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Front page photo: Inflorescence of Tartary buckwheat, cv. Zlata, see paper of Germ et al., page 21.

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Research Paper

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

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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

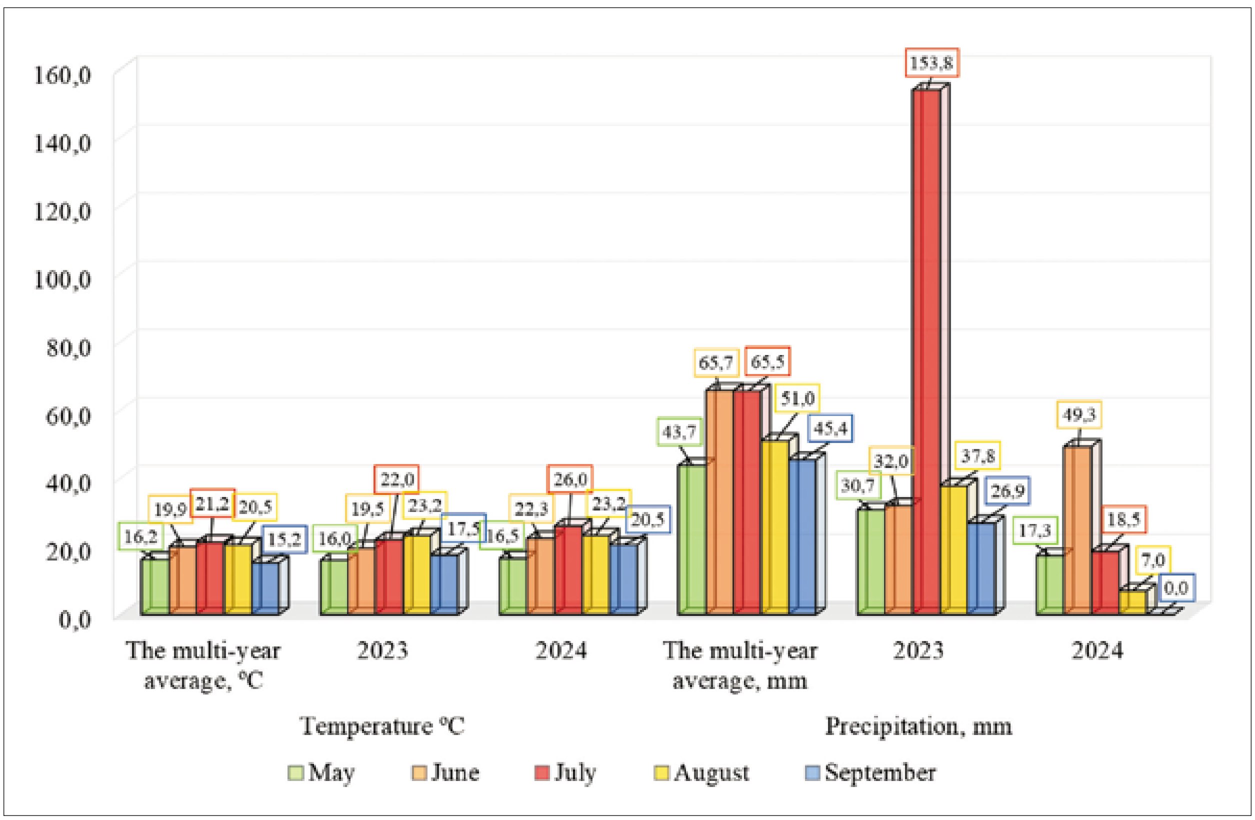

__Figure 1.__ Meteorological parameters in the study location, in 2023 and 2024.

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-

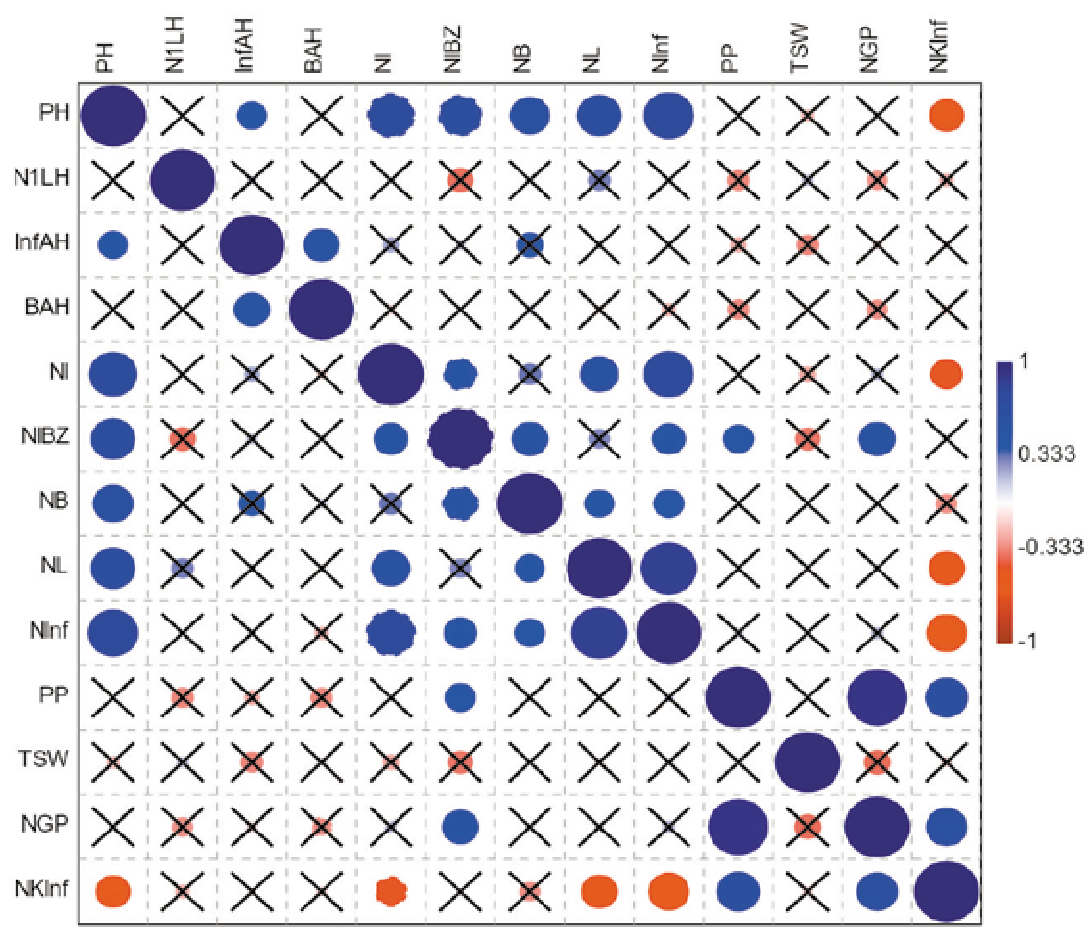

Figure 2. *Correlations between the studied characteristics in the determinant common buckwheat accessions.*
PH - plant height; N1LH – first node location height; InfAH - inflorescence attachment height; BAH – branch attachment height; NI - number of internodes; NIBZ - number of internodes in the branching 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.

