ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 108, No. 2 (2021), p. 133–140
DOI 10.13080/z-a.2021.108.017

The new waxy winter wheat cultivar 'Minija DS'

Žilvinas LIATUKAS, Vytautas RUZGAS

Lithuanian Research Centre for Agriculture and Forestry
Instituto 1, Akademija, Kėdainiai distr., Lithuania
E-mail: zilvinas.liatukas@lammc. lt

Abstract

The new waxy winter wheat (*Triticum aestivum* L.) cultivar 'Minija DS' was developed at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. The cultivar is very well adapted to harsh winter conditions. The mean cold tolerance score was 9.0 and surpassed the well adapted and widely grown standard cultivar 'Skagen' (score 8). The snow mould resistance (score 2.0) considerably surpassed that of the standard cultivars (4.0–6.0, mean score 4.9). The cultivar exhibits good grain pre-harvest sprouting resistance, which is important for stable grain quality after maturity. The cultivar can be grown under high input conditions; however, due to the low lodging resistance, maximal doses of plant growth regulators are necessary. The mean yield in 5 testing locations of the cultivar over three experimental years was 8.7 t ha^{-1}, or 83.0%, compared to the yield of the standard cultivars. The mean protein content of 'Minija DS' was 13.5%, gluten content – 28.2%, sedimentation value – 31 mL, whereas the corresponding values of the standard cultivars were 12.6%, 25.2% and 43.0 mL, respectively. As a waxy winter wheat cultivar, 'Minija DS' has specific grain quality traits such as very low falling number – 65 s (mean of the standard cultivars – 340 s), lower flour output – 47% (67.2%) and higher dough water absorption – 73.5% (60.2%). The new cultivar is resistant to leaf rust and snow mould, medium resistant to powdery mildew but susceptible to leaf spot diseases, root rots and Fusarium head blight. The cultivar has been included in the Lithuanian National List of Plant Varieties and EU Database of Registered Plant Varieties.

Key words: waxy wheat, amylopectin, grain quality, cultivar.

Introduction

Development of the new winter wheat cultivars is increasingly focused on non-traditional genotypes having an added value for the wheat processing industry and human health (Singh et al., 2018). One of the wheat breeding directions at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry is the production of so-called waxy (amylose free) wheat. Lithuania usually produces about 3 million tonnes of wheat grains per year, but about half of them are exported as low-price raw material (LSD, 2019).

Waxy wheat (*Triticum aestivum* L.) carries three non-functional alleles at loci *Wx-A1*, *Wx-B1* and *Wx-D1* encoding the enzyme granule-bound synthase and produces endosperm starch almost free (1–3%) of amylose (Chao et al., 1989; Nakamura et al., 1995). Wheat is not unique in this trait, as possibly all cereals carry genes encoding starch free of amylose (Bertoft, 2017).

Breeding of waxy wheat for the industry is done mainly in the USA (Graybosch et al., 2014; 2018) and the range of Asian countries, including Japan (Nakamura et al., 1993), Republic of Korea (Park et al., 2009) and China (Wang et al., 2015). Breeding of such wheat in Europe was performed in Germany (Bundessortenamt, 2017), France (SECOBRA Recherches, 2018) and Italy (Caramanico et al., 2018). Some breeding activity takes place in Ukraine (Iorgachova et al., 2018) and Russia (Vafin et al., 2018). Other types of waxy wheat with different (5–20%) amylose content can be also developed. These wheat genotypes have utility for the South-East Asia region, where partially waxy wheat is traditionally common for special noodles production (Yong et al., 2009).

Amylopectin starch shows unique traits, and it is suitable for a range of applications for food product improvement due to a high-water holding capacity (Hung et al., 2006). Waxy flour can be added to typical wheat flour to improve the shelf life of baked products. Percent of waxy flour in flour mix usually ranges between 10–20% (Choi et al., 2012; Caramanico et al., 2018). Also, amylose free starch is more efficient in ethanol and maltodextrins production (Wang et al., 2015). Waxy wheat starch can be used in the production of modified food starches and in other food and industry applications (Hung et al., 2006; Ohm et al., 2019). One of the most promising applications of waxy flour is use for frozen finished or semi-finished dough products due to unique ability to strongly decrease the starch retrogradation process (Wang et al., 2015; Jia et al., 2017; Ohm et al., 2019). The decreased cooking temperature needed to gelatinize waxy wheat starch increases its marketing potential as a thickener in microwaved foods as well the

Please use the following format when citing the article:
Liatukas Ž., Ruzgas V. 2021. The new waxy winter wheat cultivar 'Minija DS'. Zemdirbyste-Agriculture, 108 (2): 133–140. DOI 10.13080/z-a.2021.108.017

reduced cooking temperature saves energy (Wang et al., 2015; Caramanico et al., 2018).

To date, no waxy wheat cultivars have been released in Northern Europe. Our research on USA waxy wheat material used for the development of our own new cultivar showed a rather poor agronomic background for high input growing (unpublished data). Waxy wheat cultivars released in Central and Southern Europe possess low winterhardiness and/or low resistance to lodging (Bundessortenamt, 2017; Caramanico et al., 2018; SECOBRA Recherches, 2018).

To meet the Lithuanian climate conditions, a waxy winter wheat cultivar 'Minija DS' (VATŽŪM, 2018 b; EU Database…, 2020) with outstanding winter hardiness and drought resistance was developed, released and registered. The newly developed cultivar might broaden the range of grain processing industry products as well as increase incomes from new products with greater attractiveness to consumers.

