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Breeding value of naked-oat genotypes in terms of a set of utility characteristics

***Alla Kravchenko, Tetiana Hoptsii, Dmytro Chuiko**
State Biotechnological University, Department of Genetics, Breeding and Seed Production,
UA62483, Dokuchaievske village, Kharkivska Oblast, Ukraine

Abstract. To determine dependence patterns, we studied a collection comprising 45 naked-oat accessions of different ecological, geographical and genetic origins. To assess the accessions for a set of investigated characters, cluster analysis was conducted. The cluster analysis distinguished four groups of accessions according to the panicle performance constituents. The accessions of clusters one and two were identified as valuable starting materials for naked-oat breeding to create high-yielding cultivars suitable for cultivation in the Eastern Left-Bank Forest-Steppe of Ukraine. The selected naked-oat accessions in clusters one and two are valuable for further breeding because they exhibit altered correlations between plant height, panicle performance, and the number of kernels per panicle. The correlations between panicle performance and plant height, and between the number of kernels per panicle and plant height, are negative in these clusters (r= -0.41 and r= -0.41, respectively), unlike the correlations in the entire studied collection, where these traits were positively correlated or were hardly correlated (r= 0.42 and r= 0.19, respectively). The selected accessions are characterised by the following features: the plant height of 78.5–86.2 cm, the panicle length of 16.9–18.8 cm, 33.5–39.2 spikelets per panicle, 47.3–52.4 kernels per panicle, the weight of kernels per panicle of 1.2–1.3 g, and the thousand-kernel weight of 27.0–27.3 g.
Key words: Naked oat, yield components, variation, cluster analysis.

Introduction

For many years, Ukraine has been a top producer and exporter of grain in the world. The favourable natural and climatic conditions and fertile land allowed for growing grain crops and obtaining high-quality food products that satisfy domestic needs and are successfully exported. Wheat, barley and corn are the most widely grown grain crops on the territory of Ukraine. However, today, it is appropriate to add oats, including naked oats, to promising grain crops (Kushniruk & Tolmach, 2016; Kravchenko *et al.*, 2023; Buniak, 2019).

Naked oats are increasingly used in production. Thanks to intensive breeding in Ukraine, new high-quality naked food and fodder oat cultivars have been created. Interest in this multifunctional crop is attributed to a number of beneficial economically valuable characteristics.

Naked oats boast several potential advantages that have yet to be fully explored, but this crop already has significant potential, and in the future can guarantee a breakthrough both in the food industry and in other branches of agriculture. Grain is a valuable source of raw materials to produce foods, including dietary and preventive products, medical and cosmetic goods and fodder (Köse et al., 2021; Biel *et al.*, 2014).

Among the main economically valuable characteristics affecting naked-oat yield is the thousand-kernel weight, which depends on seed size and plumpness (Wang *et al.*, 2020; De Koeyer *et al.*, 2004). Breeding for this trait is a promising way to increase the crop yield (Yan *et al.*, 2023). In naked oats, there is a significant relationship between grain yield and structural elements such as panicle length, the number of kernels per panicle, and the number of panicles per unit area (Leišová-Svobodová *et al.*, 2019). At the same time, several recent and older studies in different countries worldwide, including Ukraine, showed a significant impact of growing conditions of naked oats on their yield stability (Buniak, 2019; Yan

* Corresponding Author's email address: allavitchenko@gmail.com

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et al., 2016; Becher, 2007; Holland *et al.*, 2002). Such variation in naked-oat yield results from insufficient adaptation to the environmental conditions (Kabashov *et al.*, 2018). To date, the problem of weak adaptation of naked oats has not been solved, and the greatest interest is in cultivars that could tolerate external factors, effectively use favourable conditions, and fulfil their productive potential.

The plant height is an important element in oat breeding, as it is primarily related to the negative phenomenon of the crop lodging. In some studies, a great plant height was found to be the primary cause of cereal lodging, while traits such as stem strength and peculiarities of the root system were secondary factors (Berry *et al.*, 2015; Stanca *et al.*, 1979). Since 1990s, as a result of breeding, a number of dwarf oat cultivars (subspecies *A. sativa subsp. sativa* and *A. sativa subsp. nudisativa*) were implemented. It is the presence of several dwarfism genes (for example, *Dw6* and *Dw7*) in the oat genome that made it possible to increase the oat yield due to improved yield index (Federizzi *et al.*, 1989; Matiello *et al.*, 1989). At the same time, a significant decrease in the height of oats and other cereals can reduce yields, which was confirmed by several studies (Flintham *et al.*, 1997; Tumino *et al.*, 2017; Piñera-Chavez *et al.*, 2020; Shah *et al.*, 2019). Thus, naked-oat breeding should focus on developing and evaluating genotypes with improved panicle performance, higher thousand-kernel weight, and the optimal plant height.

In meeting this challenge, scientists have proven the feasibility of using multivariate statistics methods, specifically factor clustering, for comprehensive assessments of breeding materials for a set of characteristics (Tishchenko *et al.*, 2004; Litun *et al.*, 2009; Bilyavska & Rybalchenko, 2020).

Cluster analysis has become widely used in studies of starting materials. Its use in breeding practice, in addition to solving classification tasks, allows one to get clear patterns of differences between different clusters (groups) and, based on this, to identify different morpho-biological types of cultivars (Marukhniak *et al.*, 2019; Klimova, 2014). Multivariate analyses in breeding help breeders to considerably shorten the breeding process duration due to more complete and comprehensive assessments of factors affecting the fulfilment of genetic potentials of plants (Pushchak *et al.*, 2021; Klimova, 2014).

The purpose of our study was to select the best naked-oat accessions with valuable economic characteristics for the development of high-yielding cultivars adapted to cultivation in the eastern part of the Left-Bank Forest-Steppe of Ukraine.

To select the best naked-oat accessions for further use in breeding, we comprehensively evaluated a set of panicle performance characters, using a multivariate statistics method (the K-means method).

Materials and Methods

The study was conducted at the Scientific, Educational Production Centre "Dokuchaievske Experimental Field" of the State Biotechnology University. Forty-five domestic and foreign naked-oat (*A. sativa subsp. nudisativa*) accessions, provided by the National Centre for Plant Genetic Resources of Ukraine and the N.I. Vavilov All-Russian Institute of Plant Genetic Resources were studied. This collection is represented by three varieties of the subspecies *A. sativa subsp. nudisativa* with wide eco-geographical and genetic diversity from different countries of Europe (Ukraine, the Czech Republic, Lithuania, Germany, Great Britain, Belarus and Russia), Asia (China), and North America (Canada). In 2019–2021, the collection accessions were analysed for the panicle performance (Table 1).

