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Adaptiveness, selection and nutritional value of clonal populations of *Allium sativum* L. ssp. *sativum* in the forest steppe of Ukraine

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Abstract: The purpose of this study was to identify the degree of emergence and impact on the yield of weakened shoots of softneck forms of garlic and comprehensive study of the parameters of adaptive variability and selection value. During 2020–2022, nine local and introduced samples of garlic were studied in the field conditions. Research has established that the formation of a reduced flower-bearing shoot reduces the mass of the bulb by 7.6–31.1 %, and the yield by 6.1–38.6 %. The results indicate that the higher the relationship between the genetic and environmental coefficient of variation, the higher the heritability value. The following samples were selected as the starting material for further selection based on the yield: according to adaptability and ecological plasticity – Nos. 'A.s.16/16' and 'A.s.44/17'; in terms of stability – Nos. 'A.s.19/16', 'A.s.35/16' and 'A.s.43/17' and samples of the intensive type – 'A.s.16/16', 'A.s.27/16', 'A.s.33/16' and 'A.s.44/17', which will ensure high yields in optimal cultivation conditions. The obtained data will serve as the basis for the selection research scheme in the conditions of introduction in Ukraine. As a result of the research, a working collection of raw material was created for the selection of garlic.

Key words:: bulb mass, ecological variation, genetic variation, reduced scape, stability, yield

Prilagodljivost, selekcija in prehranska vrednost klonskih populacij česna (*Allium sativum* L. ssp. *sativum*) v lesostepju Ukrajine

Izvleček: Namen te raziskave je bil določiti velikost vznika in njegov vpliv na pridelek česna brez cvetočih poganjkov kot tudi obširnejša raziskava parametrov prilagodljivosti s selekcijsko vrednostjo. V rastnih sezonah 2020–2022 je bilo preučevanih devet lokalnih in tujih vzorcev česna v poljskih razmerah. V razsikavi je bilo ugotovljeno, da tvorba cvetočih poganjkov zmanjša maso čebulic za 7,6–31,1 % in pridelek za 6,1–38,6 %. Rezultati nakazujejo, da večje kot je razmerje med koeficientoma genetske in okoljske variabilnosti, večja je vrednost dedovanja. Naslednji vzorci so bili izbrani kot začetni material za bodočo selekcijo na osnovi pridelka: glede na prilagodljivost in ekološko plastičnost vzorca Nos. 'A.s.16/16' in 'A.s.44/17'; glede na stabilnost vzorci Nos. 'A.s.19/16', 'A.s.35/16' in 'A.s.43/17' ter vzorci intenzivnega tipa 'A.s.16/16', 'A.s.27/16', 'A.s.33/16' in 'A.s.44/17', ki zagotavljajo velike pridelke in optimalne pridelovalne razmere. Pridobljeni podatki bodo služili kot osnova za načrt selekcije pri uvajanju v razmere pridelovanja v Ukrajini. Kot rezultat raziskave je bila osnovana zbirka izhodiščnega materiala za selekcijo česna.

Ključne besede: masa čebulic, ekološka spremenljivost, genetska spremenljivost, zmanjšani cvetoči poganjki, stabilnost, pridelek

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1 INTRODUCTION

The Alliaceae family, which includes staple crops such as onions, garlic, leeks, and chives, is the second most important family of monocots after the Poaceae. Garlic (*Allium sativum* L.) is the main crop of the family after onion (*Allium cepa* L.) (Benke et al., 2020; Khandagale et al., 2020) and was thought to have originated in Central Asia (Seung-Hyun et al., 2021). It is well known that garlic (*Allium sativum* L.) is one of the most important bulb vegetables and is mainly used as a spice or flavoring agent for food products. It is used in several types of products such as garlic oil, powder, salt, paste and flakes.

Garlic is less effective in genetic improvement than onions due to sexual sterility, and as a result does not produce true seeds, so bulbs are used for vegetative propagation (Tesfaye, 2021). The vast majority of the world's garlic genetic resources are non-flowering (Etoh and Simon, 2002). Garlic clones that do not produce scape are considered softneck, but hardneck types of garlic flower on rare occasions, but did not form seed ovaries due to underdeveloped gametophytes, which cause male and female sterility (Singh et al., 2018). As a result, garlic propagates only by cloves or air bulbils and has great difficulties with classical breeding methods (Benke et al., 2020). A study by Hirata et al. (Hirata et al., 2016), on garlic cultivars worldwide, finds a diversity of garlic phenotypes expressing a wide variety of traits such as bulb mass, number of bulbils per plant, bulb integuments, leaf length, false diameter stems, the number of leaves on a plant, ability to bloom, resistance to biotic stress and abiotic stress. The diversity of garlic varieties is an important basis for the creation and introduction of new garlic varieties for the efficient use of genetic resources and for the improvement of breeding programs. Garlic varieties often have specific physiological compatibility with specific agro-climatic conditions, resulting in a large number of different varieties (Mario et al., 2008). Accordingly, it seems necessary to choose more compatible and high-yielding varieties of garlic for the climatic conditions of Ukraine. The low productivity of garlic is a problem for all parties to develop cultivation technology in order to improve quality. The use of garlic cultivation technology that can increase productivity includes the selection of plant population varieties. At the moment, there is a selection of garlic to obtain high-yielding varieties that meet the existing requirements. Garlic breeding is necessary to obtain improved cultivars that are well adapted to local environmental conditions (Zheng et al., 2007).

