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Development of the new waxy winter wheat cultivars Eldija and Sarta

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Abstract: Two new waxy winter wheat (*Triticum aestivum* L.) cultivars, Eldija and Sarta, were developed at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry and released in Lithuania in 2021. The cultivars were developed using waxy wheat material from Nebraska, the United States of America. The mean yield of Eldija and Sarta at five locations over three testing years was 7.56 and 7.21 t/ha or 79.63 and 75.95%, respectively, compared to the yield of the standard cultivars. Eldija and Sarta should be grown under high input conditions due to the relatively low resistance to leaf spot diseases and Fusarium head blight and medium tolerance to lodging. An amylose content of 0.68% and 0.36% of Eldija and Sarta, respectively, a very low falling number (about 60 s), a lower flour yield and higher water absorption compared to common wheat and the reaction to iodine staining (brown colour) characterised the new cultivars as fully waxy wheats. These cultivars are intended for the potential demand from commercial companies for special use in the food industry.

Keywords: amylopectin; grain quality; *Triticum aestivum*

Waxy wheats are new cultivars produced to meet the nutritional and industrial requirements of the market, adding new value to the wheat processing industry and human health (Singh et al. 2018). Waxy wheat (*Triticum aestivum* L.) carries three non-functional alleles of the *granule-bound starch synthase I* (*GBSSI*) or *Waxy* gene at the loci *Wx-A1*(7AS), *Wx-B1*(4AL) and *Wx-D1*(7DS) (Yamamori et al. 1994) and produces endosperm starch almost free (1–3%) of amylose (Chao et al. 1989; Nakamura et al. 1995).

The development of waxy wheat has been reported on mainly in the USA (Graybosch et al. 2014, 2018, 2019; Morris et al. 2021) and in some Asian countries, including Japan (Nakamura et al. 1995), South Korea (Park et al. 2009) and China (Wang et al. 2015). The development of waxy wheat in Europe was recently reported in Germany (Bundessortenamt 2017), Italy (Caramanico et al. 2018) and France (Debiton et al. 2010; SECOBRA Recherches 2021). The breeding of waxy wheat has been taken up in Ukraine (Iorgachova et al. 2018) and Russia (Vafin et al. 2018) as well.

Amylopectin (amylose-free) starch has many benefits for a range of applications for food product improvement due to the high water-holding capacity (Hung et al. 2006). The storage period of the baked products can be prolonged by adding 10–20% of the waxy flour into the common wheat flour (Choi et al. 2012; Caramanico et al. 2018). Apart from that, amylose-free starch is more efficient for the production of ethanol and maltodextrins (Wang et al. 2015). Waxy starches might be useful for certain types of

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human foods and animal feeds because, in comparison to non-waxy starches, they are more rapidly digested. Waxy wheat starch can be used in the production of modified food starches and industrial applications (Hung et al. 2006; Ohm et al. 2019).

Up to now, no agronomically advanced waxy wheat cultivars have been released in Northern Europe. The waxy wheat cultivars developed in Southern and Central Europe have limited potential to be cultivated in the Northern latitudes (Bundessortenamt 2017; Caramanico et al. 2018; SECOBRA Recherches 2021). To meet the potential demand from commercial companies for a waxy wheat adapted to Baltic climate conditions, the Lithuanian Research Centre for Agriculture and Forestry (LAMMC) Institute of Agriculture developed and released a red waxy winter wheat cultivar Eldija and a white waxy winter wheat cultivar Sarta (SPSMA 2021b).

MATERIAL AND METHODS

Development of the breeding material. Field experiments were conducted at the LAMMC Institute of Agriculture (55°39'N, 23°57'E) during 14 growing seasons (2007–2020). Both cultivars Eldija and Sarta (tested as DS6460-1 and DS6460-3, respectively) were selected from the population derived from the cross NX05M4475-1/NX05M4179-5. These parental waxy wheat lines have been developed in Lincoln, NE, USA and provided by R. Graybosch in 2007. The F_1 generation was bulk harvested, threshed, and sown as one plot. Five-hundred single heads were selected in the F_2 generation, threshed, and grouped by grain colour (red and white) in two subpopulations. The grains from 60 selected heads were separately sown in one-meter rows by a single row sowing machine. Single heads were further selected from the F_{3-6} generation lines with desirable agronomic traits and threshed separately. Untypically coloured grains were removed. The grains were also checked with a diluted iodine-potassium iodide solution (I_2KI) (Nakamura et al. 1995) for the detection of complete waxy grains. In the F6 generation, the most promising single head rows were each bulk selected and individually threshed. The most promising lines (two from each population) were selected from both populations for further experiments.