The study was conducted by methods of the state trials of agricultural crop varieties (Volkodav, 2000). This field technique regulates the major stages of growing and harvesting cereals and groat crops, the determination of the relevant record area in each plot, and sampling fully biologically mature sheaves for analyses.

In compliance with this technique, we determined the following parameters:

- the mean panicle length was determined by measuring the lengths of 25 panicles with an accuracy of 0.5 cm and calculating their average length;
- the mean number of spikelets per panicle was determined by counting spikelets in 25 panicles and calculating the average number per panicle;
- the mean weight of kernels per panicle was calculated by dividing the weight of kernels in a sheaf sample (g) by the number of productive stems;
- the mean number of kernels (X) per panicle was calculated by the following formula:

$$X = \frac{Y \times 1000}{F},$$

where: Y – the mean weight of kernels per spike (panicle), g;
F – thousand-kernel weight, g.

The plant height (without awns) was measured from the soil surface to the top of the inflorescence on the primary stem before harvesting. It was measured in five equally distanced sites of the plots, in two non-adjacent replications; then the mean height was calculated.

Table 1

Origins of the naked-oat accessions

Variety	Subspecies	Country of origin
Skarb Ukrainy, OM 2803, OM 11-3007/3, TR 12-115, N.N. REN nuda	*A. sativa var. inermis*	Ukraine
Abel, Jakub, Saul	*A. sativa var. inermis*	Czech Republic
Litovskij Nadij	*A. sativa var. inermis*	Lithuania
Solomon, Samuel	*A. sativa var. inermis*	Germany
Rhianon	*A. sativa var. inermis*	Great Britain
Bai Jan 2	*A. sativa var. chinensis*	China
Hua Zao 2	*A. sativa var. inermis*	China
AC Percy, Boudrais, AC Ernie	*A. sativa var. inermis*	Canada
Belorusskiy, Golz, Vandrounik, Marafon, Vladyka, Korolyok	*A. sativa var. inermis*	Belorus
Valdin 765, Agramak, Persheron, Bekas, Levsha, Sibirskiy Golozyornyy, Inermis, Pushkinskiy, Vyatskiy, Tyumenskiy Golozyornyy, Baget, Virovets, Murom, Pomor, Taydon, Gavrosh, Ofenya, Progress, Golets, Samson 57, Tarskiy Golozyornyy	*A. sativa var. inermis*	Russia
Aldan	*A. sativa var. inermis abbinis*	

The collection nursery was planted in plots of 1 m²; the plots were arranged systematically in four replications. The predecessor was black fallow. The soil in the experimental field is Calcic Voronic Chernozem CL UE1. Naked-oat seeds were sown manually in rows with an interrow width of 15 cm. Seeds were buried at 4 cm. The seeding rate was 600 seeds per m². The thousand-kernel weight was measured in accordance with DSTU ISO 520:2015 (ISO 520:2010, IDT).

The results of field and laboratory measurements were used to analyse the collection of naked oats: plant height (cm), panicle length (cm), number spikelets per panicle (spikelets), number of kernels per panicle (kernel), weight of kernels per panicle (g) and thousand-kernel weight (g).

The weather in 2019 had a sufficient amount of precipitation, with a gradually increasing air temperature. The precipitation amount was 44.5 mm in April and 43.4 mm in May, with the multi-year average of 34.9 mm and 43.7 mm, respectively. The average air temperature was 11.5 °C in April and 18.2 °C in May, exceeding the multi-year average temperature by 3.2 °C and 2.0 °C, respectively, which had a positive effect on the emergence of seedlings and further growth and development of plants in all naked-oat accessions.

The summer months were characterised by high temperatures and insufficient precipitation. The precipitation amount was 15.2 mm in June and 38.8 mm in July, or only 23.1% of the multi-year average precipitation. The average air temperature was 24.5 ºC in June and 21.4 ºC in July. The maximum air temperature reached 31–36 ºC. However, the soil water storage and the amount of spring precipitation enabled naked-oat plants to develop without significant deviations from the norm under these conditions.

The meteorological conditions in 2020 were slightly dry, with deviations of the main indicators from the multi-year average values. The spring weather was cooler. The average temperature was 8.8 °C in April. In May, the temperature was 13.5 °C, with the multi-year average of 15.1 °C. At the same time, in April, 13.7 mm of precipitation fell, and, in May, there was almost three times as much precipitation as the multi-year average (108.3 mm or 226%). Prolonged cool weather and excessive moisture in May negatively affected the growth and development of the crop, causing plant lodging among other effects.

The summer period, in general, was characterised by higher average daily temperature, which amounted to 21.9 °C in June and 22.4 °C in July. The average monthly precipitation in June-July was below the multi-year value (54.2 mm and 27.2 mm, respectively).

The 2021 growing season was notable for the most favourable vegetation period supporting the growth and development of naked-oat plants. The spring months and June were characterised by optimal air temperatures, similar to the multi-year average values. The multi-year average air temperature is 8.7 °C in April, 16.1 °C in May and 20.9 °C in June. As to precipitation, the spring and the beginning of summer had values that were close to the multi-year average values. The precipitation amount was 37.3 mm in April, 52.1 mm in May and 82.0 mm in June, with the multi-year average values of 34.9 mm, 43.7 mm and 65.7 mm, respectively. July was dry; the air temperature was 24.5 °C; the precipitation amount was 26.6 mm. The precipitation was well distributed during the growing period. Plants did not suffer from water deficit during the crucial phases of their development.

Experimental data were mathematically and statistically processed in Statistica 10.0. The mean values across years and replications were used for analysis. Data were statistically processed by ANOVA and correlation analysis.

Results

Genotype trait variability

The results of studying the collection of naked-oat accessions in the Eastern Left-Bank Forest-Steppe of Ukraine showed significant inter-accession variability of the performance characters.

Thus, to determine the plant morphotype of the examined naked oats, we measured the plant height. Cultivar (Cv.) ‘Tarskiy Golozyornyy’ had the tallest plants (96.2 cm). Cv. ‘Valdin 765’ was represented by short plants (69.4 cm). In the other cultivars, the mean plant height varied from 73.5 cm to 94.9 cm.

