

Naked barley varieties to ensure food security

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Purpose. To create naked food barley varieties and to provide the population with sufficient amounts of healthy and affordable food products. **Methods.** Varieties and lines were created by intra-species hybridization; collection accessions of the National Center for Plant Genetic Resources of Ukraine were taken as starting material. The experiments were conducted in compliance with qualification examination methods. Significance of differences was tested in STATISTICA 10. The protein and starch contents in grain were measured on an InfraLYUM FT-10M 09495 analyzer. The protein digestibility was determined by O. Pokrovsky and I. Ertanov's method. The total antioxidant activity was assessed by ability of ethanol extracts to neutralize the DPPH-radical. The content of phenolic compounds was determined by colorimetric analysis. Gravimetry was used to determine the oil content. The fatty acid profiles were analyzed gas chromatography. **Results.** The starting material was screened for quality characteristics and sources of high levels of valuable characteristics were identified: Gatunok as a source of a high content of ω -3 linolenic acid; Yavir, CDC Alamo and Violet 18-1207 as sources of a high content of oil; CDC Alamo, Richard, Mebere, CDC Candle, and Yavir; as sources of high antioxidant activity; CDC Alamo, Mebere, Violet 18-1207, Rondo, and Richard as sources of a high

content of phenolic compounds. Multiyear research resulted in the creation of such naked barley varieties as Yavir, Orlan, Obrii, and Rondo. **Conclusions.** Naked barley breeding is promising for Ukraine, as introduction of such varieties into production will contribute to solving the food security challenge, providing the population with nutritious and economically affordable food products. Naked varieties with pigmented grain can be a niche crop to manufacture special products - dietary or baby food. Naked barley varieties bred by the Plant Production Institute named after V.Ya. Yuriev of NAAS, Yavir and Orlan, are recommended to farmers for growing in Ukraine.

Key words: *antioxidant activity, phenolic compounds, functional nutrition, protein digestibility, waxy starch, oil, ω -3 linolenic acid*

Barley has not only been of great value as a food crop for a long time, but recently it has regained importance as a food crop again, especially in developed countries – Canada, USA, Australia, Finland, Sweden, Denmark, France, etc. [1]. In 2006, the US Food and Drug Administration (US FDA) listed barley grain as a product that reduces the risk of coronary heart disease, that is, as a functional food. The very term "functional food" appeared in Japan in the mid-1980s. This is the name of a product that has a therapeutic and preventive effect on the human body, that is, in addition to energy value, it ensures the normal physiological functioning of human systems [2, 3, 4].

Food varieties are supposed to meet a number of special requirements: high content of easily-digestible protein (>13%), high content of starch (wild-type or waxy, i.e. amylose/pectine or amylose-free) (>60%), high antioxidant activity, oil with a high content of polyunsaturated fatty acids (ω -3 linolenic at least 5.5%), high contents of dietary fibers, β -glucans, phenolic compounds and other antioxidants, which are very important for dietary products. Barley is used in food industry both in its pure form and in mixtures with other crops [5, 6, 7, 8, 9].

The value of food barley was highlighted by participants of an ICARDA symposium; therefore, the need to create local and international networks for its studies was acknowledged, and a global project on food barley was prepared with the following steps:

- Collection of initial information, filling of gaps;
- Breeding of local food barley varieties to ensure quality and stable performance;
- Creation of optimal crop management for stable production;
- Improvement of raw material storage and enrichment of barley-based food rations;
- Development of small-scale farming of food barley;
- Improvement of seed production and reproduction [10, 11].

Thus, barley grain, especially naked and waxy varieties, is a valuable food, which is capable of improving the physiological condition of a person.

Purpose. To create naked food barley varieties and to provide the population with sufficient amounts of healthy and affordable food products.

Materials and Methods. The study was conducted within the breeding process at the Laboratory of Barley Breeding and Genetics of the Plant Production Institute named after V.Ya. Yuriev of NAAS in 2010–2023. Original naked varieties (Yavir, Obrii and Orlan) and promising naked lines, including those with pigmented grain, were studied in variety trials. The varieties and lines were created by intraspecies hybridization; the starting material was collection accessions provided by the National Center for Plant Genetic Resources of Ukraine (NCPGRU) as well as domestic and foreign (Canada, the USA, the Czech Republic, Germany, etc.) varieties.