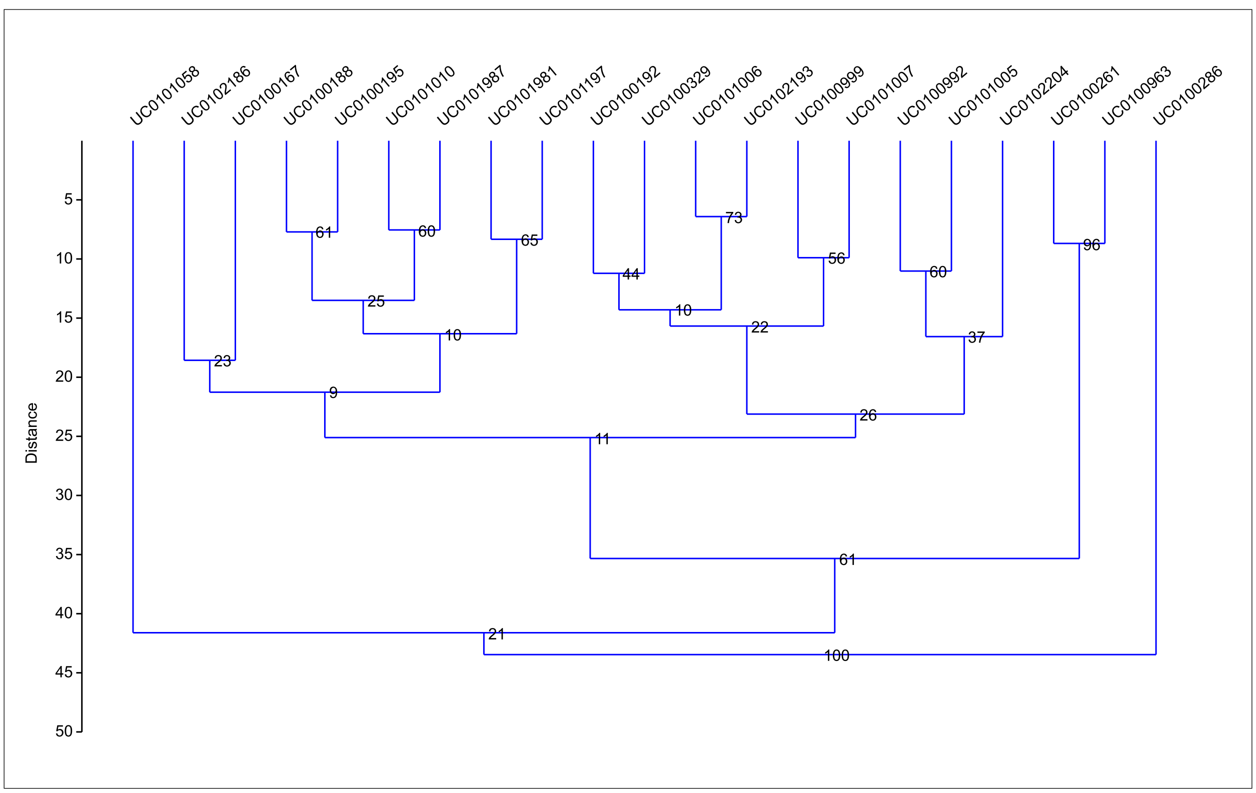

Figure 3. *Cluster dendrogram.*

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-

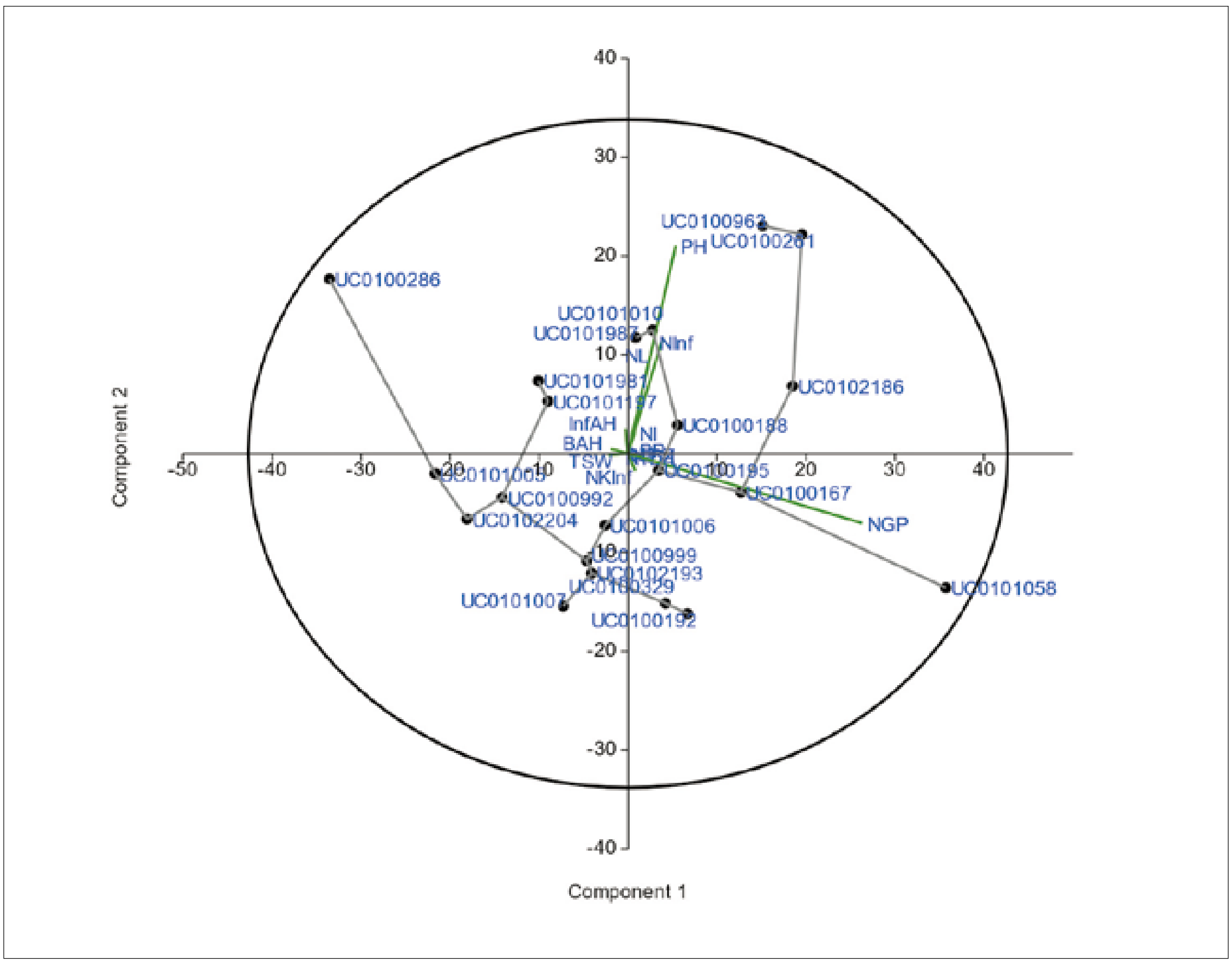

Figure 4. *PC biplot.*

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.

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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.

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Review

The potential of Si and Se as biostimulants to enhance resistance to climatic conditions and improve yields in common and Tartary buckwheat

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ABSTRACT

Common buckwheat and Tartary buckwheat are pseudocereals and grow worldwide. Due to the high concentration of flavonoids, buckwheats are potential sources of smart food. Tartary and common buckwheat are traditionally grown in mountain regions of China, Korea, the northern parts of India, Bhutan, and Nepal. Plants that grow in high elevations are exposed to intense UV radiation, which can harm susceptible sites in the plants. Plants defend themselves against intense radiation by synthesising UV-absorbing compounds. Drought will probably become more frequent and intense due to climate change. UV radiation and drought are environmental parameters that present stress to the plants. These impacts can be synergistic or antagonistic. Selenium (Se) and silicon (Si) can protect plants exposed to UV radiation or drought since Se acts as an antioxidant. Silicon is an abundant element in Earth's crust. It is present as a liquid or an amorphous or crystalline solid phase in the soil. Selenium and silicon are not essential elements for vascular plants, but they may positively affect plants. Thus, they can be added to the growth media to improve crop yield and quality, enhance resistance to abiotic and biotic stress and improve plant growth.

1 INTRODUCTION

Species of the genus buckwheat (*Fagopyrum* spp.) are assigned as pseudocereals and grow worldwide, as they have strong adaptability to many different environments (Ge and Wang, 2020) and are stress resistant (Jha et al., 2024). Due to flavonoids, buckwheat is also considered a smart food (Jha et al., 2024). Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) (Figures 1,2,3) originates in the Himalayan region. It expanded its distribution area to the southeast with the Yi people's migration. This is a minority in Southwestern China with a long history of cultivating Tartary buckwheat (He et al., 2024c). It was recently reported that, based on the whole-genome resequencing of many germplasm samples, two domestications occurred in southwestern and northern China. This led to diverse characteristics of modern Tartary buckwheat varieties (Zhang et al., 2021). Tartary and common buckwheat (*Fagopyrum esculentum* Moench) (Figures 1,4) are cultivated in the mountain regions of China, Korea, northern parts of India, Bhutan, and Nepal (Ohnishi, 1998; Zhang et al., 2017) and several European countries, USA, Canada, Brazil, Australia and recently in some countries in Africa.

