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ADAPTIVE AND PRODUCTIVE POTENTIALS OF SPRING GARLIC OF THE COLLECTION OF UMAN NATIONAL UNIVERSITY OF HORTICULTURE**Yatsenko V.V., Yatsenko N.V., Ulianych O.I., Mostoviak I.I., Karpenko V.P.**

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Among vegetables, garlic is most susceptible to genetic erosion due to no sexual reproduction. **Purpose.** To evaluate the genotypic and phenotypic diversity of local forms of spring garlic in the forest-steppe of Ukraine in order to identify valuable specimens for the following characteristics: yield, adaptability, and essential oil content. **Methods.** In 2018–2022, 12 local and introduced forms of spring garlic were studied in the field. To analyze the data obtained, regression analysis was used to determine the stability and plasticity of the cultivars. **Results.** The variability of the spring garlic bulb weight was medium ($CV = 13\%$), however, in some accessions, this characteristic varied from 12% to 37%. Accessions 'No. 33', 'No. 44', and 'No. 55' had significantly greater bulb weights than the mean value: 27.01–28.84 g (+11.9–19.4% to X_{med}). Analyzing the number and size of cloves in the bulb, we selected accessions 'No. 14' and 'No. 33', which had the smallest total numbers of the largest cloves. In general, the clove distribution in the bulb was as follows: 56% of small cloves, 39% of medium-sized cloves, and only 5% of large ones. That is, in the studied sample, there was no accession with a preponderance of large or medium-sized cloves. By essential oil content, the studied accessions were categorized as food cultivars with a minimum content of 0.220–0.253 mg/100 g ('No.', 'No. 14', 'No. 52', 'No. 53', and 'No. 54') and technical ones with a high content of 0.370 and 0.373 mg/100 g ('No. 43' and 'No. 57', respectively). By yield, 'No. 33', 'No. 44', and 'No. 52' stood out, yielding 8.94, 9.95, and 9.07 t/ha, respectively, which was statistically significantly more than X_{med} by 18.7, 32.2 and 20.4%, respectively. Statistical analysis showed that 'No. 14' was the most stable in terms of this characteristic, while the other accessions were characterized as unstable with $b_i > 1$ and $\sigma^2_d > 0$. The results of statistical processing showed that the phenotypes (CV_p) of the studied traits in garlic were characterized by high heritability, which was changeable and depended on environmental conditions (CV_e) to a greater extent than on genotype (CV_g). **Conclusions.** Our study is an example of a description of the variability of local spring garlic cultivars and an approach to quantification of local adaptation that currently contributes to their preservation.

Key words: coefficient of environmental variation, coefficient of genotypic variation, stability, bulb weight, yield.

Introduction. Garlic is a diploid species that is widely cultivated around the world and in Ukraine in particular. This is one of the most important crops of the Alliaceae family and, as scientists believe, has been cultivated for over 5,000 years. The mean annual global production of garlic is about 25 million tons on 1.5 million hectares with a mean yield of 16.9 t/ha (FAO). Over the past 50 years, its mean yield in the world has increased by 66% (FAOSTAT) due to highly efficient breeding methods and farming culture. However to create domestic competitive garlic cultivars, one should study the genetic diversity of local and introduced forms for further breeding.

Review of Recent Studies and Publications. Sites of secondary diversity of domestic crops are

concentrated in the European continent (*Ramirez-Villegas et al.*, 2022). The southern part (Mediterranean center) of the continent was the primary center of domestication of many plant species (*Yatsenko*, 2021), in particular, extensive trade networks of dominant civilizations contributed to the appearance of exotic crops in the region (*Zaki*, 2022). The introduction of crops and their varieties (cultivars) led to the emergence of a large number of local cultivars (landraces) that are typical for traditional agriculture worldwide (*Vetelainen et al.*, 2009; *Liu et al.*, 2019; *Parhusip et al.*, 2023). According to *Rau et al.* (2015), *Ruiz-Aceituno & Lázaro* (2021), *Sych et al.* (2022), and *Akan* (2022), stochastic and demographic processes (mutation, drift, migration) plus farmer and natural se-

lection were the main drivers of landrace adaptation to the microclimate, as a result of which a large number of differentiated genetic groups emerged.

Researchers describe a certain degree of phenotypic variability within a botanical variety but argue that it has a unique sensory profile that is lost when grown outside its origin region (i.e., the excellent quality of a variety is controlled by "favorable" genotype-environment interactions).

Hundreds of garlic (*Allium sativum* L.) cultivars are available from seed companies, retailers, and private or public collections. Increasingly, bulbs intended for planting are purchased from non-local sources and the final yield can be unpredictable; garlic bulbs grown from purchased seeds in another region often do not have the declared characteristics (size, shape, and color of the bulb). This results from high variations of morphological features (tunic, bulb size, yield, and palatability), which depend on growing conditions, cultivars, and year of cultivation (Sych & Kubrak, 2020; Galgaye, 2023; Kebede et al., 2023).

The development of Ukrainian garlic production remains challenging, as the identity and characteristics of many cultivars are unclear (Yarovyj & Filimonova, 2019; Kubrak et al., 2021). The most used classification is based on the morphological description of cultivars (Engeland, R.L., 1991). However, garlic is able to adapt to its environment, resulting in wide ranges of morphological characteristics within a cultivar (Mossie et al., 2021; Shrestha et al., 2022). Another result is duplicate names for a genetically identical cultivar and a single name for cultivars with different characteristics. In some countries, for example in France, there is a system of classification and certification that facilitates the unification of marketed garlic cultivars and gives access to pure, disease-free lines of planting material (Abdelrahman et al., 2021; Tesfaye, 2021, Yatsenko, 2022). With a similar system, it would be easier to develop a competitive market for Ukrainian producers.