Materials and methods

The waxy winter wheat (*Triticum aestivum* L.) cultivar 'Minija DS' presented in this study has been developed using a doubled haploid (DH) technique with maize as a haplo-producer. Waxy wheat germplasm was obtained from R. Graybosch (University of Nebraska-Lincoln, USA) in 2007. The breeding scheme is presented in 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 experimental years 2010–2011 and 2013–2014 were very favourable for the evaluation of complex winter hardiness traits, as during these seasons 60–70% of winter crops were killed in Lithuania (ŽŪIKVC, 2019). The weather conditions during the cultivar development period were favourable for the evaluation of the main diseases and lodging resistance as well as the measurement of grain yield and quality stability under dry, normal and wet weather conditions.

Genotypes characterized by completely waxy grains were selected using an iodine 0.05% water solution staining test. Fully waxy grains are stained in brown colour, and normal or non-fully those are stained in blue-black colour. The selected genotypes were re-evaluated by falling number test, as this grain type shows a very low falling number value of 60–70 s, whereas common wheat grains can normally show 250–300 s or in some cases over 400 s (Zhao, Sharp, 1998).

The data from Plant Variety Testing Divisions (PVTD) and Department of Cereal Breeding of Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry were used for analyses of cold tolerance, maturity time, plant height, lodging, grain yield, 1000 grain weight, hectolitre weight, protein and gluten contents, sedimentation value, falling number and starch content. As standards, the following cultivars of different grain quality were used: 'Skagen' (2014–2017) (high quality), 'SW Magnifik' (2014–2017) (good quality 1), 'Kovas DS' (2014–2016), 'Sedula DS' (2017) (good quality 2), 'Mulan' (2014–2015), 'KWS Ozon' (2016) and 'Artist' (2017) (medium quality) (VATŽŪM, 2015; 2016; 2017; 2018 a).

Dough quality traits, flour output, resistance to diseases and pre-harvest sprouting, autumn and spring growth data were used from the trials of Department of Cereal Breeding of Institute of Agriculture.

Characteristics of soils of the experimental sites are presented in Table 2.

Table 1. Breeding scheme of waxy winter wheat cultivar 'Minija DS'

Development stage	Year
Pedigree	NX05M4501–2/NX05M4180–4
Breeder's reference	6459–3
Crossing time	2007
Doubled haploid development	2008–2009
Selection of doubled haploid lines	2010
Plots, one replication	2011
Seed purification and multiplication	2012–2017
Replicated testing block, moderate input	2012–2017
Replicated testing block, high input	2014–2017
Replicated testing in wheat monoculture block	2012–2016
Testing for common bunt resistance and Fusarium head blight	2012–2018
Official testing	2014–2017
Year of registration	2018

Table 2. Description of soils of the testing locations of waxy winter wheat cultivar 'Minija DS'

Parameters	Testing location				
	Akademija, Kėdainiai distr.	Kaunas PVTD	Pasvalys PVTD	Plungė PVTD	Utena PVTD
Coordinates	55°39′ N 23°57′ E	55°02′ N 23°81′ E	56°03′ N 24°45′ E	55°92′ N 21°73′ E	55° 46′ N 26° 61′ E
Soil type, structure	light loam	light loam	heavy loam-light clay	light-medium loam	light-medium loam
Soil type (WRB, 2014)	*Endocalcari-Epihypogleyic-Cambisol*	*Endocalcaric-Endogleyic-Luvisol*	*Endocalcari-Endohypogleyic-Cambisol*	*Bathygleyic Dystric Glossic Retisol*	*Endoeutric Dystric Glossic Retisol*
pH	6.3	7.3	6.4	5.3	6.4
Humus %	1.8	1.9	2.3	2.2	1.8
P_2O_5 mg kg^{-1}	225	236	234	280	127
K_2O mg kg^{-1}	180	166	366	170	187
Pre-crop	black fallow	winter rape	winter rape	winter rape	pea

PVTD – Plant Variety Testing Division

The rates of PK fertilizers were calculated according to the concentration of PK elements in an individual field and ranged between 30–90 kg ha^{-1} P_2O_5 and 40–120 kg ha^{-1} K_2O. Nitrogen 90 kg ha^{-1} was applied after the resumption of vegetation in all breeding nurseries and plant variety testing stations. When plants developed 2nd to 3rd nodes, an additional 40 kg ha^{-1} N was used in moderate input plots and Plungė and Utena PVTD, and 80 kg ha^{-1} N – in Kaunas and Pasvalys PVTD.

The seeds were pesticide-treated only for replicated yield trials and plant cultivar testing, sown on 16.5 m^2 plots with 4 replications in Akademija, Kėdainiai district, and on 10–12 m^2 plots in plant variety testing divisions. The crop was planted at a seed rate of 4.5 million ha^{-1} with a small plot sowing machine "Hege" (Wintersteiger, Austria) within the first ten days of September under 2014–2017. Sowing time in plant variety testing divisions was the second ten-day period of September. Breeding lines in early doubled haploid nursery were sown by a single row machine Wintersteiger TC (Wintersteiger, Austria). Weeds in all testing locations were controlled by the recommended herbicides in the autumn and spring. One replication of moderate input plots in Akademija, Kėdainiai district was covered with chopped wheat straw after the application of autumn herbicides.