Plants that grow in high elevations are subjected to intense UV radiation. Ultraviolet radiation can damage the vulnerable tissue in plants. That is why plants protect themselves by synthesising UV-absorbing substances, making a shield from UV radiation. Protective substances mainly belong to polyphenols, with aromatic rings of six carbon atoms, double ties, and groups bound to carbon atoms, frequently with attached OH or sugar components (Kreft et al., 2022).

Plants will probably be exposed to diverse environmental constraints in the future (Bernal et al., 2015). Due to climate change, extreme events, such as drought, are expected to become more frequent and intense (Pachauri and Meyer, 2014). Water limitation will have substantial negative impacts on crop production, affecting the mechanisms and growth of the plants (Aubert et al., 2021). UV radiation and drought may pose stress to the plants, which can be synergistic or antagonistic.

Selenium (Se) and silicon (Si) can protect plants exposed to UV radiation or drought (Mavrič Čermelj et al., 2022). Selenium can act as an antioxidant under abiotic and biotic stress (Feng et al., 2013; Hashem et al., 2022) and most often exists as organic selenium like selenoprotein, selenium polysaccharide and inorganic selenium like elemental selenium, selenate (Se(VI)) and selenite (Se(IV)) (Niu et al., 2020). However, the incorporation of SeCys and SeMet instead of Cys and Met, results in the

Figure 1. *Tartary buckwheat, cv. Zlata (left plot) and common buckwheat, cv. Darja (plot to the right, behind), grown at an elevation of 1100 m a.s.l. (above sea level) (Javorje, Črna na Koroškem, Slovenia).*

Figure 2. *Inflorescence of Tartary buckwheat, cv. Zlata, grown at the elevation of 1100 m a.s.l. (Javorje, Slovenia).*

Figure 3. *Tartary buckwheat, cv. Zlata, grown at the elevation of 1100 m a.s.l. (Javorje, Slovenia, photo Franc Stopar).*

production of non-functional proteins in plants, which is why the tolerance curve is very narrow, and Se can be toxic for plants already in low concentrations. Nevertheless, SeMet and SeCys are very efficiently utilised by the animal/human body (Srikanth Lavu et al., 2016). Silicon composes 28.8% of the continental crust and is an abundant element (Wedepohl, 1995). It is present in different forms and can be found in a liquid or an amorphous or

Figure 4. *Common buckwheat, cv. Darja, grown at the experimental field of Biotechnical Faculty, in Ljubljana, Slovenia, 300 m a.s.l.*

crystalline solid phase in the soil (Mavrič Čermelj et al., 2022). Silicon is not an essential element for vascular plants, except for horsetail (Equisetaceae), but it is an essential element for the diatom algae (Bacillariophyceae) (Chen and Lewin, 1969). Silicon has a positive effect on stress-exposed plants as well as on stress-free plants. Foliar addition of Si induced Si accumulation in shoots and grain production in soybean and rice (Felisberto et al., 2021). According to the results of the study on barley, it was reported that plants were stressed due to Si deficiency (Mavrič Čermelj et al., 2022). Biostimulants are different formulations of compounds, substances, and microorganisms that can be added as catalysts to the media for improving crop yield, quality, tolerance, and resistance to abiotic and biotic stress (Azad et al., 2021), enhancing plant growth (Szparaga et al., 2018).