The first step in the development of such a system is collecting genetic material, elaboration of tools for identification and description of garlic cultivars, and investigations of adaptive and productive potentials. Morphological characteristics such as the number, size, and color of cloves and bulbs can be better indicators than the color, size, and palatability of the bulb, which vary in different environments (Polyzos et al., 2019; Yatsenko, 2021; Shemesh-Mayer et al., 2021; Yarovyj et al., 2021; Jia et al., 2023).

Since garlic is highly adaptable to growing environments, its yields remain unchanged or even may be increased when bulbs are introduced to similar conditions in another region (Lazo & Tuzon, 2022; Hadiawati, et al., 2022), so selection and evaluation of local forms of garlic are important steps in the crop breeding.

Purpose: to study the adaptive and productive potentials for yield, adaptability, and essential oil content in promising spring garlic (*Allium sativum* L. *subsp. vulgare*) accessions.

Materials and Methods. Garlic breeding was resumed at Uman National Agricultural University in 2016. Since then, a large number of breeding cultivars, landraces, and forms of garlic (winter bolters and non-bolters as well as spring garlic) have been collected.

In 2018–2022 in the Forest-Steppe of Ukraine, a study of the adaptive variability of spring garlic collection forms was conducted in the experimental field of Uman National University of Horticulture.

Collection accessions of different eco-geographical origins (Table 1) were studied; they were selected during expeditions and surveys of fields with landraces on peasants' farms.

Table 1. Origins of the test spring garlic accessions

Accessions No.	Country	Oblast/City
14	Ukraine	Ternopil'ska/Zbarazh
33	Ukraine	Cherkaska/Uman
43	Ukraine	Cherkaska/Uman
44	Ukraine	Cherkaska/Uman
51	Ukraine	Cherkaska/Uman
52	Ukraine	Kirovohrad'ska/Novoarkhanhelsk
53	Ukraine	Cherkaska/Uman
54	Ukraine	Cherkaska/Uman
55	Ukraine	Vinnytska/Vinnytsia
56	Ukraine	Vinnytska/Vinnytsia
57	China	–

The field investigations were conducted by traditional methods (Bondarenko & Yakovenko, 2001; *Methods of qualifying examination of varieties*, 2021). The experimental variants were arranged successively without replications; the record plot area was 10 m². Biometric parameters and individual performance were measured on 100 representative plants without replications.

The forecrops were early vegetables. Spring garlic was planted in the spring, at the first opportunity to go to the field, in wide rows (45x5 cm).

Essential oil content. The essential oil content was determined by hydrodistillation (Lawson & Gardner, 2005). *Genetic and statistical processing of data*

Most methods for assessing adaptability use regression analysis, the mathematical model of which for determining the stability and plasticity of varieties was proposed by K. U. Finlay and G. N. Wilkinson (Finlay & Wilkinson, 1963) and updated by S. A. Eberhart and U. G. Russell (Eberhart & Russell, 1966).

$$bi = \Sigma (X_{ij} \times I_j) / \Sigma I_j$$

where bi - regression coefficient of the trait of each (i^{th}) cultivar in an environment with improved or worsened conditions;

X_{ij} - trait value in the i^{th} cultivar in any j^{th} conditions;

I_j - index of the j^{th} conditions, which is the difference between the mean value of the trait across all cultivars in these conditions and the overall mean value of the trait across all experiments.

To systematize the results, we used the rank classification of genotypes with the following combinations of plasticity (bi) and stability (σ^2d) indicators: 1) $bi < 1$, $\sigma^2d > 0$ – better results under adverse conditions, an unstable cultivar; 2) $bi < 1$, $\sigma^2d = 0$ – better results under adverse conditions, a stable cultivar; 3) $bi = 1$, $\sigma^2d = 0$ – a cultivar responds well to improved conditions, stable; 4) $bi = 1$, $\sigma^2d > 0$ – a cultivar responds well to improved conditions, unstable; 5) $bi > 1$, $\sigma^2d = 0$ – better results under favorable conditions, a stable cultivar; 6) $bi > 1$, $\sigma^2d > 0$ – better results under favorable conditions, an unstable cultivar. At the same time, genotypes with $bi > 1$ are classified as highly plastic (relative to the group mean), and genotypes with $1 > bi > 0$ - as relatively low plastic. Nonlinear deviations from the regression line (σ^2d – stability): the lower the stability coefficient is, the more stable the cultivar is.

Homeostaticity (trait variation) of cultivars (H_{om}) was calculated by the following formula (Khangildin, 1984):

$$H_{om} = \frac{\bar{X}^2}{\sigma^2}, \text{ where}$$

\bar{X} – mean within the cultivar;

σ – pooled standard deviation.

The breeding value of a cultivar was calculated by the following formula:

$$BV_c = \bar{X} \times \bar{X}_{lim}/\bar{X}_{opt}, \text{ where}$$

\bar{X} – mean within the cultivar;

\bar{X}_{min} – minimal mean;

\bar{X}_{opt} – optimal mean.

Multiplicity coefficient (MC). To avoid a linear artifact of the regression coefficient, we used the multiplicity coefficient, which allows us to compare the trait variability. The higher the numerical value of this coefficient is, the stronger the trait changes (Dragavtsev et al., 1984):

$$MC = (\bar{X}_i + bi \cdot yi) / \bar{X}_i, \text{ where}$$

\bar{X}_i - mean of a studied trait in the i^{th} cultivar;

bi - coefficient of linear regression in the i^{th} cultivar;

yi - mean of all the mean values of all cultivars for each j^{th} experimental site.

