

GENETIC AND MORPHOLOGICAL CHARACTERISTICS IN DESCRIBING THE DIVERSITY OF SOME *ALLIUM SATIVUM* LANDRACES IN ROMANIA

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Abstract. Garlic (*Allium sativum* L.) is important for the food, pharmaceutical, cosmetic, and medical industries, with prospects for future fields of application. Four garlic landraces (AR-AM, CS-Co, HD-Do, TM-Ce) from the western part of Romania, were studied in ex situ crop conditions. The aim of the study was to comparatively analyze the four garlic populations, based on the flow cytometry parameters (G1 - presynthetic phase, S - synthesis phase, G2/M - postsynthetic phase), and the quantitative characters (PH - plant height, GBH - garlic bulb height, GBD - garlic bulb diameter, GBW - garlic bulb weight, GCN - number of cloves in garlic bulb, GCW - mean weight of a garlic clove), and to quantify the advantages of the garlic landraces for certain quantitative and agronomic characters. Correlations of different levels of intensity were recorded between quantitative parameters and FCM parameters, possibly with some advantages for quantitative characters. According to the PCA, the first two components (PC1, PC2) explained 95.718% of the variance based on FCM parameters, and 99.726% of the variance based on quantitative parameter. Based on the study results, two garlic breeds (HD-Do and TM-Ce) showed agronomic advantages for quantitative traits, and can be promoted for crops, from small to large scale.

Keywords: agronomic traits, flow cytometry, garlic, genetic advantages, quantitative parameters

Introduction

Garlic (*Allium sativum* L.) has been cultivated for more than 7000 years, a highly adaptable plant with significant ecological plasticity (Malik et al., 2017; Varga-Visi et al., 2019). Garlic, considered the second most important *Allium* crop worldwide, is produced for both dry bulb and fresh leaves (fresh plant), for food consumption (Egea et al., 2017; Malik et al., 2017; Petropoulos et al., 2018; Bhusal et al., 2019; Tesfaye et al., 2021). Among the common vegetables currently consumed, garlic is a rich source of 62 phenolic compounds, and also a plant that is part of many culinary traditions (Horváth, 2009; Bene, 2018; Bhusal et al., 2019).

As a result of its high content in active principles, garlic is an important source for the pharmaceutical, cosmetics and medical industries (Xie et al., 1992; Bayan et al., 2014; Egea et al., 2017; Malik et al., 2017; Tesfaye et al., 2021 et al., 2021; Hayat et al., 2022). Garlic bioactive compounds exhibiting antimicrobial, allelopathic and biostimulatory effects are important for agriculture, plant protection, and opening for future directions of application (Hayat et al., 2022).

The garlic genome has been analyzed at the chromosomal scale, as well as in multiple genetic assemblies, for the knowledge and understanding of the processes involved in flowering, infertility, bulb formation, as well as bioactive compounds, organoleptic insusceptibility, or aspects of tolerance to different factors (Parreño et al., 2022). Based on genomic variation data, Li et al. (2022) identified routes in garlic selection and domestication (e.g. in China), certain gene shifts, genetic architecture remodeling, and differential selection for certain bulb traits with relevance for genomics-based breeding and reproductive programs.

In genetic studies, flow cytometry (FCM) is a technique that facilitates the determination of DNA content, cell proliferation cycle and flux dynamic changes in cell division (Xie et al., 1992). Flow cytometry (FCM) is one of the most widely used methods to determine the DNA content as well as to analyze the distribution of cells in different phases of the cell cycle. Four cellular phases can be distinguished during mitotic division: G1, G2, S (DNA synthesis phase), and M (mitosis proper). However, the G2 and M phases, which have the same DNA content, cannot be discriminated separately on the basis of genetic material content alone.

Due to the importance of garlic, the realization of core collections with *Allium* germplasm is of major concern (Egea et al., 2017). An important role in the conservation of garlic genotypes is played by gene banks (e.g. Olomouc, Europe), which ensure the conservation and evaluation of genetic resources (Leišová-Svobodová et al., 2024). The study authors assessed the genotypic and phenotypic diversity of a garlic collection, identified different gene of landraces, and recorded the change of phenotypic expression in some of the studied genotypes, as an environmental influence (Leišová-Svobodová et al., 2024).

Genetic variability is the fundamental basis in plant breeding programs, and this has motivated many studies to evaluate the genetic variability and the level of correlations among agronomic, agroecological (physiological, biometric, etc.), quantitative (yield elements) and qualitative (quality indices) parameters in many garlic accessions in different countries of the world (Ragas et al., 2019; Tesfaye et al., 2021; Jo et al., 2012; Chen et al., 2014; Raja et al., 2017; Kumar et al., 2019).