The panicle length varied from 13.6 cm to 21.5 cm. The longest panicles (21.5 cm) were found in cv. ‘Aldan’. As to the average number of spikelets per panicle, cultivars (Cvs.) ‘Bai Jan 2’ (46.1), ‘Bekas’ (45.6), ‘Baget’ (45.0), and ‘Tyumenskiy Golozyornyy (45.0) should be distinguished. Accession ‘TR 12–115’ had the fewest spikelets per panicle (29.1). The other studied accessions had 31.2–44.5 spikelets per panicle.

The greatest numbers of kernels per panicle on average for three years were recorded for Cvs. ‘Pushkinskiy’ (60.4), ‘Abel’ (58.9), ‘Marafon’ (58.5), and ‘OM 11-3007/3 inermis’ (56.4), while Cv. ‘Litovskij Nadij’ had the fewest kernels per panicle (34.4). In the other accessions, this parameter varied from 35.4 to 53.8 kernels per panicle.

Accessions ‘AC Percy’ and ‘Aldan’ had high weights of kernels per panicle (1.5 g); accessions ‘N.N. REN nuda 039605’ and ‘Rhianon’ had low weights of kernels per panicle (0.9 g).

Thousand-kernel weight is a breeding-valuable character. It was revealed that thousand-kernel weight varied depending on the accession’s genotype. Thus, the plumpest seeds were formed in accessions ‘AC Percy’, ‘Korolyok’, and ‘Levsha’ (31.1 g, 29.3, and 29.1 g, respectively). The least filled seeds were in accessions ‘N.N. REN nuda 039605’, ‘Ofenya’, and ‘Rhianon’ (21.2 g, 25.8, 25.8 g, respectively).

As a result of our research, accessions with high productivity, due to various constituents of the panicle performance, were selected: ‘Valdin 765’ (47.5 kernels per panicle; weight of kernels per panicle – 1.3 g), ‘Marafon’ (58.5 kernels per panicle; thousand-kernel weight – 27.4 g), ‘Abel’ (58.9 kernels per panicle; weight of kernels per panicle – 1.4 g, thousand-kernel weight – 27.9 g), ‘Solomon’ (53.3 kernels per panicle; weight of kernels per panicle – 1.3 g, thousand-kernel weight – 27.1 g), ‘AC Percy’ (weight of kernels per panicle – 1.5 g, thousand-kernel weight – 31.1 g), ‘Murom’ (50.3 kernels per panicle; weight of kernels per panicle – 1.3 g), ‘Virovets’ (41.2 spikelets per panicle; 49.2 kernels per panicle; weight of kernels per panicle – 1.4 g; thousand-kernel weight – 27.9 g), ‘Bekas’ (45.6 spikelets per panicle; 50.6 kernels per panicle; weight of kernels per panicle – 1.4 g), ‘OM 11-3007/3’ (56.4 kernels per panicle; weight of kernels per panicle – 1.3 g.; thousand-kernel weight – 28.2 g), ‘Agramak’ (50.1 kernels per panicle; weight kernels per panicle – 1.4 g), ‘Boudrais’ (weight of kernels per panicle – 1.4 g; thousand-kernel weight – 28.0 g), ‘Aldan’ (44.3 spikelets per panicle; 53.8 kernels per panicle; weight of kernels per panicle – 1.5 g; thousand-kernel weight – 27.9 g) (Table 2).

Analysing the relationships between the traits studied in this collection by correlation analysis, we found correlations of various strengths. Thus, there was a strong positive correlation between plant height and panicle length (r = 0.77) and a moderate positive correlation between plant height and the number of spikelets per panicle (r = 0.42). We noted no significant correlations between plant height and other studied characteristics (r = -0.08 – 0.19). Panicle length was moderately positively (r = 0.46) correlated with the number of spikelets per panicle but was not correlated (r = -0.04–0.09) with other traits. There were medium positive correlations between the number of spikelets per panicle and the weight of kernels per panicle as well as between the number of kernels per panicle and the weight of kernels per panicle (r = 0.42 and r = 0.50, respectively). The weight of kernels per panicle was positively correlated with the thousand-kernel weight (r = 0.47). We observed no significant correlations between other traits (Table 3).

Thus, based on the results of correlation analysis in the whole collection of oat accessions, we can state that an increase or decrease in plant height of naked oats did not lead to significant changes in the plant performance.

Table 2

Performance characters in the collection accessions (2019–2021)

Accession	Plant height, cm	Panicle length, cm	Number of spikelets per panicle	Number of kernels per panicle	Weight of kernels per panicle, g	Thousand-kernel weight, g
Skarb Ukrainy	77.7	17.4	35.8	45.9	1.17	27.0
OM 2803 inermis	81.7	18.7	31.7	43.5	1.09	26.4
OM 11-3007/3 inermis	86.8	18.7	37.5	56.4	1.34	28.2
TR 12-115	84.5	19.2	29.1	45.8	1.17	27.3
N.N. REN nuda 039605	79.6	17.3	31.2	53.6	0.93	21.2
Abel	78.9	16.4	39.0	58.9	1.39	27.9
Jakub (Avenuda)	80.8	19.9	37.6	36.2	0.98	27.1
Saul	86.7	18.7	36.9	42.8	1.17	27.3
Samuel	85.2	18.2	37.8	52.3	1.21	27.5
Solomon	82.3	19.5	38.2	53.3	1.27	27.1
Litovskij Nadij	93.7	19.9	35.8	34.4	0.97	28.1
Rhianon	76.0	15.2	32.0	35.4	0.92	25.8
Bai Jan 2 (v. chinensis)	90.6	19.7	46.1	45.3	1.22	27.0
Hua Zao 2	84.2	16.1	35.2	43.0	1.17	27.1
AC Percy	93.7	19.8	37.1	45.0	1.54	31.1
Boudrais	75.9	17.2	36.9	45.0	1.36	28.0
AC Ernie	81.5	18.8	38.2	44.3	1.22	26.9
Belorusskiy	80.3	18.5	35.1	45.0	1.20	26.7
Vandrounik	79.6	16.7	33.1	55.7	1.19	28.0
Marafon	76.1	16.0	32.7	58.5	1.23	27.4
Vladyka	80.6	16.0	31.6	47.3	1.27	26.8
Korolyok	73.5	15.2	34.5	43.0	1.26	29.3
Golz	83.3	18.7	37.4	50.5	1.19	27.1
Sibirskiy Golozyornyy	86.9	19.5	35.2	52.4	1.22	25.1
Inermis	82.7	19.3	36.8	46.1	1.17	27.5
Pushkinskiy	84.6	19.0	39.3	60.4	1.35	25.7
Vyatskiy	78.9	19.1	34.1	53.0	1.21	25.5
Valdin 765	69.4	13.6	34.5	47.5	1.26	26.0
Agramak	84.6	16.0	39.7	50.1	1.37	27.2
Tyumenskiy Golozyornyy	81.8	17.9	45.0	43.4	1.20	27.6
Persheron	75.5	16.7	32.9	41.8	1.19	28.5
Bekas	75.6	16.6	45.6	50.6	1.36	26.9
Baget	84.3	20.8	45.0	46.8	1.25	26.7
Virovets	92.3	18.4	41.2	49.2	1.38	27.9
Levsha	79.3	15.7	34.4	41.4	1.20	29.1
Aldan	91.4	21.5	44.3	53.8	1.50	27.9
Murom	94.9	20.3	37.5	50.3	1.32	26.2
Pomor	88.2	20.5	42.7	43.8	1.26	28.7