Field evaluation of the agronomic traits. The evaluation of the grain yield and other agronomic traits of Eldija and Sarta were conducted at the LAMMC Institute of Agriculture in 2013–2020. A single plot nursery was sown in 2013. Nurseries with 4 replications in randomised complete block designs and testing in different agronomical backgrounds were set up in 2014–2020. The selected lines DS6460-1 (Eldija) and DS6460-3 (Sarta) were tested at the Lithuanian State Plant Variety Testing Divisions (PVTD) of the State Plant Service Under the Ministry of Agriculture of the Republic of Lithuania at four locations for three growing seasons (2017–2020) under the same trial design (SPSMA 2019, 2020, 2021a). The PVTD trial locations were Kaunas (55°02'N, 23°81'E), Pasvalys (56°03'N, 24°45'E), Plungė (55°92'N, 21°73'E), and Utena (55°46'N, 26°61'E). The Eldija and Sarta yield, and grain quality performance were compared relative to the standard cultivars Skagen (high-quality wheat) and Artist (bread wheat) which are both widely grown in the Baltic Sea region.

The reaction to pathogens, abiotic stress and agronomic traits were evaluated at LAMMC Institute of Agriculture during 2014–2020 and at the PVTD during 2017–2020. The wheat field resistance to pathogens causing wheat powdery mildew, leaf rust, Septoria leaf blotch (natural infection), tan spot was assessed during the booting to medium milk development stages by scores (1 – very resistant, 9 – very susceptible). The resistance to snow mould, eyespot, take-all was evaluated under monocrop growing conditions. The common bunt, Fusarium head blight (*Fusarium culmorum*) and tan spot were evaluated under artificial inoculation in nurseries.

The autumn growth rate was evaluated using a 1–5 score scale late in the autumn after cessation of the vegetation. Score 1 characterises cultivars with short tillers and a relatively low tiller mass, whereas score 5 describes cultivars with long tillers and a high tiller mass. The spring growth type was evaluated using a 1–5 score scale at the beginning of the intensive growth in spring, where 1 denotes the lowest growth rate. The winter hardiness was evaluated after the resumption of the vegetation. All the trials in the PVTD were evaluated under the natural occurrence of frost. The part of plots in the Akademija (the LAMMC Institute of Agriculture) trials were cleaned from snow cover. In the case of winter hardiness, 1 denotes that no plants survived and 9 denotes that all the plants are undamaged. The data from the year with considerably damaged winter wheat were selected for the winter hardiness description. Resistance to lodging was observed from flowering to harvesting. These traits were evaluated on a score scale of 1 to 9, where 1 denotes the lowest resistance.

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All the grain yield, resistance to disease, tolerance to abiotic factors and other traits were evaluated in 4 replicates.

The check of distinctness, uniformity and stability (DUS) was performed in Poland, at the Research Centre for Cultivar Testing in 2018–2020. Positive results were confirmed in 2020 (reports No. PSZ 8988 and PSZ 8989).

Grain and end-use quality. The grain quality characteristics (protein and gluten percent, sedimentation index (Zeleny method), starch percent, test weight) were evaluated during 2018–2020 at all five testing sites by an Infratec 1241 whole grain analyser (Foss, Denmark). The particle size index (PSI) for the wheat grain hardness (AACC 55-30) was performed using a flour preparation with an LM 3303 mill (Perten Instruments, Sweden). The Hagberg falling number (ISO 3093:2004) was analysed with a Falling number 1500 (Perten Instruments, Sweden). The white flour was prepared with a Quadrumat Junior mill using a 70GG sieve (Brabender, Germany). The rheological properties of the flours by determining the resistance of the dough against the mixing – water absorption, development time, stability, degree of softening at 10 min after mixing starts (DS10), and Farinograph quality number (ISO 5530-1:2013) were measured by a Brabender's Farinograph with an analysis duration time of 20 min.

