ductive one, the number of productive nodes and pods per node, paying attention not only to their total number and pairing, but also to the presence and plumpness of beans on the upper productive nodes. We also measure the seed number per pod. In F_3, offspring is assessed for evenness and the vegetation phase lengths. In F_{4-5}, only even high-yielding families are selected; they are threshed; and the total number of seeds is estimated. General requirements for the selection of hybrid and breeding material depend only on the direction of breeding.

Conclusions. The application of the pedigree method in pea breeding is time-consuming for breeders and demands thoroughness at all stages. However, this approach allows detailed investigating hybrid material at the beginning of the breeding process, which increases the breeding effectiveness. The effectiveness of the applied methods and selection ways is confirmed by demand for pea varieties bred at the Plant Production Institute named after VYa Yuriev and positive feedback from manufacturers.

Key words: *pea, breeding, selection, early generation, hybrid population, genetic control of a trait, productivity*

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WAXY BARLEY STARCH AS RAW MATERIAL FOR HEALTHY FOOD PRODUCTS

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The article justifies the expediency of the breeding of barley cultivars with waxy starch, grain of which can be raw material for functional food production. The study purpose was to create food barley cultivars with waxy starch. To accomplish this, qualitative parameters of barley accessions were determined, and starting material was selected for breeding. The study was conducted at the Plant Production Institute named after V.Ya. Yuriev of NAAS in 2015–2017. Twenty four chaffy and naked barley accessions of different origin were taken as the test material. Grain quality parameters of wild type and waxy accessions were compared. The yield, protein and starch contents, endosperm vitreousness, and antioxidant activity were shown to depend both on growing conditions and on genotypes. High nutritional quality of waxy barley cultivars was proved, videlicet, significantly higher content of oil compared with accessions with wild type starch and lower vitreousness of endosperm in chaffy accessions. Accessions with very valuable characteristics were selected: line 12-1014 with high digestibility of protein (61.75 mg tyrosine/g protein for pepsinolysis + trypsinolysis), line 12-945 with high antioxidant activity (2.02 mg chlorogenic acid equivalent/g), line 12-954 with a high content of oil (3.75%) and awnless line 14-1183 with a high content of polyunsaturated ω-3 linolenic acid (6.09%). These lines are valuable both as starting material for the breeding of food cultivars, and directly for functional food production. Waxy cultivars Shedevr and Amil were submitted to the state variety trials. Grain of these cultivars is noticeable for high contents of starch (>60%), oil (3.45–3.47%) and fiber (3.65–3.70%). Antioxidant activity is also sufficiently high (1.94–2.07 mg chlorogenic acid equivalent/g). Being low vitreous (40–43%), cultivars Shedevr and Amil can be used for production of flakes and flour, including extruded flour.

***Key words**: waxy starch, barley, amylose, amylopectin, antioxidant activity, protein content and digestibility, fatty acid composition of oil*

Introduction. Recently, the interest in barley grain as raw material for food products has been increasing due to its positive impact on human health. Such products lower cholesterol levels in blood, regulate the glycemic index and antioxidant activity [1]. They counteract the three most lethal diseases of the present – cardiovascular diseases, cancer and diabetes. In particular, these diseases are associated with free radical formation, and barley grain exerts a high antioxidant effect. This is especially true for waxy barley, starch of which consists of 95–100% amylopectin [2]. Therefore, creation of waxy barley cultivars that will be suitable for functional food production is an important area of barley breeding.

Starch is a major component of barley grain, as it accounts for over 70% of dry matter [3, 4] and determines its nutritional and technological properties. Starch content was found to vary in barley grain. For example, the total content of starch varied 45.7% to 66.4% in 112 Chinese barley cultivars [5]. The starch content ranged 58.1% to 72.2% in 10 Canadian genotypes [4]. The starch content in seeds of 39 barley genotypes was within 51.3%–64.2% [6].

In grain of most barley cultivars, starch contains 72–78% of amylopectin, the other component is amylose. The recessive allele of the *wax* gene almost completely blocks amylose synthesis, and its content varies 20–25% to 0–5% related to wild type starch. In the world's assortment of barley, two functional alleles and one null allele or *wax* allele of the *wax* gene were identified [7, 8]. The *wax* gene is localized in chromosome 1 (7H). Genotypes with normal (3:1 amylopectin : amylose) starch composition have the dominant *Wax* gene [9, 10]. A genetic marker was developed for the *wax* gene, and it is effectively used in breeding programs [11].