The environmental plasticity index (EPI) was calculated by the following formula (Gryaznov, 1996):

$$EPI = (Y_1/MY_1 + Y_2/MY_2 + \dots + Y_n/MY_n)/n, \text{ where}$$

Y_1, Y_2, Y_n - trait value in a cultivar in different years of trials (yield of a cultivar in different years of trials);

MY_1, MY_2, MY_n - mean value of a trait in the cultivars in each of the experimental variants (mean yield of a cultivar per year).

The absolute average coefficient of adaptability (ACA) was calculated for a cultivar by the following formula (Zhivotkov et al, 1994):

$$ACA = (X_{iV} \times 100 \times X_{my}) / 100, \text{ where}$$

X_{iV} – mean yield of a cultivar across the trial years;

X_{my} - multi-year mean yield across the cultivars.

Stress resilience (Rossielle & Hemblin, 1981) and compensatory capacity (CC) (Weiner, 2004) (response [complex of reactions] of a biosystem to an adverse impact), which compensate or at least minimize consequences of structural and functional disorders, were determined using the formulas described by O. O. Goncharenko (Goncharenko, 2005):

$$SR = Y_{min} - Y_{max}$$

$$CC = (Y_{min} + Y_{max}) / 2, \text{ where}$$

Y_{min} and Y_{max} - minimum and maximum of the cultivar's trait.

In the experiments, the phenotypic, genotypic, and environmental variabilities of the cultivars were determined by the following formulas (Burton & De Vane, 1954; Shing et al., 1994):

$$\text{Genetic variance: } \sigma_g^2 = (s_p^2 - SE_p^2) / r;$$

$$\text{Environmental variance: } \sigma_e^2 = SE_p^2;$$

Phenotypic variance: $\sigma_p^2 = \sigma_g^2 + \sigma_e^2$.

Coefficient of genotypic variation (CVg):

$$\frac{\sqrt{\sigma_g^2 \times 100}}{\bar{X}}$$

Coefficient of phenotypic variation (CVp):

$$\frac{\sqrt{\sigma_p^2 \times 100}}{\bar{X}}$$

Coefficient of environmental variation (CVe):

$$\frac{\sqrt{\sigma_e^2 \times 100}}{\bar{X}}$$

where s_p – pooled standard deviation of the trait in a population;

SE_p – pooled standard error;

r – number of replications.

Narrow-sense heritability (h^2) was calculated by standard method:

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \left(\frac{\sigma_e^2}{n}\right)}$$

Barrow-sense heritability was calculated by Falconer's method (Falconer, 1989):

$$H_{Falconer}^2 = \frac{\sigma_g^2}{\sigma_p^2}$$

Data were statistically processed using arithmetic mean (\bar{X}) and standard deviation (SD) calculated in Microsoft Excel 2019; these parameters were used to assess significance of the differences in comparisons. Correlations were determined in Statistica 12.

Results. It was shown that, on average over five years, the variation in spring garlic bulb weight was medium (13%; 12–37% in individual accessions), but in some years (2019, 2020, and 2022), the variation amounted to 17–26% under the weather influence. Thus, the weather in 2018, 2020, and 2021 was most favorable for bulb weight and the mean bulb weight was 28.39 g. The weather in 2019 and 2022 was unfavorable for this characteristic and the bulb weight was 20.41 g and 15.13 g, respectively (Table 2).

Table 2. Adaptive capacity and breeding value of spring *Allium sativum L. subsp. vulgare* plants for the "bulb weight" trait, (2018–2022)

Accession	\bar{X}	$\sigma^2 d$	bi	Hom	BV _c	MC	EPI	SR	CC	ACA
No. 14	21.84	1.62	0.30	65.9	17.2	1.34	0.95	-7	22	0.90
No. 33	28.51	2.51	1.01	112.2	22.4	1.85	1.19	-19	29	1.18
No. 43	25.80	2.41	0.92	91.9	20.3	1.86	1.08	-17	27	1.07
No. 44	28.84	2.13	0.76	114.8	22.7	1.64	1.23	-12	29	1.19
No. 51	22.68	2.90	1.31	71.0	17.8	2.39	0.91	-23	20	0.94
No. 52	25.73	2.99	1.46	91.4	20.2	2.37	1.04	-23	26	1.07
No. 53	20.48	2.39	0.96	57.9	16.1	2.13	0.84	-15	19	0.85
No. 54	23.18	2.79	1.30	74.2	18.2	2.35	0.94	-20	22	0.96
No. 55	27.01	2.55	1.00	100.7	21.2	1.89	1.12	-18	24	1.12
No. 56	22.54	2.77	1.27	49.7	17.7	2.36	0.91	-22	21	0.93
No. 57	18.98	2.26	0.72	49.7	14.9	1.91	0.79	-16	20	0.79
\bar{X}	24.15									
σ_g^2	8.6									
σ_p^2	61.0									
σ_e^2	52.5									
CVg, %	12.1									
CVp, %	32.4									
CVe, %	30.0									
CVg/CVe	0.40									
h^2	0.33									
$H_{Falconer}^2$	0.86									

By bulb weight, accessions 'No. 33' and 'No. 44' stood out: 28.51 g and 28.84 g, respectively, which was statistically ($SD = 3.10$ g) significantly higher by 18.1 and 19.4% than the corresponding mean values. The bulb weights in 'No. 43' and 'No. 52' were higher than the mean weight (25.80 and 25.73 g, respectively, or 6.9 and 6.6% higher), but the differences were insignificant. Accessions 'No. 53' and 'No. 57' had significantly lower bulb weights than the mean weight (20.48 and 18.98 g, respectively, or 15.2 and 21.4% lower). The bulb weights in 'No. 51' (22.68 g), 'No. 54' (23.18 g), and 'No. 56' (22.54 g) were insignificantly lower than \bar{X} : 6.1, 4.0, and 6.6% lower than the mean weight, respectively.

