased yield stability

Vytautas RUZGAS[1], Žilvinas LIATUKAS[1], Kristyna RAZBADAUSKIENĖ[1], Reine KOPPEL[2], Gintaras BRAZAUSKAS[1]

Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry
Instituto 1, Akademija, Kėdainiai distr., Lithuania
E-mail: ruzgas@lzi.lt

[2] Estonian Crop Research Institute
J. Aamisepa 1, 48309 Jogeva, Estonia

Abstract

The new cultivars of winter wheat 'Kena DS', 'Gaja DS', 'Sedula DS' and 'Herkus DS' were developed at Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. The cultivars are well adapted to the temperate climate conditions with occasionally low temperatures in the winter season. The mean winter hardiness of the cultivars was evaluated by 7.8, 7.3, 8.2 and 7.3 scores, respectively and surpassed the well adapted and previously widely grown check cultivar 'Zentos' (6.8 scores). The cultivars exhibit good resistance to sprouting in ears, which is important in regions with high humidity during the harvesting period. They can be grown under sustainable and high input growing conditions. The mean grain yield of cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' in high input fields during 2011–2016 was 8.7, 8.6, 9.9 and 9.1 t ha^{-1}, respectively. The grain yield of the high yielding check cultivar 'Skagen' was 8.6 t ha^{-1}. The mean protein content of cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' was 14.3, 13.3, 13.6 and 13.3 %, sedimentation value – 61.2, 49.2, 34.5 and 49.3 ml, respectively. The dough stability of the new cultivars determined by a Brabender's pharinograph was 12.7, 6.0, 7.3 and 6.9 min, volume of bread baked from 300 g of flour was 1600, 1650, 1700 and 1520 cm^3, respectively. The total baking value index of the cultivars 'Kena DS', 'Sedula DS', 'Gaja DS and 'Herkus DS' was evaluated by 700, 725, 750 and 660 scores respectively, where the excellent bread-making cultivar 'Ada' attained 670 scores. The new cultivars exhibit good resistance to powdery mildew (*Blumeria graminis* DC), acceptable resistance to tan spot (*Pyrenophora tritici-repentis* Died.), take-all (*Gauemanomyces graminis* Sacc.), Septoria glume blotch (*Phaeosphaeria nodorum* E. Müll) and Septoria leaf blotch (*Zymoseptoria tritici* (Desm.) The cultivars are included in the Lithuanian National List of Plant Varieties and EC Common Catalogue of Cultivars of Agricultural Plant Species.

Key words: agronomic characteristics, cultivars, grain quality, winter wheat.

Introduction

Winter wheat breeding was started in Lithuania in 1922 at the Dotnuva Plant Breeding Station and has been continued till now: 8 cultivars were developed during the 1922–1990 period, and 10 cultivars during the 1991 – 2011 period. The winter wheat production area has significantly increased during the last decade. During the 2006–2016 period, the wheat area in Lithuania increased by 253%, in Latvia – by 208%, in Sweden – by 124%, in Poland – by 112% and in Germany – by 103% (Eurostat, 2017). Therefore, the demand for adapted and high yielding winter wheat cultivars is high, as well as the competition among the candidate cultivars in the Official State Cultivar Testing for registration in the Lithuanian National List of Plant Varieties. The cultivars should be of high bio-potential level and meet market requirements for about 15 years (Shewry, 2009).

The up-to-date bread baking industry has new processing systems and need the raw material with different specific characteristics.

To respond to the industry's requirements, new wheat cultivars are being developed for different industrial tasks. It is possible because of the uniqueness of wheat gluten proteins which provide a wide array of end products. The screening of genetic material for glutenin composition and end use properties enable the breeders to develop proper breeding material and cultivars. Historically, the classification of wheat has been focused on technological quality attributes and wheat breeding program is constructed to fulfil this classification (Bonjean et al., 2011).

Today's agriculture requires environment friendly cultivars whose cultivation enables reducing

Please use the following format when citing the article:
Ruzgas V., Liatukas Ž., Razbadauskienė K., Koppel R., Brazauskas G. 2017. The new winter wheat cultivars 'Kena DS', 'Gaja DS','Sedula DS' and 'Herkus DS' for increased yield stability. Zemdirbyste-Agriculture, 104 (4): 291–298 DOI 10.13080/z-a.2017.104.037

chemical input. Therefore it is important that recently developed cultivars provide enhanced health benefits for end-use products, possess higher disease resistance, particularly spike diseases (Mondal et al., 2016). Winter and spring wheat occupy nearly half of the arable land in Lithuania (Eurostat, 2017). This situation creates ideal conditions for the spread and development of a range of wheat diseases, of which the most devastating are tan spot, Fusarium head blight and a complex of crown and root rots. Insufficient resistance of the majority of cultivars as well as rather limited efficacy of fungicides favour the spread of these diseases. During the years conducive to these diseases, only growing of the most resistant cultivars under high fungicide input can ensure high grain yield and quality (Ramanauskienė, Gaurilčikienė, 2016).

A crucial point in the cultivar development is a proper and purposeful germplasm collection. Cultivars developed in different environments and geographic regions have been obtained for our wheat breeding program. The grain yield improvement can be achieved using three ways. The first one is to reduce the plant height. The genes *Rht1*, *Rht2* and similar ones control the metabolism of gibberellic acid that reduces the plant height and stimulates the tillering (Wojciechowski et al., 2009). The plant height in some cultivars is controlled only by quantitative trait loci (QTL), whose impact can sometimes be equal to that of *Rht* genes (Shewry, 2009; Liatukas, Ruzgas, 2011). The second way to increase the grain yield is to improve the position of leaves. Most of the West-European cultivars have erect leaves with 30–40° angles to the stem. This leaf position allows higher solar radiation interception by lower leaves and enhance grain yield (Mohammadi et al., 2012; Mohad, Gupta, 2015). The third way is to keep the leaves green for a longer time by exploiting plant disease resistance (Thomas, Ougham, 2014).