In addition, the *wax* gene is associated with an increase in contents of potent antioxidants, β-glucans, in grain of naked and chaffy barley on average by 4.85%–6.1% [12]. There are a lot of data on stable dependence of antioxidant activity on the genotype [13, 14, 15]. However, there are reports that in some waxy genotypes genetic factors reducing contents of β-glucans were identified. Researchers attribute this phenomenon to thin walls of endosperm cells [16].

The amylose content in barley starch varies 0% to 5% in waxy barley, 20-30% in wild type accessions and is around 45% in high amylose barley [17]. The ratio of the major structural components of starch can be changed genetically. Changes in this ratio increase the content of dietary fiber, affecting functional characteristics of the gastrointestinal tract and human body in general, consequently, increasing the nutritional value of barley grain. Waxy barleys have increased levels of simple sugars (glucose, fructose, sucrose) and soluble fiber represented by β-glucans in comparison with wild type ones. The contents of β-glucans and oil are higher by 40% and 25%, respectively, in barley with the *wax* allele compared with wild type [2].

Currently, there are cultivars with starch containing 95-100% of amylopectin (waxy barley) or 40–70% of amylose (high amylose barley) [18]. The first waxy barley cultivars were created in Canada and Sweden, with cultivar Azhul as the initial one, as well as in Japan by chemical mutagenesis [12, 19, 20].

Currently, the breeding of food barley, mainly naked barley with waxy starch, is extensively conducted in Canada. Waxy cultivars with high contents of α-glucans (CDC Alamo, CDC Ascent, Enduro, CDC Fibar, CDC Rattan, CDC Marlina) are known. Analogous cultivars are also bred in Japan. Two-row naked cultivar Kirari-mochi was created; its starch entirely consists of amylopectin (waxy, amylose-free). Being highly nutritional, Kirari-mochi is suitable for groat production [21].

Work on creation of barley cultivars with various amilopectin / amylose ratios in starch is widely deployed in the Czech Republic. Genotypes with increased contents of starch are used in food production. Statistical differences in yields were revealed between cultivars with wild type and waxy starch. For example, the average yield of waxy cultivars (4.9 t/ha) was significantly lower than that of wild type ones (5.7 t/ha). The protein content was significantly higher in waxy cultivars than in wild type ones (12.1% vs. 11.5%) [22]. In another study on 30 barley accessions, there was a positive correlation between the protein content and the percentage of long chains of amylopectin, while the correlation between the protein content and the percentage of long chains of amylose was negative [23].

The Department of Genetic Foundations of Breeding of the Plant Breeding and Genetics Institute of NAAS created breeding lines with high performance, including waxy ones, with technological parameters of grain suitable for production of a wide range of products: with hard grain for production of flour, groats, noodles, pasta and with soft grain for production of flakes and drinks. Commercial Canadian naked cultivars Alamo and Candle served as sources of the *wax* gene [2, 24].

The Plant Production Institute named after V.Ya. Yuriev of NAAS breeds waxy barley with lines UA 0804955 (Belarus), UA 039699, UA 039701, U.S. 039748 (USA), and IR 6912 (Mexico) as the sources of the *wax* gene. Other breeding components were domestic cultivars. As a result, high-performance and adapted to local growing conditions lines with waxy starch were created [25, 26].

Barley is used in healthy food production due to its positive effects on human health [27]. Oxidative stress and inflammation are two key factors that contribute to atherosclerosis development. Studies of barley, in particular, of its protective function in regulation of antioxidant protection, revealed powerful protective features of barley in oxidative processes and the potential role of barley in preventing chronic inflammation in cardiovascular diseases [28]. Japanese researchers reported that consumption of waxy barley groats improved the intestine functioning, especially in the elderly [29].

Food products made from barley grain or flour with various amylopectin / amylose ratios considerably differ in technological properties and quality. Products made from waxy barley are characterized by reduced hardness compared to products made from wild type barley. Tortillas from waxy barley are better rolled and less fragile [17].

Thus, the starch properties have a significant impact on the food quality, and creation of barley cultivars with modified amilopectin / amylose ratios is essential for healthy food production.

Purpose and objective. The study purpose was to create waxy barley cultivars suitable for functional food production. For this purpose, quality parameters of barley accessions were determined and starting material was selected for breeding.