The field experiments were conducted in sustainable, monoculture and high input (since 2014) growing conditions. The nitrogen application in the sustainable and monoculture nurseries was N_{130}, in high input nursery – N_{170}. In high input nursery and plant variety testing divisions, plant growth regulators (PGR), fungicides and insecticides were applied at recommended rates and time.

The primary assessment of biotic and abiotic stress resistance was carried out in the doubled haploid nursery. During the further cultivar development period, plant diseases were comprehensively investigated in the replicated testing blocks and simultaneously in the special wheat monoculture nursery for take-all and snow mould resistance, grain yield, 1000 grain and test weight. The seeds in this nursery were sown in 3.0 m^2 plots with four replications by a sowing machine Wintersteiger TC (Wintersteiger, Austria). The application of fertilizers and pesticides was the same as in the replicated testing block with moderate input. Leaf diseases: powdery mildew (*Blumeria graminis* f. sp. *tritici*), Septoria leaf blotch (*Zymoseptoria tritici* (Desm.)), tan spot (*Pyrenophora tritici-repentis*), leaf (*Puccinia triticina* Eriks.) and stripe rusts (*Puccinia striiformis* f. sp. *tritici*), 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 in percent. The seeds inoculated with *Tilletia caries* spores at a rate of 10 g spores per 1 kg seed were sown at the end of September under 2012–2018. Also, the cultivars were evaluated for Fusarium head blight resistance. At the beginning of flowering, wheat heads were inoculated with a suspension of *Fusarium culmorum* at a spore concentration of 1.5×10^5 ml. Resistance to grain sprouting in ears and coleoptile length were screened in a laboratory conditions at Department of Cereal Breeding. Resistance to diseases and grain sprouting in ears were evaluated on a 1–9 score scale, where 1 denotes the highest resistance.

The autumn growth rate was evaluated late in the autumn after cessation of vegetation. Spring growth type was evaluated at the beginning of intensive growth in spring. The growth rate was evaluated on a 1–5 score scale, where 1 denotes the lowest growth rate. Winter hardiness was evaluated after the resumption of vegetation. 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.

Grain quality traits and dough rheological properties of the samples obtained from the replicated yield trials were evaluated using standard methods in the Chemical Research Laboratory of Institute of Agriculture and by device Infratec 1241 in the Department of Plant Pathology and Protection of Institute of Agriculture, Lithuanian Research Centre of Agriculture and Forestry. The elasticity of the dough was measured by a Brabender's pharinograph Brabender (Germany), whose operations are based on physical methods. The pharinograph showed direct indexes: water absorption, dough development time, stability and other traits.

The research data were statistically processed by employing least significant difference (LSD_{05}) at 95% probability level using statistical software *SAS*, version 7.1 (SAS Institute Inc., USA).

Results and discussion

Cultivars with a complex abiotic stress tolerance are becoming increasingly relevant under changing climate conditions. High winter hardiness is one of the main traits of a successful winter wheat cultivar. Autumn growth rate indirectly influences overwintering. Usually, genotypes characterized by intensive autumn growth are less tolerant to frost and snow mould damage (Liatukas et al., 2012). Cultivar 'Minija DS' has very fast autumn growth (5 scores) compared to the standard cultivars (1.5–3.5 scores) (Table 3). Considering this, the proposed sowing date is medium or medium late – the third ten-day period of September.

'Minija DS' is very tolerant to frost and snow mould compared to the standard cultivars. However, overgrown crop after harsh winter does not look very attractive due to damaged leaves, although killed plants make up only several percent of the total population.

Spring growth was exceptionally intensive (5 scores), most of the standard cultivars showed slow to medium (2–3 scores) spring growth. Very intensive growth in the autumn and spring suggests a shorter period of optimal herbicide application but better competition with weeds at the juvenile stages. The cultivar is characterized by a much shorter vegetation period (8 days) compared to the mean of the standard cultivars. As grain combines are relatively clean from common wheat grains during this period, this could minimize contamination of waxy wheat grains with common wheat grains.

The plant height (103 cm) of 'Minija DS' was statistically similar to that of the majority of standard cultivars. However, lodging resistance was very low (1 score) without the application of PGR but medium (6 scores) with PGR. The only standard cultivar 'Skagen' was medium tolerant (7.5 scores) to lodging with PGR, and the rest of the cultivars were very tolerant (8–9 scores) to lodging. Considering susceptibility to lodging, 'Minija DS' should be grown under a moderate nitrogen fertilization level with the application of high rates of PGR. This cultivar should be grown in soils with low to medium fertility levels.

The coleoptile length of 'Minija DS' was slightly longer (7.5 cm) than that of the rest of the cultivars (4.8–7.0 cm). Cultivars with longer coleoptiles can be sown deeper to reach wet soil for even and faster

Table 3. Abiotic stress tolerance of waxy winter wheat cultivar 'Minija DS' and standard cultivars (mean 2014–2017)

Cultivar	Autumn growth, scores	Frost tolerance, scores	Spring growth, scores	Days from 1st January to heading	Plant height cm	Lodging, scores*	Coleoptile length cm	Pre-harvest sprouting, scores
'Minija DS'	5.0	9.0	5.0	149	103	1.0/6.0	7.5	4.5
'Skagen'	2.5	8.0	3.0	158	98	6.0/7.5	6.7	4.5
'SW Magnifik'	1.5	8.5	2.0	159	104	7.0/9.0	6.9	7.5
'Kovas DS' / 'Sedula DS'	3.5 / 1.5	6.5 / 7.5	3.0 / 2.0	156 / 157	82 / 84	8.5/9.0 / 8.5/9.0	4.8 / 5.1	4.0 / 5.0
'Mulan' / 'KWS Ozon' / 'Artist'	3.5 / 3.0 / 3.0	6.0 / 7.0 / 7.0	4.0 / 3.0 / 3.5	156 / 157 / 156	97 / 85 / 98	6.0/8.0 / 8.5/9.0 / 7.0/9.0	7.0 / 4.8 / 6.9	6.0 / 5.0 / 3.5
LSD_{05}	0.15	0.45	0.20	1.80	7.6	0.78/1.20	0.64	0.56