One of the most important areas of selection of any crop, including winter garlic, is the detection of the reaction of plants to the environment, to its stressful conditions, determination of the level of reaction of plants to biotic and abiotic factors. In the process of growth and development, plants constantly interact with the environment, resulting in the process of adaptation of the organism. The process of adaptation never ends and takes place throughout the life of the plant. The basis of adaptation is variability, a property of the organism, reflecting the mechanisms of its interaction with the environment, it is the most important factor of evolution, which ensures the suitability of species and populations to changing environmental conditions. (Filipchenko, 1923). Variability characterizes the rate of reaction of a species to the influence of environmental factors, its ability to adapt. Hence the purpose of selection, according to E.H. Pivovarov. and Dobrutskaya M., consists in the creation of genotypes that possess the desired rate of variability (Pivovarov and Dobrutskaya, 2000). Currently, several forms of variability are distinguished: genetic (varietal), environmental, geographic, phenotypic. Many scientists note the primary importance for selection of the study of patterns of phenotypic variability. This is not an inherited variability, but it must be taken into account when obtaining varieties, since it makes it difficult to recognize valuable genotypes. The study of population composition of varieties and ontogenesis of plants, different morphobiotypes should be observed on different ecological backgrounds. Sudden changes in environmental factors, for example, photoperiodic or temperature regime, leading to the splitting of the population, which reveals variability in a number of characteristics and the possibility of isolating plant morphobiotypes within it, i.e., conducting selection (Sinskaya, 1963).

This study is devoted to the manifestation of reduced scape in garlic clonal populations, as it is known that this phenomenon significantly reduces the marketability of bulbs and garlic yield. Today, softneck varieties of garlic are of great interest among industrial producers, since the technology of their cultivation excludes a rather expensive item of expenditure – the removal of the scape, regardless of whether this technological operation is carried out manually or mechanized. Therefore, the main goal of this study was to evaluate the adaptive and productive potential of softneck collection samples of winter garlic and the prospects of their use in breeding programs for the climatic conditions of the Forest Steppe of Ukraine.

2 MATERIALS AND METHODS

In the course of 2020–2022, in the soil and climatic conditions of the Right Bank Forest Steppe of Ukraine, a study was conducted on the study of the adaptive

Table 1: Origin of research clonal populations of A*llium sativum* ssp. *sativum*

No. samples	country	district
A.s.1/16	Spain	Catalonia
Hloria	Ukraine	Zbarag
A.s.16/16	France	Cadours
A.s.19/16	Ukraine	Uman
A.s.27/16	Ukraine	Mankivka
A.s.33/16	Ukraine	Uman
A.s.35/16	Azerbaijan	Ağstafa
A.s.43/17	Ukraine	Uman
A.s.44/17	Ukraine	Uman

variability of the collection forms (clonal populations) of garlic on the experimental field of the educational and production department of Uman National University of Horticulture.

Collected specimens of different ecological and geographical origin with distinctive morphological features were used for the study which were selected by the expedition method, when surveying crops of landraces in peasant farms in the respective regions of Ukraine and Europe.

The establishment of experiments was performed by systemically design. Repetition of the experiment – four times. The accounting area one variant of the research land is 100 m^2. Garlic planting was carried out on October, 10–15 according to the 45 × 6 cm scheme. Garlic was harvested on June 20–July 2.

Data from Uman weather station served as the information base for the analysis of meteorological conditions during the years of the study (2020–2022). The course of agrometeorological factors over the years of research created suitable conditions for the growth and development of garlic plants.

The analysis of given data on air temperature and amount of atmospheric precipitation during the research period was generally characterized as favorable for the growth and development of garlic. A characteristic feature of the 2019–2020 agricultural year was the elevated temperature background, insufficient precipitation in the summer and autumn periods. A characteristic feature of the 2020–2021 agricultural year was a favorable temperature background and a sufficient amount of precipitation. The total amount of precipitation for the year was 655.7 mm, which exceeded the long-term average by 69 mm. The weather conditions of the 2021–2022 agricultural year were characterized by a significantly lower level of precipitation compared to previous years and multi-year average data, and the temperature regime was close to the multi-year average data (Fig. 1).

The weather conditions of the growing season of winter garlic in 2020–2022 were not the same, so the results of the study were evaluated objectively.

Biometric measurements and indicators of individual productivity were performed on 100 typical plants without repetitions.

The experimental design was a systematic design with four replicates.

2.1 GENETIC AND STATISTICAL PROCESSING OF THE RESULTS.

A large number of methods are used to assess adaptability. Most of them are based on the method of regression analysis, the mathematical model of which for determining the stability and plasticity of varieties was calculated according to Eberhart and Russell, and is also based on the principles of combining and transforming the effects of the environment and the interaction of the genotype with growing conditions. The coefficient of linear regression of yield of a variety shows its reaction to changes in growing conditions. The higher the value of the coefficient ($bi > 1$), the better the response of the variety. In the case of $bi < 1$, the variety reacts weakly to changes in environmental conditions. Under the condition that $bi = 1$, there is a complete correspondence of the change in the yield of the variety in accordance with the change in growing conditions. Nonlinear deviations from the regression line ($\boldsymbol{\sigma}^2 d$ – stability). The lower the stability coefficient, the more stable the variety (Eberhart and Russell, 1966).