Materials and methods. The study was conducted at the Plant Production Institute named after V.Ya. Yuriev of NAAS. Twenty four chaffy and naked barley accessions of different origin with waxy and wild type starch were taken as the test material. Cultivar Vzirets, which is the best in the zone of our investigations, was taken as the standard.

The data were statistically processed by analysis of variance; a posteriori comparison was performed using homogeneous groups (Fisher LSD test) in software STATISTICA 10. Relationships between traits were evaluated using correlation and regression coefficients.

The protein and starch contents were measured on an InfraLUM FT-10M 09495. vitreousness was determined on a diaphanoscope. Waxy genotypes were identified by dyeing with Lugol‟s iodine solution (modified Juliano's method). Starch granules of waxy barley are discolored to dark red or brown, and wild type starch granules – to dark-blue [30].

The antioxidant activity (AOA) of barley accessions was evaluated by capacity of ethanol extracts to neutralize the DPPH (2,2-diphenyl-1-picyrylhydrazyl) radical. The method is based on discoloration of ethanol solution of the stable DPPH• in the presence of ethanol extracts of grain products containing antioxidants that are proton donors capable of neutralizing the DPPH radical and translate it into a decolorized reduced form. The antiradical activity was determined as described by S. Arabshahi and A. Urooj [31].

The *in vitro* ability of protein to be digested by proteolytic enzymes was determined by O. Pokrovsky and I. Ertanov‟s method, which consists in gradual action of proteinases (crystalline pepsin and trypsin) on proteins [32].

Results and discussion. Weather conditions are important to obtain top-quality raw materials. For example, there is evidence that high temperature during ear formation increases the protein content and decreases the starch content in grain, depending on the genotype. There is also evidence that waxy genotypes are more responsive to high temperatures than wild type ones [33].

The weather conditions during the study period were various; however, they were favorable for the growth and development of barley plants in the "emergence-tillering" phase. In 2015, there was a drought in the crucial phases of earing and grain filling, and in 2016 an excessive amount of precipitation caused plant lodging during this period (Table 1).

Table 1

Weather conditions during the development periods of spring barley

Year	Emergence-tillering			Tillering-ear formation			Ear-formation-grain filling			Grain filling-ripening		
	Σ ef. t °C	Σ preci-pitati-on, mm	HTC	Σ ef. t °C	Σ preci-pitati-on, mm	HTC	Σ ef. t °C	Σ preci-pitati-on, mm	HTC	Σ ef. t °C	Σ preci-pitati-on, mm	HTC
2015	291	46.4	**1.59**	162	7.0	0.43	350	30.0	0.86	665	117.1	**1.76**
2016	243	69.0	**2.84**	222	119.0	**5.36**	263	38.0	**1.44**	559	102.0	**1.82**
2017	327	39	**1.19**	277	33	**1.19**	277	9	0.32	719	37	0.51

The yields of barley accessions were the highest in 2017 and the lowest in 2015, which is accounted for the weather conditions during the "ear formation" and "grain flilling" phases, however, no significant difference in the yields was noticed over the years. The performance of the naked cultivars significantly differed from that of chaffy ones, both in the group with wild type starch and in the waxy group (Table 2). The lower yield of naked cultivars is due to the absence of glume, which makes up 8–10% of the grain weight. The yields of waxy accessions were lower than those in the group with wild type starch, but this difference was not significant. Thus, in our study, the yields of waxy accessions are similar to those of accessions with wild type starch, which is at odds with other researchers" results [22].

Table 2

Yields of barley accessions, t/ha

Type of accessions	Yield			
	2015	2016	2017	Average
Chaffy with wild type starch				
mean	4.90	4.89	6.08	5.29
max	5.16	5.45	6.65	5.75
min	4.73	4.28	5.63	4.88
Chaffy with waxy starch				
mean	4.71	4.68	5.67	5.02
max	5.08	5.35	6.18	5.54
min	4.47	3.99	5.09	4.52
Naked with wild type starch				
mean	3.38	3.47	4.35	3.73
max	3.90	4.25	4.75	4.30
min	3.11	2.77	3.85	3.24
Chaffy with waxy starch				
mean	2.89	3.38	4.17	3.48
max	3.05	3.67	4.48	3.73
min	2.65	3.03	3.85	3.18
LSD_{05}	0.38	0.34	0.33	

Footnote. Significance level P ≥ 0.95.