2 RESPONSES OF BUCKWHEAT TO ENVIRONMENTAL PARAMETERS

2.1 Drought

Drought is a more and more common stressor for plants, including crops like buckwheat. There is little research regarding the effects of drought on buckwheat. Aubert et al. (2021) grew common buckwheat and Tartary buckwheat in a greenhouse under two water regimes: control and water stress. Common buckwheat and Tartary buckwheat responded differently to water stress. The vegetative growth was affected in the former but not in the latter. Water stress negatively affects growth parameters and stomatal conductance, transpiration rate, and photosynthesis rate in common buckwheat but not in Tartary buckwheat. The content of chlorophyll increased in water-stressed common buckwheat and Tartary buckwheat. Water stress affected the reproductive phase in both species (Table 1). According to the results, authors concluded that Tartary buckwheat is more resistant to water stress than common buckwheat. The research of Defalque et al. (2025) showed a greater impact of drought and high temperatures on generative development compared to vegetative growth in common buckwheat plants. Both species also have different strategies to cope with water limitations. Common buckwheat exhibited traits with drought avoidance characteristics, while Tartary buckwheat had drought tolerance characteristics (Aubert et al., 2021). The response to stress within a species may partially depend on the genotype/variety/cultivar (Yuan et al., 2024; Defalque et al., 2025). Recently Martínez-Goñi et al. (2024) stated that common buckwheat showed higher water-use efficiency and photosynthesis under drought than wheat and suggested this species as an alternative crop to wheat in the future. Recently, the effects of drought during the flowering phase on Tartary buckwheat's carbon and nitrogen metabolism were studied (He et al., 2024b). The authors found out that the treatment increases the antioxidant enzyme activities and activities of enzymes of carbon and nitrogen metabolism (Table 1) that increases the ca-

Table 1. *The effect of drought on morphological, physiological and biochemical properties of common (CB) and Tartary buckwheat (TB) (According to Aubert et al., 2021)*

Parameter	/Stress factor/species	CB	TB
Leaf production	drought	↓	–
Leaf FW	drought	↓	–
Leaf DW	drought	↓	–
Stomatal conductance	drought	↓	–
Transpiration rate	drought	↓	–
Photosynthesis	drought	↓	–
Chlorophyll fluorescence	drought	–	–
Chlorophyll content	drought	↑	↑
Antioxidant content	drought	–	↑
N of inflorescences	drought	↓	↓
Pollen production	drought	↓	↓

– No response ↑ increased ↓ decreased

pability of Tartary buckwheat to drought stress and also increases plant yield.

Sytar et al. (2023) emphasised in their study regarding drought effects on two common buckwheat cultivars that the impact of drought on phenolic compound substances encompasses the complexity of metabolic responses to environmental constraints. They also concluded that the studies, including genotype x environment interaction, are very important. Dziedzic et al. (2025) observed a slight decrease in most phenolic compounds in leaves, stems, seeds and husk of Tartary buckwheat exposed to drought stress.

We can conclude that common and Tartary buckwheat have different strategies for coping with drought and that drought affects the synthesis of phenolic substances in both buckwheat species.

2.2 UV and drought

Plants growing under natural conditions are continuously exposed to multiple environmental stressors. Climate change increasing the frequency and seriousness of droughts, so combination of high UV-B irradiance and drought particularly at mid to low latitudes is a big concern (Barnes et al., 2023). In the future, plants will probably be exposed to increased UV radiation and limited water supply simultaneously. Thus, Germ et al. (2013) studied the effect of the combination of enhanced UV-B radiation and water limitation on common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*) in semi-controlled conditions. The negative effect of elevated UV-B radiation on growth parameters in common buckwheat was highly significant in watered plants but less pronounced in plants exposed to water limitation. However, in Tartary buckwheat, UV-B radiation mitigated the adverse effects of water limitation, resulting in increased biomass production (Table 2). We can conclude that UV radiation and drought interfere with the response of both buckwheats.

At higher elevations, environmental conditions are harsher and impose constraints on the plants. Golob et al. (2022) cultivated common and Tartary buckwheat at different elevations (300, 600, and 1100 m a.s.l.). They reported that in common buckwheat grown at the high-

Parameter	/Stress factor/species	CB	TB
Chlorophyll content	Drought	↓	–
Chlorophyll content	Enhanced UV	↓	↓
Chlorophyll content	Drought x UV	↑	–
UV absorbing compounds	Drought	↑	↑
UV absorbing compounds	Enhanced UV	↑	–
Fv/Fm	Drought	–	–
Fv/Fm	Enhanced UV	–	–
ΔF/Fm'	Drought	↑	↓
ΔF/Fm'	Enhanced UV	–	↓
ΔF/Fm'	Drought x UV	–	↓
Stomata	Enhanced UV	↓ (closing stomata)	↓ (closing stomata)
Stomata	Drought	↓ (closing stomata)	↓ (closing stomata)
Biomass of seeds	Enhanced UV	↓	–
Biomass of seeds	Drought	↓	↓

– No response ↑ increased ↓ decreased

Table 2. *The effect of drought, enhanced UV radiation and combination on common (CB) and Tartary buckwheat (TB) (According to Germ et al. (2013)). Fv/Fm – potential quantum yield of photosystem II; deltaF/Fm' – quantum yield of PSII II*

est elevation, plants increased investment in secondary metabolism and decreased in primary metabolism; the synthesis of UV-absorbing compounds increased while the amounts of chlorophylls and carotenoids decreased. The amounts of UV-absorbing compounds and photosynthetic pigments were similar in plants grown at different elevations in Tartary buckwheat. The authors assume that this is because of the better adaptation of this species to conditions at higher elevations.

3 THE EFFECT OF BIOMINERALS ON BUCKWHEATS

3.1 Selenium

Another combination for the research is also interesting: UV radiation, which increases the formation of free radicals but is also an important environmental factor that regulates plant growth and development, and Se, an antioxidant that increases plant tolerance to various environmental constraints (Golob et al., 2018). Thus, the authors exposed hybrid buckwheat plants to full (+UV) and reduced (–UV) ambient UV radiation without (–Se) and with (+Se) foliar Se treatment (10 mg L^{-1} sodium selenate). Plants exposed to ambient UV radiation and Se treatment experienced a trade-off between primary and secondary metabolism. It means high levels of protective substances like anthocyanins, UV-absorbing compounds, and low levels of photosynthetic pigments. All plants grown in ambient UV radiation were shorter than those under the reduced UV, while biomass production was highest for plants without the addition of Se and under ambient UV radiation and lowest for ambient and Se-exposed plants. The authors found out that the addition of Se and conditions under ambient UV radiation separately positively affects the growth and production of hybrid buckwheat, while the combination of the addition of Se treatment and ambient UV leads to lower yields. It was concluded that under Se treatment and ambient UV radiation, the hybrid buckwheat had good protection against the different environmental constraints due to climate changes.