The general homeostaticity of varieties (H_{om}) was calculated according to the formula (Khangildin, 1984).

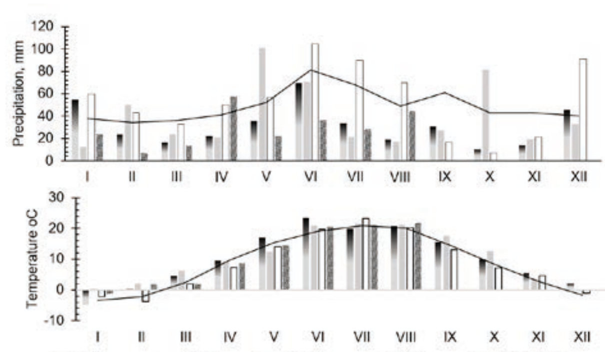


Figure 1: Climate chart for the study period (2020–2022)

$$H_{om} = \frac{\overline{X}^2}{\sigma},$$

where: x̄ – arithmetic average by grade;
σ – generalized root mean square deviation.
Breeding value of the variety:

$$(S_c) = \overline{X} \times \frac{\overline{X}_{lim}}{\overline{X}_{opt}},$$

where: $\overline{X}$ – arithmetic average by grade;
$\overline{X}_{lim}$ – limited arithmetic mean;
$\overline{X}_{opt}$ – optimal arithmetic mean.

Coefficient of multiplicity (CM). To avoid the linear artifact of the regression coefficient, V. A. Dragavtsev in 1981 introduced a new parameter - the coefficient of multiplicity, which allows comparing the variability of the trait. The higher the numerical value of this coefficient, the stronger the sign changes:

$$C_M = \frac{\overline{X}i + bi \cdot yi}{Xi},$$

where $\overline{X}$i – average value of the studied characteristic in the *i* variety;
bi – linear regression coefficient of *i* variety;
yi –average value for all averages for all grades *yi* for each *j* point of the experiment.

According to the method of A. O. Gryaznov, the average index of ecological plasticity is calculated

$$IEP = \frac{\left(\frac{YC_1}{AYC_1} + \frac{YC_2}{AYC_2} + \dots + \frac{YC_n}{AYC_n}\right)}{n},$$

where – YC_1, YC_2, YC_n value of trait (yield) in the variety in different years of trials; AYC_1, AYC_2, AYC_n –average value of quality of the varieties in each of variants of the experiment (Gryaznov, 1996).

Coefficient of adaptability (CA). To determine the adaptive capacity, the coefficient of adaptability of the variety (CA) was used.

The annual adaptability coefficient (CA) is calculated for the variety according to the formula (Zhivotkov et al., 1994):

$$CA = \frac{(Xij) \times 100 \times X)}{100},$$

where Xij – yield of a certain variety in the year of testing; X –average variety yield of the year.
The absolute average coefficient of adaptability (CAA) is calculated for the variety according to the formula:

$$CAA = \frac{(XiA) \times 100 \times Xm)}{100},$$

where XiA – average yield of the variety over years of testing, Xm –multi-year average variety yield.

Stress resistance and compensatory ability of varieties were determined by Rossielle and Hemblin (1981):

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

$$CA = \frac{Y_{min} + Y_{max}}{2},$$

where Y_{min} and Y_{max} –minimum and maximum value of the variety characteristic.

The coefficient of variation is a relative value used to characterize the dispersion (variability) of a feature. It is the ratio of SD mean square deviation to the arithmetic mean, expressed as a percentage:

$$CV = \frac{SD}{\overline{X}}.$$

Coefficient of variation on the following ratio scale:
CV < 10 % – variation is weak; CV 11–25 % – variation is average; CV > 25 % –variation is significant.

In the experiments, phenotypic, genotypic and ecological variability of varieties was determined (Burton et al., 1953; Shing, et al., 1993) according to the following formulas:

Genetic variance:

$$\sigma_G^2 = \frac{CM_p - CM_e}{r};$$

Environmental variance:

$$\sigma_A^2 = CM_e;$$

Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2.$$

Coefficient of genotypic variation:

$$\frac{\sqrt{\sigma_G^2}}{\overline{X}} \times 100;$$

Coefficient of phenotypic variation:

$$\frac{\sqrt{\sigma_P^2}}{\overline{X}} \times 100;$$

Coefficient of ecological variation:

$$\frac{\sqrt{\sigma_A^2}}{\overline{X}} \times 100,$$

where CM_p –generalized root mean square value of the population trait; CM_e –generalized root mean square error, r – number of repetitions.