Note. * – 1st/2nd numbers mean lodging without/with plant growth regulators; autumn and spring growth scores: 1 is the lowest growth rate; frost tolerance and lodging – 1 is the lowest tolerance; preharvest sprouting – 1 is the lowest damage.

germination. This trait has not been relevant for a long time for Northern Europe climate conditions, but recent weather anomalies due to climate change have made breeders develop climate-resilient cultivars (Kahiluoto et al., 2019).

Waxy wheat grains are characterized by a very low (about 60 s) falling number. Therefore, a common method for evaluation of grain amylase by falling number test is not applicable, and direct testing of amylase activity should be done (Zi et al., 2018). Pre-harvest sprouting resistance of 'Minija DS' was similar or higher to that of the rest of the cultivars. Timing of winter wheat harvesting is difficult in Lithuania due to rainy weather, as precipitation occurs two or three days per week. Because of the medium pre-harvest sprouting resistance of 'Minija DS', its harvesting time after maturity can be similar to that of the rest of the common wheat cultivars.

The mean grain yield potential of 'Minija DS' compared to standard cultivars yield mean was lower by 17% (Table 4). However, grain yield among the testing locations and experimental years was considerably different due to contrasting climatic conditions. Grain yield ranged from 6.0 to 12.0 t ha^{-1} during the 2017 testing period. The lowest yield was observed in Akademija, Kėdainiai distr. – 6.0–7.4 t ha^{-1} (mean 6.8 t ha^{-1}), and the highest in Pasvalys PVTD – 8.6–12.0 t ha^{-1} (mean 10.6 t ha^{-1}).

Table 4. Yield of waxy winter wheat cultivar 'Minija DS' under high input growing conditions (2014–2017)

Testing location	Cultivar	Yield	2014	2015	2016	2017	Average
			Yield				
Plungė PVTD	Standards-		nd	11.9	9.3	10.3	10.5
	'Minija DS'	t ha^{-1}	nd	9.6	9.0	8.2	8.9
	'Minija DS'	%*	nd	80.7	98.2	79.4	86.1
Kaunas PVTD	Standards		10.4	10.9	9.8	9.9	10.2
	'Minija DS'	t ha^{-1}	10.7	9.1	8.5	8.4	8.7
	'Minija DS'	%	103.9	83.5	86.2	84.7	84.8
Pasvalys PVTD	Standards		nd	13.6	11.6	11.5	12.2
	'Minija DS'	t ha^{-1}	nd	11.3	12.0	8.6	10.6
	'Minija DS'	%	nd	83.1	103.7	74.7	87.2
Utena PVTD	Standards		nd	11.7	9.08	9.5	10.1
	'Minija DS'	t ha^{-1}	nd	10.0	7.7	8.3	8.7
	'Minija DS'	%	nd	85.3	85.9	87.4	86.2
Akademija, Kėdainiai distr.	Standards		5.5	9.5	9.1	10.2	9.6
	'Minija DS'	t ha^{-1}	6.0	6.7	6.1	7.4	6.8
	'Minija DS'	%	109.0	74.0	65.9	72.9	70.9
Average	Standards		7.9	11.5	9.7	10.3	10.5
	'Minija DS'	t ha^{-1}	8.4	9.4	8.7	8.2	8.7
	'Minija DS'	%	106.5	81.3	88.0	79.8	83.0

Note. * – relative yield of 'Minija DS' compared to the standard cultivars; nd – no data, trials were discarded due to heavy winterkill; PVTD – Plant Variety Testing Division.

Outstanding yield of 'Minija DS' was recorded in 2014, when more than 50% of the winter wheat crops were winter-killed. 'Minija DS' outyielded the mean of the standard cultivars by 3.9% and 9.0% in Kaunas PVTD and Akademija, Kėdainiai distr., respectively. Also, the grain yield of 'Minija DS' was higher than that of the standard cultivars by 3.7% in 2016 in Pasvalys PVTD. Relative yield compared to that of the standard cultivars was lower by 26.0–34.1% in Akademija Kėdainiai distr., 16.9–25.3% in Pasvalys, 1.8–20.6% in Plungė, 13.8–16.5% in Kaunas and 12.6–14.7% in Utena PVTD. Relative grain yield of 'Minija DS' was by on average 29.07% lower in Akademija, Kėdainiai distr. and by 12.83–15.9% in the rest of the testing locations. The lower yield of 'Minija DS' was caused by several reasons such as shorter vegetation period, lower tolerance to lodging and diseases. The standard cultivars were medium late; such cultivars usually outyield the early maturing cultivars by up to 20% (Slafer et al., 2014).

The origin of parental material also had considerable influence on 'Minija DS' traits, as it originates from Nebraska, USA, where wheat yield is generally low due to water deficiency during vegetation. On the other hand, 'Minija DS' inherited high frost and drought tolerance from the parental lines.