Grain quality for food production is primarily determined by protein and starch contents. Proteins are extremely important for the human body, since they belong to essential irreplaceable substances. In our study, the protein content was significantly higher in naked cultivars both with waxy (14.30%) and wild type (14.03%) starch (Table 3). There was no significant difference in the protein content between chaffy cultivars with wild type and waxy starch (12.41% and 12.34%. respectively). In other studies [22, 23], the protein content was significantly higher in all waxy accessions. i.e. our data are consistent with these results.

There was no significant difference in the starch content between the groups of accessions (59.52%, 60.32%, 60.80%, 59.53%) (see Table 3). Depending on the year conditions. the starch content was significantly higher in 2016 compared with the other years. This is in line with the literature data indicating that low temperature during "ear formation-grain filling" period increases the starch content [33].

Table 3

Protein and starch contents in grain of barley accessions, %

Type of accessions	Protein content				Starch content			
	2015	2016	2017	Average	2015	2016	2017	Average
Chaffy with wild type starch								
mean	12.88	12.21	12.15	12.41	57.90	61.54	59.13	59.52
max	13.24	12.97	12.56	12.92	59.67	63.49	60.41	61.19
min	11.86	10.59	11.28	11.24	56.94	59.30	57.69	57.81
Chaffy with waxy starch								
mean	12.42	12.65	11.95	12.34	58.73	62.08	60.14	60.32
max	14.31	14.02	13.47	13.93	59.82	62.78	61.20	61.27
min	10.33	11.05	10.33	10.57	57.88	60.77	59.21	59.29
Naked with wild type starch								
mean	14.22	13.90	13.98	14.03	57.97	64.27	60.16	60.80
max	17.40	15.85	15.22	16.16	59.27	67.15	63.29	63.24
min	13.65	12.46	12.03	12.71	54.80	62.95	58.72	58.82
Naked with waxy starch								
mean	14.27	13.61	15.03	14.30	56.50	62.19	59.89	59.53
max	14.76	14.47	16.74	15.32	57.11	64.18	60.34	60.54
min	13.74	12.59	13.96	13.43	56.00	58.70	59.04	57.91
LSD_{05}				0.35				2.42

Footnote. Significance level P ≥ 0.95.

In addition to protein content in foods, one should know the level of protein absorption by the human body. This parameter is determined by the biological value of protein, which depends on the presence of essential amino acids, their ratio to nonessential ones and digestibility in the gastrointestinal tract. Enzymatic hydrolysis can be carried out in conditions close to the conditions of digestion in a living organism, which is a biochemical method for assessing protein digestibility. In this case, *in vitro* attackability of proteins is determined, which gives the complex characterization of the protein under investigation compared to the reference (casein). We distinguished waxy line 12-1014 by the amount of soluble products of pepsinolysis and trypsinolysis (61.75 mg tyrosine/g protein). Other lines and cultivars had significantly lower digestibility than that of line 12-1014 (Table 4).

According to the current requirements to food barley cultivars, they are expected to have vitreous endosperm. Vitreousness is an external trait of the grain quality; it reflects the structure of internal tissues of grain. In ripe barley grain, starchy endosperm cells are filled with starch granules immersed in the protein matrix. For floury endosperm, weak bonds between starch grainules and proteins are intrinsic. In vitreous endosperm, such bonds are very strong. Vitreousness is influenced by growing conditions during the "grain filling" and "ripening" phases: the more frequent dry days are, the higher this index is. Vitreous grain usually contains more protein than floury one.

Table 4

***In vitro* digestibility of waxy barley proteins by gastrointestinal digestive enzymes, 2017**

Accession	Amounts of soluble products of proteinolysis, mg tyrosine/g protein		
	Pepsinolysis	Trypsinolysis	Pepsinolysis + trypsinolysis
Amil	9.15	34.65	43.80
CDC Alamo	7.70	39.60	47.30
12-954	15.95	21.00	36.95
12-952	11.15	28.70	39.85
12-1014	14.85	46.90	**61.75**

Footnote. Significance level: n= 5, P ≥ 0.95, ε ≤ 5.

In our study, the vitreousness of chaffy cultivars was significantly lower (49%, 51%) than that of naked ones (94%, 88%). At the same time, waxy cultivars had a lower vitreousness than wild type cultivars, but this difference was insignificant (Table 5). Thus, having soft grain, waxy accessions are suitable for production of flour, including extruded flour, and flakes.