Winter hardiness is a very important trait for European countries in North-West region. Cultivars possessing good winter hardiness slowly grow in the autumn period and have short and narrow leaves (McCallum, DePauw, 2008). Young plants are the most resistant to sub-zero temperatures. The cultivars with high tillering capacity use significant part of the reserve material for tiller development. Therefore, the main tiller grows slowly and such genotypes are less damaged during winter (Mokanu, Fayt, 2008). The most effective crosses in the breeding program for winter hardiness improvement are those in which one parental form is well adapted to local conditions and has good winter hardiness. As a rule, cultivars with high winter hardiness are tall growing and lower yielding; they transfer more negative traits to offspring. Winter hardiness is inherited as a complex of physiological mechanisms, which involve many cell and plant traits and depends on the parental forms (Braun, Săulescu, 2002).

The productivity is one of the most important and desirable traits of a cultivar. This trait is controlled by many genes. The length of vegetation, winter hardiness, resistance to diseases, productivity and density of spikes have the greatest impact on grain yield. The grain yield is strongest correlated with a thousand grain weight ($r = 0.65$). Plant height negatively correlates with yield ($r = -0.27$).

The reduction in height raises wheat grain yield due to increased spike productivity and crop density (Zhao et al., 2015; Zhang et al., 2016). The use of the parental forms from different ecological groups is recommended for the development of promising cultivars. This increases genetic fragmentation and the likelihood of selecting desirable lines (Zhang et al., 2016). Wheat grain is intended for many products. The applicability of grain depends in most cases on the protein content and quality. The protein content depends on the genotype, growing conditions and negatively correlates with grain yield, grain size, but modern cultivars are improved and can effectively use the mineral nutrition. Nevertheless, it is important to increase the capacity of protein synthesis in new cultivars (Bonjean et al., 2011; Zhao et al., 2015).

The new winter wheat cultivars are intended to be multiplied in Lithuania and the neighbouring countries, therefore good adaptability to different environmental conditions and resistance to biotic and abiotic stresses are highly relevant. The winter hardiness is a critical point in winter wheat breeding, because severe winters usually occur in the Baltic States 2–3 times per decade.

The market demand for winter wheat grain and local growing conditions have prompted development of late and early ripening hard red winter wheat cultivars with good bread-making quality.

We expect that the new winter wheat cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS', presented in this paper, will be able to compete with the best currently available cultivars in terms of agronomic performance, yield and end-use quality.

Materials and methods

The cultivars presented in this study have been developed using a conventional pedigree method ('Kena DS') and a doubled haploid technique using maize as a haplo-producer ('Gaja DS', 'Sedula DS' and 'Herkus DS') (Table 1). The weather conditions during the cultivar development period and official testing were highly contrasting and similar to those typical of North-West European countries. The seasons 2005–2006, 2009–2010, 2010–2011 and especially 2013–2014 were favourable for the evaluation of winter hardiness. During the latter season 60–70% of winter crops were killed in Lithuania (www.vic.lt). The weather conditions during the cultivar development period were favourable for the evaluation of the main diseases and lodging resistance as well as measurement of grain yield and quality stability.

The soil of the experimental site is an *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*), light loam. The trial was preceded by black fallow. It contained 1.5–2.0% humus, available phosphorus (P_2O_5) ranging from 190 to 240 mg kg^{-1}, available potassium (K_2O) from 180 to 260 mg kg^{-1}, and pH from 6.5 to 7.0. The rates of these fertilizers were calculated according to the concentration of PK elements in an individual field. Nitrogen 90 kg ha^{-1} was applied after resumption of vegetation in all breeding nurseries and additional 70 kg ha^{-1} N was used in high input plots when plants developed 2nd to 3rd nodes. The seeds were pesticide-treated only for replicated yield trials, sown on 17.5 m^2 plots with four replications. The crop was planted at a seed rate of 4.5 million ha^{-1} with a small plot sowing machine within the first week of September. Breeding lines in early generation nursery were sown by a single row machine. Weeds were controlled by the recommended herbicides in the autumn. One replication was covered with chopped wheat straw after application of autumn herbicides.

The field experiments were conducted in sustainable, monoculture and high input (since 2014)

Table 1. History of development and registration of the new winter wheat cultivars

Development stage	Cultivars			
	'Kena DS'	'Gaja DS'	'Sedula DS'	'Herkus DS'
Pedigree	Astron / Olivin	Hermann / Olivin // Picus	Turkis / Olivin	Haven / Dean // Pentium /// SW Maxi
Breeder's reference	DS 5450-1	DS 5899-16	DS 5823-8	DS 6045-1
Crossing time	2002	2005	2005	2003
Testing years in breeding nurseries:	2003–2007	–	–	2004–2008
doubled haploid lines selection,	–	2008	2008	2005
plots, one replication,	2008	2009	2009	2009
replicated testing block,	2009–2016	2010–2016	2010–2016	2010–2016
additional testing for common bunt resistance,	2009–2016	2010–2016	2010–2016	2010–2016
additional testing in wheat monoculture block,	2009–2016	2010–2016	2010–2016	2010–2016
official testing.	2011–2013	2012–2014	2012–2014	2013–2015
Year of registration	2014	2015	2015	2016

growing conditions. The nitrogen application in the sustainable and monoculture nurseries was N_{120}, in high input block – N_{200}. In high input nurseries, growth regulators, fungicides and insecticides were applied at recommended rates and time, the plots were sown later, at the end of the second ten-day period of September.