Variety trials were carried out in accordance with qualifying examination methods [12].

Significance of differences between variants was tested by analysis of variance; post hoc comparison was performed by homogeneous groups using the Fisher test in STATISTICA 10. The protein and starch contents in grain were

determined on an InfraLUM FT-10M 09495 analyzer. The protein digestibility was evaluated in the Laboratory of Medical and Biological Problems of Food Technology at the Department of Chemistry, Microbiology and Nutrition of Kharkiv State University of Nutrition and Trade. The *in vitro* protein digestibility by proteolytic enzymes was determined by O. Pokrovskyi and I. Ertanov's method [13].

Vitreousness was determined on a diaphanoscope, 50 kernels in two replications. Half of semi-vitreous kernels were added to the number of vitreous ones and the sum was expressed as a percentage related to the total number of analyzed kernels. The total antioxidant activity (AOA) of barley accessions was assessed by ability of ethanol extracts to neutralize the DPPH• (2,2-diphenyl-1-picrylhydrazyl) radical. The antiradical activity was determined, as S. Arabshahi and A. Urooj described [14].

The content of phenolic compounds in barley grain was determined on a colorimeter using the Folin-Ciocalteu reagent [15, 16].

The oil content was determined from the weight of dry, defatted residue by S.V. Rushkovsky's modified method (gravimetric analysis) [17]. The fatty acid composition of oil was analyzed by gas chromatography of methyl esters of fatty acids on a Selmichrom-1 gas chromatograph.

Results and Discussion. In the pre-breeding phase, the starting material was examined for quality indicators. Accessions with better characteristics were chosen as parents for hybridization. In particular, yield, performance constituents, resistance to biotic and abiotic factors, contents and qualities of protein, starch and oil, various phytonutrients, and antioxidant activity (as quality indicators) were taken into account.

As a result, chaffy varieties, Parnas and Ratnyk, and naked varieties, CDC Alamo, Richard, Omskiy Golozyornyy 1, Mebere, CDC Candle, CDC Hilose, Yavir, Akhiles, and Gatunok were selected as parents.

Parnas, Yavir, and Omskiy Golozyornyy 1 were noticeable not only for their high protein content (12.7%, 14.2%, and 14.5%, respectively). The ability of their

proteins to be digested by proteolytic enzymes was also analyzed and Parnas and Yavir were shown to contain highly digestible protein (69.80–74.20 mg/g). The trypsinolysis level was especially outstanding (54.60–48.70 mg of tyrosine/g of protein) [18]. Varieties with such parameters are very valuable in the breeding of food varieties for dietary products. For comparison: the digestibility of protein from Doskonala wheat is 53.90 mg/g, and trypsinolysis is 36.85 mg of tyrosine/g of protein.

Creation of waxy varieties (with starch consisting of 95–100% amylopectin) is an line in barley breeding. Such varieties are suitable for functional food production, as due to their high antioxidant activity, they can prevent cardiovascular diseases, cancer and diabetes. Since 2011, Canadian naked varieties, CDC Alamo, CDC Candle and Mebere, have served as sources of the waxy mutation. Oil content and its fatty acid composition are also important indicators of the nutritional value of barley grain. The oil content in barley grain is very low (about 3%); hence, this parameters is very little variable and oil content-oriented breeding is not popular among scientists. What is interesting is not the content, but the composition of oil, as barley oil is very rich in polyunsaturated ω -3 linolenic acid, which is a powerful antioxidant.

In our study, varieties with a relatively high oil content were identified - Yavir (3.08%) and CDC Alamo (3.04%). As for the fatty acid composition of oil, a high content of ω -3 linolenic acid was detected in Ratnyk (6.28%), Gatunok (6.23%), Parnas (6.11%), and Omskiy Golozyornyy 1 (6.11%); a high content of linoleic acid – in Gatunok (55.01%) and CDC Candle (54.80%); a high content of oleic acid – in CDC Alamo (18.55%), Akhiles (18.44%), Richard (18.38%), and CDC Candle (16.77%).