Table 5

Endosperm vitreousness in barley accessions, %

Type of accessions	Vitreousness			
	2015	2016	2017	Average
	Chaffy with wild type starch			
mean	51	44	59	51
max	56	53	80	63
min	48	32	45	42
	Chaffy with waxy starch			
mean	47	51	49	49
max	49	56	54	53
min	36	25	41	34
	Naked with wild type starch			
mean	92	94	96	94
max	99	99	99	99
min	84	90	91	88
	Naked with waxy starch			
mean	84	86	97	89
max	94	99	100	98
min	65	67	93	75
LSD_{05}				9.5

Footnote. Significance level P ≥ 0.95.

The effects of the growing conditions during the crucial phases of vegetation on endosperm vitreousness in spring barley cultivars were investigated. The precipitation during the "ear formation – grain filling" period reduced vitreousness, especially in naked cultivars (r = -0.846). There was only a positive tendency between the sum of effective temperatures in the "ear formation – grain filling" phase and vitreousness in chaffy cultivars, while in naked ones there was a significant positive correlation (r = 0.803).

Rise in temperature in the "grain filling – ripening" phase significantly increases endosperm vitreousness, with the correlation coefficient ranging within 0.526–0.875. The dependence of vitreousness on the precipitation amount in the "grain filling – ripening" phase is insignificant, since a negative tendency was only observed. This is accounted for the fact that in the research area precipitation is usually very rare and showery during the "grain filling – ripening" period in barley, which can not significantly affect the parameters under investigation.

The antioxidant activity is a major factor determining the value of food for human health. The level of this parameter in barley is one of the highest among cereals. We found that the antioxidant activity depended both on the genotype and on the conditions of cultivation and analysis type. Thus, the highest AOA was recorded in 2016, the lowest - in 2015 (Table 6). At the same time, there was a steady dependence of the AOA on the genotype, which is consistent with numerous data of other researchers [13, 14, 15]. Under any conditions, the AOA was the highest in naked genotypes with waxy starch. This parameter had no significant differences within the other groups of accessions, with the lowest values in chaffy accessions with wild type starch (see Table 6).

Table 6

Antioxidant activity of barley accessions, mg chlorogenic acid equivalent/g

Type of accessions	Antioxidant activity			
	2015	2016	2017	Average
	Chaffy with wild type starch			
mean	1.07	2.33	2.21	1.87
max	1.25	2.84	2.42	2.17
min	1.01	1.63	1.98	1.54
	Chaffy with waxy starch			
mean	1.06	2.57	2.22	1.95
max	1.12	2.84	2.43	2.13
min	1.00	1.99	2.06	1.68
	Naked with wild type starch			
mean	1.01	2.74	2.29	2.01
max	1.21	2.99	2.83	2.34
min	0.85	2.44	2.08	1.79
	Naked with waxy starch			
mean	1.14	3.14	2.37	2.22
max	1.29	3.46	2.60	2.45
min	0.92	2.96	2.18	2.02
LSD_{05}				0.18

Footnote. Significance level $P \geq 0.95$.

It should be noted that among all the accessions the highest AOA was in naked cultivar Alamo (up to 3.46 mg chlorogenic acid equivalent/g), which is considered the reference for this parameter in the world.

According to the literature data, genetic factors that control the waxy trait can be associated with genetic factors that increase the lipid content in barley [12, 34]. Our results are consistent with these data. The oil content in grain of waxy accessions is significantly higher (2.92–3.52%) than that both in chaffy (2.55%) and in naked (2.53%) accessions with wild type starch (Table 7). Among the waxy accessions, the oil content is significantly higher in chaffy accessions (3.52%) compared to naked ones (2.92%).

After burning barley grain, organic carbon-free ash, which is a concentrate of grain minerals, remains. We found that the ash content was, expectedly, significantly higher in chaffy accessions. This parameter does not depend on starch composition. The fiber content is of great importance for the digestive processes. Total fiber, as a complex of nutritional value, consists of insoluble and soluble components. We revealed that the average content of fiber in waxy accessions was higher than that in wild type ones, but the difference was insignificant (Table 7). This is only partially consistent with other researchers" results [12, 35, 36].

As a part of vegetable oils, including barley oil, unsaturated fatty acids are very important for healthy human nutrition. Barley oil is different from others by high levels of such acids, in particular, of polyunsaturated ω-3 linolenic acid. In our study, the linolenic acid content was the highest in chaffy cultivars with wild type starch bred at the Plant Production Institute nd. a V.Ya. Yuriev of NAAS: in Lider (6.64%), Krasen (6.52%), Vzirets (6.50%), and Ahrarii (6.30%).