The starch/gluten isolation was performed using a modified version of the dough ball hand washing method (procedure described in Kim and Seib (1993) and LST 1522). A Gluten Index Centrifuge 2015 (Perten, Sweden) was used to force the received wet gluten through a sieve to evaluate the quality of the gluten – gluten index (GI) as described in the Gluten Index Method (ICC 155). For the starch sample preparation: a starch slurry was passed through a 75 µm nylon sieve, centrifuged with a Rotofix 32A (Xettich, Germany) at 3 600 g for 10 min and the obtained supernatant were discarded. The starch tailings (creamy colour) in the upper layer of the pellet were carefully removed. The cleaning of the tailings was repeated using distilled water, stirring and centrifugation. The obtained starch pellets were dried with air convection at 40 °C and, before further analysis, crushed using a Pulverisette 0 vibratory micro mill (Fritsch, Germany).

The A-type starch granules (percentage volume, when diameter >10 µm) were measured in the wet starch suspensions by particle size distribution using a Mastersizer 2000 laser scattering instrument with a Hydro 2000MU module. The particles were assumed to have a refractive index of 1.52, the used dispersant was distilled water.

The amylose content of the starch was analysed using cold sample dispersion in a 1N NaOH solution by the iodine binding-spectrophotometry based method according to Zhu et al. (2008) with slight modifications.

The pasting properties of the winter wheat starch were measured using a Rapid Visco-Analyser (RVA) Techmaster (Newport Scientific, Australia).

The quality of the whole-kernel, flour, dough and starch was evaluated at the LAMMC Institute of Agriculture in locally 2018–2020 grown wheat grain samples repeating the analyses in the 4 field and at least 2 laboratory replicates.

Determination of the high-molecular weight glutenin subunits (HMW-GS) alleles. Genomic DNA was extracted from the fresh leaves of at least 10 plants per genotype using a GeneJET Plant Genomic DNA Purification Kit (ThermoFisher Scientific, Lithuania). The allele-specific primers were used to amplify the genes encoding the HMW-GS.

Statistical evaluation. All the evaluation data was statistically processed by employing the least significant difference (LSD 0.05) at a 95% probability level using the statistical software SAS, Ver. 7.1 (SAS Institute Inc., USA).

RESULTS AND DISCUSSION

Yield potential. The mean grain yield potential of Eldija and Sarta was lower in comparison to the standard cultivars yield mean by 20.37% and 24.05%, respectively (Figure 1). However, the grain yield among the testing locations and experimental years varied considerably due to the contrasting climatic and soil conditions. The grain yield of Eldija and Sarta ranged from 5.86 to 9.17 t/ha and from 6.07 to 9.21 t/ha, respectively, during 2018–2020. The highest relative yield of Eldija in comparison to the standard cultivar Skagen was 93.5 and 95.7% in 2018 and 2020, respectively, at Plungė PVTD. The relative yield (93.3 and 102.3%) of Eldija was also high in 2018 and 2019 at Akademija LAMMC, respectively.

The lower yield of Eldija and Sarta might be explained by a shorter vegetation period. The standard cultivars were medium late and such cultivars usually outyield the early maturing cultivars by up to 20% (Slafer et al. 2014). Another reason for the lower yield potential is the weakened starch synthesis in