The primary disease assessment was carried out in the early generations. During the further cultivar development period, plant diseases were comprehensively investigated in the replicated testing block and simultaneously in the special wheat mono-crop nursery for take-all and snow mould resistance, grain yield, 1000 grain and test weight. The seeds in this nursery were sown by a sowing machine Wintersteiger TC 2700 (Austria) in 3.0 m^2 plots with four replications. Application of fertilizers and pesticides was the same as in the replicated testing block. Leaf diseases (powdery mildew, Septoria leaf blotch, tan spot, leaf and stripe rusts) were assessed during booting to medium milk development stages in scores. Snow mould was evaluated at the end of winter or beginning of spring after the snow had melted and damaged plants had developed pink colour typical of snow mould. The cultivars were evaluated for common bunt resistance. The seeds inoculated by Tilletia caries (DC) spores at a rate of 10g spores per 1 kg seed were sown later than other plots (Szunics, 1990).

Also, the cultivars were evaluated for Fusarium head blight resistance after inoculating heads during beginning of flowering with suspension of *Fusarium culmorum* (W.G. Sm.) at spore concentration 5 × 10^5 ml. Disease severity was evaluated two weeks after inoculation. Resistance to grain sprouting in ears was screened in a laboratory and coleoptile length was measured in cm (Botwright et al., 2001). Resistance to diseases, grain sprouting in ears were evaluated on a 1–9 score scale, where 1 denotes the highest resistance. Resistance to common bunt was evaluated in percent.

Autumn growth rate was evaluated late in the autumn after the end of vegetation. Winter hardiness was evaluated after resumption of vegetation. Spring growth type was evaluated at the beginning of intensive growth in spring. Resistance to lodging was evaluated from flowering to harvesting. These traits were evaluated on a 1–9 score scale, where 1 denotes the lowest resistance.

Protein content, gluten content, sedimentation value, falling number, dough rheological properties were evaluated using standard methods in the Chemical Research Laboratory of Institute of Agriculture, Lithuanian Research Centre of Agriculture and Forestry on the samples obtained from the replicated yield trials. High molecular weight glutens were evaluated by the methods described in Paplauskienė et al. (2009).

Bread making properties were assessed at the Estonian Crop Research Institute. The baking tests on 300 g of flour were done using special laboratory baking equipment.

After mixing, the dough was maintained at a temperature of 28–30°C for 45 minutes. This was followed by rolling out the dough twice with resting periods. After this, the dough was placed in the fermentation chamber for 90 minutes. The bread was baked for 20 minutes. The next day, the volume of bread was measured and the following characters were evaluated: appearance (the general exterior of the bread): A – good, D – bad; crumb: A – good, C – satisfactory; colour, crumb and taste: A – good, C – satisfactory. Elasticity (loaf resilience) was measured from a slice of loaf (5 × 5 × 5 cm) by depressing the loaf texture 3.0 cm with a lead cube for 5 seconds. After the lead cube was released the reversion of loaf texture was measured in centimetres. The reversion was determined using a scoring system 0–10 (poor to good). Structure and structure value of crumb texture were determined by the pore size using a scoring system of 1–8 (small to large).

The research data were statistically processed by employing LSD_{05} (95% probability level) using statistical package *ANOVA* (Tarakanovas, Raudonius, 2003).

Results and discussion

The new cultivars of winter wheat are designed for growing in the temperate climate conditions with a risk of sub-zero temperature spells in the winter time. They are characterized by slow development in the autumn, resistance to re-growth in winter mild weather period and are intended for high input growing conditions. The spikes belong to *lutescens* class; the grains are hard-red type.

Plant height of cultivars 'Gaja DS' and 'Sedula DS' averaged 82–83 cm, 'Herkus DS' and 'Kena DS' 97 cm. Lodging resistance of all cultivars was good due to medium straw length and strength (Table 2). Optimal plant height for the conditions of many European countries is 80–90 cm (Semenov et al., 2014). Nevertheless, use of growth regulators for all cultivars is recommended when a yield of over 8 t ha^{-1} is targeted. Our cultivars showed perfect lodging resistance in the trials with plant growth regulators. Later maturity of these genotypes in combination with acceptable plant height and disease resistance allows formation of high grain yield.

Table 2. Agronomic traits of new winter wheat cultivars, 2011–2016

Cultivar	Plant height cm	Coleoptile length cm	Resistance to lodging, scores	Earliness: days from 1st January to heading	Winter hardiness, scores	1000 grain weight g	Test weight g l-1	Falling number s	Pre-harvest sprouting, scores
Zentos (standard)	105	7.0	7.4 / 9.0*	156	6.8	45.2	814	385	4.0
Skagen (standard)	97	6.7	5.9 / 7.5*	158	8.0	45.7	801	402	4.5
Kena DS	99	6.5	7.3 / 9.0*	159	7.8	40.2	832	408	3.5
Sedula DS	83	4.7	8.8 / 9.0*	159	7.3	39.8	783	386	4.0
Gaja DS	82	4.4	8.8 / 9.0*	160	8.2	38.7	755	314	5.0
Herkus DS	97	7.1	7.8 / 9.0*	160	7.3	43.3	782	308	4.0

* – with plant growth regulators

All cultivars had the same medium-late maturity 159–160 days from 1st January to heading. The standard cultivar 'Skagen' was 1–2 days earlier than other tested cultivars. Cultivars of such maturity are usually characterized by higher yield potential than the earlier ones.

Cultivars 'Sedula DS' and 'Gaja DS' have short coleoptiles (4.7 and 4.4 cm, respectively), 'Kena DS' and 'Herkus DS' have coleoptiles of medium length (6.5 and 7.1 cm). Cultivars with longer coleoptiles have no exceptional advantage for European countries. Longer coleoptiles improve stand establishment where stubble retention is practiced (Rebetzke et al., 2005).

Plants with longer coleoptiles are characterised by higher seedling vigour, higher competitive ability against weeds, better crop establishment, more efficient soil water use, and better penetration trough soil crust (Spielmeyer et al., 2007).