Another reason for the lower yield is the metabolic peculiarities of glucose conversion to starch of waxy wheat compared to common wheat (Sathish et al., 1995; Zi et al., 2018). Graybosch et al. (2018) suggest that the yield gap between common and waxy wheat can be eliminated during the breeding process. The data on European waxy wheat is very limited, but, according to Bundessortenamt (2017), German waxy wheat yield was the lowest compared to all other wheat genotypes bred in Europe.

A 1000 grain weight (46.1 g) of 'Minija DS' was similar to that of the standard cultivars 'Skagen' (48.0 g) and 'Artist' (47.2 g) and was higher than that of the rest of the cultivars (37.5–44.7 g) (Table 5). Hectolitre weight (804 g L^{-1}) was similar to that of the cultivars characterized by the highest values (800–808 g). It is an important trait for the milling industry as it positively influences flour output. Protein content of 'Minija DS' was highest (13.5%) compared to standard cultivars (12.1–13.2%).

Table 5. Grain quality traits of waxy winter wheat cultivar 'Minija DS' and standard cultivars (mean 2014–2017)

Cultivar	1000 grain weight g	Hecto-litre g L^{-1}	Protein %	Gluten %	Sedimen-tation ml	Falling number s	Starch %	Flour output %
'Minija DS'	46.1	804	13.5	28.2	31.2	65	66.3	47.0
'Skagen', high quality	48.0	808	13.2	29.1	54.1	428	70.5	70.0
'SW Magnifik', good quality 1	37.5	800	12.7	25.6	43.6	291	66.4	68.4
'Kovas DS'/ 'Sedula DS', good quality 2	42.0	765	12.5	25.3	42.7	355	68.1	65.5
'Mulan' / 'KWS Ozon' / 'Artist', medium quality	45.1	772	12.4	23.7	38.3	316	67.9	67.0
LSD_{05}	4.36	12.2	1.04	1.90	2.40	14.7	2.83	5.47

Gluten content of 'Minija DS' also was high (28.2%) and similar to that of high-quality cultivar 'Skagen' (28.1%). High protein and gluten contents are very important for the grain processing industry due to higher amount of vital gluten after grain processing. Sedimentation value (31.2 ml) of 'Minija DS' shows that protein quality is rather weak. Worldwide, most of the waxy wheat cultivars are characterized by lower protein quality compared to bread wheat cultivars (Graybosch et al., 2014; Caramanico et al., 2018; Ohm et al., 2019), but protein quality can be improved during the breeding process (Graybosch et al., 2018; SECOBRA Recherches, 2018). The falling number (65 s) of 'Minija DS' is completely in line with that obtained by other researchers (Hung et al., 2006; Choi et al., 2012; Zi et al., 2018).

The starch content (66.3%) in 'Minija DS' grains was lower than the mean (68.1%) of the standard cultivars. Flour output was considerably lower (47.0%) than that of the other cultivars tested. The main reason is technological peculiarities of grain processing influenced by high amylopectin amount (Hung et al., 2006; Graybosch et al., 2014; 2018). However, flour output can be improved by modifications of milling process, when grains with higher moisture content are used (Xu et al., 2018). 'Minija DS' starch consists mainly of amylopectin, and amylose content ranges between 2–3% (data not shown). Amylose content in waxy wheat is variable (0.5–3.0%) (Nakamura et al., 1995; Yong et al., 2009; Graybosch et al., 2014; Zi et al., 2018) but in some cases can exceed 6% (Cho et al., 2019).

The rheological properties predict the dough characteristics of wheat flour (Table 6).

Water absorption of 'Minija DS' was typical of waxy wheat (Kowalski et al., 2017; Graybosch et al., 2018; Kleyn, 2018) and exceeded the mean (13.3%) of the standard cultivars. Dough development time and dough stability of 'Minija DS' were similar to those of the standard cultivars. The dough was more stable after 10 min, but a 15 min test showed slightly higher softening than that of the standard cultivars. Brabender's quality index showed that dough could be used for baking of high-quality products. However, dough produced from fully waxy flour cannot be used for direct baking but as an addition to common wheat flour can considerably improve bread shelf life (Hung et al., 2006; Choi et al., 2012; Iorgachova et al., 2018; Kleyn, 2018). Higher water absorption considerably improves quality of products made from the frozen dough (Jia et al., 2017; Kowalski et al., 2017).

'Minija DS' is moderately resistant to powdery mildew (3.0 scores), very resistant to leaf rust (1.0 score) and resistant to snow mould (2.0 scores) (Table 7).

Table 6. Dough quality traits of waxy winter wheat cultivar 'Minija DS' and standard cultivars (mean 2016–2017)

Cultivar	Water absorption %	Dough development time, min	Dough stability, min	Degree of softening after 10 min, Brabender's unit	Degree of softening after 15 min, Brabender's unit	Brabender's quality index
'Minija DS'	73.5	5.8	6.0	28	88	102
'Skagen'	60.4	4.8	6.7	47	71	90
'Kovas DS' / 'Sedula DS'	60.7	1.5	4.4	53	64	41
	59.4	4.5	7.2	44	65	87
LSD_{05}	3.41	0.26	0.38	2.47	4.25	5.70

Table 7. Disease resistance of waxy winter wheat cultivar 'Minija DS' and standard cultivars (mean 2014–2017)