Similarly Breznik et al. (2005) in their experiment, exposed common (*Fagopyrum esculentum*) - CB and Tartary (*Fagopyrum tataricum*) - TB buckwheat to three levels of UV-B radiation and the addition of selenium. Plants grew outdoors from sowing to ripening. At week 7, they were foliarly sprayed with a solution containing 1 g (Se) m^{-3}. Elevated UV-B radiation, corresponding to a 17% reduction of the ozone layer, induced the production of UV-absorbing compounds. In both buckwheat species, the amounts of chlorophyll a were also lowered. In Tartary buckwheat, this negative effect was more evident when selenium was added. The effective quantum yield of PSII was reduced in both buckwheat species due to UV-B radiation, but the addition of Se ameliorated this effect. The content of UV-B absorbing compounds in leaves did not differ much between buckwheat species. Common buckwheat and Tartary buckwheat have similar potential to cope with stress due to UV-B radiation since the amount of UV-B and UV-A absorbing compounds was similar. The addition of Se treatment alleviated the stunting effect of UV-B radiation and lowering the biomass in common buckwheat. UV-B radiation and the addition of Se interfere with mechanisms of metabolic pathways that affect growth and development in common buckwheat and Tartary buckwheat.

3.2 Silicon

Silicon is a biostimulant with positive effects on plants, especially when exposed to stress conditions (Mavrič Čermelj et al., 2022). She et al. (2018) recorded that adding Si reduced the lodging degree in common buckwheat. Azad et al. (2021) showed that Si significantly influenced the growth and bioactive compound accu-

Table 3: *The effect of Si addition on common (CB) and Tartary buckwheat (TB) according to Azad et al. (2021).*

Parameter	Silicon	Species	
		CB	TB
Total phenolic content	Low dose	↑	↑
Total phenolic content	High dose	↑	↑
Total flavonoid content	Low dose	↑	↑
Total flavonoid content	High dose	↑	↑
Rutin	Low dose	↑	↑
Rutin	High dose	↑	↑
Plant fresh weight	Low dose	↑	↑
Plant fresh weight	High dose	↑	↑

↑ increased

mulation in both buckwheat species. Additionally, it was found that lower doses of Si enhanced the growth characteristics, total and single phenolic substances, total flavonoids, rutin, quercetin content, and antioxidant capacity in common buckwheat. Higher doses of Si had a similar effect on Tartary buckwheat (Table 3) (Azad et al., 2021). Qi et al. (2024) proved that Si alleviates the toxic effect of Al on buckwheat plants by limiting its accumulation in roots and increasing the activity of antioxidant enzymes (POD and APX), phenolic (flavonoid) content and free radical scavenging capacity (DPPH and ABTS). It can be concluded that the addition of Si enhanced the fitness of buckwheat in stress and in no stress conditions.

4 CONCLUSIONS

Common and Tartary buckwheat originate from high altitudes and contain high levels of secondary substances that protect them from UV radiation. Plants will be even more exposed to UV radiation and drought in the future because of climate changes. Research aimed at identifying and understanding the molecular mechanism of buckwheat tolerance to drought stress provides an opportunity to limit the effects of stress in new cultivars (He et al., 2024a; Li et al., 2025). Biostimulants such as Se and Si can protect plants. The addition of Se ameliorated negative effects of UV radiation in buckwheats. The addition of Si enhanced growth and bioactive compound accumulation in both buckwheat species.

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IZVLEČEK

Odziv navadne in tatarske ajde na okoljske parametre in dodajanje mineralov

Ključne besede: navadna ajda, tatarska ajda, UV sevanje, suša, elementi

Navadna ajda in tatarska ajda sta vrsti ajde, ki rasteta po vsem svetu. Zaradi visoke koncentracije flavonoidov je ajda živilo, ki ima pozitivne vplive na ljudi. Tatarsko in navadno ajdo tradicionalno pridelujejo v gorskih območjih držav, kot so Kitajska, Koreja, severni deli Indije, Butan in Nepal. Rastline, ki rastejo na visokih nadmorskih višinah, so izpostavljene močnemu UV-sevanju, ki lahko poškoduje občutljiva mesta v njihovih tkivih. Pred močnim sevanjem se

rastline branijo s sintezo UV-absorbirajočih spojin. Zaradi podnebnih sprememb bodo suše verjetno postale pogostejše in intenzivnejše. UV-sevanje in suša sta stres za rastline, vplivi so lahko sinergistični ali antagonistični. Selen (Se) in silicij (Si) lahko zaščitita rastline, izpostavljene UV-sevanju ali suši, saj Se deluje kot antioksidant. Silicij je eden najbolj razširjenih elementov v Zemljini skorji. Prisoten je v tleh v tekoči, amorfni ali kristalinični trdni fazi. Silicij ni esencialni element za višje rastline, vendar ima pozitiven učinek tako na rastline, izpostavljene stresu, kot tudi na rastline, ki niso izpostavljene stresu. Biostimulante, kot sta Se in Si, dodajajo gojitvenemu mediju za izboljšanje kakovosti pridelka, za povečanje odpornosti na abiotski in biotski stres ter za spodbujanje rasti rastlin.

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Review

History and Achievements of Buckwheat Breeding in the Republic of Tatarstan

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ABSTRACT

Common buckwheat (*Fagopyrum esculentum*) is an agricultural crop in the Russian Federation, which has been cultivated since the 15th century. Scientific breeding of buckwheat in the Republic of Tatarstan has a history of more than a century. During this time, 20 varieties of Tatar breeding have been included in the State Register of Breeding Achievements of the Russian Federation in different years. The article presents the history of breeding school and retrospective analysis of methods and achievements in buckwheat breeding at the Tatar Research Institute of Agriculture (before 1969 Kazan Republican Breeding and Experimental Station) on the basis of scientific reports of the laboratory of cereal crops and archival data.

Research work with common buckwheat (*Fagopyrum esculentum*) on the territory of the Republic of Tatarstan was first started at the Bugulma Experimental Station in 1912. Along with varietal studies, the development of the most important agro-techniques was carried out here, which helped to increase the yield of this crop in the Republic.