Genetic and statistical analysis of this trait showed that 'No. 14' was the most stable (by σ^2d , MC, and Hom). As to combinations of plasticity (bi) and stability (σ^2d) parameters, 'No. 51', 'No. 52', 'No. 54', and 'No. 56' had $bi > 1$ and $\sigma^2d > 0$, i.e. they showed better results under favorable growing conditions. Accessions 'No. 14', 'No. 33', 'No. 43', 'No. 44', 'No. 53', 'No. 55', and 'No. 57' had $bi < 1$ and $\sigma^2d > 0$, i.e. they showed better results under adverse conditions.

Accession 'No. 14' was distinguished due to the stress resilience index (SR), which indicated its stable performance regardless of growing conditions ($SR = -7$). The accessions under investigation had more or less similar compensatory capacity (CC); however, 'No. 33', 'No. 43', and 'No. 44' had the highest values of this parameter, i.e. these accessions responded weakly to changes in environmental conditions.

The most adaptable accessions with ACA of > 1 were identified by absolute adaptability: 'No. 33', 'No. 43', 'No. 44', 'No. 52', and 'No. 55'. Accessions 'No. 14', 'No. 51', 'No. 53', 'No. 54', and 'No. 56' were classed as moderately adaptable and 'No. 57' was assessed as low-adaptable.

Results of statistical processing of data showed that the phenotype (CVp) of this trait depended rather on environmental conditions (CVe) than on genotype (CVg): the coefficient of environmental variation (CVe) was high (30.0%) and the genetic/environmental variation ratio (CVg/CVe) was medium (0.40). Vencovsky (1978) reported that high performance required a CVg/CVe ratio close to 1 or greater than 1, because in these cases the genetic variation was greater than the environmental variation, so selection driven by this trait would have the best results through the lens of clonal selection. In our study, the coefficient of

genotypic variation was lower than the coefficient of environmental variation, so the CVg/CVe ratio was significantly lower than 1.

The broad-sense heritability of this trait was high ($h^2_{Falconer} = 0.86$) and the narrow-sense heritability was considerable ($h^2 = 0.33$), indicating significant effects of external factors on this characteristic. High heritability for a trait means that it is least affected by environmental fluctuations and that phenotype-based selection will be efficient.

Oldenbroek & van de Waaij (2015) stated that there were several misconceptions about heritability: 1) "X heritability means that X% of a trait is determined by genetics." This is a very common mistake that arises from a misunderstanding of the definition of heritability. A heritability of 0.40 means that 40% of all phenotypic variations of a trait are attributed to variations in the genotype of this trait. This differs significantly from the misunderstanding that 40% of the trait expression in each plant is determined by genes and the rest - by other factors. 2) "Low heritability means that traits are not determined by genes." A heritability greater than 0 always indicates that genes influence the phenotype. Heritability is determined by genetic variance/phenotypic variance ratio.

Heritability estimate in a population depends on partition of the observed variability into components that reflect unobserved genetic and environmental factors. In other words, researchers recognize that there are genetic and/or environmental variations, but they may not be able to measure them directly. However, this does not prevent them from being able to estimate the relative influence of both genes and environment on the phenotype. Here, heritability can be estimated from empirical data on observed (empirical, broad-sense) and expected (narrow-sense) similarity between genotypes. The expected similarity between genotypes depends on assumptions about environmental and genetic determinants of the trait (Charmantier, & Garant, 2015). Interestingly, heritability is not constant and can change over time, as differences in genetic expression may change, variation induced by environmental factors may change, and gene-environment interactions may change. Genetic variance may change if new forms appear in the population (eg. through migration or mutation, which are common for garlic), or if existing forms only contribute to genetic variance after an altera-

tion in genetic background or the environment. The same trait measured throughout the life cycle (vegetation period) of garlic can be affected by different genetic and environmental factors; so deviations are a function of age and/or reproduction of vegetatively propagated plants. For example, differences in the bulb weight in the 1st reproduction are attributed to planting material weight and external conditions, while differences in the bulb weight in the 5th reproduction are caused by planting material weight, external conditions, and infections that were accumulated during the previous cycles of cultivation, but differences in planting material weight are unlikely to be influenced by factors of the parental form growing to obtain the 1st reproduction, which themselves have both genetic components and environmental conditions. Heritability can be manipulated by changing the environmental variance. Empirical evidence for morphometric traits suggests lower heritability in poorer environments. Understanding how heritability changes under the influence of environmental factors is important for understanding evolutionary drivers in natural populations.

Thus, a low heritability may indicate low genetic variance compared to phenotypic variance (both may be small). For example, the number of cloves in a garlic bulb is largely genetically determined, but since most genotypes used in current garlic breeding programs have very similar numbers of cloves, the genetic variance is very low.

Since it is clear that the variability in a biological population is a result of the genetic constitution of an organism and the prevailing environment, breeders can achieve the best result if the variance is largely determined by additional genes and evaluated with regard to heritability.