Table 7

Oil, ash and fiber contents in grain of barley accessions, % (2017)

Type of accessions	Oil content	Ash content	Fiber content
	Chaffy with wild type starch		
mean	2.55	2.29	4.19
max	2.88	2.40	5.03
min	2.07	2.17	3.08
	Chaffy with waxy starch		
mean	3.52	2.11	4.32
max	3.75	2.35	4.90
min	3.35	1.83	3.65
	Naked with wild type starch		
mean	2.53	1.66	2.13
max	3.08	1.78	2.85
min	2.02	1.45	1.70
	Naked with waxy starch		
mean	2.92	1.74	2.19
max	3.04	1.80	2.33
min	2.80	1.68	2.05
LSD_{05}	0.26	0.18	0.16

Of the waxy barley lines and cultivars, the highest contents of polyunsaturated fatty acids were found in cultivar Shedevr (linolenic acid 5.85%, linoleic acid 54.68%), awnless line 14-1183 (linolenic acid 6.09%), and naked cultivar Candle (linoleic acid 54.80%) (Table 8).

Table 8

Fatty acid composition of oil in waxy barley grain, methyl esters of fatty acids, % related to the sum

Accession	Myristic	Myristoleic	Palmitinic	Palmitoleic	Stearinic	Oleic	Linoleic	Linolenic	Arachidonic	Eicosenic
	C14:0	C14:1	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1
Vzirets	0.81	0.67	21.78	0.65	1.26	14.82	52.24	**6.50**	0.43	0.06
Shedevr	0.19	-	20.68	0.30	1.39	16.28	**54.68**	**5.85**	0.23	0.10
12-954	0.37	0.22	19.85	0.28	1.19	18.80	53.35	5.29	0.29	0.09
14-1183	0.61	0.45	21.28	0.42	1.01	16.53	53.05	**6.09**	0.21	0.06
CDC Candle	0.21	-	20.63	0.40	1.44	16.78	**54.80**	5.12	0.22	0.07
CDC Alamo	0.22	-	21.00	0.38	1.51	18.55	52.75	5.13	0.22	0.07

The waxy lines with the best quality and economic parameters were submitted to the state variety trials: lines 12-473 and 12-476 called Shedevr and Amil, respectively. The yields of these lines amount to 5.38–5.43 t/ha, which is higher by 8–12% than that of standard Vzirets. The protein content is medium; the starch content is high (>60%) (Table 9). The oil content (3.45–3.47%) and fiber content (3.65–3.70%) are high. The antioxidant activity is also sufficiently high (1.94–2.07 mg chlorogenic acid equivalent/g). Grain of cultivars Shedevr and Amil is characterized by low vitreousness (40–43%), therefore, it is suitable for production of flakes and flour, including extruded flour.

The lines of high nutritional quality of grain are used in breeding as starting material for hybridization. Cultivars Shedevr and Amil were submitted to the state variety trials.

Table 9

Characteristics of waxy barley cultivars (2015–2017)

Cultivar	Indication							
	Yield, t/ha	Protein content, %	Starch content, %	Vitreous-ness, %	Oil content, %	Ash content, %	Fiber content, %	Antioxi-dant ac-tivity, mg/g
Shedevr	5.43	11.13	60.11	43	3.45	3.20	3.65	1.94
Amil	5.38	12.70	60.66	40	3.47	3.21	3.70	2.07

Conclusions. Thus, as a result of the study, high nutritional qualities of grain of barley waxy cultivars were demonstrated. In particular, such barley genotypes have significantly higher oil contents than wild type accessions, and their endosperm is less vitreous in chaffy accessions. Several accessions with very valuable characteristics were selected: line 12-1014 with a high protein digestibility (61.75 mg tyrosine/g protein for pepsinolysis + trypsinolysis), line 12-945 with a high antioxidant activity (2.02 mg chlorogenic acid equivalent/g). Line 12-954 was singled out due to the oil content (3.75%); awnless line 14-1183 – due to a high content of polyunsaturated ω-3 linolenic acid in oil (6.09%). Such lines are valuable both as starting material for the breeding of food cultivars and directly for functional food production. Having appropriate economic and qualitative parameters, cultivars Shedevr and Amil can be used for production of flakes and flour.

