Fagopyrum 42 (1): 5-17 (2025)

Research Paper

Expression of Useful Traits in Determinant Buckwheat Accessions in the East of Ukraine

Dmytro CHUIKO[1], Oleh TRYHUB[2]

[1] *State Biotechnological University, Department of Genetics, Breeding and Seed Production 61002, 44 Alchevskykh Str., Kharkiv, Ukraine.*

[2] *Ustymivka Experimental Station of Plant Production of the Yuriev Plant Production Institute of NAAS of Ukraine, Ustymivka, Poltavska Oblast, Ukraine.*

E-mail addresses of authors: chuiko93ua@gmail.com (DC); trygub_oleg@ukr.net (OT)

DOI https://doi.org/10.3986/fag0044

Received: January 15, 2025; accepted February 3, 2025
Key words: buckwheat, determinant, collection, breeding, productivity, development.

ABSTRACT

The article presents results of studying a collection of determinant buckwheat (*Fagopyrum esculentum* Moench) genotypes in the East of Ukraine. The purpose of the study was to select highly productive and stress-resistant genotypes for breeding. We noted a considerable variability of biometric and agronomic characteristics between genotypes. The highest productivity (3.2 g/plant) was recorded for accession UC0101058 (UA) and the highest thousand-kernel weight (37.4 g) was recorded for accession UC0100286 (BY). There was a strong positive correlation between the number of kernels per plant and productivity (r = 0.93). Using multivariate statistics methods, we distinguished major clusters of genotypes. Promising accessions (UC0100167 (UA), UC0101058 (UA), and UC0102186 (UA)) were selected for further breeding. Using principal component (PC) biplot analysis, we evaluated genetic relationships between the studied accessions and genetically distant genotypes (UC0101058 (UA), UC0100286 (BY), and UC0100963 (UA)) were identified as potential outliers.

INTRODUCTION

Buckwheat (*Fagopyrum esculentum* Moench) is one of the leading pseudocereals in Ukraine and several other countries worldwide. It is valued as a source of protein, flavonoids, rutin and as a gluten-free crop (Kasajima et al., 2024; Horash & Klymyshena, 2018; Ahmed et al. ., 2014). Today, buckwheat is grown all over the world as a niche crop and its acreage is constantly tending to decrease. Among the main reasons for the buckwheat acreage diminishment are poor adaptability of the crop to unfavorable growing conditions, relatively low yield, and breeding complexity, which in turn narrows the diversity of cultivars (Vilchynska et al., 2020; Kwiatkowski, 2023; FAOSTAT, 2024).

Buckwheat belongs to the family *Polygonaceae*, subfamily *Polygonoideae*, genus *Fagopyrum*, and species *Fagopyrum esculentum* Moench (Luthar et al., 2021; Tang et al., 2019). The genus *Fagopyrum*, according to *The Plant List* database (international taxonomy database), is represented by 24 approved species and several more are being discussed to be recognized. In Ukraine, common buckwheat (*F. esculentum* Moench) is only grown as an agricultural crop, while another species, Tartary buckwheat (*F. tataricum* (L.) Gaertn.), is a difficult-to-separate weed. Tartary buckwheat is grown as a field crop in Asian and some European countries. Since common buckwheat (*F. esculentum* Moench) is the main taxonomic species, the name and foremost description of the family and genus is based on *F. esculentum* Moench (Tryhub et al., 2020; Alekseyeva, 2004; Joshi et al., 2020).

By the end of 2024, 31 common buckwheat cultivars were registered in the State Register of Plant Varieties Suitable for Dissemination in Ukraine. Most of them were registered in the last 10 years. However, such cultivars (cvs.) as ‘Sumchanka’ and ‘Lileia’, which had been in the Register for almost 40 years, and cvs. ‘Hloriia and ‘Viktoriia’, which had been in the register for almost 60 years, were excluded in 2022 (UIPVE, 2024).

At the time being, buckwheat genome is not fully understood and being intensively investigated by biotechnological methods (Luthar et al., 2021). The growth and development of buckwheat plants, in particular the primary shoot growth cessation, are genetically controlled by a set of genes (*D-d, Dm-dm*). In buckwheat, indeterminate growth type is mainly controlled by dominant alleles of these genes and determinant growth type – by recessive alleles. These genes influence the hormonal balance of the plant, in particular levels of auxins, cytokinins, and gibberellins. Determinant growth type can result from epistasis (interaction between genes), when one gene suppresses or modifies the action of another. Existence of modifying genes that affect the degree of determinacy is also possible. Differences in promoters or regulatory sequences of genes responsible for syntheses of growth hormones can stop the primary shoot growth after inflorescence formation (Fesenko, 1968; Taranenko et al., 2010).

It is believed that determinant buckwheat plants may have evolved as a result of natural or induced mutations in genes that control the plant growth (Yatsyshen, 2014). Buckwheat determinacy is a polygenic trait, which is closely related to the regulation of growth processes and is controlled by changes in the expression of key genes regulating hormonal balance and shoot growth. The breeding of determinant cultivars is among today’s buckwheat breeding mainstreams. It is continuous elongation of the main stem leading to continuous formation of new branches of various orders and inflorescences as well as to continuous consumption of macronutrients by the plant to form rather vegetative mass than kernels, that is the main drawback of indeterminate buckwheat morphotypes (Vilchynska et al., 2023).

Determinant *F. esculentum* morphotypes have a number of beneficial features that make such cultivars useful for agriculture. Among such features, we can mention early and uniform ripening and enhanced resistance to lodging. Depending on pedo-climatic conditions and cultivation technologies, the productivity of plants of both morphotypes can vary significantly. Therefore, breeding for productivity is the main direction for buckwheat (Tryhub, 2012; Kabanets et al., 2018).

Our purpose was to select the best determinant buckwheat (*F. esculentum* Moench) genotypes according to a set of useful traits in the East of Ukraine for their further inclusion in breeding to create new high-yielding cultivars.

MATERIALS AND METHODS

The field studies on the collection of determinant common buckwheat (*F. esculentum* Moench) accessions were conducted in the experimental fields of the Department of Genetics, Breeding and Seed Production of the State Biotechnology University (formerly Kharkiv National Agrarian University named after V.V. Dokuchaev) in 2023–2024. The experimental fields are located in the central part of the Kharkivska Oblast (Dokuchaievske

Village, Ukraine), on the border of two natural and climatic zones (eastern forest-steppe and steppe; geographic coordinates - 49.902144, 36.446238).