Cultivar	Powdery mildew	Septoria leaf blotch	Tan spot	Leaf rust	Fusarium head blight	Common bunt, %	Eye-spot	Take-all	Snow mould
'Minija DS'	3.0	7.0	7.5	1.0	7.0	55.0	7.1	6.5	2.0
'Skagen'	1.5	4.0	5.0	4.0	4.0	8.5	6.3	4.5	4.5
'SW Magnifik'	1.0	5.5	6.0	7.5	5.5	1.0	5.0	5.0	4.3
'Kovas DS' / 'Sedula DS'	2.0 / 1.0	5.5 / 5.0	6.0 / 5.5	4.0 / 3.0	6.0 / 4.0	28.0 / 45.5	5.0 / 3.5	5.0 / 5.0	4.0 / 5.5
'Mulan' / 'KWS Ozon' / 'Artist'	4.0 / 3.0 / 3.0	5.0 / 5.0 / 5.0	5.0 / 6.0 / 4.5	4.5 / 4.5 / 3.0	4.5 / 4.0 / 4.5	85.4 / 50.3 / 5.8	5.3 / 5.0 / 5.5	5.3 / 6.0 / 5.1	5.3 / 6.0 / 5.0
LSD_{05}	0.14	0.41	0.56	0.27	0.43	8.6	0.7	0.59	0.48

Disease resistance scores: 1 – no damage, 9 – damaged ≥80%

Resistance to leaf rust and snow mould was outstanding compared to that of the standard cultivars. However, 'Minija DS' was susceptible to Septoria leaf blotch (7.0 scores) and tan spot (7.5 scores), eyespot (7.1 scores), Fusarium head blight (7.0 scores) and medium susceptible to take-all (6.5 scores) and common bunt (55.0%).

Both parental lines used for 'Minija DS' breeding originated from Nebraska, USA, which is characterized by cold winters and hot summers. Resistance to different rusts is an essential trait for wheat grown in this area. Waxy wheat material of Graybosch et al. (2014; 2018) was characterized as resistant to rusts, but other leaf diseases were not mentioned. Therefore, low resistance level of 'Minija DS' to leaf spot diseases and crown and root rots is a consequence of low resistance of the initial breeding material. There are very few publications addressing disease resistance of waxy wheat. However, it was determined that susceptibility to Fusarium head blight is not related to wheat type (Funnell-Harris et al., 2019). Therefore, further breeding involving locally adapted cultivars can considerably improve disease resistance level of waxy wheat.

No differences were observed between waxy and common wheat response to fungicide efficiency. Lower fungicide doses could be applied to 'Minija DS' considering the much shorter vegetation of this cultivar.

Conclusions

1. The new Lithuanian waxy winter wheat cultivar 'Minija DS' is winter hardy and drought resistant. The cultivar possesses good resistance to pre-harvest sprouting. The plant height of the new cultivar is medium short. However, lodging resistance is low without the application of plant growth regulators and moderate with plant growth regulators.

2. The 'Minija DS' performs well under high input growing conditions. The mean yield of three experimental years ranged from 6.8 to 10.6 t ha^{-1} in Akademija, Kėdainiai district and Pasvalys Plant Variety Testing Division, respectively. The mean yield of 5 testing locations over three years was 8.7 t ha^{-1}, or 83.0%, compared to that of the standard cultivars.

3. The grain of the 'Minija DS' is of specific chemical composition due to a very low amylase content (2–3%) and a very low falling number (65 s), which is typical of fully waxy wheat. Dough water absorption was 73.5% and exceeded that of the standard cultivars by 13.3%. The new cultivar surpassed the standard cultivars by the mean 1000 grain weight, hectolitre weight, protein and gluten contents, but sedimentation value, starch content and flour output were lower.

4. The 'Minija DS' possesses low resistance to the majority of the evaluated diseases, except powdery mildew, leaf rust and snow mould.

Received 10 04 2020
Accepted 16 10 2020

References

Bertoft E. 2017. Understanding starch structure: recent progress. Agronomy, 7 (3): 56. https://doi.org/10.3390/agronomy7030056

Bundessortenamt. 2017. Beschreibende Sortenliste – Getreide, Mais, Öl- und Faserpflanzen, Leguminosen, Rüben und Zwischenfrüchte. Hannover, 325 p. (in German).

Caramanico R., Marti A., Vaccino P., Bogetta G., Cappa C., Lucisano M., Pagani M. A. 2018. Rheological properties and baking performance of new waxy lines: strengths and weaknesses. Food Science and Technology, 88: 159–164. https://doi.org/10.1016/j.lwt.2017.09.035

Chao S., Sharp P. J., Worland A. J., Warham E. J., Koebner R. M. D., Gale M. D. 1989. RFLP-based genetic maps of wheat homoeologous group 7 chromosomes. Theoretical and Applied Genetics, 78 (4): 495–504. https://doi.org/10.1007/BF00290833

Cho S.-W., Ko H. S., Kim C., Kang C.-S., Park C. S. 2019. Effect of flour color and starch pasting properties on color of noodle dough sheet and texture of cooked noodles in Korean wheat cultivars. International Journal of Agriculture and Biology, 21: 271–281.