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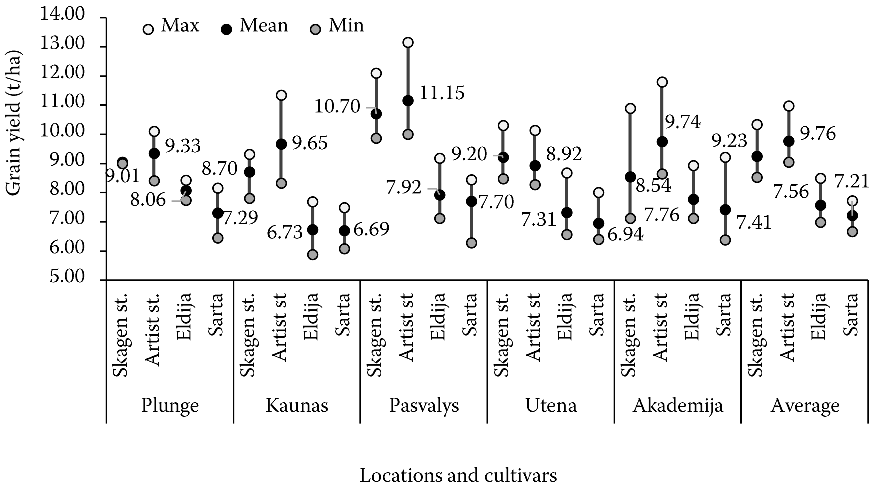

Figure 1. Grain yield (t/ha) of the waxy winter wheat cultivars Eldija and Sarta and the standard cultivars Skagen and Artist under high input growing conditions (2018–2020)

the latter stage of grain filling of waxy wheat (Zi et al. 2018). Nevertheless, Graybosch et al. (2018) suggested that the yield gap between common and waxy wheat could be eliminated during the breeding process. The data on European waxy wheat is very limited, but, according to Bundessortenamt (2017), the yield performance of German waxy wheat was considerably lower when compared to other wheat genotypes bred in Europe. It seems, that breeding high-yielding waxy wheat cultivars for intensive growing in Europe will require significant efforts from the breeders.

Grain and end-use quality. The protein and gluten content of Eldija and Sarta was similar to the high-quality cultivar Skagen (Table 1). A high protein and gluten content are very important for the grain processing industry contributing to a higher amount of vital gluten after grain processing. The sedimentation value of waxy cultivars was comparable with the bread wheat Artist, but lower than in Skagen. About the slightly lower insoluble proteins quality – weaker gluten of waxy – confirms not only the sedimentation, but also the gluten index. Worldwide, most of the waxy wheat cultivars are characterised by a lower protein quality compared to bread wheat cultivars (Graybosch et al. 2014; Caramanico et al. 2018; Ohm et al. 2019), but the protein quality could be improved during the breeding process (Graybosch et al. 2018; SECOBRA Recherches 2021). The very low falling number of waxy wheat cultivars is completely in line with that obtained by other researchers (Hung et al. 2006; Choi et al. 2012; Zi et al. 2018). Apart from that, Eldija and Sarta were characterised by a higher test weight mass, but much smaller grains. The lower 1 000 grain weight and grain yield values of the waxy wheat than those of the non-waxy wheat were also found by Zi et al. (2018). Our waxy cultivars had a softer kernel texture (higher PSI) than

Table 1. Grain quality characteristics of the waxy winter wheat cultivars Eldija and Sarta and the standard cultivars (mean 2018–2020)

Cultivar	P	G	PSI	GI	S	FN	TW	TGW
		(%)			(mL)	(s)	(g/L)	(g)
Eldija	12.7	26.2	9.4	76.7	35.1	64	790	37.1
Sarta	12.7	25.8	10.0	87.8	36.2	63	781	37.3
Skagen	12.9	25.7	6.4	91.5	43.4	366	794	45.2
Artist	11.9	23.8	–	–	35.1	280	797	44.0
LSD 0.05	0.37	0.54	0.51	5.42	1.12	18.8	13.1	0.86

P – protein; G – gluten; PSI – particle size index; GI – gluten index; S – sedimentation (Zeleny); FN – falling number; TW – test weight; TGW – thousand grain weight

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Table 2. Flour and dough quality traits of the waxy winter wheat cultivars Eldija and Sarta and the standard cultivar Skagen (mean 2018–2020)

Cultivar	FY	WA	DDT	DS	DS (BU)	FQN
	(%)		(min)			
Eldija	52.7	73.8	8.5	6.7	9.1	143.1
Sarta	56.4	68.7	5.0	7.9	30.9	121.4
Skagen	67.8	59.1	3.8	6.0	32.1	86.5
LSD 0.05	1.32	2.99	0.56	0.66	2.93	4.87