Heritability (h^2) narrow sense was calculated according to the following equation:

$$\frac{\sigma_G^2}{\sigma_A^2}$$

Heritability (according to Falconer, 1989) in a broad sense:

$$H^2_{Falconer} = \frac{\sigma_A^2}{\sigma_P^2}$$

The nutritional value. Proteins, fats, carbohydrates and ash content were determined by using standard methods described in the procedures of the American Organization of Analytical Chemists (International Organization of International, AOAC International) (Horwitz, Latimer, 2005). The crude fat was determined using a Soxhlet apparatus (Behr R 106 S, Germany) with petroleum ether, according to the AOAC 920.85 methodology (Horwitz, Latimer, 2016). The content of ash was determined by burning at 600 °C to constant mass following procedures AOAS 923.03 (Horwitz, Latimer, 2016). The energy was calculated by the formula:

The statistical processing of obtained results was carried out with the calculation of arithmetic mean (X) of the standard deviation (SD), calculated using Microsoft Excel 2019. Correlation dependencies were determined by using Statistica 10 Software.

To assess the quality of connection between dependent variable and factors in the correlation-regression model, we used the value of coefficient of the determination based on Chaddock scale.

3 RESULTS AND DISCUSSION

The coefficient of variation (CV) of the bulb mass in plants that formed a reduced peduncle and those that did not was at an average level – 16.9 and 17.7 %; the coefficient of variation of the environment (CVA) in the same variants was within high limits – 33.5 and 26.6 % (Table 2).

For bulb mass, the relationship between the coefficient of genetic and environmental variation (CVG/CVA) was significant (0.43 and 0.50) both in plants without a reduced scape and with its formation. For the yield trait, the relationship between the coefficient of genetic and environmental variation (CVG/CVA) was also noticeable (0.44 and 0.53), however, the coefficients of variation in garlic plants that formed a reduced scape were insignificantly higher (in terms of bulb mass and yield). The absence of a statistical error in samples No. 'A.s.19/16' and No. 'A.s.44/17' is explained by the fact that some of their plants formed a reduced scape only in 2020 (data not provided), Table 2).

According to Vencovsky (1992), high performance requires a CVG/CVA ratio close to unity or greater than unity, because in these cases, genetic variation is greater than environmental variation, indicating that selection for a given trait will have the best conditions with point of view of clonal selection.

The results shown in Table 1 indicate a low heritability of garlic, it is higher only in the case of shoot, which is caused by adverse environmental conditions in a specific year of testing. The given results indicate that the higher the relationship between the genetic and environmental coefficient of variation, the higher the value of heritability.

Samples No. 'A.s.16/16' and 'A.s.44/17' were characterized by a high mass of the bulb – 57.22 and 52.24, respectively, but they were unstable – $\sigma^2 d$ = 3.99 and 3.03. Samples numbered 'A.s.35/16' ($\sigma^2 d$ = 2.02), 'A.s.43/17' ($\sigma^2 d$ = 2.06) and 'A.s.19/16' ($\sigma^2 d$ = 2.18) with a bulb mass of 34.88–42.33 g were relatively stable. Cultivar 'Hloria' with a bulb mass of 38.15 g and trait stability of 1.93 (data not shown). Collection samples of softneck garlic were divided into three groups: I) – with a large bulb mass (<50 g) – samples numbered 'A.s.16/16' and 'A.s.44/17'; II) – average bulb mass (35–49 g) – cultivar

Table 2: Bulb mass and yield of softneck forms of clonal populations of garlic (X ± SD)

Sample	Mass of the bulb, g		Yield, t ha^{-1}		Number of cloves pcs. per bulb	
	WRS	RS	WRS	RS	WRS	RS
A.s.1/16	40.97 ± 7.31	37.83 ± 7.16	15.62 ± 2.00	14.28 ± 0.81	17 ± 4.1	8 ± 1.6
Hloria	38.15 ± 3.72	31.23 ± 9.57	14.68 ± 1.63	9.01 ± 7.17	13 ± 2.5	8 ± 0.8
A.s.16/16	57.22 ± 15.90	51.80 ± 19.92	19.09 ± 3.09	13.29 ± 3.11	16 ± 2.5	10 ± 0.9
A.s.19/16	42.33 ± 4.74	34.00 ± 0.00	14.83 ± 1.11	12.00 ± 0.0	19 ± 2.2	8 ± 0.9
A.s.27/16	34.87 ± 8.97	33.87 ± 8.49	14.71 ± 3.47	11.89 ± 1.84	14 ± 0.9	10 ± 1.6
A.s.33/16	36.72 ± 8.85	33.63 ± 7.53	14.63 ± 2.45	13.54 ± 1.94	13 ± 1.7	9 ± 1.2
A.s.35/16	38.42 ± 4.10	30.27 ± 9.43	14.82 ± 0.37	13.06 ± 3.99	18 ± 1.9	8 ± 1.7
A.s.43/17	34.88 ± 4.26	33.55 ± 2.57	14.63 ± 1.01	13.73 ± 0.51	22 ± 1.2	9 ± 1.2
A.s.44/17	52.24 ± 9.15	36.00 ± 0.0	19.11 ± 2.31	13.50 ± 0.0	19 ± 1.7	9 ± 0.9
$\bar{X}$	41.76 ± 6.97	35.80 ± 8.53	15.79 ± 1.13	12.7 ± 1.96	16.7	8.9
σ_G^2	123.8	143.4	7.9	13.6	1.7	0.5
σ_F^2	23.0	35.6	1.6	3.8	16.0	3.0
σ_A^2	146.7	179.0	9.4	17.4	14.3	2.4
h2	0.19	0.20	0.16	0.28	0.12	0.22
$H^2_{falconer}$	0.84	0.80	0.84	0.10	0.89	0.82
CVG, %	11.5	16.7	7.9	15.3	7.8	8.3
CVF, %	29.0	37.4	19.4	32.9	23.9	19.3
CVA, %	26.6	33.5	17.8	29.1	22.6	17.5
CVG/CVA	0.43	0.50	0.44	0.53	0.34	0.47

Note: WRS – plants that did NOT form a reduced scape; RS – plants that formed a reduced scape.