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СОРТИ ЯЧМЕНЮ З WAXY-КРОХМАЛЕМ ЯК СИРОВИНА ДЛЯ ПРОДУКЦІЇ ЗДОРОВОГО ХАРЧУВАННЯ

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У статті обґрунтовано доцільність селекції сортів ячменю з waxy-крохмалем, зерно яких може бути сировиною для виробництва продуктів функціонального харчування.

Мета дослідження. Метою дослідження було створення харчових сортів ячменю з waxy-крохмалем. Для цього було визначено показники якості зразків ячменю та виділено вихідний матеріал для селекції.

Матеріали та методи. Дослідження проведено в Інституті рослинництва ім. В.Я. Юр"єва НААН у 2015–2017 рр. Вихідним матеріалом були 24 плівчастих та голозерних зразки ярого ячменю різного походження.

Обговорення результатів. У результаті дослідження проведено порівняння показників якості зерна зразків зі звичайним та waxy-крохмалем. Установлено залежність урожайності, вмісту білка, крохмалю, склоподібності ендосперму, антиоксидантної активності як від умов вирощування, так і від генотипу. Встановлено високу поживну якість зерна таких сортів – істотне перевищення вмісту олії у порівнянні із зразками зі звичайним крохмалем, більш низька склоподібність ендосперму плівчастих зразків. Виділено окремі зразки з дуже цінними характеристиками – лінія 12-1014 з високою перетравлюваністю білка (61,75 мг тирозину на 1 г білка за сумою пепсинолізу і трипсинолізу), лінія 12-945 з високою антиоксидантною активністю (2,02 мг/г за еквівалентом хлорогенової кислоти), лінія 12-954 за вмістом олії (3,75 %) та безоста лінія 14-1183 за вмістом поліненасиченої ω-3 ліноленової кислоти (6,09 %). До Державного сортовипробування передано сорти з waxy-крохмалем Шедевр і Аміл. Зерно цих сортів має високий вміст крохмалю (понад 60 %), олії (3,45–3,47 %) та клітковини (3,65–3,70 %). Достатньо високою є антиоксидантна активність (1,94–2,07 мг/г за еквівалентом хлорогенової кислоти). За низькою склоподібністю (40–43 %) сорти Шедевр і Аміл можуть бути використаними для виробництва пластівців та борошна, в тому числі екструдованого.

Висновки. Таким чином, установлено високу харчову цінність сортів ячменю з крохмалем зміненого складу. Виділено лінії з високим вмістом поживних речовин, які є цінними і як вихідний матеріал для селекції харчових сортів, так і безпосередньо для виготовлення продуктів функціонального харчування. До Державного сортовипробування передано сорти Шедевр і Аміл, Шедевр внесений до Державного реєстру сортів рослин, придатних для поширення в Україні з 2019 р.

Ключові слова: *ячмінь, селекція, waxy-крохмаль, амілоза, амілопектин, антиоксидантна активність, вміст та перетравлюваність білка, жирнокислотний склад олії*

СОРТА ЯЧМЕНЯ С WAXY-КРАХМАЛОМ КАК СЫРЬЕ ДЛЯ ПРОДУКТОВ ЗДОРОВОГО ПИТАНИЯ

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В статье обоснована целесообразность селекции сортов ячменя с waxy-крахмалом, зерно которых может быть сырьем для производства продуктов функционального питания.

Цель исследования. Целью исследования было создание пищевых сортов ячменя с waxy-крахмалом. Для этого были определены показатели качества образцов ячменя и выделен исходный материал для селекции.

Материалы и методы. Исследования проведены в Институте растениеводства им. В.Я. Юрьева НААН в 2015–2017 гг. Исходным материалом были 24 пленчатых и голозерных образца ярового ячменя различного происхождения.

Обсуждение результатов. В результате исследования проведено сравнение показателей качества зерна образцов с обычным и waxy-крахмалом. Определена зависимость урожайности, содержания белка, крахмала, стекловидности эндосперма, антиоксидантной активности как от условий выращивания, так и от генотипа. Установлены высокие питательные качества зерна таких сортов – существенно более высокое содержание масла в сравнении с образцами с обычным крахмалом, более низкая стекловидность эндосперма пленчатых образцов. Выделены отдельные образцы с очень ценными характеристиками – линия 12-1014 с высокой переваримостью белка (61,75 мг тирозина на 1 г белка по сумме пепсинолиза и трипсинолиза), линия 12-945 с высокой антиоксидантной активностью (2,02 мг/г по эквиваленту хлорогеновой кислоты), линия 12-954 по содержанию масла (3,75 %) и безостая линия 14-1183 по содержанию полиненасыщенной ω-3 линоленовой кислоты (6,09 %). В Государственное сортоиспытание переданы сорта с waxy-крахмалом Шедевр и Амил. Зерно этих сортов характеризуется высоким содержанием крахмала (свыше 60 %), масла (3,45–3,47 %) и клетчатки (3,65–3,70 %). Достаточно высокой является антиоксидантная активность (1,94–2,07 мг/г по эквиваленту хлорогеновой кислоты). По низкой стекловидности (40–43 %) сорта Шедевр и Амил могут быть использованы для производства хлопьев и муки, в тому числе экструдированной.