FY – flour yield; WA – water adsorption; DDT – dough development time; DS – dough stability, degree of softening after 10 min; BU – Brabender's units; FQN – Farinograph quality number

normal wheat. Both Eldija and Sarta possess the high-molecular glutenin protein subunits 2*, 7+9, 5+10. The white wheat Sarta grains contain a low tannin concentration compared to the red grain wheat. White wheats have the same advantages compared to red wheats due to a less bitter taste and lighter colour of the whole grain products. Currently, the use of whole grain products has become popular, but the usual wheat, due to its sharper taste, alienates some consumers (Grafenauer et al. 2020). The cultivar Sarta makes it possible not only to prolong the use of certain products, but also to increase the attractiveness of whole-grain products.

The flour yield of Eldija and Sarta was much lower than Skagen, but the flour output can be improved if a specific milling process is used for waxy wheat (Xu et al. 2018). Characterising the dough rheological properties can be effective for predicting the processing behaviour and for controlling the quality of the food products. A higher water absorption of Eldija and Sarta flour was typical for amylose-free wheat (Graybosch et al. 2018) (Table 2) and exceeded the standard cultivar Skagen by 14.7 and 9.6% points, respectively. The Farinograph measurements – dough development time was longer, but the dough stability time of Eldija and Sarta was comparable to the standard cultivar. A higher value of the dough softening degree indicates a degraded dough. The degree of dough softening (DS10) of Eldija was different from Sarta and Skagen – the dough softening of Eldija was significantly lower, and, at the 10 min kneading moment, the dough was more stable than those of the other two cultivars.

The higher values of Farinograph quality index for the investigated waxy cultivars showed that the technological performances of the flours are supposed to be better, and this could be used to improve the baking properties. Our data showed that the nature of the waxy cultivars is important – and this can be seen in comparison with other studies: the waxy wheat flour researched by Zhang et al. (2014) exhibited better processing characteristics (water-holding capacity, dough development time) than normal wheat flour, but exhibited some defects – lower protein content, higher degree of softening and a lower Farinograph quality number for waxy wheat flour.

The dough produced from full waxy flour is typically not used for direct baking, but as an addition to common wheat flour, it can considerably improve the bread shelf life due to the retardation of the staling, also can improve the loaf expansion during baking and reduce the loaf firmness of breads (Hung

Table 3. Starch quality characteristics of the waxy wheat cultivars Eldija and Sarta and the standard cultivar Skagen (mean 2018–2020)

Cultivar	S	AS	A	P	T	FV	PT (min)	PTe (°C)
		(%)			(RVU)			
Eldija	68.4	73.4	0.68	374.7	143.9	184.0	3.5	67.5
Sarta	68.9	72.5	0.36	367.4	136.0	176.6	3.4	67.7
Skagen	66.4	69.0	25.9	276.2	197.7	312.7	6.4	83.3
LSD 0.05	0.65	4.12	0.09	21.1	7.91	13.9	0.27	17.5

S – starch; AS – A starch; A – amylose; P – peak; T – trough; FV – final viscosity; PT – peak time; PTe – pasting temperature; RVU – rapid visco units

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et al. 2006; Choi et al. 2012; Shevkani et al. 2017; Iorgachova et al. 2018).