Taydon	88.6	18.2	37.4	45.9	1.28	27.9
Gavrosh	91.7	19.7	38.6	43.8	1.23	28.0
Ofenya	86.1	20.1	39.5	50.3	1.30	25.8
Progress	89.9	19.4	35.8	43.2	1.21	27.9
Tarskiy Golozyornyy	96.2	21.3	41.7	43.4	1.16	26.6
Golets	92.5	19.9	44.5	45.2	1.22	27.0
Samson 57	90.5	19.2	38.1	45.8	1.25	27.4
$LSD_{0.5}$	5.1	0.9	2.8	8.8	0.08	0.9

Cluster analysis

Based on the results of structural analysis, we selected naked-oat accessions, which not only differed biologically because of their genetic diversity but also, in many cases, differed in the genetic potential of the panicle performance. To prove this statement, we conducted cluster analysis.

Based on the results of K-means clustering, the entire collection of naked oat accessions was divided into four clusters based on the investigated characteristics. Each of these clusters represents a separate morphobiological type and is characterised by specific levels of individual performance constituents. The Y-axis shows the trait indices (from 0.6 to 1.3), which are computed automatically in Statistica 10.0. From absolute values of the traits, indices of normalised values are computed by dividing the absolute value of a trait for each breeding accession by the mean value of that trait in the experiment. They can be calculated manually using the following formula (Litun *et al.*, 2009):

$$I_i = \frac{x_i}{x_{...}},$$

where: Ii - index of the normalised value $;

x_i - absolute value of the trait for each breeding accession;

$x...$ - mean value of the trait in the experiment.

This makes it possible to reduce the genotypic values to a single measure - indices of normalised values, which reflect the distance of the trait value in a specific breeding accession from the adaptive norm. The investigated traits are indicated along the X-axis (Fig. 1).

Cluster I was the largest group (15 accessions): ‘Skarb Ukrainy’, ‘OM 2803’, ‘TR 12-115’, ‘N.N. REN nuda 039605’ (Ukraine), ‘Hua Zao 2’ (China), ‘Boudrais’ (Canada), ‘Belorusskiy’, ‘Vandrounik’, ‘Marafon’, ‘Vladyka’, ‘Korolyok’ (Belarus), ‘Vyatskiy’, ‘Valdin 765’, ‘Persheron’, and ‘Levsha’ (Russia).

The accessions of cluster 1 were medium-tall (78.5 cm), had long panicles (16.9 cm), and were

Table 3

Correlation analysis of the traits in naked oats, r±Sr

	Plant height, cm	**Panicle length, cm**	**Number of spikelets per panicle**	**Number of kernels per panicle**	**Weight of kernels per panicle, g**	**Thousand-kernel weight, g**
Plant height, cm	1	–	–	–	–	–
Panicle length, cm	0.77±0.13*	1	–	–	–	–
Number of spikelets per panicle	0.42±0.14*	0.46±0.16*	1	–	–	–
Number of kernels per panicle	-0.08±0.15	-0.04±0.15	0.07±0.15	1	–	–
Weight of kernels per panicle, g	0.19±0.15	0.09±0.15	0.42±0.16*	0.50±0.14*	1	–
Thousand-kernel weight, g	0.16±0.15	0.00±0.15	0.16±0.15	-0.25±0.15	0.47±0.14*	1

Note: $*t_{obs.} > t_{0.5}$

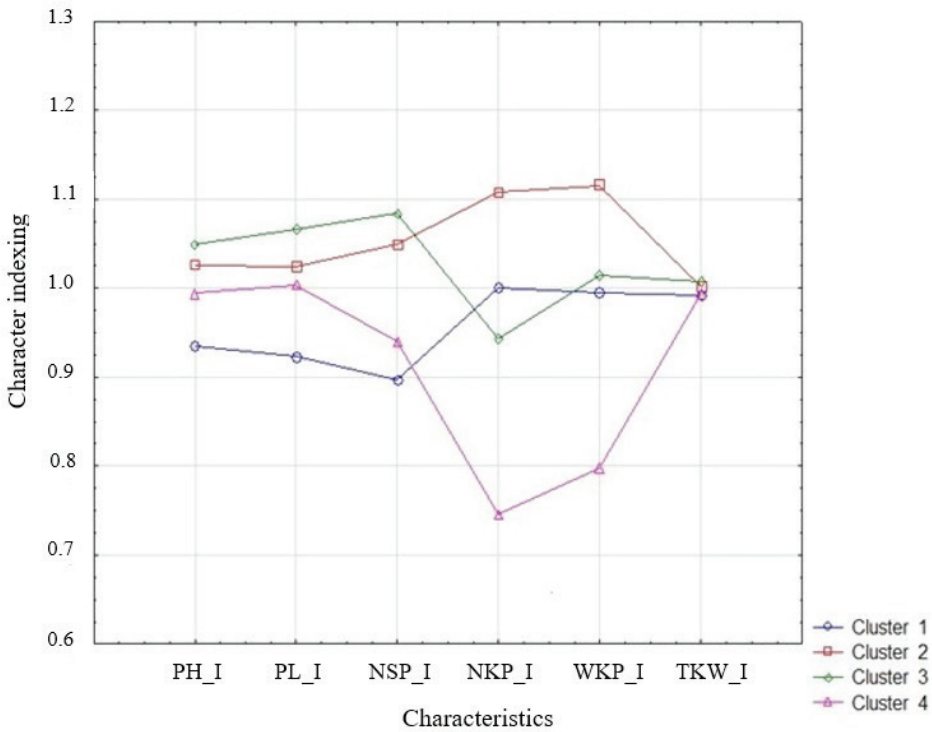

Figure 1. Mean cluster values of the panicle performance characters in the collection of naked-oat accessions (2019–2021).