Unique dietary properties of barley result from the fact that it is one of the richest sources of phenolic compounds among cereals. However, AOA is concentrated in the peripheral layers of the caryopsis; so, when products are manufactured from chaffy barley, some healthy nutrients are lost during grain rubbing. Hence, naked barley is attracting more and more attention from

manufacturers. In our studies in 2015-2017, barley varieties and starting material with high AOA, which are suitable for food production, were identified and created. The highest AOA was recorded for CDC Alamo (3.46 mg/g chlorogenic acid equivalent), Richard, Mebere (2.99 mg/g), CDC Candle, Yavir (2.96 mg/g) [19]. In 2016–2017, CDC Alamo (0.94 mg/g gallic acid equivalent), Omskiy Golozyornyy 1 (0.91 mg/g), and Mebere (0.89 mg/g) were distinguished due to a high content of phenolic compounds; in 2021–2022, Violet 18-1207 var. *nudidubium* (1.04 mg/g), CDC Alamo (0.94 mg/g), Rondo, Mebere (0.89 mg/g), Richard (0.85 mg/g), and Yavir (0.81 mg/g) were distinguished. Thus, we established that the ranking of varieties by level of phenolic compounds almost does not change, except for inclusion of new accessions in the study, that is, the content of phenolic compounds depends on genotype.

Later (2016–2023), naked barley accessions not only with yellow grains, but also with pigmented grains were included in breeding (Table 1).

1. Starting material for pre-breeding and hybridization, 2016–2023

Accession	Variety	Origin	Features
CDC Alamo	<i>nudum</i>	CDC, Canada	Waxy starch, very high total AOA, high contents of β -glucans, oil and phenolic compounds
Mebere	<i>nudum</i>	AAFC, Canada	Waxy starch, rounded caryopsis, high AOA, high contents of oil and phenolic acids
CDC Hilose	<i>nudum</i>	CDC, Canada	High-amylose starch, vary high content of oil (> 4.70 %), very long spike (> 10 cm)
Yavir	<i>nudum</i>	PPI, Ukraine	High AOA, high contents of oil and phenolic acids
Gatunok	<i>nudum</i>	ISA, Ukraine	High content of polyunsaturated ω -3 linolenic acid
Rondo	<i>nudum</i>	PPI, Ukraine	High content of phenolic acids, rounded caryopsis
UA 5462	<i>daghestan i-cum</i>		Grey-green caryopsis, long spike, very high contents of starch (>65%) and oil

UA 0663	<i>viride</i>		Green caryopsis, very high content of protein (>17 %),
UA 0989	<i>violaceum</i>		Purple caryopsis, high content of anthocyanins
Violet 18-1207	<i>nudidubium</i>	PPI, Ukraine	Purple caryopsis, very high contents of starch (> 66 %), oil and anthocyanins
Jet	<i>nigrinudum</i>	Ethiopia	Black caryopsis, drought-resistant
UA 0645	<i>nudimelanocritum</i>		Black caryopsis, erectoid, very high content of protein (> 17 %)

The purpose of breeding barley with colored grain in Ukraine is biofortification of the grain's nutritional value, as high content of polyphenols means good AOA and inhibits α -glucosidase. As a result, colored barley can be a powerful antioxidant and hypoglycemic product [20, 21, 22, 23]. It is exemplified by Violet 18-1207 variety *nudidubium* created at the Institute. Entire plants of this line are bright purple; caryopses contain very large amounts of anthocyanins, starch and oil. This line can be a source of these features in breeding.

Multi-year studies resulted in Yavir, Orlan, Obrii, and Rondo barley variety *nudum*.

Yavir. Breeding line 13-728. It was created by hybridization of Parnas with Omskiy Golozyornyy 1. In the Institute's competitive trials, Yavir yielded 98% related to the check variety, Vzirets, which, given the absence of glumes, is high. In 2017, the mean yield was 4.55 t/ha; maximum – 5.52 t/ha. The protein content in grain is 14.20%; the starch content is 62.59%. Yavir is mid-ripening; its vegetation lasts 84 days, which is three days shorter than in the check variety. The lodging resistance is 8.1–8.7 points (Vzirets 8.5–9.0 points). The endosperm vitreousness is 95%. The antioxidant activity is high (2.96 mg/g chlorogenic acid equivalent), which is very valuable for healthy food production.