Analysis of the results on the spring garlic clove weight distribution helped to identify accessions with the maximum number of medium-sized and large cloves in the bulb. Thus, the total number of cloves varied from 9 to 17 per bulb, with the mean of 13.3. Accessions 'No. 43', 'No. 53', 'No. 55', and 'No. 56' were noticeable for large numbers

of cloves of 15-17, which was 13.0 - 28.1% more than the mean. The number of cloves in 'No. 44' and 'No. 52' was greater than the mean (14 or 5.5% more than the mean), but the difference was insignificant. Accessions 'No. 51' and 'No. 54' had significantly fewer cloves compared to the mean (12 or -9.6% from the mean). There were also significantly fewer cloves in 'No. 14', 'No. 33', and 'No. 57' (9-11 or 17.1-32.2% less than the mean) (Table 3).

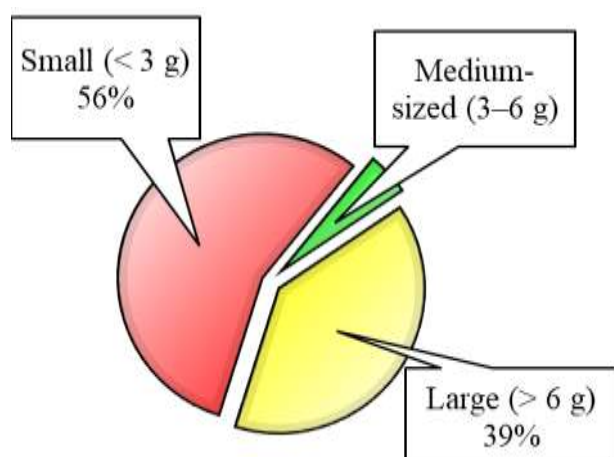
From the results of statistical processing, it can be seen that the total number of cloves depended rather on environmental conditions (C_{Ve}) than on genotype (C_{Vg}): the coefficient of environmental variation (C_{Ve}) was medium (19.4%) and the coefficient of genotypic variation/coefficient of environmental of variation ratio (C_{Vg}/C_{Ve}) was very low (0.09). The broad-sense heritability of this was high ($H^2_{\text{Facloner}} = 0.99$) and the narrow-sense heritability was low ($h^2 = 0.02$), indicating that genetic factors play a great role in the formation of the "number of cloves" trait and that this trait changes insignificantly under the influence of external conditions.

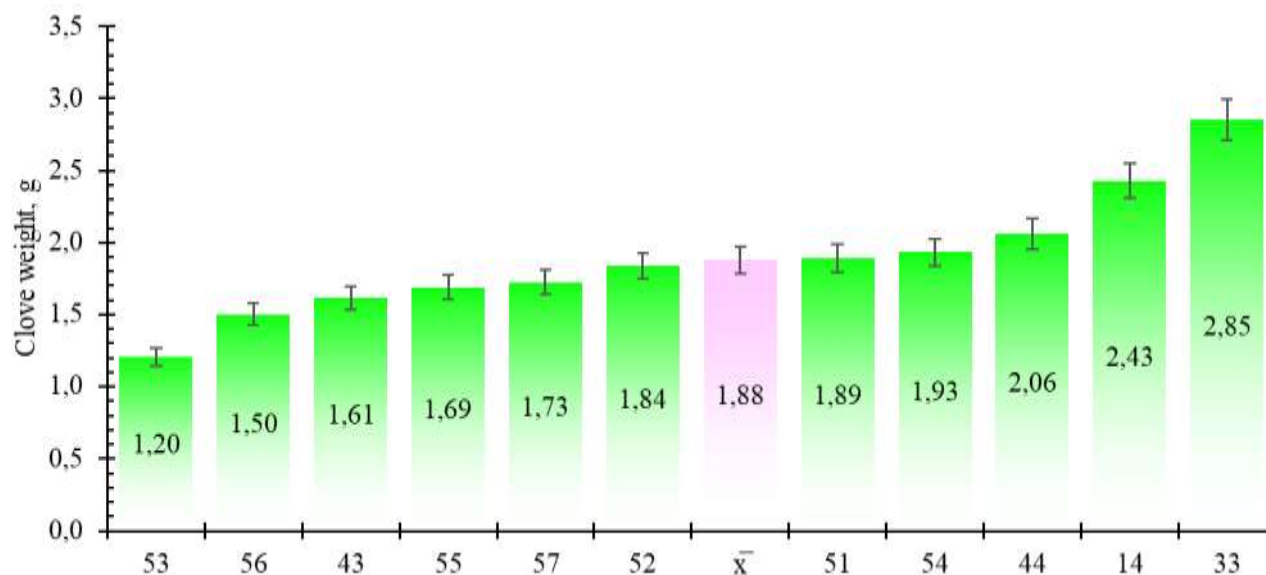
In general, the distribution of cloves in the bulb by size was as follows: small cloves accounted for 56%, medium-sized - for 39%, and the share of large cloves was only 5% (Fig. 1). That is, no accessions with predominant numbers of medium-sized or large cloves were found in the sample under investigation.

There was a significant differentiation of the accessions by mean clove weight; this characteristic ranged from 1.20 to 2.85 g. Accessions 'No. 14' and 'No. 33' stood out with the largest mean clove weights (2.43 and 2.85 g, respectively, or 28.8 and 51.3% higher than the sample mean). Accession 'No. 44' was noticeable for a significantly higher mean clove weight; the mean clove weights in 'No. 51' and 'No. 54' were higher than the sample mean, but the differences were insignificant; and in the other accessions, the mean clove weights were significantly lower than the sample mean (by 8.4-36.1%) (Fig. 2).