Choi I., Kang Ch.-S., Cheong Y-K., Hyun J.-N., Kim K.-J. 2012. Substitution normal and waxy- type whole wheat flour on dough and baking properties. Preventive Nutrition and Food Science, 17: 197–202. https://doi.org/10.3746/pnf.2012.17.3.197

EU Database of Registered Plant Varieties. 2020. Common catalogue of varieties of agricultural plant species. Consolidated version. https://ec.europa.eu/food/sites/food/files/plant/docs/plant-variety-catalogues_agricultural-plant-species.pdf

Funnell-Harris D. L., Graybosch R. A., O'Neil P. M., Dura Z. T., Wegul S. N. 2019. Amylose-free ("waxy") wheat colonization by *Fusarium* spp. and response to Fusarium head blight. Plant Disease, 103: 972–983. https://doi.org/10.1094/PDIS-05-18-0726-RE

Graybosch R. A., Baenziger P. S., Santra D. K., Regassa T., Jin Y., Kolmer J., Wegulo S., Bai G., Amand P. St., Chen X., Seabourn B., Dowell F., Bowden R., Marshall D. M. 2014.

Registration of 'Mattern' waxy (amylose-free) winter wheat. Journal of Plant Registrations, 8: 43–48. https://doi.org/10.3198/jpr2013.08.0045crc

Graybosch R. A., Baenziger P. S., Bowden R. L., Dowell F., Dykes L., Jin Y., Marshall D. S., Ohm J.-B., Caffe-Treml M. 2018. Release of 19 waxy winter wheat germplasm with observations on their grain yield stability. Journal of Plant Registrations, 12: 152–156. https://doi.org/10.3198/jpr2017.03.0018crg

Hung P. V., Maeda T., Morita N. 2006. Waxy and high-amylose wheat starches and flours – characteristics. Functionality and application. Trends in Food Science and Technology, 17: 448–456. https://doi.org/10.1016/j.tifs.2005.12.006

Iorgachova K., Makarova O., Khvostenko K. 2018. The influence of the waxy wheat flour on the cake's staling. Applied Research in Technics, Technologies and Educations, 6: 359–362. https://doi.org/10.15547/artte.2018.04.012

Jia C., Yang W., Yang Z., Ojobi O. J. 2017. Study of the mechanism of improvement due to waxy wheat flour addition on the quality of frozen dough bread. Journal of Cereal Science, 75: 10–16. https://doi.org/10.1016/j.jcs.2017.03.007

Kahiluoto H., Kaseva J., Balek J., Olesen J. E., Ruiz-Ramos M., Gobin A., Kersebaum K. C., Takač J., Ruget F., Ferrise R., Bezak P., Capellades G., Dibari C., Mäkinen H., Nendel C., Ventrella D., Rodriguez A., Bindi M., Trnka M. 2019. Decline in climate resilience of European wheat. Proceedings of the National Academy of Sciences of the United States of America, 116: 123–128. https://doi.org/10.1073/pnas.18043871165

Kleyn M. E. 2018. Influence of waxy wheat flour blends on dough and bread baking quality as well as shelf life. Thesis of Master of Science. Stellenbosch University, 100 p.

Kowalski R. J., Meldrum A., Wang S., Joyner H., Ganjyal G. M. 2017. Waxy wheat flour as a freeze-thaw stable ingredient through rheological studies. Food and Bioprocess Technology, 10: 1281–1296. https://doi.org/10.1007/s11947-017-1899-y

Liatukas Ž., Ruzgas V., Razbadauskienė K., Brazauskas G., Koppel R. 2012. Winter wheat cultivars 'Kovas DS', 'Zunda DS', 'Vikaras DS', 'Kaskada DS' for high input farming: development and characterization. Zemdirbyste-Agriculture, 99 (3): 255–264.

LSD. 2019. Lietuvos statistikos departamentas (in Lithuanian). https://osp.stat.gov.lt/statistiniu-rodikliu-analize?hash=9c8de48e-bdc3-4477-895f-ea4840c97c91#/

Nakamura T., Yamamori M., Hirano H., Hidaka H. 1993. Identification of three Wx proteins in wheat (*Triticum aestivum* L.). Biochemical Genetics, 31: 75–86. https://doi.org/10.1007/BF02399821

Nakamura T., Yamamori M., Hirano H., Hidaka H., Nagamine T. 1995. Production of waxy (amylose-free) wheats. Molecular Genetics and Genomics, 248: 253–259. https://doi.org/10.1007/BF02191591

Ohm J.-B., Dykes L., Graybosch R. A. 2019. Variation of protein molecular weight distribution parameters and their correlations with gluten and mixing characteristics for winter waxy wheat. Cereal Chemistry, 96 (2): 302–312. https://doi.org/10.1002/cche.10124

Park C.-S., Pena R. J., Baik B.-K., Kang C.-S., Heo H.-Y., Cheong Y.-K., Woo S.-H. 2009. Allelic variation of glutenin, granule-bound starch synthase I and puroindoline in Korean wheat cultivar. Korean Journal of Crop Science, 54 (2): 181–191.

Sathish P., Sun C., Lönneborg A., Jansson C. 1995. Modified starch metabolism in mutant and transgenic plants. Progressive Botany, 56: 301–318. https://doi.org/10.1007/978-3-642-79249-6_13

SECOBRA Recherches. 2018. Waxy wheat. https://secobra.fr/en/accueil

Singh S., Vikram P., … Pixley K. V. 2018. Harnessing genetic potential of wheat germplasm banks through impact-oriented-prebreeding for future food and nutritional security. Scientific Reports, 8: 12527. https://doi.org/10.1038/s41598-018-30667-4

Slafer G. A., Savin R., Sadras V. O. 2014. Coarse and fine regulation of wheat yield components in response to genotype and environment. Field Crop Research, 157: 71–83. https://doi.org/10.1016/j.fcr.2013.12.004

Vafin R., Rzhanova I., Askhadullin D., Askhadullin D., Vasilova N. 2018. Screening of the genotypes of bread wheat (*Triticum aestivum* L.) by the allelic variants of waxy genes and HMW glutenin subunits. Acta Agrobotanica, 71: 1746. https://doi.org/10.5586/aa.1746

VATŽŪM. 2015. Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos. Augalų veislių ūkinio vertingumo 2014 metų tyrimo duomenys. Vilnius, 105 p. (in Lithuanian).