The experimental plots were laid out in a breeding crop rotation in accordance with conventional methods. The predecessor was black fallow. Seeds were sown on May 15. Each studied accession was sown by hand in four replicates. The rows were 1 m long. The sowing rate was 60 germinable seeds per meter. The replicate plots were arranged systematically (Ermantraut et al., 2014). The crop was not additionally fertilized; herbicides were not applied. The soil in the experimental fields is Calcic Voronic Chernozem CL UE1 according to the FAO classification (Jahn et al., 2006).

A collection of 21 determinant common buckwheat accessions from Ustymivka Experimental Station of Plant Production of the Yuriev Plant Production Institute of NAAS of Ukraine was studied. The collection consists of buckwheat genotypes of different eco-geographical origins (Ukraine (UA) – 15 accessions, Belarus (BY) – 5 accessions, Russia (RU) – 1 accession). The common buckwheat accessions under investigation are described in the detail in Table 1.

Monitoring and records in the experimental plots were carried out in accordance with the “Methodological Instructions for Studying Collection Accessions of Corn, Sorghum and Groats Crops (Millet, Buckwheat, Rice)” (Shmaraev et al., 1968) and “Methods of State Variety

Table 1. *Characteristics of the F. esculentum Moench. accessions*

National Catalog ID	Region and country of origin	Name	Ploidy (n)
UC0100167	Poltavska Oblast (UA)	–	*
UC0100188	Poltavska Oblast (UA)	–	*
UC0100192	Poltavska Oblast (UA)	–	*
UC0100195	Poltavska Oblast (UA)	–	*
UC0100261	Primorsky Kray (RU)	Mariya	Diploid (2n)
UC0100286	Minsk Region (BY)	Svityaz	Tetraploid (4n)
UC0100963	Poltavska Oblast (UA)	–	*
UC0100992	Poltavska Oblast (UA)	–	*
UC0100999	Poltavska Oblast (UA)	–	*
UC0101005	Poltavska Oblast (UA)	–	*
UC0101006	Sumska Oblast (UA)	Krupynka	Diploid (2n)
UC0101007	Poltavska Oblast (UA)	–	*
UC0101010	Poltavska Oblast (UA)	–	*
UC0101058	Poltavska Oblast (UA)	–	*
UC0100329	Poltavska Oblast (UA)	–	*
UC0101981	Sumska Oblast (UA)	Yuvileina 100	Diploid (2n)
UC0101987	Minsk Region (BY)	Karmen	Diploid (2n)
UC0101197	Minsk Region (BY)	Smuglyanka	Diploid (2n)
UC0102186	Sumska Oblast (UA)	Sumchanka	Diploid (2n)
UC0102193	Minsk Region (BY)	Vlada	Diploid (2n)
UC0102204	Minsk Region (BY)	Lakneya	Diploid (2n)

Note: ** – ploidy level is not known.*

Trials of Agricultural Crops (Cereals, Groats Crops and Grain Legumes)" (Volkodav, 2001).

The weather during the field study period differed significantly. 2023 had the most favorable weather: the temperature was close to the multi-year average. August (23.2°C) and September (17.5°C) were warmer (the multi-year average was 20.5°C and 15.2°C, respectively). The precipitation amount in 2023 was sufficient for normal plant development. In May and June, the precipitation amount was 30.7 and 32.0 mm, respectively, which was less than the multi-year average (43.7 mm and 65.7 mm, respectively), but this was enough for timely emergence and plant development at the initial stages. In July 2023, there was an unprecedented precipitation amount of 153.8 mm, which was 234.8% relatively to the multi-year average. August and September 2023 were sufficiently wet. The precipitation amount in these months was 37.8 mm and 26.9 mm, respectively, which was less than the multi-year average (51.0 mm and 45.4 mm, respectively); however, due to the fact that the bulk of the precipitation fell as long torrential rains, the soil accumulated moisture.

In 2024, the weather was critical for the development of buckwheat plants. During the vegetation period, the temperature was high, significantly exceeding the multi-year average, specifically by 0.3°C in May, by 2.4°C in June, by 4.8°C in July, by 2.7°C in August, and 5.3°C in September. There was no or too little precipitation in these months, specifically 17.3 mm in May, which fell as short rains. This was not enough for buckwheat emergence. Because of lack of precipitation, buckwheat seedlings only emerged on June 14. June was the wettest month, with 49.3 mm of precipitation. Thanks to this amount, the main processes of buckwheat plant development occurred. In July and August, the precipitation amount was catastrophically low (18.5 mm and 7.0 mm, respectively); it fell as short sprinkles, which in combination with high temperatures resulted in rapid evaporation. In September, according to Kharkiv Regional Hydrometeorological Center, for the first time since 1945, there was no precipitation (0.0 mm) in the Kharkivska Oblast (Fig. 1).

Data were statistically processed in PAST 4.17 (Hammer & Harper, 2001). Cluster analysis with Euclidean