Table 3. Clove weight distribution in the collection spring garlic (*Allium sativum* L. subsp. *vulgare*) accessions (2018-2022)

Accession	Total number	Large (> 6 g)	Medium-sized (3–6 g)	Small (< 3 g)
No. 14	9±0.13	2±0.02	4±0.08	3±1.31
No. 33	10±0.30	3±0.10	3±0.10	4±1.69
No. 43	16±0.27	0	6±0.04	10±4.40
No. 44	14±0.32	0	5±0.07	9±4.00
No. 51	12±0.44	0	5±0.14	7±3.03
No. 52	14±0.52	0	6±0.18	8±3.55
No. 53	17±0.59	0	6±0.14	11±4.84
No. 54	12±0.42	0	4±0.12	8±3.38
No. 55	16±0.33	0	8±0.14	8±3.44
No. 56	15±0.23	0	4±0.16	11±4.64
No. 57	11±0.28	0	6±0.07	5±2.14
\bar{X}	13.3	0.5	5.2	7.6
SD	2.53	0.99	1.34	2.57
CV, %	19	20	26	34
σ_g^2	0.06			
σ_p^2	6.72			
σ_e^2	6.66			
CVg, %	1.8			
CVp, %	19.5			
CVe, %	19.4			
CVg/CVe	0.09			
h^2	0.02			
H^2_{Facloner}	0.99			

**Fig. 1.** Averaged distribution of cloves in the bulb by weight in spring garlic *Allium sativum* L subsp. *vulgare*, %



Results of statistical processing									
$\bar{X} \pm SD$	σ_g^2	σ_p^2	σ_e^2	CVg, %	CVp, %	CVe, %	CVg/CVe	h^2	H^2_{Falconer}
1.96±0.20	0.04	0.46	0.42	10.6	34.5	32.9	0.32	0.24	0.91

Fig. 2. Mean clove weight in the collection spring garlic (*Allium sativum L. subsp. vulgare*) accessions, (2018–2022)

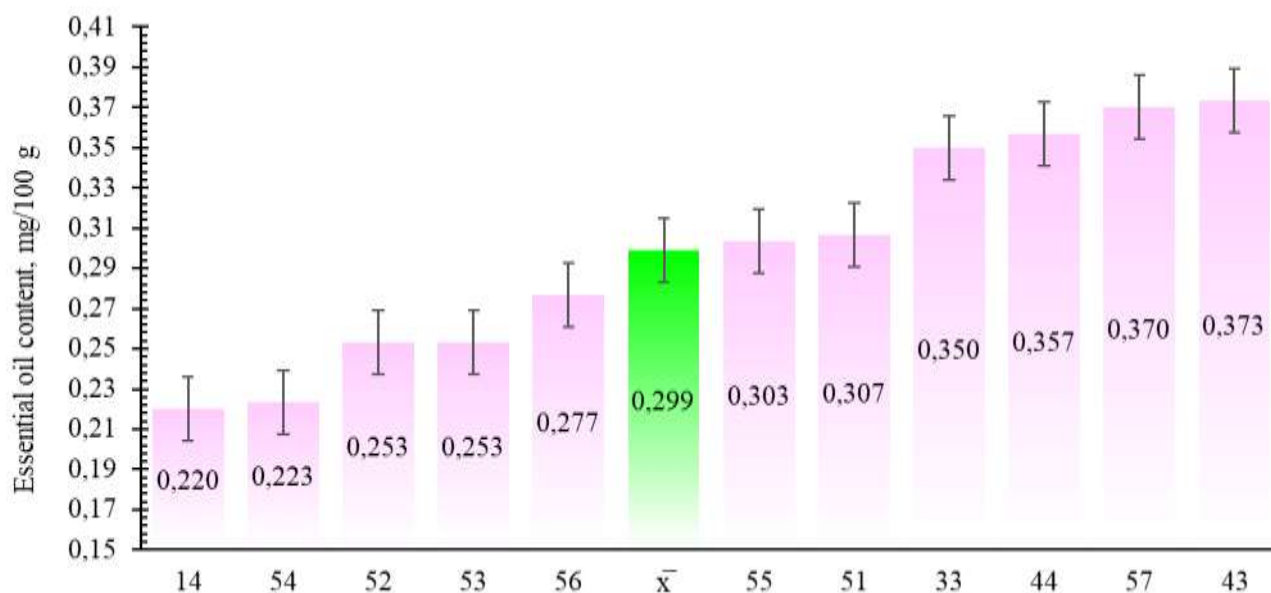
Screening of the accessions for essential oil concentration showed that the variability of this characteristic was moderate (CV= 18%); it ranged from 0.220 to 0.373 mg/100 g, i.e. all the studied accessions can be categorized as food cultivars. However, 'No. 43' (0.373 mg/100 g) and 'No. 57' (0.370 mg/100 g) had the highest concentration of essential oil. Accessions 'No. 14', 'No. 52', 'No. 53', and 'No. 54' accumulated the lowest levels of essential oil (0.220–0.253 mg/100 g) (Fig. 3).

Statistical processing revealed that the phenotype (CVp) of this trait depended to a greater extent on environmental conditions (CVe): the coefficient of environmental variation (CVe) was high (23.5%) and the coefficient of genotypic variation/coefficient of environmental of variation ratio (CVg/CVe) was medium (0.28). A moderate influence of the environment was also confirmed by low narrow-sense heritability of this trait ($h^2 = 0.19$) and high broad-sense heritability of 0.93%.