PH_I – plant height, PL_I – panicle length, NSP_I – number of spikelets per panicle, NKP_I – number of kernels per panicle, WKP_I – weight of kernels per panicle, TKW_I – thousand-kernel weight.

noticeable for high expression of the panicle performance characters (33.5 spikelets per panicle; 47.3 kernels per panicle; weight of kernels per panicle – 1.2 g) and moderate values of the thousand-kernel weight (27.0 g) (Table 3).

The correlation analysis showed that there was a negative correlation between the plant height and the number of spikelets per panicle (r = -0.40), and between the plant height and the weight of kernels per panicle (r = -0.40) in cluster 1, unlike the result of the correlation analysis in the whole collection of naked oats, where the correlation was positive or negligible weak (r = 0.42 and r = 0.19, respectively). Theoretically, this means a possibility to carry out selection for reduced plant height in this cluster without decreasing plant performance. Other correlations did not differ significantly from those in the whole collection.

Cluster 2 consisted of 14 accessions: ‘OM 11-3007/3’ (Ukraine), ‘Abel’ (Czech Republic), ‘Solomon’, ‘Samuel’ (Germany), ‘AC Percy’ (Canada), ‘Golz’ (Belarus), ‘Sibirskiy Golozyornyy’, ‘Pushkinskiy’, ‘Agramak’, ‘Bekas’, ‘Virovets’, ‘Aldan’, ‘Murom’, and ‘Ofenya’ (Russia).

The accessions of cluster 2 were short (86.2 cm) and showed the lowest mean values of the studied characters: the panicle length was 18.8 cm, the number of spikelets per panicle was 39.2, the number of kernels per panicle was 52.4, the weight of kernels per panicle was 1.3 g, and the thousand-kernel weight was 27.3 g.

The correlation analysis showed that in cluster 2, the negative correlation between the plant height and the number of kernels per panicle was strengthened (r = -0.41) (r = -0.08 in the whole collection). There was no correlation between the number of kernels per panicle and the weight of kernels per panicles (r = -0.13) in cluster 2 (r = 0.50 in the whole collection). There was no significant correlation between the panicle length and the number of spikelets per panicle either (r = -0.14), unlike the result of the correlation analysis in the whole collection (r = 0.46).

Cluster 3 included 13 accessions: ‘Saul’ (Czech Republic), ‘AC Ernie’ (Canada), ‘Bai Jan 2’ (China), ‘Inermis’, ‘Tyumenskiy Goolozyornyy’, ‘Baget’, ‘Pomor’, ‘Taidon’, ‘Gavrosh’, ‘Progress’, ‘Tarskiy Golozyornyy’, ‘Golets’, and ‘Samson 57’ (Russia). In cluster 3, the accessions showed great weights of kernels per panicle and thousand-kernel weights (1.2 g and 27.4 g, respectively); however, these accessions were tall (88.1 cm) and had long panicles (19.5 cm).

In cluster 3, there were no correlations between the traits, or they were very weak. In some cases, they were

Table 3

Mean cluster values of the performance characters in the collection of naked-oat accessions

Character	Cluster			
	1	2	3	4
Plant height (PH)	78.5	86.2	88.1	83.5
Panicle length (PL)	16.9	18.8	19.5	18.4
Number of spikelets per panicle (NSP)	33.5	39.2	40.5	35.1
Number of kernels per panicle (NKP)	47.3	52.4	44.6	35.3
Weight of kernels per panicle (WKP)	1.2	1.3	1.2	1.0
Thousand-kernel weight (TKW)	27.0	27.3	27.4	27.0

similar to those in the whole collection. For example, these were the correlations between plant height and panicle length (r = 0.52; r = 0.77 in the whole collection), between the number of kernels per panicle and weight of kernels panicle (r = 0.47; r = 0.50 in the whole collection), and between panicle length and the number of spikelets per panicle (r = 0.36; r = 0.46 in the whole collection). The other correlations were similar to those in the whole collection, varying from r = -0.28 to r = 0.36, depending on the trait.

Cluster 4 was the smallest group and comprised the following accessions: 'Jakub' (the Czech Republic), 'Litovskij Nadij' (Lithuania), and 'Rhianon' (Great Britain). The accessions were medium-tall (83.5 cm), had medium-long panicles (18.4 cm), and contained many kernels per panicle (35.3), but at the same time, they showed low levels of expression of other performance characteristics.

We did not use correlation analysis in cluster 4, as it comprised only three naked-oat accessions. Thus, there were too few variables to obtain robust results.

Therefore, the cluster analysis results demonstrated that each of these clusters differed both in the panicle performance and in the expression of individual constituents of the performance. The genotypes of clusters 1 and 2, which comprised the best accessions with high levels of such performance constituents as the weight of kernels per panicle and thousand-kernel weight and combined these features with medium height of plants (because it is important when creating lodging-resistant cultivars), are of particular interest.

Thus, using cluster analysis, we were able to prove that the previously selected accessions ('Valdin 765', 'Marafon', 'Boudrais' (cluster 1), 'Solomon', 'AC Percy', 'Murom', 'Virovets', 'Bekas', 'OM 11-3007/3', 'Agramak', and 'Aldan' (cluster 2) are worth using as promising starting materials in further breeding of naked oats for productivity.

Discussion

The primary objective of comparing naked-oat accessions from the collection, as with other agricultural crops, is to select the best plant genotypes for further use in breeding (Plăcintă & Murariu, 2022; Necheporenko & Orlov, 2019).