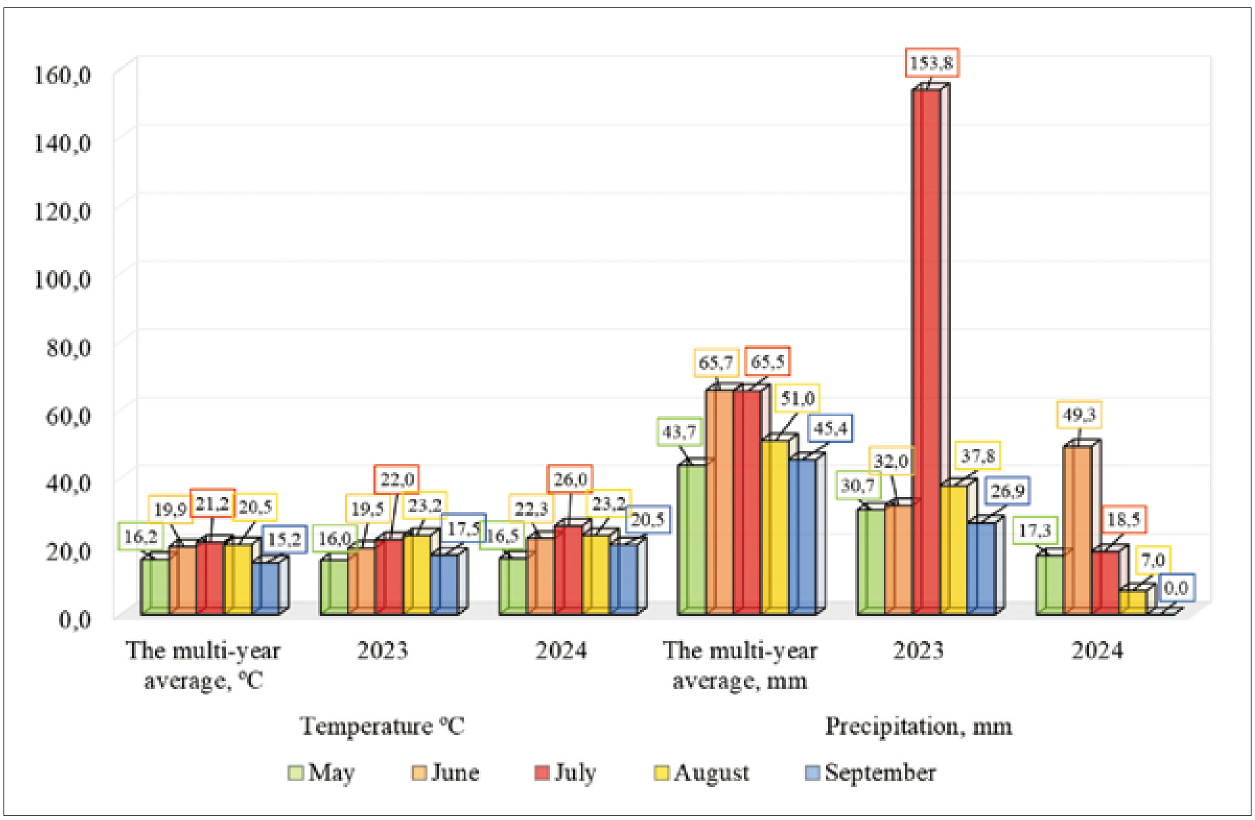

Figure 1. *Meteorological parameters in the study location, in 2023 and 2024.*

distances and Principal component (PC) biplot analysis were used to characterize the studied accessions. Relationships between traits were evaluated by Pearson's linear correlation analysis.

RESULTS AND DISCUSSION

Plant height in buckwheat is determined genetically, but, as in most agricultural crops, it is greatly influenced by growing conditions (Alekseyeva et al., 2004; Berry et al.,

Table 2. *Biometric characteristics in the common buckwheat collection, mean across the years.*

National Catalog ID	Plant height, cm	First node location height, cm.	Inflorescence attachment height, cm.	Branch attachment height, cm.	Number of internodes.	Number of internodes in the branching zone	Number of branches.	Number of leaves.	Number of inflorescences
UC0100167	83.6	4.2	35.8	18.5	11.6	5.8	4.4	25.2	25.0
UC0100188	83.2	5.6	39.0	19.2	12.3	5.8	5.2	36.5	25.2
UC0100192	66.3	5.2	31.5	19.6	9.6	5.5	3.7	30.3	22.1
UC0100195	79.4	4.8	37.2	20.5	12.4	5.3	3.8	31.4	25.9
UC0100261	96.4	5.6	34.8	15.9	14.4	6.0	5.4	45.9	43.7
UC0100286	88.1	6.5	37.3	18.1	12.4	4.8	4.4	35.5	27.6
UC0100963	98.5	5.2	37.5	16.6	12.4	5.4	4.2	47.4	37.9
UC0100992	70.5	5.4	33.3	23.7	9.8	4.9	4.1	35.2	23.8
UC0100999	67.1	5.1	32.1	13.3	12.7	4.8	3.3	31.7	23.7
UC0101005	68.7	6.2	35.0	21.2	10.5	4.1	3.9	38.3	24.3
UC0101006	75.3	6.2	37.8	22.2	10.8	5.1	4.0	29.1	19.9
UC0101007	64.7	5.4	28.0	11.7	9.3	4.7	4.3	29.0	20.7
UC0101010	90.3	4.8	37.3	19.1	11.4	6.0	5.3	39.1	30.2
UC0101058	77.3	5.3	35.5	16.6	11.6	5.4	4.0	32.2	22.8
UC0100329	69.8	5.0	35.8	13.3	9.4	5.0	4.1	30.0	16.7
UC0101981	87.8	4.9	34.7	18.8	11.5	5.6	4.4	31.4	23.3
UC0101987	90.8	5.7	38.2	15.2	11.5	5.4	4.3	37.0	28.0
UC0101197	85.3	4.9	38.3	24.8	11.8	5.5	4.3	33.0	21.7
UC0102186	88.4	6.4	37.2	20.1	12.1	5.6	5.0	42.1	27.6
UC0102193	72.1	5.9	37.2	18.7	10.3	5.0	4.1	26.7	16.6
UC0102204	72.5	5.2	42.9	24.8	9.9	4.6	4.8	27.5	17.8
Min	**64.7**	**4.2**	**28.0**	**11.7**	**9.3**	**4.1**	**3.3**	**25.2**	**16.6**
Max	**98.5**	**6.5**	**42.9**	**24.8**	**14.4**	**6.0**	**5.4**	**47.4**	**43.7**
Std. error	**2.3**	**0.1**	**0.7**	**0.8**	**0.3**	**0.1**	**0.1**	**1.3**	**1.4**
Coeff. var	**13.0**	**10.9**	**8.6**	**19.4**	**11.5**	**9.4**	**12.5**	**17.7**	**25.8**

2015). Based on plant height, we grouped the collection of determinant common buckwheat accessions in several groups. The tallest plants were recorded in accessions UC0101010 (UA), UC0101987 (BY), UC0100261 (RU), and UC0100963 (UA). The plant height ranged from 90.3 cm to 98.5 cm. The shortest plants (64.7-70.5 cm) were in Ukrainian (UA) accessions: UC0100192, UC0100992, UC0100999, UC0101005, and UC0101007. The coefficient of variation in this sample was medium (13.0%). Such peculiarities of the plant height distribution in the studied sample can be explained by their eco-geographical grouping and genetic features, which was also noted in other studies (Amelin et al., 2020; Kasajima et al., 2016; Kharchenko & Tryhub, 2018).

No significant differences were observed in the first node location height and inflorescence attachment height, which was evidenced by low coefficients of variation for these traits (10.9% and 8.6%, respectively). The height of the first node varied from 4.2 cm in accession UC0100167 (UA) to 6.5 cm in tetraploid buckwheat UC0100286 (BY). The lowest attachment of inflorescences (28.0 cm) was detected in accession UC0101007 (UA) and the highest (42.9 cm) – in accession UC0102204 (BY).

Branch attachment height is an important feature of the buckwheat plant architectonics and affects the productivity zone formation. In the collection under investigation, the coefficient of variation for this trait was relatively high (19.4%). The smallest and largest values of this trait were recorded for previously mentioned accessions UC0101007 (UA) and UC0102204 (BY): 11.7 cm and 24.8 cm, respectively.