Hloria and samples numbered ‘A.s.19/16’, ‘A.s.33/16’, ‘A.s.35/16’; III) – with a small bulb mass (> 35 g) – samples numbered ‘A.s.27/16’ and ‘A.s.43/17’ (Table 2).

Research revealed a significant decrease in the number of clove in the bulb for plants that formed a reduced scape. On average, this indicator decreased from 16.7 pcs. to 8.9 pcs./bulb, which also affected the average mass of the clove, which on average increased in plants with a reduced scape to 4.08 g. However, statistical analysis showed that in plants that formed a reduced scape, the dependence of the number of clove on the genotype (CVG, %) increased, and on the contrary, it decreased on environmental conditions (CVA, %), compared to varieties that did not form a reduced scape. From which we can make an assumption that the researched garlic varieties will form a full-fledged scape in wild conditions. A strong linear dependence of the average tooth mass on their number in the bulb was also found, where $r^2 = 0.7285$ (Figure 2).

An increase (by 24–137 %) in the mass of the tooth was noted in plants that formed a reduced scape. The smallest difference in the change of this indicator was found in cultivar ‘Hloria’ and samples No. ‘A.s.16/16’, ‘A.s.33/16’ and ‘A.s.44/17’. The dependence between the coefficient of genetic and environmental variation (CVG/CVA) was noticeable (0.51), but too small to obtain high productivity (Figure 3).

Analyzing the adaptive capacity in terms of yield, samples numbered ‘A.s.16/16’ (19.09 t ha^{-1}, CA = 1.21) and ‘A.s.19/16’ (19.11 t ha^{-1}, CAA = 1.21) turned out to be high-yielding and adaptive, however they were unstable – σ^2d = 1.76 and 1.52 and were characterized as samples of the intensive type (bi = 15.4 and 1.71), that is, only with optimal provision of all factors, these samples will provide high productivity. As a result of the genetic and statistical

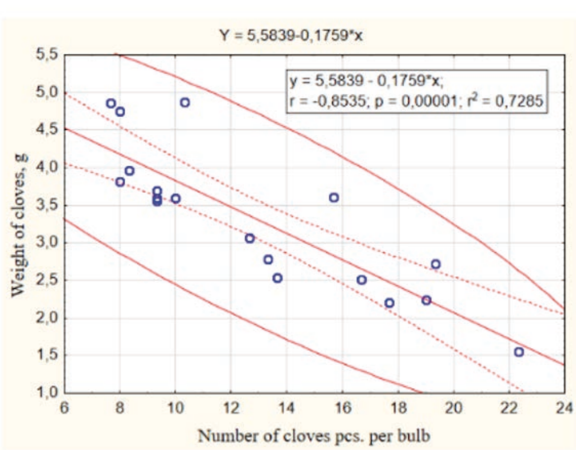
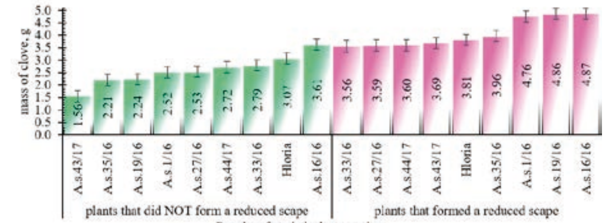


Figure 2: Point graphs and theoretical regression line for the linear correlation between clove weight and number of cloves



Results of statistical processing

	$\bar{X} \pm$ SD	σ^2_G	σ^2_F	σ^2_A	CVG, %	CVF, %	CVA, %	CVG/CVA	h^2	$H^2_{Falconer}$
WRS	2.58 ± 0,54	0.075	0.595	0.520	10.6	29.9	27.9	0.38	0.30	*0.87*
RS	4.08 ± 0,54	0.373	1.788	1.415	15.0	32.8	29.2	0.51	0.44	*0.79*

Figure 3: The average mass of tof clonal populations of *Allium sativum* L. subsp. *vulgare* that did not form and formed a reduced scape (2020-2022)

Note: WRS – plants that did NOT form a reduced scape; RS – plants that formed a reduced scape.

analysis, the two most stable samples (σ^2d = 0.61 and 1.00) were selected – Nos. ‘A.s.35/16’ and ‘A.s.43/17’ with a yield of 14.82 and 14.63 t ha^{-1}. However, the ecological regression coefficient indicates their negative reaction to changes in external environmental factors (bi = 0.33 and 0.89) and weak adaptive capacity – CAA = 0.94 and 0.93.