Analyzing the spring garlic yield over time, we found that the weather in 2018, 2020, and 2021 was most favorable for this parameter. On average, during the research period, the variation of this parameter ranged from 16 to 30%. The greatest

variation was noted in the unfavorable year for growing spring garlic (2022). Across the accessions, the variation was 15–37%. By yield, 'No. 33', 'No. 44', and 'No. 52' stood out: they yielded 8.94, 9.95, and 9.07 t/ha, respectively, which was statistically significantly (SD = 1.34 t/ha) more than the mean yield by 1.41, 2.42, and 1.54 t/ha or by 18.7, 32.2, and 20.4%, respectively. Accessions 'No. 43', 'No. 51', and 'No. 55' yielded more than the mean yield, but the differences were insignificant. Accession 'No. 54' yielded insignificantly less than the mean yield; and 'No. 14', 'No. 53', 'No. 56', and 'No. 57' yielded significantly less.

Genetic and statistical analysis of this trait showed that 'No. 14' was the most stable accession (according to σ^2d , MC, and Hom). By combination of plasticity (bi) and stability (σ^2d) parameters, all the accessions had $bi > 1$ and $\sigma^2d > 0$, i.e. they gave better results under favorable growing conditions, except for 'No. 14' with $bi < 1$ and $\sigma^2d > 0$ (i.e. it was stable regardless of growing conditions) (Table 4).



Results of statistical processing									
$\bar{X} \pm SD$	σ_g^2	σ_p^2	σ_e^2	CVg, %	CVp, %	CVe, %	CVg/CVe	h^2	H^2_{Facloner}
0.299±0.055	0.0004	0.0053	0.0049	6.5	24.4	23.5	0.28	0.19	0.93

Fig. 3. Essential oil concentration in cloves of the collection spring garlic (*Allium sativum L. subsp. vulgare*) accessions, (2018–2022)

Table 4. Adaptive capacity and breeding value of spring garlic (*Allium sativum L. subsp. vulgare*) plants for the "yield" trait, t/ha (2018–2022)

Accession	\bar{X}	$\sigma'd$	bi	Hom	BV _c	MC	EPI	SR	CC	ACA
No. 14	6.04	0.94	-0.39	15.1	4.4	0.52	0.93	-2	6	0.80
No. 33	8.94	1.57	0.36	33.0	6.5	1.30	1.21	-8	9	1.19
No. 43	8.02	1.34	0.21	26.6	5.8	1.20	1.07	-5	8	1.06
No. 44	9.95	1.45	0.16	40.9	7.2	1.12	1.31	-6	10	1.32
No. 51	7.59	1.48	0.35	23.8	5.5	1.34	0.94	-6	6	1.01
No. 52	9.07	1.72	0.75	34.0	6.6	1.62	1.08	-8	8	1.20
No. 53	6.33	1.38	0.44	16.6	4.6	1.52	0.78	-5	5	0.84
No. 54	7.22	1.55	0.61	21.6	5.2	1.64	0.91	-7	6	0.96
No. 55	7.72	1.41	0.17	24.6	5.6	1.16	1.11	-5	7	1.03
No. 56	6.50	1.56	0.61	12.3	4.7	1.71	0.88	-7	6	0.86
No. 57	5.45	1.27	0.21	12.3	4.0	1.28	0.77	-5	6	0.72
\bar{X}	7.53									
SD	1.34									
σ_g^2	0.8									
σ_p^2	6.7									
σ_e^2	5.8									
CVg, %	12.0									
CVp, %	34.3									
CVe, %	32.1									
CVg/CVe	0.37									

h^2	0.29
H^2_{Falconer}	0.88

By stress resilience (SR), 'No. 14' stood out; it indicates it showed higher performance under adverse growing conditions. By compensatory capacity (CC), the studied accessions varied significantly but 'No. 33', 'No. 43', 'No. 44', and 'No. 52' showed the highest performance; it means that they were able to maintain high performance when environmental conditions changed. By absolute adaptability (ACA), 'No. 33', 'No. 43', 'No. 44', 'No. 51', 'No. 52', and 'No. 55' were the most adaptable accessions with ACA of >1 .

Statistical processing revealed that the phenotype (CVp) of this trait depended rather on environmental conditions (CVe) than on genotype (CVg): the coefficient of environmental variation (CVe) was high (32.1%) and the coefficient of genotypic variation/coefficient of environmental of variation ratio (CVg/CVe) was medium (0.37). The broad-sense heritability of this trait was high ($H^2_{\text{Falconer}} = 0.88$) and the narrow-sense heritability was medium ($h^2 = 0.29$), indicating moderate dependence of this trait on both external conditions and genotype.

Discussion. Climatic variables such as air temperature and precipitation are major abiotic factors affecting plant growth and development. They induce ontogenetic development, in particular of onion plants, which can be observed during their vernalization (Sych & Kubrak, 2020; Sych et al., 2022). This may be manifested as an increase in the number of cloves per bulb and a decrease in their weight, which is consistent with our results (Yatsenko, 2022). Observations on domestic plants showed relatively low adaptability to climatic variables, such as periodic droughts, therefore, the genetic potential of yield cannot be fully used when weather changes (Tesfaye, 2021); these data are in agreement with our research, where the yield dropped/rose over the years depending on changes in environmental conditions. Therefore, it is necessary to search for genotypes capable of effectively adapting to adverse environmental conditions.