The total number of internodes and the number of internodes in the branching zone are genetically quite stable, even allowing identification of genotypes by these traits. In our studies, the coefficient of variation for these traits was 11.5% and 9.4%, respectively. Accession sample UC0101007 (UA) had the fewest internodes (9.3) and accession UC0100261 (RU) had the most internodes (14.4). The number of primary branches on plants varied from 3.3 (UC0100999 (UA)) to 5.4 (UC0100261 (RU)).

Medium and high coefficients of variation for the studied buckwheat traits are typical for cross-pollinated crops in most cases and were also noted in other studies on buckwheat (Bisht et al., 2018; Roik & Lytvyniuk, 2004; Kabanets et al., 2017).

A large number of inflorescences and their poor provision with photosynthetic surface are among central problems in buckwheat growing. The mean leaf/inflorescence ratio per plant in this collection was 1.4:1.0 and, depending on genotype, was higher (for example, 1.8:1.0 in UC0100329 (UA)) or lower (for example, 1.0:1.0 in UC0100167 (UA) (Table 2).

Analyzing the collection for yield constituents, we noted a pronounced year-to-year variability in the genotypes. First of all, this can be attributed to different meteorological conditions during the growing period and the low amount of precipitation in 2024. It was found that tetraploid buckwheat UC0100286 (BY) had the least productive plants (1.1 ± 0.3 g) and accession UC0101058 (UA) had the most productive ones (3.2 ± 1.5 g.). A high productivity of 2.5 ± 1.8 g was also intrinsic to accession UC0100167 (UA). The coefficient of variation for this trait was high in the studied collection (23.8%), indicating big inter-accession differences.

Thousand-kernel weight is characterized by complex genetic impact. Kernel and fruit coat sizes are inherited independently, contributing to the evolvement of plants with winged fruits (Alekseyeva et al., 2004). In our collection, tetraploid buckwheat UC0100286 (BY) showed the greatest weight of thousand kernels (37.4 ± 4.3 g). At the same time, in the other diploid accessions and accessions of different/unknown ploidy, the value of this trait varied from 25.3 ± 3.9 g (UC0101987 (BY)) to 33.0 ± 1.0 g (UC0101007 (UA)).

The number of kernels per plant and the number of kernels per inflorescence are calculated indicators, which are related to each other. High coefficients of variation of 23.7% and 35.3%, respectively, were established for these traits. We distinguished accessions with the highest values of these traits: UC0101058 (UA), UC0102186 (UA), UC0100167 (UA), and UC0100261 (RU), which had 102.9 ±35.6, 81.1 ±68.6, 78.2 ±48.5, and 77.5 ±36.4 kernels per plant, respectively. Accessions UC0101058 (UA), UC0102186 (UA), and UC0100167 (UA) also had a lot of kernels per inflorescence: 5.6 ±4.2, 3.0 ±2.5, and 3.1 ±1.8, respectively (Table 3).

Analyzing the obtained data on the yield structure, we can conclude that the majority of buckwheat accessions studied in the East of Ukraine were highly productive, being, compared to studies in other ecological regions of Ukraine and the world, within the mean range of 2.0–3.0 g/plant (Amelin et al., 2020; Kasajima et al., 2016; Roik & Lytvyniuk, 2004; Bisht et al., 2018; Kabanets et al., 2017).

Correlation analysis revealed that there were no relationships between most of the investigated traits in this collection of buckwheat. Positive correlations were found between plant height and the following characteristics: inflorescence attachment height (r= 0.44), the number of internodes (r= 0.73), the number of internodes in the branching zone (r= 0.67), the number of branches (r= 0.61), the number of leaves (r= 0.67), and the number of inflorescences (r= 0.77). In addition, there was a negative correlation between plant height and the number of kernels per inflorescence (r= -0.52) (all r values are significant at P > 0.05).

It should be noted that the number of kernels per inflorescence was also negatively correlated with the following traits: the number of internodes (r= -0.48), the number of leaves (r= -0.55), and the number of inflorescences (r= -0.62). The number of kernels per inflorescence was positively correlated with productivity per plant (r=

Table 3. *Yield structure in the common buckwheat accessions, mean across the years.*

National Catalog ID	Productivity per plant, g ± SE	Thousand-kernel weight, g ± SE	Number of kernels per plant ± SE	Number of kernels per inflorescence ± SE
UC0100167	2.5 ±1.8	30.3 ±4.2	78.2 ±48.5	3.1 ±1.8
UC0100188	2.0 ±2.2	25.7 ±5.2	69.4 ±72.3	2.8 ±2.8
UC0100192	2.1 ±1.2	26.7 ±6.9	75.2 ±25.3	3.4 ±0.9
UC0100195	2.0 ±1.1	28.9 ±3.1	68.7 ±31.8	2.9 ±2.1
UC0100261	2.2 ±1.1	28.6 ±1.3	77.5 ±36.4	1.8 ±0.7
UC0100286	1.1 ±0.3	37.4 ±4.3	28.3 ±4.8	1.0 ±0.0
UC0100963	2.1 ±1.5	26.9 ±3.4	73.2 ±45.8	1.9 ±1.2
UC0100992	2.0 ±1.5	35.3 ±4.6	52.9 ±35.3	2.8 ±2.7
UC0100999	1.7 ±1.1	26.5 ±4.3	62.3 ±30.0	2.7 ±0.0
UC0101005	1.4 ±0.9	30.2 ±4.1	44.5 ±23.5	2.1 ±1.6
UC0101006	1.9 ±1.2	27.8 ±4.5	64.5 ±32.1	3.3 ±2.0
UC0101007	2.0 ±1.4	33.0 ±1.0	61.2 ±39.5	3.2 ±2.5
UC0101010	2.2 ±2.1	30.2 ±7.8	64.4 ±50.9	2.2 ±1.9
UC0101058	3.2 ±1.5	30.0 ±3.9	102.9 ±35.6	5.6 ±4.2
UC0100329	2.3 ±0.8	30.8 ±3.2	72.6 ±17.4	4.8 ±2.7
UC0101981	1.5 ±0.6	28.1 ±3.2	53.1 ±14.3	2.3 ±0.1
UC0101987	1.6 ±0.5	25.3 ±3.9	62.2 ±8.6	2.3 ±0.4
UC0101197	1.4 ±0.0	25.9 ±0.2	55.1 ±0.2	2.7 ±0.7
UC0102186	2.2 ±2.0	27.0 ±1.3	81.1 ±68.6	3.0 ±2.5
UC0102193	1.9 ±1.4	27.6 ±3.8	64.0 ±42.9	4.3 ±3.5
UC0102204	1.4 ±0.7	27.6 ±3.1	49.6 ±21.7	3.2 ±2.4
Min	**1.1**	**25.3**	**28.3**	**1.0**
Max	**3.2**	**37.4**	**102.9**	**5.6**
Std. error	**0.1**	**0.7**	**3.3**	**0.2**
Coeff. var	**23.8**	**10.8**	**23.7**	**35.3**

0.63) and with the number of kernels per plant (r= 0.61). Strong positive correlations were observed between productivity and the number of kernels per plant (r= 0.93) (all r values are significant at P > 0.05).