The first studies were carried out at the Shushar experimental field of the Arsk canton; it was there that work on the study of buckwheat variability was initiated, and the forms of *Fagopyrum esculentum* Moench, *F. emarqinatum* Roth, and *F. tataricum* Gaertner occurring in the Shushar area were described. The collected material was characterised by heterogeneity both in plant morphology, productivity and grain size. The maximum productivity of plants was 2.1 g with a 1000 fruit weight of 14 g. Average inflorescence productivity was negligible (0.1 g), plant productivity was ensured mainly due to abundant branching and prolonged flowering.

***Figure 1.** I.I. Stutzer, 1930*

During this period, using group selection methods, work was started on the study and selective improvement of local forms from peasant crops. Soon, convinced of the low efficiency of group selection, breeders switched to repeated individual selection from local populations, which remained the main method of selection until the early 1930s. This work had no practical completion in this period: the isolated medium-ripening and early-ripening large-fruited material was lost without a trace.

After the reorganisation of the Kazan Agricultural Experimental Station and its incorporation into the Verkhnevolzhsky Breeding Centre, breeding work with buckwheat was resumed under the leadership of Alexandra Filippovna Shubina and Tatiana Vasilievna Tikhonova. During this period, the source material was considerably expanded due to the samples of the VIR collection. Along with local samples, forms from Transbaikal, Buryato-Mongol, Bashkir, Mordovian Republics, Central Black Earth Region, Ukraine and Belarus were studied. The main method of creating genetic variability was self-pollination and repeated individual selection. A.F. Shubina published works on revealing the hidden variability in the gene pool of buckwheat, and the use of inbreeding as a method of liberation from undesirable recessive traits (1936). Involvement in hybridisation of isolated new forms, such as dwarfism, terry florets, green-floweredness, albinism was not realised by the development of a new variety due to the low economic value of the isolated forms. High-yielding, drought-resistant samples of Buryato-Mongol buckwheat, large-fruited samples of Transbaikal buckwheat and early maturing local forms were promising for breeding improvement at that time.

***Figure 2.** A.F. Shubina, 1932*

In order to create a variety with high yields, resistant to spring low temperatures and summer dry spells, attempts were made to develop the material on selective backgrounds of ultra-early sowing, and the study of reproductive biology of plants under drought conditions was initiated. However, even this work, due to limited volumes and methodological errors, did not result in the creation of a new variety.

It became effective since the discovery of highly productive old-growth seed material in the collective farm "Avangard" of the Yudinsky district of Tatarstan and involvement of the method of intervarietal hybridisation with individual selection from hybrid offspring in breeding work. In 1936, A.F. Shubina isolated several productive forms, one of which became the basis for breeding the variety "Kazanskaya Local". In 1938, this variety was zoned for a number of regions of the Non-Black Earth Region and TASSR, cultivated in crops until 1975. Due to its early maturity and drought resistance, it differed from the Bogatyr variety widely spread in those years with a higher stable yield and early ripening. In a competitive trial, the Kazanskaya local variety surpassed the standard and other varieties under breeding study by 15% with earlier ripening and fruit quality at the level of the standard variety Bogatyr.

From 1941 to 1945 at the Kazan Experimental Station a famous breeder and systematist Alexey Stepanovich Krotov worked with cereal crops. He began to study the effect of inter-sort free cross-pollination on buckwheat yield, obtained inter-sort hybrid populations from cross-pollination of local samples with varieties Kazanskaya, Bogatyr. The efficiency of the use of this method in breeding for increasing productivity, changing the vegetation period of hybrid offspring was shown. During this period, the main efforts of breeders were directed to the study of methodological issues of breeding and seed production, the causes of low drought resistance of buckwheat were analysed, the search for ways to protect crops from the effects of dry winds was conducted.

Since 1947, breeding work with buckwheat has been headed by Maria Nikolaevna Shumkova. Having analysed the reasons for the deterioration of the local population Kazanskaya in the process of seed production by progeny selection, and having summarised the results of intervarietal hybridisation, M.N. Shumkova started to create complex hybrid populations from free overpollination and to make selections from them. The method allowed to obtain two varieties of buckwheat - Kazanskaya 1 and Kazanskaya 26, but they did not spread due to the lack of advantage in yield, despite the rapid maturity and better technological qualities of fruits.

Figure 3. *M.N. Shumkova*

Analysis of the results of this period showed that the applied method of intervarietal crosses and formation of complex hybrid populations in the absence of reliable spatial isolation did not provide deep qualitative changes in the selected material. Even less effective was the method of re-pollination of mechanical variety mixtures, in which, regardless of the breeding value of the mixed components, there was only levelling of the traits on which selection was carried out.

Since 1968, a new stage in buckwheat breeding began at the Tatar Agricultural Experimental Station on the basis of the material formed by the outstanding breeder Natalia Nikolaevna Petelina at the All-Union Research Institute of Grain Legumes and Cereals. The original large-fruited diploid buckwheat gene pool created by her formed the basis for all subsequent buckwheat varieties of the Kazan period of her breeding activity, and was also used by other breeders during hybridisation as a source of economically valuable traits.

Figure 4. *N.N. Petelina*

Until the middle of the last century, the cultivated varieties were dominated by low-yielding, lodging, strongly branching and long flowering varieties from local populations.

To stabilise buckwheat yields at a higher level required a significant restructuring of the architectonics and biological nature of the buckwheat plant. Academician Engel Danilovich Nettevich, Professor Elena Semyonovna Alekseeva, Doctor of Agricultural Sciences Nikolai Valerianovich Fesenko and many other breeders of the Soviet Union who worked with buckwheat worked together with Natalia Nikolaevna to solve this complex problem.

To obtain genetic variability, along with vegetative-sex hybridisation, the method of polyploidisation was developed in breeding in those years. The first tetraploid buckwheat was obtained at the Institute of Biology of the USSR Academy of Sciences by Vladimir Vladimirovich Sakharov. From that moment in crosses conducted by N.N. Petelina, the tetraploid variety became an obligatory component - as a source of alien genetic material.

The first changes manifested themselves in the form of a slight enlargement of the seed, which were linked to a number of economically valuable plant traits. The material obtained formed the basis for the creation of a series of fundamentally new, high-quality large-fruited varieties. The first large-fruited varieties: Krasnostreletskaya and Mayskaya, released in 1971 - 1973, Kazanskaya large-grained - since 1983 widely cultivated in many buckwheat-growing regions of Russia, Ukraine, Belarus, Moldova and Kazakhstan.