Выводы. Таким образом, установлена высокая пищевая ценность сортов ячменя с крахмалом измененного состава. Выделенные линии, характеризующиеся высоким содержанием питательных веществ, являются ценными и как исходный материал для селекции пищевых сортов, так и непосредственно для изготовления продуктов функционального питания. В Государственное испытание переданы сорта Шедевр и Амил, Шедевр внесен в Государственный реестр с 2019 г.

Ключевые слова: *ячмень, селекция, waxy-крахмал, амилоза, амилопектин, антиоксидантная активность, содержание и переваримость белка, жирнокислотный состав масла*

WAXY BARLEY STARCH AS RAW MATERIAL FOR HEALTHY FOOD PRODUCTS

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Purpose and objective. The study purpose was to create waxy barley cultivars suitable for functional food production. For this purpose, quality parameters of barley accessions were determined and starting material was selected for breeding.

Materials and methods. The study was conducted at the Plant Production Institute named after V.Ya. Yuriev of NAAS in 2015–2017. Twenty four chaffy and naked barley accessions of different origin with waxy and wild type starch were taken as the test material.

The data were statistically processed by analysis of variance; a posteriori comparison was performed using homogeneous groups (Fisher LSD test) in software STATISTICA 10. Relationships between traits were evaluated using correlation and regression coefficients.

The protein and starch contents were measured on an InfraLUM FT-10M 09495, vitreousness was determined on a diaphanoscope. Waxy genotypes were identified by dyeing with Lugol‟s iodine solution (modified Juliano's method). The antioxidant activity (AOA) of barley accessions was evaluated by capacity of ethanol extracts to neutralize the DPPH (2,2-diphenyl-1-picyrylhydrazyl) radical. The antiradical activity was determined as described by S. Arabshahi and A. Urooj. The *in vitro* ability of protein to be digested by proteolytic enzymes was determined by O. Pokrovsky and I. Ertanov‟s method, which consists in gradual action of proteinases (crystalline pepsin and trypsin) on proteins.

Results and discussion. Grain quality parameters of wild type and waxy accessions were compared. The yield, protein and starch contents, endosperm vitreousness, and antioxidant activity were shown to depend both on growing conditions and on genotypes. High nutritional quality of waxy barley cultivars was proved, videlicet, significantly higher content of oil compared with accessions with wild type starch and lower vitreousness of endosperm in chaffy accessions. Accessions with very valuable characteristics were selected: line 12-1014 with high digestibility of protein (61.75 mg tyrosine/g protein for pepsinolysis + trypsinolysis), line 12-945 with high antioxidant activity (2.02 mg chlorogenic acid equivalent/g), line 12-954 with a high content of oil (3.75%) and awnless line 14-1183 with a high content of polyunsaturated ω-3 linolenic acid (6.09%). These lines are valuable both as starting material for the breeding of food cultivars, and directly for functional food production. Waxy cultivars Shedevr and Amil were submitted to the state variety trials. Grain of these cultivars is noticeable for high contents of starch (>60%), oil (3.45–3.47%) and fiber (3.65–3.70%). Antioxidant activity is also sufficiently high (1.94–2.07 mg chlorogenic acid equivalent/g). Being low vitreous (40–43%), cultivars Shedevr and Amil can be used for production of flakes and flour, including extruded flour.

Conclusions. Thus, the high nutritional value of barley varieties with modified starch composition was proven. High-nutrient lines, which are valuable both as starting material for the breeding of food varieties and directly for the production of functional foods, were distinguished. Varieties Shedevr and Amil were submitted to the State variety trials, and Shedevr has been entered in the State Register of Plant Varieties Suitable for Dissemination in Ukraine since 2019.

Key words: *waxy starch, barley, amylose, amylopectin, antioxidant activity, protein content and digestibility, fatty acid composition of oil*