The peculiarity of the correlations in the buckwheat collection under investigation is that there was no correlation between plant productivity and thousand-kernel weight (r= -0.05), unlike other agricultural crops, which show strong correlations between these traits (Fig. 2).

Thus, when creating high-yielding buckwheat cultivars, breeding should be based on the number of kernels per plant and increased photosynthetic potential of the plant to provide flowering and fruiting with macronutrients. Similar conclusions were also drawn by other researchers and the correlation coefficients in their studies largely confirm our findings (Kabanets et al., 2017; Bisht et al., 2018; Strakholis et al., 2022).

Cluster analysis showed that the program logarithm required about 45 Euclidean steps to incorporate all clus-

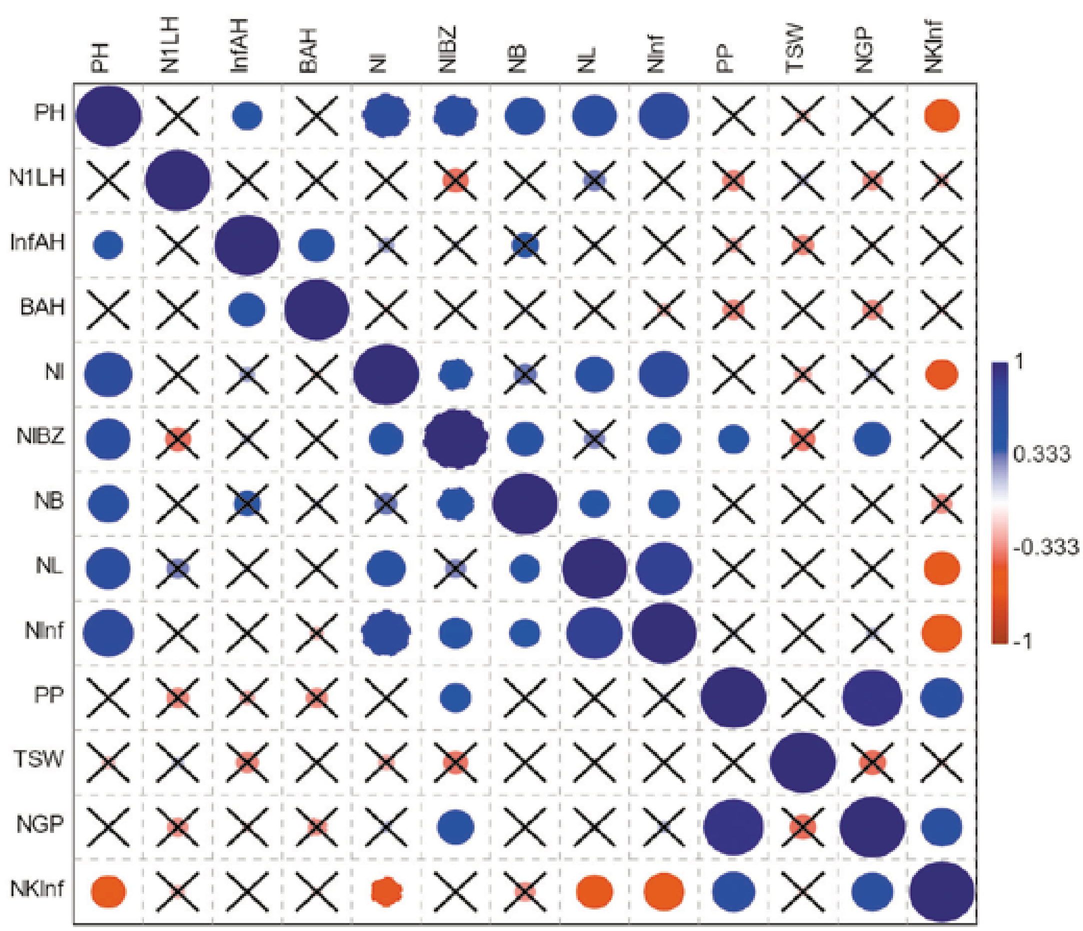

Figure 2. *Correlations between the studied characteristics in the determinant common buckwheat accessions.*
PH - plant height; N1LH – first node location height; InfAH - inflorescence attachment height; BAH – branch attachment height; NI - number of internodes; NIBZ - number of internodes in the branching zone; NB – number of branches; NL - number of leaves; NInf - number of inflorescences; PP - productivity plant; TKW – thousand-kernel weight; NKP - number of kernels per plant; NKInf – number of kernels per inflorescence.

ters. We distinguished four major clusters of the studied buckwheat accessions with a 25-step distance between them.

Tetraploid buckwheat accessions UC0100286 (BY) and UC0101058 (UA), due to their peculiarities of the traits under investigation, formed two separate clusters (clusters I and II), which were combined into one cluster as the most similar ones as the Euclidean distance was decreased. Cluster III formed by the program logarithm consisted of two accessions: UC0100261 (RU) and UC0100963 (UA), which had the largest photosynthetic surface, the greatest number of inflorescences, and the medium number of kernels per inflorescence. Cluster IV was largest and included 17 accessions. This cluster was divided into two major subclusters, which in turn formed smaller subclusters as the Euclidean distance was decreased.

Of such subclusters, the subcluster consisting of accessions UC0102186 (UA) and UC0100167 (UA) should be singled out, as they were noticeable for rather high values of yield constituents (plant productivity, thousand-kernel weight, number of kernels per plant, and number of inflorescences) and appeared to be most optimal in terms of plant height, the first branch attachment height, and the first inflorescence attachment height (Fig. 3).

Biplot analysis helped visualize relationships between the buckwheat accessions and the investigated traits and to establish major patterns in the data volume. From the plot, several conclusions can be drawn. The first principal component (PC 1) and the second principal component (PC 2) account for a significant portion of the data variations, confirming their feasibility for analysis and interpretation. PC 1 (X-axis) represents the greatest proportion of the variations associated with such traits as the number of kernels per plant. PC 2 (Y axis) introduces additional variations, focusing on other traits, such as plant height.

Most of the accessions are concentrated in the central part of the plot (near the origin of coordinates). This attests to their similarity in most of the investigated characteristics. Distant points such as UC0100286 (left) and UC0101058 (right) are potential outliers. Their distance may be attributed to specific or unique values of the investigated traits.