The total starch and A starch content in the waxy wheat was slightly higher than that of the standard cultivar (Table 3). The amylose content (0.68% and 0.36% in Eldija and Sarta, respectively), very low falling number, lower flour yield, higher water adsorption and reaction to I_2KI proved that the new cultivars are full waxy wheat. The very low content of amylose characterises our varieties as exquisite waxy wheat, since many studies show that, as a rule, waxy wheat has 1 – 3% or even more amylose (Nakamura et al. 1995; Hung et al. 2006; Zi et al. 2018). The starch pasting characteristics, as measured by a Rapid Visco Analyzer also differed considerably from the standard and were typical for waxy wheat. Due to the specific properties – waxy wheat starches are preferred for applications where higher water absorption (higher swelling ability reduce overall water availability), greater viscosities (RVA peak), a low retrogradation rate (from the trough to final viscosity) and high digestibility (due to the predominant amylopectin) are desired (Shevkani et al. 2017). Also, waxy starches attributed to higher gelatinisation temperatures, hydrolysed rapidly and more completely than normal starches; thus, these can be used for the development of starch-based sweeteners and industrial alcohol as in these products' quantitative conversion of starch to sugar is desirable. Based on the property of the lower starch setback (difference between the final and trough viscosity), which is also confirmed in our research, blending waxy wheat flour with normal flour can be used in bread and frozen food to reduce the speed of retrogradation and, thus, prolong the shelf-life of the products (Zhang et al. 2014).

Abiotic factors tolerance. Cultivars with complex abiotic stress tolerances are desired for more sustainable cultivation under changing climate conditions. High winter hardiness is one of the main traits of a successful winter wheat cultivar. The autumn growth rate indirectly influences overwintering as cultivars with intensive growth develop longer tillers when sowing terms are early. In the case of a cold winter with thin snow cover, such a cultivar can be damaged more compared to cultivars with a shorter tiller. Usually, genotypes characterised by intensive autumn growth are less tolerant to frost and snow mould damage. The cultivars Eldija and Sarta have very fast autumn growth (score of 4.5) compared to the standard cultivars (scores of 1.5–4.0) (Table 4). Considering this, the proposed sowing date is medium or medium late – the third ten-day period of September. Eldija and Sarta have a very high freezing tolerance. However, the overgrown crop after a harsh winter does not look very attractive due to the damaged leaves although dead plants make up only a small part of the total population. The frost tolerance of Eldija and Sarta was higher in most cases compared to other cultivars. The cultivar Kena DS was one of the most tolerant to frost in a range of

Table 4. Tolerance to abiotic stress and the agronomic characteristics of the waxy winter wheat cultivars Eldija and Sarta and the standard cultivars (mean 2017–2020)

Cultivar	AG	FT	SG	LT*	LT**	PST	DH***	CL	PH
	(scores)							(cm)	
Eldija	4.5	8.5	3.8	7.9	6.0	5.3	151	7.1	81.2
Sarta	4.5	8.5	3.5	8.4	7.0	5.5	152	7.3	82.8
Skagen	2.8	8.0	3.0	7.7	4.0	4.5	157	6.8	87.0
Artist	4.0	7.0	4.5	8.5	5.0	3.6	153	6.6	78.3
Sedula DS	1.5	7.5	2.0	9.0	8.5	4.9	152	5.0	80.8
SW Magnifik	1.5	8.5	2.0	8.5	7.0	7.4	153	7.0	90.8
KWS Emil	3.5	7.5	3.5	8.7	8.0	5.7	154	5.8	79.5
Janne	2.5	7.0	3.5	8.1	7.5	6.1	156	6.2	86.8
Kena DS	2.5	8.0	3.0	9.0	8.0	3.0	157	7.2	105.6
LSD 0.05	0.33	0.30	0.20	0.38	0.66	1.50	1.00	0.08	5.1

AG – autumn growth; FT – frost tolerance; SG – spring growth; *LT – lodging tolerance; with PGR; **LT – lodging tolerance, without PGR; PST – preharvest sprouting tolerance; ***DH – days to heading, counted from 1st January; CL – coleoptile length; PH – plant height

Score 1 for FT and LT denotes lowest tolerance, for PST – highest tolerance, for AG and SG denotes slowest growing rate

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winter wheat genotypes investigated for freezing tolerance by Gorash et al. (2017). Eldija and Sarta showed a higher frost tolerance (score 8.5) compared to the comprehensively investigated cultivar Kena DS (score 8.0).

The spring growth was moderate, most of the standard cultivars showed slower spring growth. The 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 cultivars are characterised by short vegetation. As grain harvesters are relatively clean from common wheat grains during this period, this could minimise the blending of waxy wheat grains with common wheat grains on a farm scale.