Yield is an integrated feature that characterises a set of different biotic and abiotic relationships in plants. Considering oat plant height, some researchers noted its direct impact on the crop lodging, which accordingly reduced yields (Tumino *et al.*, 2017; Berry *et al.*, 2015; Stanca *et al.*, 1979). At the same time, this interpretation could be attributed, in most cases only, to the crop lodging, where a positive correlation between these characteristics was indeed observed (Tumino *et al.*, 2017), because there was no correlation between the plant height and yield (the panicle performance) in our and other authors' studies (Leišová-Svobodová *et al.*, 2019; Kapoor *et al.*, 2011; Kumar *et al.*, 2016). The same was true of the correlation between yield (the panicle performance) and the panicle length. In most cases, the correlation between panicle height/length and yield (panicle performance) was negligibly weak, which is consistent with our and the above-mentioned other studies. The reduction in plant height of cereals, and its effect on yields was among the primary objectives of the Green Revolution in the 20th century (Flintham *et al.*, 1997). However, it has not been fully resolved for oats to date despite a considerable quantity of studies (De Koeyer *et al.*, 2004; Winkler *et al.*, 2016; Tanhuanpää *et al.*, 2012; Berry *et al.*, 2004; Pendleton, 1954). In particular, it is the wide polymorphism of this genus, and its low adaptability, which can be the potential causes of such problems with oats.

It is the adaptability that is a cause why the same genotype shows significant varietal differences under different growing conditions. Thus, according to Marchenkova *et al.*, (2020), Cv. 'Vyatskiy' in the

Moscow region had the following parameters: the plant height was 71.8 cm and the thousand-kernel weight was 31.8 g, while in our research on this cultivar during the same period, the plant height was 78.9 cm and the thousand-kernel weight was significantly lower (25.5 g). In an earlier study, Burrows (1993) described Cv. 'AC Percy' in the provinces of Ontario and Quebec (Canada). There, the plant height in this cultivar was 126 cm and the thousand-kernel weight was 33.2 g, while in our study these parameters were 93.7 cm and 31.1 g, respectively. A study was carried out by the Agricultural Research Institute Kromí, Ltd. (the Czech Republic) (Machán, 1998) to investigate a collection of naked oats. Thus, we can compare three cultivars ('Abel', 'Solomon' and 'AC Percy') from this study with our results. The author noted that the cultivars in his study could be classed as very tall (130 cm, 135 cm and 155 cm, respectively), with the thousand-kernel weight of 23.6 g, 26.6 g and 39.6 g, respectively. Comparing Machán 's results with ours (Table 2), we should point out that Cvs. 'Abel', 'Solomon' and 'AC Percy' in the eastern part of the Forest-Steppe of Ukraine had significantly lower values of these characteristics. This especially applied to the plant height. Some other naked-oat accessions from our collection showed similar variability compared with a study by Popov *et al.* (2022). Even taking for comparison the plant height and the thousand-kernel weight of naked oats only, we can see their wide variability, depending on the climatic conditions of cultivation. The plant height is a very unstable trait, which varies greatly under different growing conditions. Therefore, it is necessary to select the best accessions for further breeding, especially by plant height, based solely on results of studying collections of accessions in the area where the would-be cultivar will be bred and grown.

Multivariate statistics, including the cluster analysis and principal component analysis, has already been successfully used in breeding practice when oat collections were investigated in other studies (Achleitner *et al.*, 2008; Marukhniak *et al.*, 2019). It was also used for other crops (Kokhaniuk *et al.*, 2019; Klimova, 2014; Melnyk, 2013; Biljavska & Rybalchenko, 2020).

As for correlations between the characteristics under investigation, we revealed that the panicle performance was moderately positively correlated with the number of spikelets per panicle, the number of kernels per panicle, and the thousand-kernel weight in naked oats. Such results are more consistent with several other studies of oats (Hawerroth et al., Buniak, 2012; 2015; Sait & Ramazan; 2020; Kapoor *et al.*, 2011; Krishna *et al.*, 2014).

Conclusions

Having studied 45 naked-oat breeding genotypes to identify those with superior panicle performance, we conducted the cluster K-means analysis. Based on the analysis results, four clusters were identified; they differed in the levels of expression of the studied characters. The identified accessions are valuable starting materials in the breeding of naked oats for panicle performance; it is expedient to involve them in breeding to create highly productive naked-oat cultivars, which will be suitable for cultivation in the Eastern Left-Bank Forest-Steppe of Ukraine. Clusters 1 and 2 are the most valuable for practical breeding, since they had altered correlations between the plant height and the panicle performance constituents. There was a negative correlation between these characteristics, theoretically making it possible to carry out breeding selections to reduce plant height in these accessions without a negative impact on their yields and even with a possibility of an increase in the yields.

References

Achleitner, A., Tinker, N. A., Zechner, E., & Buerstmayr, H. (2008). Genetic diversity among oat varieties of worldwide origin and associations of AFLP markers with quantitative traits. *Theoretical and Applied Genetics*, *117*, 1041–1053. DOI: https://doi.org/10.1007/s00122-008-0843-y

Becher, R. (2007). EST-derived microsatellites as a rich source of molecular markers for oats. *Plant Breeding*, *126*(3), 274–278. DOI: https://doi.org/10.1111/j.1439-0523.2007.01330.x

Berry, P. M., Kendall, S., Rutterford, Z., Orford, S., & Griffiths, S. (2015). Historical analysis of the effects of breeding on the height of winter wheat (*Triticum aestivum*) and consequences for lodging. *Euphytica*, *203*(2), 375–383. https://doi.org/10.1007/s10681-014-1286-y

Berry, P. M., Sterling, M., Spink, J. H., Baker, C. J., Sylvester-Bradley, R., Mooney, S. J., Tams, A. R., & Ennos, A. R. (2004). Understanding and reducing lodging in cereals. *Advances in Agronomy*, *84*, 215–269. DOI: https://doi.org/10.1016/S0065-2113(04)84005-7

Biel, W., Jacyno, E., & Kawecka, M. (2014). Chemical composition of hulled, dehulled and naked oat grains. *South African Journal of Animal Science*, *44*(2), 189–197.

Biljavska, L. H., & Rybalchenko, A. M. (2020). Кластерний аналіз у класифікації сортів сої за господарськими ознаками *(Cluster analysis in soybean varieties classification by economic characteristics)*. *Agrobìologìâ*, *2*(161), 7–15.