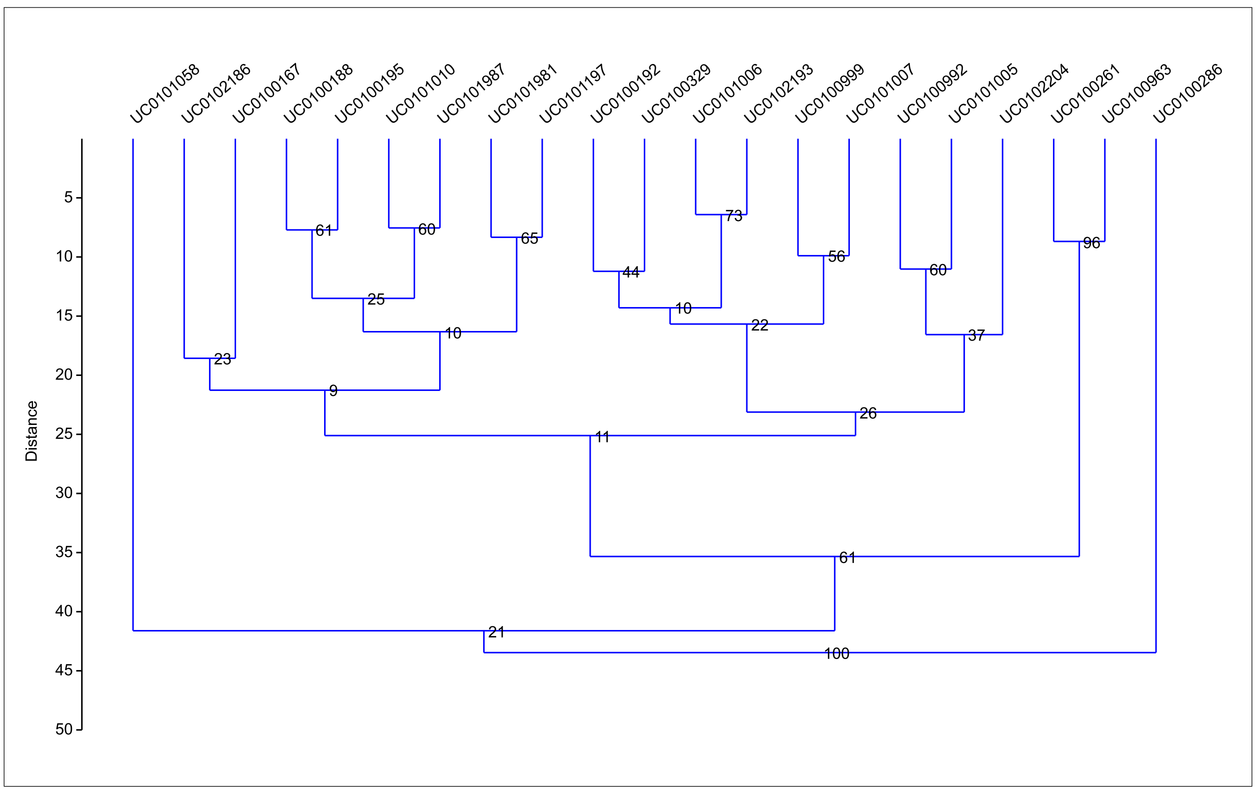

Figure 3. Cluster dendrogram.

The NKP (number of kernels per plant) and PH (plant height) vectors are at an acute angle, indicating a strong positive correlation between these traits. Perpendicular vectors (for example, PH and IAH (inflorescence attachment height)) indicate weak or no relationship between these traits. Traits with longer vectors, such as NKP and PH, make greater contributions to the differences between accessions, suggesting their importance for selecting promising genotypes.

Of the unique accessions, UC0101058 and UC0100286 were singled out, because UC0101058 had a lot of kernels per plant, which confirms its high productivity, and UC0100286, because it is distant from the main cluster, suggesting specific agronomic characteristics, which are primarily related to the ploidy level of this accession (Fig. 4).

Multivariate statistics in breeding is an effective method to select plant genotypes based on their useful characteristics. Cluster analysis and principal component analysis (PCA) are widely used methods in the breeding of different crops: buckwheat (Han et al., 2024; Singh et al., 2024; Vilchynska et al., 2017), wheat (Khodadadi et al., 2011; Rufati & Manasievska, 2022), rapeseed (Melnyk, 2013), sorghum (Enyew et al., 2021), etc. It is PC biplot analysis that allowed us to analyze the genetic kinship of the accessions or their distance.

CONCLUSION

The number of kernels per plant, the number of kernels per inflorescence, and the photosynthetic potential of plants were demonstrated to be the main character-