The plant height of Eldija and Sarta was statistically similar to that of the majority of the standard cultivars. The lodging resistance was slightly lower without the application of any plant growth regulators (PGR), but comparable to the standard cultivars with a PGR application. Our research on the USA waxy wheat material has shown that this group of wheat is sensitive to lodging. Inheritance of this negative trait was rather high even in the crosses with the high yielding and lodging tolerant European wheat (unpublished data). The coleoptile length of the waxy cultivars was slightly longer than that of the rest of the cultivars. The pre-harvest sprouting resistance of Eldija and Sarta was similar to most of the cultivars under investigation. The timing of the winter wheat harvesting is difficult in Lithuania due to the prevailing rainy weather, as precipitation occurs two or three days per week. The medium pre-harvest sprouting resistance of Eldija and Sarta ensures that the harvesting time will be similar to that of the rest of the common wheat cultivars. As a rule, white grain wheat is significantly less tolerant to pre-harvest sprouting compared to red grain wheat (Graybosch et al. 2019). However, the tolerance of the white gain cultivar Sarta indicates that breeding efforts can improve this trait.

Disease resistance. Eldija and Sarta are moderately resistant to powdery mildew (scores of 3.0 and 2.0, respectively), very resistant to leaf rust (score of 1.0) and similar to the standard cultivars' resistance to snow mould (scores of 6.5 and 4.5, respectively) (Table 5). However, Eldija and Sarta are susceptible to Septoria leaf blotch (scores of 7.0 and 7.5, respectively) and tan spot (score of 7.5), eyespot (score of 7.0), Fusarium head blight (score of 7.0), take-all (score of 7.0) and medium susceptible to common bunt (3 and 5 scores, respectively).

Both parental lines used for the Eldija and Sarta breeding originated from Nebraska, USA, which is characterised by cold winters and hot summers. Resistance to different rusts is an essential trait for wheat grown in this area. The waxy wheat material developed by Graybosch et al. (2014, 2018, 2019) was characterised as resistant to rusts and some virus diseases, but other fungal leaf diseases were not mentioned. Therefore, the low resistance level of Eldija and Sarta to leaf spot diseases, crown and root rots is possibly due to the low resistance of the parental breeding material. There are limited reports on disease resistance of waxy wheat. However, it was shown that low resistance to Fusarium head blight is

Table 5. Disease resistance of the waxy winter wheat cultivars Eldija and Sarta and the standard cultivars (mean 2014–2020)

Cultivar	PM*	SLB*	TS**	LR*	FHB**	ES***	TA***	SM***	CB**
	(scores)								
Eldija	3.0	7.0	7.5	1.0	7.0	7.0	7.0	6.5	3.0
Sarta	2.0	7.5	7.5	1.0	7.0	7.0	7.0	4.5	5.0
Skagen	1.5	4.0	4.5	6.0	4.0	6.0	5.0	4.0	2.0
Artist	3.0	5.5	6.0	6.0	6.5	6.0	6.0	6.0	8.1
Sedula DS	1.0	5.0	5.5	3.0	4.5	4.0	5.0	6.0	4.7
SW Magnifik	1.0	5.5	6.0	8.0	5.0	6.0	6.0	5.0	1.0
KWS Emil	2.0	5.0	5.5	1.0	6.0	5.5	5.0	5.0	4.0
Janne	2.0	5.5	6.0	4.0	5.5	6.0	6.0	6.0	5.8
LSD 0.05	0.47	0.53	0.48	0.51	0.67	0.49	0.61	0.51	0.52

PM – powdery mildew; SLB – Septoria leaf blotch; TS – tan spot; LR – leaf rust; FHB – Fusarium head blight; ES – Eye spot; TA – Take-all; SM – snow mould, CB – common bunt; *natural infection; **artificial infection; ***monocrop field; score 1 – very resistant, 9 – very susceptible

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not tightly associated with the waxy type (Funnell-Harris et al. 2019). Considering the low resistance to fungal diseases of the initial waxy wheat material, the development of new waxy wheat cultivars for high-input agriculture under wet climates should include the most disease resistant European cultivars of common wheat. However, no differences were observed between the waxy and common wheat response to the fungicide efficiency.

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