In Lithuania, winter wheat reaches harvesting maturity during the period from end of July–beginning of August and lasts for 3–4 weeks. Long-term observations indicate that during the harvesting period rain occurs every third day. This means that the problem of pre-harvest sprouting is relevant. The new cultivars have medium to high resistance to grain sprouting in ears. Pre-maturity alpha-amylase activity as an indicator of pre-harvest sprouting occurrence is shown by falling number analyses. Prediction of sprouting resistance by alpha-amylase activity is possible only in some cases. Nevertheless, the falling number analysis in practical wheat growing is one of the important traits predicting the gain quality. The requirements for falling number for high quality wheat is >300 seconds, for acceptable quality 200 seconds. The new cultivars had the following falling number index: 'Kena DS' – 408, 'Sedula DS' – 386, 'Gaja DS' – 314 and 'Herkus DS' – 308 seconds. This means that all cultivars fit the highest requirements for alpha-amylase activity and can be grown in wet climate conditions.

During the testing period 2005–2016, the winters were suitable for elimination of cold and snow mould susceptible genotypes. The winter of 2009–2010 was favourable for the evaluation of complex winter hardiness due to low temperatures, thin snow cover and very wet soils. Stress factors, responsible for winterkill, are very complex and include traits such as extreme air or soil temperatures below critical rate for wheat cultivars (winter of 2009–2010), inadequate hardening level (winter 2006–2007), long period of cold-induced desiccation, prolonged sub-zero temperatures (Gusta et al., 1997). In particular, temperatures below −15°C during mid-winter result in rapid loss of winter hardiness (winter of 2009–2010).

The problematic situation for winter wheat was in 2013–2014 when prolonged warm period lasted till mid-January. The plants slowly vegetated, depleted the reserve materials, which weakened their cold tolerance for the rest of the winter period. The overall winter-kill losses of winter wheat area in Lithuania that year amounted to 60–70% (http://www.vic.lt/?mid=786). A similar situation is described by Fowler et al. (2015).

Alternate freezing and thawing, which results in increased injury from ice crystal growth with each freeze, occurs constantly, but at different rate during Lithuanian winters and beginning of spring. Good winter hardiness correlates with lower yield. Therefore, breeding for winter hardiness is possible by applying very high selection pressure in segregating populations. The mean winter hardiness of the cultivars presented in this study was as follows: 'Kena DS' – 7.8, 'Sedula DS' – 7.3, 'Gaja DS' – 8.2 and 'Herkus DS' – 7.3 scores. The highly resistant cultivar 'Zentos' was evaluated by 6.8, 'Skagen' – by 8 scores.

Test weight positively correlates with rheological properties of dough, protein content and flour output, which is important for milling industry (Mohad, Gupta, 2015). The grain with more than 730 g l^{-1} is attributed to the first grain quality class (LST 1524:2003/2K:2014. Wheat. Requirements for purchase and supply). An average test weight of the cultivar 'Kena DS' was 832 g l^{-1}, 'Sedula DS' – 783 g l^{-1}, 'Gaja DS' – 755 g l^{-1} and 'Herkus DS' – 782 g l^{-1}.

A 1000 grain weight has a positive correlation with field germination and negative with protein content (Mohammadi et al., 2012). The highest thousand grain weight for cultivar 'Herkus DS' was 43.3 g, 'Kena DS' – 40.2 g, 'Sedula DS' – 39.8 g and Gaja DS' – 38.7 g.

Productivity is the most important trait of winter wheat cultivars. The grain yield depends on many factors, including winter hardiness, resistance to plant diseases, effectivity of photosynthesis, duration of vegetation (Mohammadi et al., 2012). The grain yield is determined by productivity of spike, number of spikelets and grains per ear and efficient density (Zhang et al., 2016).

The focus of selection for grain productivity improvement is the stoutness of grain (r = 0.56). The number of grains per spike has no influence on the grain yield (r = 0.35–0.50), because as a rule the plants re-compensate the productivity of spikes. If the spikes are short, the grains are bigger, and *vice versa*. Plant height has a negative correlation with productivity (r = −0.27).

The shorter stems have positive impact on plant productivity due to improved spike density and higher resistance to lodging. To improve the productivity, it is recommended to include parental cultivars which belong to different ecological groups in the hybridization programme. The hybrids obtained from such cross have a higher diversity for selection of desirable genotypes (Zhao et al., 2015).

The grain yield potential of the tested winter wheat cultivars is high. The investigations done over a 6-year period demonstrated that the mean grain yield exceeded that of the check cultivar in sustainable and high input nurseries (Table 3). The mean grain yield of 'Gaja DS' was 9.9 t ha^{-1}, 'Herkus DS' – 9.1 t ha^{-1}, 'Kena DS' – 8.7 t ha^{-1} and 'Sedula DS' – 8.6, t ha^{-1} under high input and 6.7, 6.8, 6.6 and 6.2 t ha^{-1} under sustainable growing conditions. Grain yields under monoculture were similar to those in sustainable growing conditions and were 7.5, 6.7, 6.7 and 6.9 t ha^{-1} for 'Gaja DS', 'Herkus DS', 'Kena DS' and 'Sedula DS', respectively. The statistical analysis showed that the lowest significant differences in 2011, 2012 and 2014 exceeded the 5% level, due to the high influence of unfavourable winter and water regime conditions. This suggests that wheat breeding should focus on those traits that ensure plant survival, i.e. winter hardiness, resistance to diseases, water fluctuation, etc.