Figure 5. *Planting a breeding nursery in 1972*

Natalia Nikolaevna laid the foundation for a fundamentally new method of creating source material and developed a new direction in buckwheat breeding. Her efforts and the work of her followers in the Tatar Research Institute of Plant Industry and Breeding, Siberian Research Institute of Plant Industry and Breeding, Samara Research Institute of Plant Industry and Breeding, Research Institute of Grain Farming of Kazakhstan created high-yielding large-fruited varieties of diploid buckwheat, the most important advantages of which are early maturity at high maturity, heat resistance and environmental plasticity, high quality of fruits and groats, manufacturability and cost-effectiveness of processing.

At present in Russian regions, about 300 thousand ha are sown with large-fruited buckwheat varieties of the Tatar Research Institute of Agriculture, the progenitor of which was the first large-fruited buckwheat variety Krasnostreletskaya, created by N.N. Petelina, which is about 20% of the area under buckwheat.

Since 1983 the work on buckwheat breeding in Tatar Research Institute of Agriculture was continued by N.N. Petelina's student Kadyrova Fanusya Zagitovna together with Galaktionova Vera Mikhailovna, Nizhegorodtseva Lubov Stepanovna, Kadyrova Luiza Ravilevna, Husnutdinova Alsu Tagirovna. During the years of joint work and subsequently created 16 varieties of buckwheat, which in different years have been zoned in buckwheat-sowing regions of the Russian Federation, the Republic of Moldova, Belarus and Ukraine. In co-operation with other breeding institutions of the Tatar NIISKh, buckwheat varieties Kuibyshevskaya 85, Irmenka, Shortanda large-grained buckwheat were developed.

Since this period and up to now, breeding work with buckwheat is aimed at increasing the adaptive potential of buckwheat varieties for regions with unstable agro-ecological conditionsThe method developed and tested in the Tatar NIISKh, which includes introgressive hybridisation with family-group selection of hybrid progeny on provocative backgrounds, is used in breeding for the increase of adaptive properties. This method of breeding allows to significantly expand the genetic variability of the source material for ecological stability of plants, as well as to improve the qualitative traits of yield. The result of work in this direction was a line of ecologically plastic and highly productive varieties, such as cold-resistant variety Kama and drought-resistant varieties Saulyk, Cheremshanka, Chatyr Tau.

In connection with the transfer of Kadyrova F.Z. to teaching, breeding work with buckwheat from 2017 continued at Kazan State Agrarian University and resumed again at the Tatar Research Institute of Agriculture, from 2022 under the guidance of her student Klimova Lilia Rafkatovna with the materials of her master's and PhD theses.

Figure 6 shows the yield dynamics of buckwheat varieties in the competitive variety trial of the Tatar Research Institute of Agriculture.

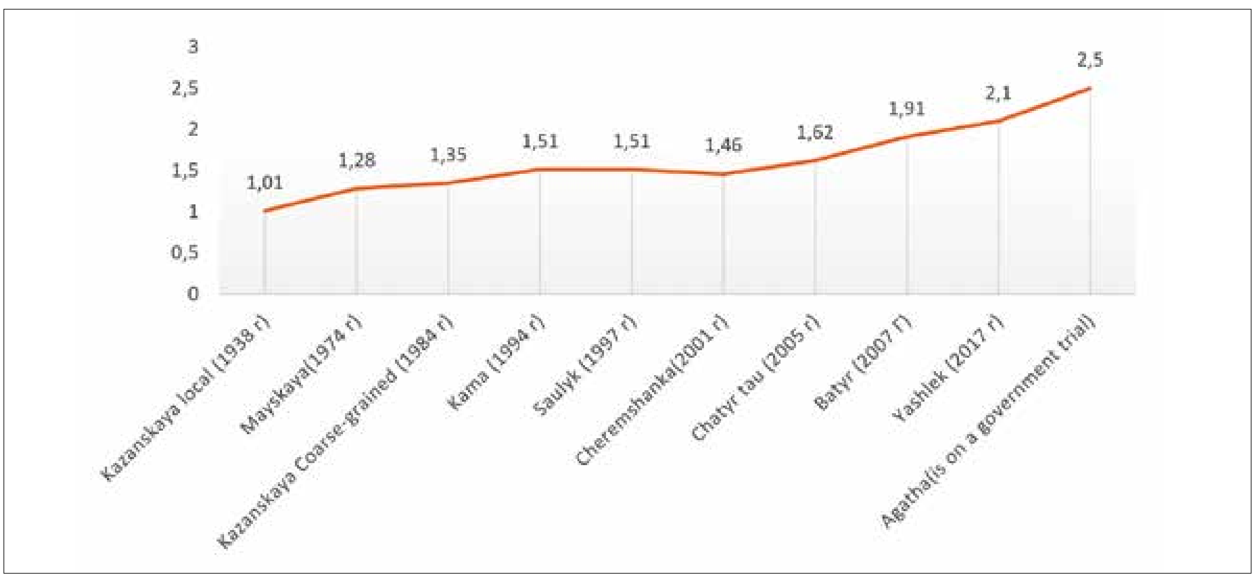

Figure 6. *Average yield of varieties obtained in the competitive variety trial, tonnes/ha*

Table 1 *- Morphostructural indices of* Fagopyrum esculentum *of TatNIISKh selection*

Variety name	Year of inclusion in the State Register	Plant height, cm.	Average number of nodes per plant, pcs.	Number of branches of the 1st order, pcs.	Number of inflorescences, pcs.	Grain weight per plant, g
Kazanskaya coarse-grained	1984	93.1	12.1	3.6	19.1	0.80
Kama	1994	85.4	10.7	3.6	17.9	0.92
Saulyk	1997	78.4	10.0	3.1	14.5	1.28
Cheremshanka	2001	76.3	11.2	3.6	19.2	0.92
Chatyr tau	2005	64.4	9.0	2.9	6.35	1.66
Batyr	2007	66.8	10.05	3.32	9.3	1.76
Yashlek	2017	63.9	9.29	2.43	6.5	2.29
Agatha	2024	60.9	9.11	2.48	5.5	2.52

Achievements of Kazan breeders of this century to create new varieties of buckwheat is the inclusion in the register of varieties allowed for cultivation in the regions of the Russian Federation, varieties Batyr (2008), Nikolskaya (2013), Yashlek (2017).

The data show that a noticeable increase in yield occurs with the involvement in breeding technology large diploid material and the first large-fruited varieties created by N.N. Petelina. Simultaneously with the increase in fruit size, over the years of breeding, the quality of the crop has increased due to the improvement of grain processing technology for groats, increase in the yield of pure kernel groats, its nutritional and dietary value.