VATŽŪM. 2016. Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos. Augalų veislių ūkinio vertingumo 2015 metų tyrimo duomenys. Vilnius, 98 p. (in Lithuanian).

VATŽŪM. 2017. Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos. Augalų veislių ūkinio vertingumo 2016 metų tyrimo duomenys. Vilnius, 98 p. (in Lithuanian).

VATŽŪM. 2018 (a). Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos. Augalų veislių ūkinio vertingumo 2017 metų tyrimo duomenys. Vilnius, 87 p. (in Lithuanian).

VATŽŪM. 2018 (b). Valstybinė augalininkystės tarnyba prie Žemės ūkio ministerijos. Nacionalinis augalų veislių 2018 metų sąrašas. Vilnius, 24 p. (in Lithuanian).

Wang S., Wang J., Zhang W., Li C., Yu J., Wang S. 2015. Molecular order and functional properties of starches from three waxy wheat varieties grown in China. Food Chemistry, 181: 43–50. https://doi.org/10.1016/j.foodchem.2015.02.0665

WRB. 2014. World reference base for soil resources. World Soil Resources Reports No. 106. FAO, 191 p.

Xu B., Mense A., Ambrose K., Graybosch R., Shi Y.-C. 2018. Milling performance of waxy wheat and wild type wheat using two laboratory milling methods. Cereal Chemistry, 95 (5): 708–719. https://doi.org/10.1002/cche.10086

Yong Z. D., Wen D. Q., Guo C. Z., Yun C. X., An L. Y. 2009. Breeding of new waxy spring wheat lines on Qinghai Plateau and determination of their amylose. Journal of Triticeae Crops, 30: 34–38.

Zhao X. C., Sharp P. J. 1998. Production of all eight genotypes of null alleles at 'waxy' loci in bread wheat. *Triticum aestivum* L. Plant Breeding, 117: 488–490. https://doi.org/10.1111/j.1439-0523.1998.tb01979.x

Zi Y., Ding J., Song J., Humphreys G., Peng Y., Li C., Zhu X., Guo W. 2018. Grain yield, starch content and activities of key enzymes of waxy and non-waxy wheat (*Triticum aestivum* L.). Scientific Reports, 8: 4548. https://doi.org/10.1038/s41598-018-25219-9

ŽŪIKVC. 2019. Žemės ūkio informacijos ir kaimo verslo centras (in Lithuanian). https://www.vic.lt/statistine-informacija/

Nauja vaškinio žieminio kviečio veislė ‘Minija DS’

Ž. Liatukas, V. Ruzgas

Lietuvos agrarinių ir miškų mokslų centras

Santrauka

Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institute sukurta nauja vaškinio žieminio kviečio (*Triticum aestivum* L.) veislė ‘Minija DS’. Šios veislės žieminiai kviečiai yra labai gerai prisitaikę prie nepalankių žiemojimo sąlygų. Vidutinis atsparumas šalčiui buvo 9 balai – tai viršijo gerai prisitaikiusios ir plačiai auginamos veislės ‘Skagen’ žieminių kviečių atsparumą (8 balai). Atsparumas pavasariniam pelėsiui (2 balai) gerokai viršijo standartinių veislių kviečių atsparumą (4–6 balai, vidutiniškai 4,9 balo). Šios veislės žieminiai kviečiai pasižymi geru atsparumu grūdų dygimui varpose; tai yra svarbu siekiant stabilios grūdų kokybės po subrendimo. Jie gali būti auginami taikant intensyvią technologiją, tačiau dėl mažo atsparumo išgulimui būtina purkšti maksimaliomis normomis augimo reguliatorių. Trejų tyrimo metų duomenimis, penkiuose Augalininkystės tarnybos augalų veislių tyrimo skyriuose žieminių kviečių vidutinis derlingumas buvo 8,7 t ha^{-1}, arba 83,0 %, lyginant su standartinių veislių. Vaškinių žieminių kviečių vidutinis baltymų kiekis buvo 13,5 %, glitimo – 28,2 %, sedimentacijos vertė – 31 ml; standartinių veislių kviečių – atitinkamai 12,6 %, bei 25,2 % ir 43 ml.

Kaip vaškiniams kviečiams, veislei ‘Minija DS’ būdingi saviti grūdų kokybės požymiai: labai mažas kritimo skaičius – 65 s (standartinių veislių – vidutiniškai 340 s), mažesnė miltų išeiga – 47 % (standartinių – 67,2 %), didesnis tešlos vandens sugėrimas – 73,5 % (standartinių – 60,2 %). Naujos veislės žieminiai kviečiai yra atsparūs rudosioms rūdims ir pavasariniam pelėsiui, vidutiniškai atsparūs miltligei, bet jautrūs lapų dėmėtligėms, pašaknio puviniams ir varpų fuzariozei.

Veislė ‘Minija DS’ yra įtraukta į Lietuvos nacionalinį augalų veislių sąrašą ir ES žemės ūkio augalų rūšių veislių bendrąjį katalogą.

Reikšminiai žodžiai: vaškiniai kviečiai, amilopektinas, grūdų kokybė, veislė.