Table 3. Grain yield (t ha^{-1}) of the new winter wheat cultivars in sustainable, high input growing conditions and monoculture, 2011–2016

Cultivar	Growing conditions	Testing year						Average
		2011	2012	2013	2014	2015	2016	
Skagen (standard)	sustainable	5.9	5.3	5.0	5.4	6.8	6.0	5.7
	high input	–	–	–	7.9	9	8.8	8.6
	monoculture	5.4	6.6	7.3	6.6	10.0	7.7	7.3
Kena DS	sustainable	6.0	5.6	5.1	5.7	7.3	6.4	6.0
	high input	–	–	–	8.1	8.7	9.4	8.7
	monoculture	5.1	6.4	6.7	6.0	9.1	6.9	6.7
Sedula DS	sustainable	6.1	5.7	4.8	6.3	6.9	7.6	6.2
	high input	–	–	–	8.0	8.8	8.9	8.6
	monoculture	5.2	6.2	6.9	6.3	8.9	7.7	6.9
Gaja DS	sustainable	6.5	5.9	5.4	6.8	7.8	7.9	6.7
	high input	–	–	–	9.3	10.6	9.9	9.9
	monoculture	5.7	6.5	7.5	6.9	10.3	8.3	7.5
Herkus DS	sustainable	7.5	6.4	5.4	6.4	8.0	6.8	6.8
	high input	–	–	–	8.4	9.4	9.5	9.1
	monoculture	4.2	6.7	6.7	6.3	9.1	7.1	6.7
LSD_{05}		0.50	0.51	0.39	0.82	0.43	0.36	0.50

The winter wheat cultivars are divided into several quality groups based on their suitability for bread-making, signalled by protein quantity and quality. These features are the most important for wheat breeding program design. According to the Lithuanian grain procurement standards (LST 1524:2003. Wheat. Requirements for purchase and supply), the protein content for the first class is required to be ≥13,0%, the second – ≥11.5% and third – ≥10.5%. The growing conditions during the period of investigations were favourable for high quality winter wheat; therefore grain protein content exceeded the first grain quality class requirements (Table 4).

Table 4. Grain quality of the new winter wheat cultivars, 2011–2016

Cultivar	Protein content %	Gluten content %	Sedimentation value ml	High molecular weight glutenin composition			
				GluA1	Glu B1	Glu D1	scores
Zentos (standard)	13.2	26.7	61.2	0	7 + 9	5 + 10	7
Skagen (standard)	13.8	28.7	57.0	1	6 + 8	5 + 10	8
Kena DS	14.3	30.1	61.2	1	7 + 9	5 + 10	9
Sedula DS	13.3	26.3	49.2	0	7 + 9	5 + 10	7
Gaja DS	13.6	29.9	34.5	1	6 + 8	2 + 12	7
Herkus DS	13.3	23.8	49.3	0	7	5 + 10	6

It is well known that gluten content strongly correlates with protein content. Nevertheless the gluten content provides additional information about grain quality, especially when the maturity period is very dry (2011) or rainy (2012). In 2016, the rainy period occurred when the grains were completely ripe. The protein content in grain did not change in this period, but gluten content decreased considerably. In this case, the gluten molecules re-formed to shorter forms and total amount decreased (Shewry, 2009). The protein and gluten are highly informative but not the only indicators of grain quality. To more precisely predict gluten quality, the sedimentation value is used (Seaburn et al., 2012). For grain quality of the first, second and third classes the lowest sedimentation values are 35, 25 and 20 ml, respectively. The highest sedimentation value (61.2 ml) was determined in grain of cultivar 'Kena DS'. The sedimentation value of cultivars 'Sedula DS' and 'Herkus DS' was 49 ml, 'Gaja DS' – 34.5 ml.

It is important to know grain quality of the developed lines at early breeding stages. The analyses of high molecular weight glutenin composition enabled us to predict grain quality type from a small amount of grain. The best value of high molecular weight glutenin compositions was exhibited by the new cultivar 'Kena DS'.

The rheological properties predict the dough characteristics of wheat. The elasticity of the dough was measured by a Brabender's pharinograph, whose operations are based on physical methods. The diagram (pharinogram) showed direct indexes: water absorption, dough development time, stability and other traits. The best dough development indexes were identified for the cultivars 'Kena DS', 'Sedula DS' and 'Herkus DS' (Table 5). The highest dough stability was demonstrated by the cultivar 'Kena DS', while the other cultivars either surpassed or were similar to the check cultivars 'Zentos' and 'Skagen'. Brabender's quality index is an integrated indicator of all rheological properties. It shows that all cultivars can be included in wheat groups of excellent or good bread-making quality.

Table 5. The rheological properties of the new winter wheat cultivars, 2011–2016

Trait	Cultivar						LSD_{05}
	Zentos	Skagen	Kena DS	Sedula DS	Gaja DS	Herkus DS	
Flour output %	71.7	70.7	71.2	67.6	58.3	71.7	2.3
Dough development time, min	2.0	4.2	4.9	3.2	2.7	3.5	1.3
Water absorption %	58.5	56.3	55.0	57.2	54.7	55.8	2.4
Dough stability, min	2.6	6.2	12.7	6.0	7.3	6.9	3.4
Degree of softening after 10 min, Brabender's unit	110	50	29	47	49	55	18.9
Degree of softening after 12 min, Brabender's unit	133	67	52	79	68	70	19.9
Brabender quality index	34	91	99	75	74	74	6.7

The baking properties were investigated at the Estonian Crop Research Institute. The grain samples harvested in 2013 were used for the analyses. The growing conditions that year were favourable for grain development.

The check cultivar 'Ada', characterised by excellent bread-making quality, was taken for baking test. The bread volume, baked from 300 g flour was from 1520 cm^3 ('Gaja DS') to 1700 cm^3 ('Sedula DS'), baking losses were 9.7–11.2% (Table 6). General appearance of loaves and taste were good for all cultivars. The total baking value of the investigated cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' was 700, 750, 660 and 725, respectively. The total baking value of 'Ada' was 670. The new high yielding cultivars are of excellent or good bread-making quality.

Table 6. The baking properties of the new winter wheat cultivars

Cultivar	Volume of bread cm^3	Appearance A–C	Taste evaluation, A–C	Baking losses %	Structure evaluation, scores	Total baking value, points
Ada	1540	AB	A	10.3	4–5	670
Kena DS	1600	B	A	11.2	5–6	700
Sedula DS	1700	B	A	10.7	4–5	750
Gaja DS	1520	BC	A	9.7	4–5	660
Herkus DS	1650	AB	A	10.4	4–5	725

Resistance to plant diseases is one of the most important traits alongside the grain yield and quality. Up-to-date requirements to reduce the pesticide pressure on the environment means that wheat breeders should focus on the development of gene-based resistance to major plant diseases. Growing of resistant cultivars make the constraints for development of fungicide resistant pathogens (Lo lacono et al., 2013).