According to yield, collection varieties of winter garlic were grouped as follows: high-yielding – Nos. ‘A.s.16/16’ and ‘A.s.44/17’; medium-yielding – cultivar Hloria and Nos. ‘A.s.1/16’, ‘A.s.19/16’, ‘A.s.27/16’, ‘A.s.33/16’, ‘A.s.35/16’ and ‘A.s.43/17’; stable yielders – Nos. ‘’ A.s.35/16, ‘A.s.43/17’ and cultivar Hloria (Table 3).

Conducting a regression analysis, the results of which are shown in Figure 4, showed a change in the dependence of the yield on the mass of the bulb. According to the obtained data, the relationship between the above indicators (according to the Chaddock scale) in plants that did not shoot was very strong – $r^2 = 0.8814$ and decreased to the level of «no connection» in plants that formed a reduced scape – $r^2 = 0,0772$.

With the introduction of local varieties (specimens) of garlic, the genotype is transferred from one zone to another, approaching or moving away from the center of origin, which can manifest itself in the emergence of full or weakened shoots or, conversely, the absence of scape in varieties that previously formed a full-fledged scape. For the most part, weakened shooting in softneck forms of garlic manifests itself under adverse weather conditions, in particular drought. The results of the research on the emergence of weakened shooting of garlic are shown in Table 4, indicating a significant differentiation of the samples according to this feature. Thus, among the researched collection samples of winter garlic, cultivar Hloria and samples No. ‘A.s.19/16’ and ‘A.s.44/17’ stand out with the lowest percentage of plants that formed reduced scape – from 0 to 2 % (by year)

Table 3: Parameters of adaptive capacity and breeding value of garlic plants that did not form a scape according to the trait "yield"

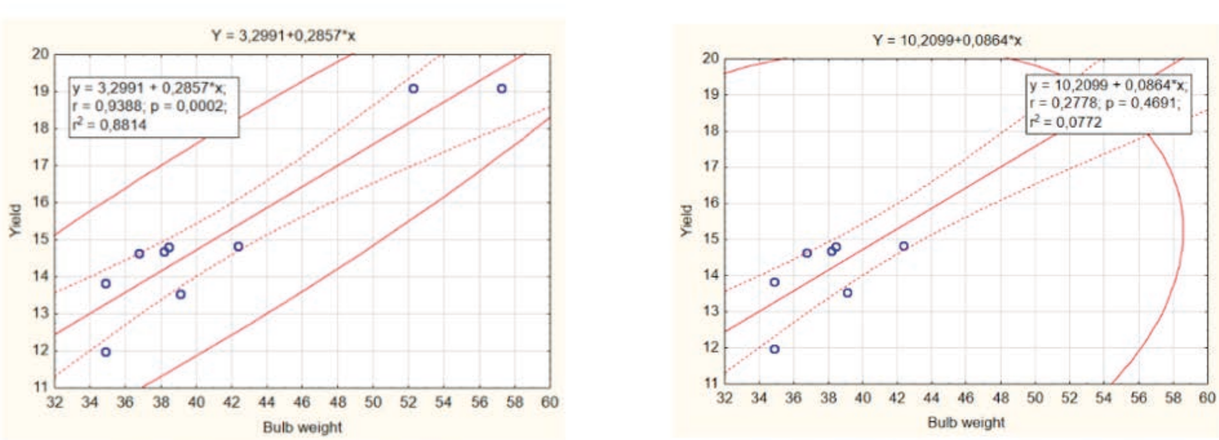
Sample	$\bar{X}$	CV, %	$\sigma^2 d$	bi	Hom	Sc	CM	IEP	SR	CA	CAA
A.s.1/16	15.62	4	1.42	0.76	87.0	14.6	1.76	0.99	-5	31	0.99
Hloria	14.68	11	1.28	-0.23	76.8	13.7	0.75	0.94	-4	28	0.93
A.s.16/16	19.09	16	1.76	1.54	129.9	17.8	2.27	1.21	-8	38	1.21
A.s.19/16	14.83	7	1.05	-0.95	78.4	13.8	-0.01	0.95	-3	29	0.94
A.s.27/16	14.71	15	1.86	2.83	77.1	13.7	4.04	0.92	-7	27	0.93
A.s.33/16	14.63	17	1.57	2.12	76.3	13.6	3.29	0.92	-6	28	0.93
A.s.35/16	14.82	3	0.61	0.33	78.2	13.8	1.35	0.94	-1	30	0.94
A.s.43/17	14.63	4	1.00	0.89	76.3	13.6	1.97	0.93	-1	28	0.93
A.s.44/17	19.11	12	1.52	1.71	130.1	17.8	2.41	1.21	-5	40	1.21

Note: CV, % – coefficient of variation; $\sigma^2 d$ – stability; bi – coefficient of linear regression; Hom – homeostaticity; Sc – breeding value; CM – coefficient of multiplicity; *IEP* – index of ecological plasticity; SR – stress resistance; CA – compensatory ability; CAA – absolute average coefficient of adaptability.

and the weakest emergence of shoots – cultivar Hloria formed a reduced scape, which broke the pseudostem of the plant at a height of 2 to 4 cm and No. 'A.s.44/17', in which an underdeveloped inflorescence was visible at a level of 0 to 15 cm. Level 0 was taken to be the placement of an underdeveloped inflorescence under the covering scales of the garlic bulb, which is shown in Figure 5.