DOI: https://doi.org/10.33245/2310-9270-2020-161-2-7-15 (in Ukrainian)

Buniak, O. I. (2012). Characteristics of naked grain varieties (*A. sativa* subsp. *nudisativa*) in the conditions of the Nosivska selection and experimental station. *Selektsiya i nasinnytstvo*, (102), 169–177. DOI: https://doi.org/10.30835/2413-7510.2012.59846

Buniak, O. I. (2019). Адаптивність сортів голозерного вівса носівської селекції за основними цінними господарськими ознаками *(Adaptability of naked oat varieties bred in Nosivka for major valuable economic characteristics)*. *Myronivskyi Visnyk*, *9*, 5–10. DOI: https://doi.org/10.31073/mvis201909-01 (in Ukrainian)

Burrows, V. D. (1993). AC Percy oat. *Canadian Journal of Plant Science*, *73*, 835–837.

De Koeyer, D. L., Tinker, N. A., Wight, C. P., Deyl, J., Burrows, V. D., O'Donoughue, L. S., Lybaert, A., Molnar, S. J., Fedak, G., & McElroy, A. R. (2004). A molecular linkage map with associated QTLs from a hulless × covered spring oat population. *Theoretical and Applied Genetics*, *108*(7), 1285–1298. DOI: https://doi.org/10.1007/s00122-003-1556-x

Federizzi, L. C., & Qualset, C. O. (1989). Genetics of plant height reduction and panicle type in oat. *Crop Science*, *29*(3), 551–557. DOI: https://doi.org/10.2135/cropsci1989.0011183X002900030001x

Flintham, J. E., Börner, A., Worland, A. J., & Gale, M. D. (1997). Optimizing wheat grain yield: Effects of Rht (gibberellin-insensitive) dwarfing genes. *The Journal of Agricultural Science*, *128*(1), 11–25. DOI: https://doi.org/10.1017/S0021859696003942

Hawerroth, M. C., da Silva, J. A. G., Woyann, L. G., Zimmer, C. M., Groli, E. L., de Oliveira, A. C., & de Carvalho, F. I. F. (2015). Correlations among industrial traits in oat cultivars grown in different locations of Brazil. *Australian Journal of Crop Science*, *9*(12), 1182–1189.

Holland, J. B., Bjørnstad, Å., Frey, K. J., Gullord, M., & Wesenberg, D. M. (2002). Recurrent selection for broad adaptation affects stability of oat. *Euphytica*, *126*, 265–274. DOI: https://doi.org/10.1023/A:1016394208780

Kabashov, A. D., Kolupayeva, A. S., Razumovskaya, L. G., & Filonenko, Z. V. (2018). Предварительные итоги селекции голозерного овса *(Preliminary results of naked oat breeding)*. *Selektsiya, Semenovodstvo i Genetika*, *4*(22), 20–24. DOI: https://doi.org/10.24411/2413-4112-2018-10003 (in Russian)

Kapoor, R., Bajaj, R. K., Sidhu, N., & Kaur, S. (2011). Correlation and path coefficient analysis in oat (*Avena sativa* L.). *International Journal of Plant Breeding*, *5*(2), 133–136.

Klimova, O. Ye. (2014). Кластерний аналіз рекомбінантних ліній цукрової кукурудзи за сукупністю селекційних ознак *(Cluster analysis of recombinant sweet corn lines based on a set of breeding traits)*. *Biuleten Instytutu Silskoho Hospodarstva Stepovoi Zony NAAN Ukrainy*, (7), 56–62. (in Ukrainian)

Kokhaniuk, N. V., Temchenko, I. V., Shtuts, T. M., Lekhman, A. A., & Barvinchenko, S. V. (2019). Кластерний аналіз у селекції зернобобових культур *(Cluster analysis in grain legume breeding)*. *Kormy i Kormovyrobnytstvo*, *87*, 9–19. DOI: https://doi.org/10.31073/kormovyrobnytstvo201987-02 (in Ukrainian)

Köse, Ö. E., Mut, Z., & Akay, H. (2021). Assessment of grain yield and quality traits of various oat (*Avena sativa* L.) genotypes. *Annali di Botanica*, 55–66.

Kravchenko, A., Hoptsii, T., Kyrychenko, V., Hudym, O., & Chuiko, D. (2023). Transgressive variation in productivity traits in F2 naked oat hybrids. *Scientific Horizons*, *26*(8), 23–32. DOI: https://doi.org/10.48077/scihor8.2023.23

Krishna, A., Ahmed, S., Pandey, H. C., & Kumar, V. (2014). Correlation, path and diversity analysis of oat (*Avena sativa* L.) genotypes for grain and fodder yield. *Journal of Plant Science & Research*, *1*(2), 1–9.

Kumar, P. A. R. B. H. A. T., Phogat, D. S., & Kumari, P. U. M. M. Y. (2016). Correlation and path coefficient analysis studies in oat (*Avena sativa* L.). *Forage Research*, *42*(3), 198–200.

Kushniruk, V. S., & Tolmach, O. V. (2016). Розвиток та ефективність зернового виробництва на аграрних підприємствах Новоодеського району *(Development and efficiency of grain production at agrarian enterprises of the Novoodeskyi District)*. *Ekonomika ta Upravlinnia Pidpryiemstvamy*, *13*, 298–302. (in Ukrainian)

Leišová-Svobodová, L., Michel, S., Tamm, I., Chourová, M., Janovska, D., & Grausgruber, H. (2019). Diversity and pre-breeding prospects for local adaptation in oat genetic resources. *Sustainability*, *11*(24), 6950. DOI: https://doi.org/10.3390/su11246950

Litun, P. P., Kyrychenko, V. V., Petrenkova, V. P., & Kolomatska, V. P. (2009). Системний аналіз у селекції польових культур *(Systemic analysis in field crop breeding)*. Kharkiv: Mahda. (in Ukrainian)

Machán, F. (1998). Performance and quality of naked oat cultivars of the world collection. Agricultural

Research Institute Kromí, Ltd., Czech Republic. Retrieved August 25, 2024, from https://wheat.pw.usda.gov/ggpages/oatnewsletter/Macha.html