The new cultivars possess high resistance to powdery mildew (*Blumeria graminis* DC) (Table 7). The cultivars previously registered in Lithuania and accessions grown in the genetic collection are less resistant (Liatukas et al., 2012). The highest resistance to powdery mildew was shown by the cultivar 'Sedula DS'.

Tan spot (*Pyrenophora tritici-repentis*) is currently a more aggressive and less controlled disease than Septoria leaf blotch when wheat is continuously grown after wheat. Winter and spring wheat are predominant crops in the crop rotations and together with triticale and rye occupy nearly half of the arable land in Lithuania and considerable part in other European countries (Eurostat, 2017).

Table 7. Disease resistance of the new winter wheat cultivars, 2011–2016

Cultivar	Powdery mildew	Tan spot	Septoria leaf blotch	Take-all	Snow mould	Eye-spot	Fusarium head blight	Common bunt	Septoria glume blotch
Zentos (standard)	3.2	6.7	6.4	5.9	6.0	6.0	5.8	49.6	5.8
Skagen (standard)	2.0	5.0	4.3	4.6	4.5	6.0	5.3	8.8	5.3
Kena DS	2.3	4.8	3.8	4.4	5.0	6.0	5.9	71.8	5.9
Sedula DS	2.0	5.5	4.6	5.0	5.0	4.5	5.0	50.3	5.0
Gaja DS	2.7	5.0	4.2	5.3	3.5	4.0	4.2	16.8	4.2
Herkus DS	2.3	5.3	4.6	5.1	5.5	4.5	6.1	29.2	6.1
LSD_{05}	0.13	0.35	0.33	0.57	0.74	0.69	0.41	13.5	0.28

Note. Score 1 means no infection; resistance to common bunt indicated in the %, where 0% means no infection.

It was indicated that the pathogen has some genotypes with high pathogenicity and resistance to fungicides (Patel et al., 2012). The most resistant to tan spot was cultivar 'Kena DS' (4.8 scores), the least resistant was the cultivar 'Sedula DS'.

The new cultivars were more resistant to Septoria leaf blotch than the check cultivar 'Zentos'. Cultivars 'Kena DS' (3.8 scores) and 'Gaja DS' (4.2 scores) were more resistant than the new check cultivar 'Skagen' (4.3 scores). 'Sedula DS' and 'Herkus DS' were less resistant and evaluated by 4.6 scores.

Many Septoria tritici bloch (*Stb*) genes provide efficient resistance only against some *Zymoseptoria tritici* (Desm.) isolates. However, cultivars without quantitative resistance genes will possess acceptable resistance for a shorter period (Brown et al., 2015).

The recent investigations have shown that it is possible to improve the take-all resistance through plant breeding, where infection of the most susceptible cultivars was evaluated in 8–9 scores (Liatukas et al., 2010). The new cultivars presented in this paper were infected less and evaluated in 4.4–5.3 scores. The main evaluation of lines was done in the nurseries growing under sustainable conditions.

Snow mould (*Monographell nivalis* (Schaffnit) is one of the main reasons for poor winter wheat overwintering. Most West European winter wheat cultivars are not characterized by resistance to this disease due to the absence of prolonged snow cover in the countries of their origin.

Some information is available from the review of Thachenko et al. (2015). But this paper does not provide information about resistance of new European cultivars. Some limited information is available from Northern European and Northern American countries, Russia and Japan. Among our new cultivars, 'Gaja DS' was the most resistant (3.5 scores), the rest of the cultivars possessed resistance around 5 scores.

Eye-spot (*Oculimacculla yalundae* (Wallwork & Spooner)) is one of the main diseases in the crop rotations with high cereal proportion as is the case in Lithuanian farms. The new cultivar 'Gaja DS' was most resistant (4 scores), 'Sedula DS' and 'Herkus DS' were moderately resistant (4.5 scores). 'Kena DS' and the check cultivars were susceptible to eye-spot. Eye-spot damage is severe only in some years as the pathogen develops and infects plants for a long period from seedling appearance to node development stage under wet and cool weather conditions (Ramanauskienė, Gaurilčikienė, 2016).

The new cultivars were rather susceptible to common bunt (*Tilletia caries*). The infection scale of cultivar 'Kena DS' was 71.8%, 'Sedula DS' – 50.3%, 'Herkus DS' – 29.2% and 'Gaja DS' – 16.8%. The common bunt in conventional growing conditions is not an important disease, because the seed treatment effectively prevents the infection. However, common bunt-susceptible cultivars are not recommended to be grown under organic conditions.

Resistance to Fusarium head blight is economically important, because fusarium mycotoxines are strictly controlled due to their hazardous effects on human and animal health. Among the new cultivars the most resistant was 'Gaja DS' (4.2 scores) and 'Sedula DS' (5.0 scores). The cultivars 'Kena DS' and 'Herkus DS' were more susceptible (5.9 and 6.1 scores).

Resistance to Septoria glume blotch among our new cultivars varied from 4.2 ('Gaja DS') to 6.1 ('Herkus DS') scores.

Conclusions

1. The new Lithuanian winter wheat cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' are winter hardy and thus well adapted to growing under temperate climate conditions. The cultivars exhibit good resistance to pre-harvest sprouting, which is important in the regions with high humidity during harvesting period.

2. The plant height of the new cultivars is medium short and medium tall. Nevertheless the lodging resistance was high even without plant growth regulators. No lodging was observed under intensive use of plant growth regulators. The cultivars are of medium-late maturity.

3. All cultivars perform well in sustainable and high input growing conditions. The mean grain yield of cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' under high input conditions was 8.7, 8.6, 9.9 and 9.1 t ha^{-1}, respectively.