In general, based on the weather conditions of a specific growing year, it can be seen that in the years with less moisture supply and higher temperatures (2020 and 2022), the percentage of shoot plants and the degree of emergence of a reduced scape was the highest, which is confirmed by a higher level of environmental variation relative to genetic (CVG = 47.7 %; CVA = 154.2 %). Also, the results of statistical processing indicate the independence of this trait from the genotype, that is, a low level of inheritance (h^2 = 0.10), from which it can be concluded that the degree of emergence of a reduced scape with the formation of air bulbyls does not depend on varietal characteristics, only on the degree of selection of the variety and environmental conditions in which the phenotype was formed.

Analyzing the number of bulbils in the inflorescence, their strong variation by year is noticeable (CV = 58–73 %, data not shown). The obtained results also confirm that environmental conditions have a greater influence (CVA = 154.2 %) than genetic ones (CVG = 47.7 %) on the formation of this trait.. Samples Nos. 'A.s.33/16', 'A.s.35/16', and 'A.s.43/17' (5.6–6.4 pieces) formed a larger number of bulbils than the average indicator by 7.5–24.1 %. All other samples formed 0.8–23.0 % less bulbils



a) garlic plants without scape   b) garlic plants that formed reduced scape

Figure 4: Point graphs and theoretical regression line for the linear correlation between bulb mass and yield of garlic

Figure 5: Zero value of the emergence of weakened shoot of garlic plants, which formed a reduced scape

Table 4: The degree of emergence of weakened scape of clonal populations of garlic

Sample	Number of plants that formed r educed scape, %	Height at which of a reduced scape is formed, min–max, cm	Number of bulbils pcs. per plant (X ± SD)	Mass of 1000 pcs. of bulbils, g,
A.s.1/16	3	0–9	5.0 ± 1.41	1151.6
Hloria	1	2–4	2.7 ± 2.05	1042.0
A.s.16/16	8	0–15	4.3 ± 0.54	1225.7
A.s.19/16	1	0–6	0.0 ± 0.00	–
A.s.27/16	35	0–15	5.2 ± 0.64	1638.0
A.s.33/16	14	0–8	5.6 ± 1.23	1127.7
A.s.35/16	5	0–6	5.9 ± 0.66	966.3
A.s.43/17	4	3–11	6.4 ± 0.42	946.0
A.s.44/17	1	–	0.0 ± 0.00	–
$\overline{X}$	8.0	0–8	3.89	1156.8
σ_G^2	151.4		0.3	62994.1
σ_F^2	14.5		6.7	5232.6
σ_A^2	165.8		6.3	68226.7
h2	0.10		0.05	0.08
$H^2_{falconer}$	0.91	–	0.84	0.92
CVG, %	47.7		14.9	6.3
CVF, %	161.4		66.4	22.6
CVA, %	154.2		64.7	21.7
CVG/CVA	0.31		0.23	0.29

than the average value, and samples No. 'A.s.19/16' and 'A.s.44/17' did not form bulbils at all.

For a mass of 1000 bulbils, CV and CVA were at an average level. Based on the mass of 1000 bulbils, the correlation between the coefficient of genetic and environmental variation (CVG/CVA) was weak – 0.29. Regarding the mass of 1000 bulbils garlic plants presented a very low heritability – h^2 = 0.08, but the heritability in a broad sense is reliable for the purposes of comparing characteristics and the degree of emergence of the trait and for predicting the results of breeding studies (Vencovsky and Barriga, 1992). According to Stanfield (1971), traits are considered highly heritable at a level of heritability (h^2) greater than 0.50, medium heritability – 0.20–0.50, and low heritability – less than 0.20.

From the author's previously published data, it can be seen that the mass of 1000 bulbils depends on their number in the inflorescence. The number of bulbils of softneck samples depended to a greater extent on environmental conditions than on varietal characteristics, which, accordingly, affected the formation of the mass of 1000 pcs. (CVG = 6.3 %; CVA = 21.7 %). A high coefficient of ecological variation indicates the dependence of this indicator on the conditions of the environment in which it was formed.

Nutritional value of the studied garlic genotypes is presented in Table 5. The results show that, it can be seen that according to the set of indicators of the nutritional value , sample cultivar 'Hloria' stood out with an elevated content of protein, carbohydrates, with a low content of fat (including essential oil), which characterizes it as a table variety. The highest concentration of essential oil was noted in sample No. 'A.s.1/16', where this indicator prevailed over other varieties by 6.31–58.36 %, that is, according to this feature, it can be classified as a technical variety. The minimum accumulation of essential oil was in cultivar 'Hloria' – 0.26 ± 0.02 mg 100 g f. m.–1, which is 39.17 % less than the average value for all varieties, which allows it to be classified as a table variety – fresh consumption. Statistical processing of the data showed a strong influence of ecological growing conditions on the formation of this indicator. Yes, significant changes in the dynamics of essential oil accumulation were observed over the years, but intervarietal withdrawal was stable - if a variety had a high concentration of essential oil, it always had it. According to CVG and CVA, the dependence of indicators of the nutritional value on environmental growing conditions was revealed, which confirms the high plasticity of garlic culture.