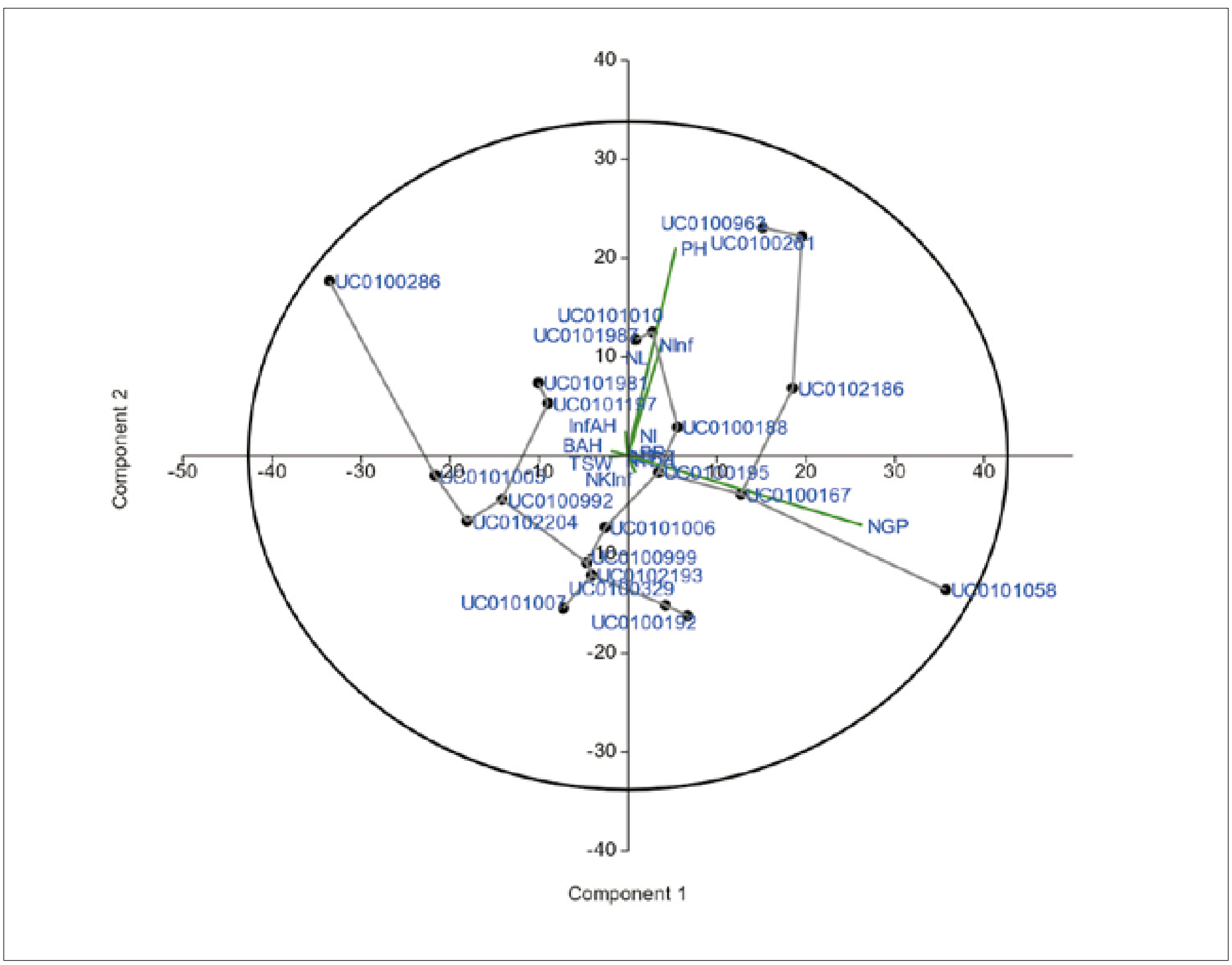

__Figure 4.__ PC biplot.

istics for the breeding of high-yielding determinant buckwheat cultivars. Accessions UC0101058 (UA), UC0102186 (UA), and UC0100167 (UA) showed the best values of the yield constituents. Accession UC0101058 (UA) was noticeable for the highest productivity and number of kernels (102.9 kernels/plant); accessions UC0100167 (UA) and UC0102186 (UA) were characterized by optimal combinations of plant height, productivity and kernel weight. Cluster analysis resulted in four clusters of genotypes. Despite the extreme weather factors in 2024, genotypes that can be used in determinant common buckwheat breeding for increased adaptability and productivity were selected for the conditions in the East of Ukraine.

Figure 5. *Terminal inflorescences of buckwheat plants of the determinant genotype originating from Poltava region (Ukraine), with the number of the national catalog of genetic resources UC0100963.*

REFERENCES

Ahmed, A., Khalid, N., Ahmad, A., Abbasi, N. A., Latif, M. S. Z., & Randhawa, M. A. 2014. Phytochemicals and biofunctional properties of buckwheat: A review. *The Journal of Agricultural Science, 152*(3), 349–369. https://doi.org/10.1017/S0021859613000166

Alekseyeva, Ye. S. 2004. Directions and prospects of buckwheat breeding. *Scientific Papers of the Institute of Bioenergy Crops and Sugar Beet, 7*, 79–84. [in Russian].

Alekseyeva, O. S., Taranenko, L. K., & Malina, M. M. 2004. Genetics, breeding, and seed production of buckwheat. Kyiv: Vyshcha Shkola, 213 p. [in Ukrainian]

Amelin, A. V., Fesenko, A. N., Chekalin, E. I., Fesenko, I. N., & Zaikin, V. V. 2020. Higher yielding varieties of common buckwheat (*Fagopyrum esculentum* Moench) with determinate growth habit (single mutation det) manifest higher photosynthesis rate at stage of grain filling. *Acta Agriculturae Slovenica, 115*(1), 59-65. DOI: http://dx.doi.org/10.14720/aas.2020.115.1.1316

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. DOI: https://doi.org/10.1007/s10681-014-1286-y

Bisht, A. S., Bhatt, A., & Singh, P. 2018. Studies on variability, correlation, and path coefficient analysis for seed yield in buckwheat (*Fagopyrum esculentum* Moench) germplasm. *Journal of Pharmacognosy and Phytochemistry, 7*(5S), 35-39.

Ermantraut, E. R., Hoptsii, T. I., Kalenska, S. M., Kryvoruchenko, R. V., Turchynova, N. P., & Prysiazhnyuk, O. I. 2014. Methodology of breeding experiments (in crop production). KhNAU named after V.V. Dokuchaev, 229 p. [in Ukrainian]

FAOSTAT. 2024. Crops and livestock products. Retrieved from https://www.fao.org/faostat/en/#data/QCL/visualize

Fesenko, N. V. 1968. Genetic factor determining the determinate plant type in buckwheat. *Genetika*, 4(4), 165-166. [in Russian]

Hammer, Ø., & Harper, D. A. 2001. Past: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1), 1-9.

Horash, O., & Klymyshena, R. 2018. Efficiency of selection in buckwheat breeding. *Bulletin of Lviv National Agrarian University. Agronomy, 22*(1), 96–100. [in Ukrainian]

Jahn, R., Blume, H. P., Asio, V. B., Spaargaren, O., & Schad, P. 2006. Guidelines for soil description. FAO.

Joshi, D. C., Zhang, K., Wang, C., Chandora, R., Khurshid, M., Li, J., ... & Zhou, M. 2020. Strategic enhancement of genetic gain for nutraceutical development in buckwheat: A genomics-driven perspective. *Biotechnology Advances, 39*, 107479. https://doi.org/10.1016/j.biotechadv.2019.107479

Kabanets, V. M., Strakholis, I. M., Berdin, S. I., & Onyshko, V. I. 2017. Performance of buckwheat initial material depending on the region of origin. *Bulletin of Sumy National Agrarian University. Series: Agronomy and Biology*, (2), 164-168. [in Ukrainian]

Kabanets, V., Strakholis, I., & Klitsenko, A. 2018. Breeding of buckwheat varieties of different morphotypes and their distribution in Ukraine. *Bulletin of Agrarian Science*, 96(11), 141-146. [in Ukrainian]

Kasajima, S., Namiki, N., & Morishita, T. 2016. Characteristics relating to the seed yield of determinate common buckwheat (*Fagopyrum esculentum cv. Kitanomashu*). *Fagopyrum, 33*, 1-5.