Orlan. Breeding line 15-1289. It was created by hybridization of Omskiy Golozyornyy 1 with Parnas. Orlan is mid-ripening. In the Institute's competitive trials, the mean yield was 5.00 t/ha (108% related to the check variety). The protein

content in grain is 13.33%; the starch content is 68.36%. The endosperm vitreousness is high (90%). The thousand kernel weight is 42.0 g. The lodging resistance is 8.5 points; the plant height is 68 cm. Orlan is suitable for healthy food production.

Obrii. Breeding line 13-1000. It was created by hybridization of Vzirets with Omskiy Golozyornyy 1. In the Institute's competitive trials, Obrii yielded 97% related to the check variety, Vzirets, which, given the absence of glumes, is high. In 2017, the mean yield was 5.24 t/ha; maximum – 5.72 t/ha. The protein content in grain is 13.33%; the starch content is 68.36%. Obrii is mid-ripening; its vegetation lasts 84 days, which is two days shorter than in the check variety. The lodging resistance is 8.1–8.7 points (Vzirets 8.5–9.0 points). Obrii is characterized by high total AOA, which makes it suitable for healthy food production.

Rondo. Breeding line 17-1798. It was created by hybridization of Ratnyk with Omskiy Golozyornyy 1. Rondo plants are light-green, without a wax coating. Rondo is mid-ripening. It yields 4.68–5.22 t/ha, or 87–100% related to the check variety. Its stems are short (65-75 cm); the lodging resistant is 7.5-8.5 points. The caryopsis is rounded and large; the thousand kernel weight is 50.0 g. These features are very useful in processing industry. The test weight is high (730–740 g/L). The protein content in grain is 14.00–15.05%; the starch content is 61.18–61.78%; the oil content is 3.05%; the content of phenolic compounds is 0.89 mg/g gallic acid equivalent. Rondo is very resistant to head smut (9 points), rust (8 points), moderately resistant to net blotch (5 points) and corn flies (6 points).

Yavir, Obrii, Orlan, and Rondo were submitted for qualifying examination; results of preliminary trials are available (Table 2).

2. Results of field qualifying examination of the variety conducted by the Ukrainian Institute of Examination of Plant Varieties for suitability for dissemination

Zone	Yield		Plant height, cm	Vegetation length, days	Thousand kernel weight,	Resistance to, score				
	t/ha	% related				lodging	drought	powdery mildew	net blotch	smut

		to the check variety			g			w		
Yavir										
Woodlands	2.56	70	60	81	52.4	9	9	7	7	9
Forest-Steppe	5.97	142	53	74	56.4	9	9	8	8	9
Steppe	1.33	48	51	87	43.6	9	9	9	9	9
Orlan										
Woodlands	4.58	109	73	84	47.0	6	8	6	6	9
Forest-Steppe	6.58	162	50	76	47.7	7	9	9	8	9
Steppe	4.68	107	65	73	46.5	9	5	7	5	9

The examination results demonstrated that Yavir was suitable for growing in the forest-steppe, and Orlan – in any natural/climatic zone of Ukraine.

Conclusions. Naked barley breeding seems to be promising for Ukraine, as introduction of such varieties into agricultural production will help solve the food security problem, namely, provide the population with nutritious, functional and economically affordable food products.

Naked varieties with pigmented grain can be a niche crop to manufacture limited amounts of special food products - dietary or baby food.

In the naked barley breeding, Gatunok became a source of high content of polyunsaturated ω -3 linolenic acid; Yavir, CDC Alamo and Violet 18-1207 served as sources of high content of oil; CDC Alamo, Richard, Mebere, CDC Candle, and Yavir – of high antioxidant activity; CDC Alamo, Mebere, Violet 18-1207, Rondo, and Richard - of high content of phenolic compounds.

The naked barley varieties bred by the Plant Production Institute named after V.Ya. Yuriev of NAAS, Yavir and Orlan, are suitable for growing in Ukraine and recommended to producers for wide implementation.

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