4. The grain of the new cultivars is of excellent or high bread-making quality. The mean protein content of cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' is 14.3, 13.3, 13.6 and 13.3 %, sedimentation value – 61.2, 49.2, 34.5 and 49.3 ml, gluten content – 30.1, 26.3, 29.9 and 23.8 %, respectively.

5. The new cultivars are characterized by high resistance to powdery mildew – 2.0–2.7 scores (1 = no infection). The cultivars 'Kena DS', 'Sedula DS', 'Gaja DS' and 'Herkus DS' showed good resistance to Septoria leaf blotch and medium resistance to tan spot. The cultivar 'Gaja DS' showed the highest complex disease resistance.

Received 15 05 2017
Accepted 28 08 2017

References

1. Bonjean A. P., Angus W. J., van Ginkel M. (eds.). 2011. The world wheat book. A history of wheat breeding, vol. 2, 1201 p.
2. Botwright T. L., Rebetzke G. J., Condon A. G., Richards R. A. 2001. Influence of variety, seed position and seed source on screening for coleoptile length in bread wheat (*Triticum aestivum* L.). Euphytica, 119 (3): 349–356. https://doi.org/10.1023/A:1017527911084
3. Braun H. J., Săulescu N. N. 2002. Breeding winter and facultative wheat. Curtis B. C. et al. (eds.). Bread wheat. Improvement and production. FAO Plant Production and Protection Series No. 30.
4. Brown J. K. M., Chartrain L., Lasserre-Zuber P., Saintenac C. 2015. Genetic of resistance to *Zymoseptoria tritici* and application to wheat breeding. Fungal Genetics and Biology, 78: 33–41. https://doi.org/10.1016/j.fgb.2015.04.017
5. Eurostat. 2017 http://ec.europa.eu/eurostat/statistics-explained/index.php/Main_annual_crop.
6. Fowler D. B., Byrns B. M., Greer K. J. 2015. Overwinter low-temperature responses of cereals: analyses and simulations. Crop Science, 54: 2395–2405. https://doi.org/10.2135/cropsci2014.03.0196
7. Gusta L. V., Willen R., Fu P., Robertson A. J., Wu G. H. 1997. Genetic and environmental control of winter survival of winter cereals. Acta Agronomica Hungarica, 45 (3): 231–240.
8. Lo Iacono G., van den Bosch F., Giligan C. A. 2013. Durable resistance to crop pathogens: an epidemiological framework to predict risk under uncertainty. PLoS Computational Biology, 9 (1): e1002870. https://doi.org/10.1371/journal.pcbi.1002870
9. Liatukas Ž., Ruzgas V. 2011. Coleoptile length and plant height of modern tall and semi-dwarf European winter wheat varieties. Acta Societatis Botanicorum Poloniae, 80 (3): 197–203. https://doi.org/10.5586/asbp.2011.018
10. Liatukas Ž., Ruzgas V., Razbadauskienė K. 2010. Winter wheats resistance to take-all. Agronomy Research, 8 (3): 653–662.
11. Liatukas Ž., Ruzgas V., Razbadauskienė K., Brazauskas G., Koppel R. 2012. Winter wheat cultivars 'Kovas DS', 'Zunda DS', 'Kaskada DS' and 'Vikaras DS' for high input farming: development and characterization. Zemdirbyste-Agriculture, 99 (3): 255–264.
12. McCallum B. D., DePauw R. M. A. 2008. A review of wheat cultivars grown in the Canadian prairies. Canadian Journal of Plant Sciences, 88 (4): 649–677. https://doi.org/10.4141/CJPS07159
13. Mohad D., Gupta R. K. 2015. Relevance of physiological efficiency in wheat grain quality and the prospects of improvement. Physiology and Molecular Biology of Plants, 21 (4): 591–596. https://doi.org/10.1007/s12298-015-0329-8
14. Mohammadi M., Sharifi P., Karamizadeh R., Shefazadeh K. 2012. Relationship between grain yield and yield components in bread wheat under different water availability. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 40 (1): 195–200.