Marchenkova, L. A., Pavlova, O. V., Chavdar, R. F., Markova, A., & Chebanenko, S. I. (2020). Оценка линий овса голозерного по ряду хозяйственно-биологических признаков в условиях Центрального Черноземья *(Evaluation of lines of bare oats for several economic and biological traits in the conditions of Central Black Earth)*. *Vestnik Ryazanskogo gosudarstvennogo agrotehnologicheskogo universiteta im. PA Kostyicheva*, *2*(46), 42–48. DOI: https://doi.org/10.36508/RSATU.2020.44.16.006 (in Russian)

Matiello, R. R., Sereno, M. J. C. M., Barbosa Neto, J. F., Carvalho, F. I. F. D., Pacheco, M. T., Pegoraro, D. G., & Taderka, I. (1999). Characterization for plant height and flowering date in the biological species oat. *Pesquisa Agropecuária Brasileira*, *34*, 1393–1398. DOI: https://doi.org/10.1590/S0100-204X1999000800011

Necheporenko, L. P., & Orlov, S. D. (2019). Селекційна цінність ліній і сортів вівса посівного (*Avena sativa* L.) *(Breeding value of common oat lines and cultivars)*. *Zernovi Kultury*, *3*(1), 18–25. DOI: https://doi.org/10.31867/2523-4544/0055 (in Ukrainian)

Pendleton, J. W. (1954). The effect of lodging on spring oat yields and test weight. *Agronomy Journal*, *46*, 265–267. DOI: https://doi.org/10.2134/agronj1954.00021962004600060006x

Piñera-Chavez, F. J., Berry, P. M., Foulkes, M. J., Molero, G., & Reynolds, M. P. (2020). Optimizing phenotyping methods to evaluate lodging risk for wheat. *Field Crops Research*, *258*, 107933. DOI: https://doi.org/10.1016/j.fcr.2020.107933

Plăcintă, D. D., & Murariu, D. (2022). Study of phenotypic variability using the varietal diversity of cultivated forms of naked and hulled oats in the intercropping system. *Journal of Applied Life Sciences and Environment*, *4*(188), 389–404. DOI: https://doi.org/10.46909/journalalse-2021-034

Popov, V. S., Khoreva, V. I., Konarev, A. V., Shelenga, T. V., Blinova, E. V., Malyshev, L. L., & Loskutov, I. G. (2022). Evaluating germplasm of cultivated oat species from the VIR collection under the Russian northwest conditions. *Plants*, *11*(23), 3280. DOI: https://doi.org/10.3390/plants11233280

Pushchak, V. I., Ilchuk, R. V., & Marukhniak, H. I. (2021). Кластерний аналіз колекцій зразків ярих зернових (овес, ярий ячмінь) за ознакою “урожайність зерна” *(Cluster analysis of spring cereal (oat, spring barley) accessions for “grain yield” trait)*. *Foothill and Mountain Agriculture and Animal Husbandry*, *2021*(1), 89–103. (in Ukrainian)

Sait, C., & Ramazan, A. (2020). Investigation of correlation coefficient for forage and grain yield with related traits in oats. *International Journal of Plant Breeding and Crop Science*, *7*(3), 922–927.

Shah, L., Yahya, M., Shah, S. M. A., Nadeem, M., Ali, A., Ali, A., Wang, J., Riaz, M. W., Rehman, S., Wu, W., Khan, R. M., Abbas, A., Riaz, A., Anis, G. B., Si, H., Jiang, H., & Ma, C. (2019). Improving lodging resistance: Using wheat and rice as classical examples. *International Journal of Molecular Sciences*, *20*(17), 4211. DOI: https://doi.org/10.3390/ijms20174211

Stanca, A. M., Jenkins, G., & Hanson, P. R. (1979). Varietal responses in spring barley to natural and artificial lodging and to a growth regulator. *The Journal of Agricultural Science*, *93*(2), 449–457. DOI: https://doi.org/10.1017/S0021859600038144

State Standard of Ukraine DSTU ISO 520:2015 (ISO 520:2010, IDT). Cereals and legumes. Determination of the 1,000-grain weight (to replace GOST 10842-89 (ISO 520-77)). Kyiv, Ukraine. (in Ukrainian)

Tanhuanpää, P., Manninen, O., Beattie, A., Eckstein, P., Scoles, G., Rossnagel, B., & Kiviharju, E. (2012). An updated doubled haploid oat linkage map and QTL mapping of agronomic and grain quality traits from Canadian field trials. *Genome*, *55*(4), 289–301. DOI: https://doi.org/10.1139/g2012-017

Tumino, G., Voorrips, R. E., Morcia, C., Ghizzoni, R., Germeier, C. U., Paulo, M. J., Azzimonti, G., Bellato, S., De Vita, P., Marè, C., Sanguineti, M. C., Terzi, V., & Smulders, M. J. M. (2017). Genome-wide association analysis for lodging tolerance and plant height in a diverse European hexaploid oat collection. *Euphytica*, *213*, 174. DOI: https://doi.org/10.1007/s10681-017-1939-8

Volkodav, V. V. (2000). Methods of the state trials of agricultural crop varieties. Kyiv: State Commission of Ukraine for Testing and Protection of Plant Varieties. (in Ukrainian)

Wang, T., Li, F. M., Turner, N. C., Wang, B. R., Wu, F., Anten, N. P., & Du, Y. L. (2020). Accelerated grain-filling rate increases seed size and grain yield of recent naked oat cultivars under well-watered and water-deficit conditions. *European Journal of Agronomy*, *116*, 126047. DOI: https://doi.org/10.1016/j.eja.2020.126047

Winkler, L. R., Bonman, J. M., Chao, S., Yimer, B. A., Bockelman, H., & Esvelt Klos, K. (2016).

Population structure and genotype–phenotype associations in a collection of oat landraces and historic cultivars. *Frontiers in Plant Science*, *7*, 1077. DOI: https://doi.org/10.3389/fpls.2016.01077

Yan, H., Deng, D., Zhou, P., Peng, Y., Dong, X., Li, S., Wu, H., Liu, K., Yin, L., & Peng, Y. (2023). Dissecting the genetic basis of grain weight and size in common oat by genome-wide association study. *Journal of Cereal Science*, *114*, 103811. DOI: https://doi.org/10.1016/j.jcs.2023.103811

Yan, W., Frégeau-Reid, J., Pageau, D., & Martin, R. (2016). Genotype-by-environment interaction and trait associations in two genetic populations of oat. *Crop Science*, *56*(3), 1136–1145. DOI: https://doi.org/10.2135/cropsci2015.11.0678