Table 5: Content of essential oil and the nutritional value of clonal populations of garlic (X ± SD)

Sample	Essential oil, mg 100 g f. m.$^{-1}$	Protein, g 100 g f. m.$^{-1}$	Carbohydrates, g 100 g f.m.$^{-1}$	Fat, g 100 g f. m.$^{-1}$	Energy, kcal 100 g f. m.$^{-1}$
A.s.1/16	0.63 ± 0.02	5.28 ± 0.25	23.90 ± 0.29	0.58 ± 0.03	121.90 ± 1.74
Hloria	0.26 ± 0.02	5.88 ± 0.27	27.39 ± 0.39	0.29 ± 0.03	135.69 ± 1.71
A.s.16/16	0.37 ± 0.03	5.10 ± 0.41	22.90 ± 0.78	0.52 ± 0.01	116.64 ± 4.76
A.s.19/16	0.39 ± 0.02	5.30 ± 0.19	25.52 ± 0.95	0.28 ± 0.02	125.76 ± 4.55
A.s.27/16	0.32 ± 0.01	5.33 ± 0.09	26.53 ± 1.09	0.36 ± 0.02	130.70 ± 4.39
A.s.33/16	0.48 ± 0.03	5.38 ± 0.17	25.67 ± 0.41	0.30 ± 0.01	126.87 ± 1.97
A.s.35/16	0.56 ± 0.03	5.40 ± 0.08	24.70 ± 0.42	0.36 ± 0.02	123.68 ± 1.88
A.s.43/17	0.44 ± 0.02	5.50 ± 0.18	25.53 ± 1.28	0.46 ± 0.01	128.25 ± 5.88
A.s.44/17	0.59 ± 0.02	5.24 ± 0.33	24.80 ± 0.91	0.52 ± 0.05	124.82 ± 4.91
$\bar{X}$	0.43	5.38	25.22	0.41	126
σ_G^2	0.0002	0.10	2.2	0.01	
σ_F^2	0.0150	0.02	0.2	0.00	
σ_A^2	0.0148	0.12	2.5	0.01	
h2	0.01	0.04	0.05	0.26	
$H^2_{falconer}$	0.99	0.84	0.98	0.91	
CVG, %	3.1	2.59	1.8	3.5	
CVF, %	27.4	6.45	6.2	27.2	
CVA, %	27.2	5.90	5.9	26.9	
CVG/CVA,	0.12	0.44	0.31	0.13	

The presence of genetic variability in a culture is of key importance for sustainable agriculture, as the improvement of any culture is directly proportional to the value of its genotypic variability, the assessment of which is primarily necessary for its effective use, especially when old varieties are replaced by new ones. In general, garlic shows a good genetic dispersion in terms of the number and quality of traits, although it reproduces vegetatively (through cloves), taking into account the future threat of genetic erosion and the uncontrolled introduction of new varieties, an assessment of the adaptive variability of promising samples of softneck garlic was carried out according to the degree of emergence of a reduced scape, mass of 1000 bulbils, bulb mass, "yield". Prior to this study, many scientists (Kumar et al. 2019; Singh et al. 2014) investigated collections of varieties, local or elite lines separately, but the number of accessions was very much less.

The difference between garlic ecotypes was significant for all vegetative characteristics, which indicates their high diversity. Many studies (Stavělíková, 2008, Polyzos et al., 2019, Anderson et al., 2014; Kıraç et al., 2022) reported a large variation in the morphological characters of garlic, which partially or fully agreed with the results obtained in this study. Bahadur et al., (2018), Valter et al., (2019), Sánchez-Virosta et al., (2021) showed that the qualitative and quantitative characteristics of garlic directly depend on the location of the plants in the field, which, in turn, depends on the genotype (G), the environment (E) and the interaction of these two factors (G × E). Different ecotypes of garlic showed great diversity in morphological characters, including leaf size, plant height, bulb size, color and shape. Differences between researchers' results are explained by the large variation between groups of garlic, as well as the different effects of climatic conditions of the study site, especially temperature and length of daylight (Kamenetsky et al., 2004; Yatsenko, 2021).

Other researchers have reported significant differences in vegetative and reproductive characteristics of different garlic ecotypes (Figliuolo et al., 2001; Gvozdanovic-Varga et al., 2002; Zahedi et al., 2007; Sandhu et al., 2015; Sho et al., 2016). The difference in garlic bulb mass may be related to genetic diversity and the ability to adapt to environmental conditions (Abdel-Razzak and El-Sharkawy, 2012, Ganesh et al., 2022).

4 CONCLUSIONS

In general, after conducting a genetic and statistical evaluation of softneck collection samples of garlic, it was found that up to 21 % of plants at a height of up to 15 cm can form a reduced scape (obviously depending on the degree of selection). As a result of the evaluation of garlic samples, high-yielding (Nos 'A.s.16/16' and 'A.s.44/17'), stable yielding (numbers 'A.s.35/16' and 'A.s.43/17'), intensive (with bi >1 – 'A.s.16/16', 'A.s.27/16', 'A.s.33/16' and 'A.s.44/17'), selectively valuable (Nos. 'A.s.16/16' and 'A.s.44/17') and highly adaptive (Nos. 'A.s.16/16' and 'A.s.44/17'). The obtained results will serve as the starting material for further selection work with promising samples selected for a complex of economically valuable traits and the creation of domestic softneck forms of garlic

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