As Póvoa et al., (2023) and Huixia et al., (2023) noted, genetic and breeding research on garlic was challenged by a large and complex genome; very little was known about its sterility and genetic architecture of *Allium* traits. In this study, we observed moderate variations in the adaptability of garlic, which makes the selected accessions valuable sources of clove size distribution in the bulb, yield, adaptability, and essential oil concen-

tration for genetic and breeding studies. Studies by Prajapati et al. (2018) and Dinu et al., (2023) showed that the large clove was associated with increased adaptability and frost tolerance of the population. Accessions with many large cloves seem to be more frost tolerant. Historically, when humans began to domesticate plants, the selection of garlic for adaptation to cold environments was based on a large size of the bulb, while good performance of the crop is a result of folk breeding (Andrade et al., 2019). This hypothesis can well explain the differential evolutionary scheme for the "bulb weight" trait, which was confirmed by Yatsenko V. V. (2021). Our results once again confirmed this pattern and indicated that garlic genotypes constantly changed (mutated) under the influence of environmental changes.

In our study, the variability of all studied traits in different genotypes of garlic was measured by variance, coefficient of genotypic variation, coefficient of phenotypic variation, and heritability as a percentage of the mean. All investigated characteristics were considerably variable. CVg and CVp differed significantly, indicating a strong influence of environmental factors. These observations are in line with data obtained by Bebel, et al., (2021) and Saurabh, et al, (2021). A high coefficient of phenotypic variation ($>20\%$) was noted for yield (34.3%), bulb weight (32.4%), and essential oil content (24.4%); it was medium for clove weight (19.5%). A large difference between CVg and CVp indicates susceptibility to environmental changes while a small difference means a lesser environmental influence on trait expression. Traits with high CVg and CVp will be effective and contribute to yield improvement through selection. Garlic demonstrates a huge morphological diversity, even one cultivar of garlic is enough to observe a high phenotypic plasticity, which depends on soil type, precipitation, and climatic zone. Natural variability, even of a single trait or part of the plant, is of economic importance, presenting a possibility of breeding improvement of garlic. We established that all the traits under investigation had high values of broad-sense heritability of 86 to 99%. High heritability was recorded for clove weight (91%), essential oil concentration in cloves (93%), and the total number of cloves per bulb (99%); slightly lower values of this parameter were noted for bulb weight (86%) and yield (88 %). Traits with high heritability were less affected by changing envi-

ronments, which is consistent with results published by Akan, (2022) and Dixit et al., (2023).

Conclusions. Analysis of the obtained results helped to select the most promising accessions for creating new spring garlic cultivars. We selected promising spring garlic accessions with rather high performance. Accessions 'No. 33', 'No. 44', and 'No. 52' were selected due to their yields. Accession 'No. 14' was distinguished because of yield stability and minimal accumulation of essential oil. We also selected 'No. 33', 'No. 43', 'No. 44', and 'No. 57' with increased levels of essential oil. Involvement of the selected accessions with predetermined features in breeding programs will contribute to shortening the breeding process and increasing its efficiency.

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Conflict of interest

The authors declare that there is no conflict of interest regarding this publication.

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АДАПТИВНО-ПРОДУКТИВНИЙ ПОТЕНЦІАЛ ЧАСНИКУ ЯРОГО КОЛЕКЦІЇ УМАНСЬКОГО НАЦІОНАЛЬНОГО УНІВЕРСИТЕТУ САДІВНИЦТВА

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Серед овочевих культур часник найбільше піддається генетичній ерозії за рахунок відсутності статевого розмноження. **Мета.** Оцінити генотипову та фенотипову різноманітність місцевих форм часнику ярого в межах Лісостепу України для виявлення цінних зразків за ознаками: врожайність, адаптивність і вміст ефірної олії. **Методи.** Упродовж 2018–2022 рр. у польових умовах досліджували 12 місцевих та інтродукованих форм часнику ярого. Для аналізу отриманих результатів використали метод регресійного аналізу для визначення стабільності та пластичності сортів. **Результати.** Проведені дослідження показали середню варіацію маси цибулини часнику ярого ($CV = 13\%$), проте окремі зразки варіювали від 12 до 37%. Істотно більшу масу цибулини від середнього значення утворювали зразки за номерами 33, 44 і 55, де даний показник складав 27,01–28,84 г (+11,9–19,4% до X). Аналізуючи фракційний склад зубків у цибулині, виділено зразки за номерами 14 і 33, які мали найменшу загальну кількість та велику фракцію зубків. У загальному розподіл зубків у цибулині за фракціями мав наступний вигляд: 56% складала дрібна фракція, 39% середня і лише 5% – велика. Тобто, серед досліджуваних зразків не виявлено зразка з переважною більшістю середньої й великої фракції зубків. За вмістом ефірної олії виділено зразки в мінімальним її вмістом (№ 14 (0,220 мг/100 г), 52 (0,253 мг/100 г), 53 (0,253 мг/100 г) і 54 (0,223 мг/100 г) – столового призначення та з високим вмістом (№ 43 і 57 – 0,370 і 0,373 мг/100 г) – технічні сорти. За ознакою «врожайність» виділилися зразки за номерами № 33, 44 і 52, де даний показник був на рівні 8,94, 9,95 і 9,07 т/га, що статистично істотно більше від X на 18,7, 32,2 і 20,4%. Статистичний аналіз показав, що найбільш стабільним за даною ознакою був зразок № 14, а всі інші досліджувані зразки за співвідношенням показників $bi > 1$, $\sigma^2 d > 0$ характеризувалися, як нестабільні. Результати статистичної обробки показали, що фенотипове (CVP) формування параметрів ознак часнику має високу спадковість, яка змінюється і в більшій мірі залежить від екологічних умов (CVA) аніж від генотипу (CVG). **Висновки.** Наше дослідження є прикладом для опису мінливості місцевих сортів часнику ярого та підхід до кількісного визначення місцевої адаптації, яке зараз сприяє їх збереженню.

Ключові слова: коефіцієнт екологічної варіації, коефіцієнт генетичної варіації, стабільність, маса цибулини, врожайність