In the last decade of the previous century and at the beginning of this century, the main trend in the creation of breeding material for the arid conditions of the Middle Volga region was the wide involvement of fascinated biotypes in the genetic basis of hybrid populations by selecting them from artificially created backgrounds unfavourable for buckwheat vegetation. This method contributed to an increase in the ecological plasticity of varieties, and an increase in the seed productivity of plants. It should be noted that these properties of varieties of Kazan varieties are manifested precisely in conditions with unfavourable period of crop formation, as evidenced by the data of varietal plots in the zones of their cultivation in the years of the State Variety Testing.

Significant changes have also occurred in the architectonics of the plant itself (Table 1). Polymorphism of populations created by selection of plants from extreme

Figure 7. *Varieties Mayskaya (1972); and Agatha (2024)*

backgrounds for vegetation allowed to form an optimal plant structure for these conditions.

Unproductive branching of plants was reduced, vegetative growth was reduced, the number of shoots and inflorescences decreased, but inflorescence size and seed production increased. Due to friendly and intensive flowering, better leaf supply of above-ground organs, the rate of attraction of plastic substances to fruits increased, and the dates of formation of the main part of the crop shifted to earlier dates. Short stems, stem thickening, its increased strength, reduction in the number and length of internodes in the branching zone of the stem, increase in the height of the first branch, which are characteristic of fasciated biotypes, allowed to shorten the time of crop formation and reduce grain losses at harvesting.

Buckwheat as a crop, corresponding to the conditions of biological farming, can become attractive for rural producers if it has the ability to form higher and more stable yields. Obviously, for this purpose it is important to increase the homeostasis of production processes in future varieties, which is able to keep the processes of plant vital activity at a stable level, which is possible by expanding the genetic diversity of the source material and the range of studied traits, moving from morphometric to a deeper assessment of physiological and biochemical properties of the material. Therefore, at present, the work of the buckwheat breeding laboratory is aimed at improving morpho-biological methods of evaluation, as well as the development and introduction of modern biotechnological and genetic studies in the process of creating new breeding material.

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IZVLEČEK

Zgodovina in dosežki žlahtnjenja ajde v Tatarstanski republiki

Navadno ajdo (*Fagopyrum esculentum*) na ozemlju Ruske federacije, pridelujejo že od 15. stoletja. Znanstveno podprto pridelovanje ajde ima v Tatarstanski republiki več kot stoletno zgodovino. V tem času je bilo v državni register žlahtniteljskih dosežkov Ruske federacije v različnih letih vključenih skupaj 20 sort ajde požlahtnjenih v Tatarstanski republiki. Članek prikazuje zgodovino žlahtnjenja in retrospektivno analizo metod ter dosežkov pri gojenju ajde na Tatarskem raziskovalnem inštitutu za kmetijstvo (pred letom 1969 se je imenoval Kazanska republiška žlahtniteljska in poskusna postaja) na podlagi znanstvenih poročil laboratorija za žita ter arhivskih podatkov.

4th European Buckwheat Symposium

2nd circular

DOI https://doi.org/10.3986/fag0047

University of Debrecen, IAREF Research Institute of Nyíregyháza and International Buckwheat Research Association (IBRA) are pleased to inform you that 4th European Buckwheat Symposium will be held on **3–5 September 2025 in Nyíregyháza**, Hungary.

EuroIBRA provides opportunity for dialogue and exchange of ideas between European buckwheat experts, so we welcome all interested parties both inside and outside Europe to the event.

Conference participants will have the opportunity to present their professional work, scientific results and practical experiences.

Planned program of the conference:	
02/09/2025	
-	Arrival to Nyíregyháza
03/09/2025	
9.00-10.00	Registration
10.00-10.30	Welcome by the University of Debrecen
10.30-12.00	Presentations
12.00-13.00	Lunch
13.00-14.30	Presentations
14.30-15.00	Coffee break
15.00-16.30	Presentations

Planned program of the conference:	
04/09/2025	
9.00-10.30	Presentations
10.30-11.00	Coffee break
11.00-12.30	Presentations
12.30-13.30	Lunch
13.30-14.30	Presentations
14.30-15.00	Coffee break
15.00-16.30	Presentations
18.00-	Gala dinner

Planned program of the conference:
05/09/2025
Visit/field visit to the Research Institute of Nyíregyháza and organized, farewell cultural program.

Planned topics of the conference:

- Genetic resources, germplasm collection
- Genetic and breeding
- Biotechnology, OMICS technology
- Physiology and responses to environmental conditions
- Cultivation technology and its development
- Nutritional values of buckwheat
- Food production and other processing technology

Registration fee includes: conference participation, gala dinner, 2 lunches, farewell cultural program (field visit and one-day excursion), publication of full text of lectures in Fagopyrum and online publication of abstracts.

Registration fee: 430 €

The official website with more details about the symposium/symposium venue/registration fee/accommodation is announced by the link:
https://konferencia.unideb.hu/en/4th-european-buckwheat-symposium

The conference will be held in traditional, in-person format.

Official language of the Symposium will be English.

SAVE THE DATE
3-5 September 2025.
See you in Nyíregyháza!

Nóra Mendler-Drienyovszki
mendlernedn@gmail.com

INSTRUCTIONS AND INVITATION TO SUBMIT THE MANUSCRIPTS TO FAGOPYRUM JOURNAL

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Manuscript should be written in standard English and submitted to the Editorial office as a word (.doc) document. Figures (photographs) should be IN SEPARATE FILE each in jpg or other original file, not imbedded in word .doc document or in PDF. Submission shall be sent to the email: ivan.kreft@guest.arnes.si. After reviewing by two reviewers and accepting the paper, the editorial office will ask the authors to provide the original figures if the first submission will not be adequate. Your manuscript should be sent to the Editor-in-Chief (Prof. Ivan Kreft). E-mail: ivan.kreft@guest.arnes.si

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Additional abstract in Slovenian will be for foreign authors made by the editors.

The literature references should be arranged alphabetically, in the text referred to as: author and year of publication, e.g., Budagovskaya (1998), (Inoue et al., 1998). If relevant, DOI number should be added at the end of the literature citation, in the suggested form: for example like https:/doi.org/10.1515/biorc-2015-0006 See last issues of the journal: (www.sazu.si/publikacije-sazu, Fagopyrum, »Preberi več«).

Deadline to submit the manuscripts for Issue 42 (2) is **May 30, 2025**. The issue is expected to be published on-line in June 2025.