15. Mokanu N. V., Fayt V. I. 2008. Differences in the effects of alleles of the genes *Vrd1* and *Ppd-D1* with respect to winter hardiness, frost tolerance and yield in winter wheat. Cytology and Genetics, 42 (6): 384–390. https://doi.org/10.3103/S0095452708060054
16. Mondal S., Rutkoski J. E., Velu G., Singh P. K., Crespo-Herrera L. A., Guzman C., Bhavani S., Lan C., He X., Singh R. P. 2016. Harnessing diversity in wheat to enhance grain yield, climate resilience, disease and insect pest resistance and nutrition through conventional and modern breeding approaches. Frontiers in Plant Science, 7: 991. https://doi.org/10.3389/fpls.2016.00991
17. Paplauskienė V., Ruzgas V., Liatukas Ž. 2009. Genetic diversity in winter wheat (*Triticum aestivum* L.) breed lines based on seed storage protein composition. Zemdirbyste-Agriculture, 96 (3): 16–26 (in Lithuanian).
18. Patel J. S., Gudmestad N. C., Meindardt S., Adhikari T. B. 2012. Pyraclostrobyn sensitivy of baseline and fungicide exposed isolats of *Pyrenophora tritici-repentis*. Crop Protection, 34: 37–41. https://doi.org/10.1016/j.cropro.2011.10.015
19. Ramanauskienė J., Gaurilčikienė I. 2016. Incidence of eyespot in winter wheat and quantification of the fungi *Ocilimacula acuformid* and *O. yullundae* in Lithuania. Journal of Plant Diseases and Protection, 123 (2): 75–81. https://doi.org/10.1007/s41348-016-0013-4
20. Rebetzke G. J., Bruce S. E., Kirkegaard J. A. 2005. Longer coleoptiles improve emergence through crop residues to increase seedling number and biomass in wheat (*Triticum aestivum* L.). Plant and Soil, 272 (1–2): 87–100. https://doi.org/10.1007/s11104-004-4040-8
21. Seaburn B. W., Xiao Z. S., Tilley M., Herald T. J., Park S.-H. 2012. A rapid, small scale sedimentation method to predict breadmaking quality of hard winter wheat. Crop Science, 52 (3): 1306–1315. https://doi.org/10.2135/cropsci2011.04.0210
22. Semenov M. A., Stratonovitch P., Alghaban F., Gooding M. J. 2014. Adapting wheat in Europe for climate change. Journal of Cereal Science, 59 (3): 245–256. https://doi.org/10.1016/j.jcs.2014.01.006
23. Shewry P. R. 2009. Wheat. Journal of Experimental Botany, 60 (6): 1537–1553. https://doi.org/10.1093/jxb/erp058
24. Spielmeyer W., Abromeit J., Joaquim P., Azanza F., Bonnett D., Ellis M. E., Moore C., Richards R. A. 2007. QTL on chromosome 6A in bread wheat (*Triticum aestivum*) is associated with longer coleoptiles, greater seedling vigor and final plant height. Theoretical and Applied Genetics, 115 (1): 59–66. https://doi.org/10.1007/s00122-007-0540-2
25. Szunics L. 1990. Data on common bunt infection in wheat varieties. Növenytermeles, 39: 297–304.
26. Tarakanovas P., Raudonius S. 2003. Agronominių tyrimų duomenų statistinė analizė taikant kompiuterines programas *ANOVA*, *STAT*, *SPLIT-PLOT* iš paketo *SELEKCIJA* ir *IRRISTAT*. Lithuanian University of Agriculture, 58 p. (in Lithuanian).
27. Thachenko O. B., Ovsyankina A. V., Shchukovskaya A. G. 2015. Snow mold: history of the study and control. Agricultural Biology, 50 (1): 16–29.
28. Thomas H., Ougham H. 2014. The stay green trait. Journal of Experimental Botany, 65 (14): 3889–3900. https://doi.org/10.1093/jxb/eru037
29. Wojciechowski T., Gooding M. J., Ramsy L., Gregory P. J. 2009. The effects of dwarfing genes on seedling root growth of wheat. Journal of Experimental Botany, 60 (9): 2565–2573. https://doi.org/10.1093/jxb/erp107
30. Zhang Y., Xu W., Wang H., Dong H., Qi H., Zhao M., Fang Y., Gao C., Hu L. 2016. Progress in genetic improvement of grain and related physiological traits of Chinese wheat in Henan Province. Field Crops Research, 199: 117–128. https://doi.org/10.1016/j.fcr.2016.09.022
31. Zhao Y., Li Z., Liu G., Jiang Y., Maurer H. P., Würschum T., Mock H.-P., Matros A., Ebmeyer E., Schachschneider R., Kazman E., Schacht J., Gowda M., Longin C. F., Reif J. C. 2015. Genome-based establishment of a high-yielding heterotic pattern for hybrid wheat breeding. Proceedings of National Academy of Sciences of the USA, 122 (51): 15624–15629. https://doi.org/10.1073/pnas.1514547112

ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 104, No. 4 (2017), p. 291–298
DOI 10.13080/z-a.2017.104.037

Žieminio kviečio naujos veislės 'Kena DS', 'Gaja DS', 'Sedula DS' ir 'Herkus DS' – derliaus stabilumo didinimui

V. Ruzgas[1], Ž. Liatukas[1], K. Razbadauskienė[1], R. Koppel[2], G. Brazauskas[1]

[1]Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institutas
[2]Estijos augalininkystės institutas

Santrauka

Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institute sukurtos žieminio kviečio veislės 'Kena DS', 'Sedula DS', 'Gaja DS' ir 'Herkus DS'. Šių veislių žieminiai kviečiai yra gerai prisitaikę augti vėsaus klimato sąlygomis, kai žiemos metu pasitaiko itin žemos temperatūros.
Nustatytas veislių Kena DS', 'Sedula DS', 'Gaja DS' ir 'Herkus DS' žieminių kviečių vidutinis žiemkentiškumo įvertinimas: 7,8, 7,3, 8,2 ir 7,3 balo, taip pat geras atsparumas dygimui varpose; tai labai svarbu kviečius auginant drėgno klimato kraštuose. Šių veislių žieminius kviečius auginant intensyviai, gautas 8,7, 8,6, 9,9 ir 9,1 t ha^{-1} vidutinis grūdų derlius. Kartu auginti standartinės veislės 'Skagen' kviečiai subrandino 8,6 t ha^{-1} grūdų. Veislių 'Kena DS', 'Sedula DS', 'Gaja DS' ir 'Herkus DS' žieminių kviečių grūdų vidutinis baltymingumas buvo 14,3, 13,3, 13,6 ir 13,3 %, sedimentacija (Zeleny testas) – 61,2, 49,2, 34,5 ir 49,3 ml. Šių veislių žieminių kviečių miltų tešlos stabilumą ištyrus Brabenderio farinografu, jis nustatytas atitinkamai 12,7, 6,0, 7,3 ir 6,9 min. Bandomojo duonos kepinio, iškepto iš 300 g miltų, tūris buvo atitinkamai 1600, 1650, 1700 ir 1520 cm^3. Bendras duonos kepimo įvertinimas pagal veisles siekė 700, 725, 750 ir 660 balų (palyginimui – gerų kepimo savybių veislės 'Ada' žieminių kviečių grūdų kepinys įvertintas 670 balų). Naujųjų veislių augalai pasižymėjo geru atsparumu miltligei, vidutinišku – lapų septoriozei, dryžligei, javaklupei ir varpų fuzariozei. Žieminio kviečio veislės Kena DS', 'Sedula DS', 'Gaja DS ir 'Herkus DS' 2014–2016 m. buvo registruotos ES žemės augalų rūšių veislių bendrajame kataloge ir Lietuvos nacionaliniame augalų veislių sąraše.

Reikšminiai žodžiai: agronominiai rodikliai, grūdų kokybė, veislės, žieminiai kviečiai.