Kasajima, S., Yoshida, M., Ishiguro, K., Hara, T., & Otsuka, S. 2024. Effect of nitrogen topdressing on seed yield and flour protein content in semidwarf common buckwheat. *Fagopyrum, 41*(2), 41–47. https://doi.org/10.3986/fag0040

Kharchenko, Yu. V., & Tryhub, O. V. 2018. Diversity of initial buckwheat material and directions of its use in breeding. *Genetic Resources of Plants*, (22), 31-43. DOI: 10.36814/pgr.2018.22.03 [in Ukrainian]

Khodadadi, M., Fotokian, M. H., & Miransari, M. 2011. Genetic diversity of wheat (*Triticum aestivum* L.) genotypes based on cluster and principal component analyses for breeding strategies. *Australian Journal of Crop Science, 5*(1), 17-24.

Knez, M., Ranic, M., Gurinovic, M., Glibetic, M., Savic, J., Mattas, K., & Yercan, M. 2023. Causes and conditions for reduced cultivation and consumption of underutilized crops: Is there a solution? *Sustainability, 15*(4), 3076. https://doi.org/10.3390/su15043076

Kwiatkowski, J. 2023. Buckwheat breeding and seed production in Poland. *Fagopyrum, 40*(2), 29–40. https://doi.org/10.3986/fag0032

Luthar, Z., Fabjan, P., & Mlinarič, K. 2021. Biotechnological methods for buckwheat breeding. *Plants, 10*(8), 1547. https://doi.org/10.3390/plants10081547

Melnyk, A. V. 2013. Use of cluster analysis in selecting spring rape varieties and hybrids for cultivation in the Left-Bank Forest-Steppe of Ukraine. *Bulletin of Poltava State Agrarian Academy*, (4), 6-11. [in Ukrainian]

Roik, M. V., & Lytvyniuk, V. V. 2004. Breeding buckwheat for quality. Collection of Scientific Papers [Institute of Sugar Beets of UAAS], (7), 85-90. [in Ukrainian]

Shmaryayev, G. E., Yarchuk, T. Ya., & Yakushevskiy, E. S. 1968. Methodological guidelines for studying maize, sorghum, and cereal crops (millet, buckwheat, rice) collection samples. Leningrad: VIR Printing House, 51 p. [in Russian]

Strakholis, I. M., Berdin, S. I., & Kabanets, V. V. 2022. Parameters of buckwheat productivity formation by determinant varieties selection of the Institute of Agriculture of the Northern East of NAAS of Ukraine. *Agrarian Innovations, 14*, 161-166. DOI: https://doi.org/10.32848/agrar.innov.2022.14.23.

Tang, Y., Shao, J. R., & Zhou, M. L. 2019. A taxonomic revision of Fagopyrum Mill from China. *Journal of Plant Genetic Resources, 20*, 646–653.

Taranenko, L. K., Yatsyshen, O. L., & Palchuk, M. F. 2010. Characterization of determinant types of buckwheat varieties by quantitative and qualitative traits. *Collection of Scientific Works of the National Scientific Center Institute of Agriculture of NAAS*, (4), 208-212. [in Ukrainian]

Tryhub, O. V. 2012. Formation of buckwheat (*Fagopyrum* Mill.) polymorphism as a result of introduction. *Plant Genetic Resources, 10–11*, 116–122. [in Ukrainian]

Tryhub, O. V., Bahan, A. V., Shakalii, S. M., Barat, Yu. M., & Yurchenko, S. O. 2020. Ecological plasticity of buckwheat varieties (*Fagopyrum esculentum* Moench.) of different geographical origin according to productivity. *Agronomy Research, 18*(4), 2627–2638. https://doi.org/10.15159/ar.20.214

UIESR. 2024. State register of plant varieties suitable for dissemination in Ukraine for 2024. Retrieved from https://sops.gov.ua/ua/derzavnij-reestr [in Ukrainian]

Vilchynska, L. A., Horodyska, O. P., & Diyanchuk, M. V. 2020. Buckwheat selection for resistance to extreme environmental factors. *Faktory Experymentalnoi Evoliutsii Orhanizmiv*, *27*, 55–60. https://doi.org/10.7124/FEEO.v27.1302 [in Ukrainian]

Vilchynska, L. A., Horodyska, O. P., Kamina, O. O., & Diyanchuk, M. V. 2017. Cluster analysis in buckwheat breeding. *Bulletin of the Ukrainian Society of Geneticists and Breeders*, (15, No. 2), 145-149. [in Ukrainian]

Vilchynska, L. A., Leshchuk, N. V., Nochvina, O. V., Svynarchuk, O. V., Sydorchuk, A. I., & Kurochka, N. V. 2023. Comprehensive evaluation of morphological and economically valuable traits of common buckwheat (*Fagopyrum esculentum* Moench) varieties. *Plant Varieties Studying and Protection, 19*(2), 81-92. https://doi.org/10.21498/2518-1017.19.2.2023.282549 [in Ukrainian]

Volkodav, V. V. 2001. Methodology for examining varieties of cereals, pseudocereals, and legumes for suitability for dissemination in Ukraine. Kyiv: UIESR, 112 p. [in Ukrainian]

Yatsyshen, O. L., & Taranenko, L. K. 2014. Evolutionary mutations in buckwheat breeding for adaptability. *Collection of Scientific Works of the National Scientific Center Institute of Agriculture NAAS, 3*, 164–173. [in Ukrainian]

IZVLEČEK

Izražanje uporabnih lastnosti pri determinantnih rastlinah ajde na vzhodu Ukrajine

V članku so predstavljeni rezultati proučevanja zbirke determinantnih genotipov ajde (*Fagopyrum esculentum* Moench) na vzhodu Ukrajine. Namen študije je bil izbrati visoko produktivne in na stres odporne genotipe za žlahtnjenje. Opazili smo precejšnjo variabilnost biometričnih in agronomskih lastnosti med genotipi. Najvišja produktivnost (3,2 g/rastlino) je bila ugotovljena za vzorec UC0101058 (UA), največja teža tisoč zrn (37,4 g) pa za vzorec UC0100286 (BY). Obstajala je močna pozitivna korelacija med številom semen na rastlino in produktivnostjo (r = 0,93). Z multivariantnimi statističnimi metodami smo razločili glavne skupine genotipov. Za nadaljnje žlahtnjenje so bili izbrani obetavni vzorci (UC0100167 (UA), UC0101058 (UA) in UC0102186 (UA)). Z dvoplotno analizo glavne komponente (PC) smo ovrednotili genetske odnose med proučevanimi akcesijami in genetsko oddaljenimi genotipi (UC0101058 (UA), UC0100286 (BY) in UC0100963 (UA)), ki so bili identificirani kot potencialno izstopajoči.