As a result of the accumulation of mutations, high diversity has been recorded for different traits in garlic (morphological, physiological, and agronomic) and different phenotypic classifications connected with genotype have been found for certain ecophysiological groups (García-Lampasona et al., 2012). Papaioannou et al. (2023) analyzed local landraces of Greek garlic and identified by appropriate analysis (Fischer tests, multinomial logistic analysis) specific associations between bulb morphological traits, chemical compounds and specific loci (SSR, ISSR).

Due to the importance of garlic crop, and the specificity of plant propagation, the study of heredity, genetic variability and genetic progress has been considered to be of high importance for trait selection (Jethava et al., 2018). Sexual propagation is restricted in garlic; vegetative propagation predominates, so selection of elite clones from different genetic resources presents importance (Bhusal et al., 2019). Some studies have reported the trend of decreasing interest in local garlic landraces and at the same time their genetic erosion, compared to modern varieties that have recorded high progress in cultivation and market (Bonasia et al., 2020; Casals et al., 2023).

Agro-morphological evaluation, by analyzing morphological, physiological and productivity traits, is of interest and has been done in different garlic varieties and landraces (Hadiawati et al., 2022). Morphological characters, respectively productivity

parameters in garlic are important for yield formation and market quality of the production. More and more studies have analyzed morphological characters in relation to garlic genotypes, environmental conditions, or crop technologies (Hadiawati et al., 2022; Atif et al., 2020; Jiku et al., 2020). The number and size of garlic cloves influenced the size of the bulb (Leiřová-Svobodová et al., 2024; Casals et al., 2023). The size of the garlic bulb determines the yield, and the market and nutritional quality of the production (Desta et al., 2021; Galgaye et al., 2023; Asnake et al., 2024).

The efficiency and profitability of garlic crop was studied, and different categories of biological, ecological, technological, socio-economic factors were identified with specific factors in each category influencing the productivity of garlic crop under the study conditions (Jiku et al., 2020; Ahmad et al., 2021; Desta et al., 2021; Lutz et al., 2022; Chekol et al., 2023; Galgaye et al., 2023). According to the previously cited bibliographic sources, the biological, ecological and technological factors influenced morphological parameters and agronomic characters in garlic (e.g. plant height, leaf number, fresh and dry weight of the leaves, diameter of the garlic bulb, fresh weight and dry weight of the garlic bulb, the number of cloves in garlic bulb), and these characters had a determining role in the formation of the yield. This shows the importance of studying and quantifying agronomic parameters, on garlic landraces and genotypes, and motivates the development of studies in this direction.

In the context of the importance of garlic, the trend of reconsideration of local germplasm, the present study comparatively analyzed four local garlic landraces in Romania by, i) flow cytometry (FCM) in order to describe the cell proliferation cycle, the differences in cell division flux, ii) by evaluating some quantitative parameters (productivity elements) in garlic bulb and garlic cloves, iii) by comparative analysis and discrimination of landraces based on FCM genetic parameters and quantitative parameters, iiiii) by quantifying the interdependence of quantitative parameters with FCM genetic parameters.

Materials and methods

Garlic landraces were collected from the Western part of Romania, and cultivated *ex situ* under uniform conditions, in order to be studied in relation to the aim of the study.

Biological material

The biological material was represented by four garlic landraces (AR-AM, CS-Co, HD-Do, and TM-Ce), collected from Arad county (AR), locality Agrisul Mare (AM), 46° 16' 0" North, 21° 46' 0" East, 91 m AMSL (above mean sea level); Caras Severin county (CS), locality Comoraste (Co), 45° 10' 54.3" North, 21° 33' 46.8" East, 125 m AMSL; Hunedoara county (HD), locality Dobra (Do), 45° 55' 0.01" North, 22° 34' 0.01" East, 170 m AMSL; and Timis county (TM), locality Cenad (Ce), 46° 7' 59.22" North, 20° 33' 44.65" East, 84 m AMSL (*Fig. 1*). The four landraces of garlic stood out for the fact that they did not present any form of disease, their conservation is much longer than the garlic purchased from the trade, which the owners confirmed to us at the time of collection.

Location and organization of the experiments

The experiments and studies were conducted in Timisoara (*ex situ*), with the involvement of the authors from ULS "King Mihai I" from Timisoara. The field

experiment was organized in Timisoara (45° 47' 4.14" North, 21° 12' 52.15" East, 90 m AMSL), under garden conditions, open field, on a non-fertilized chernozem soil.

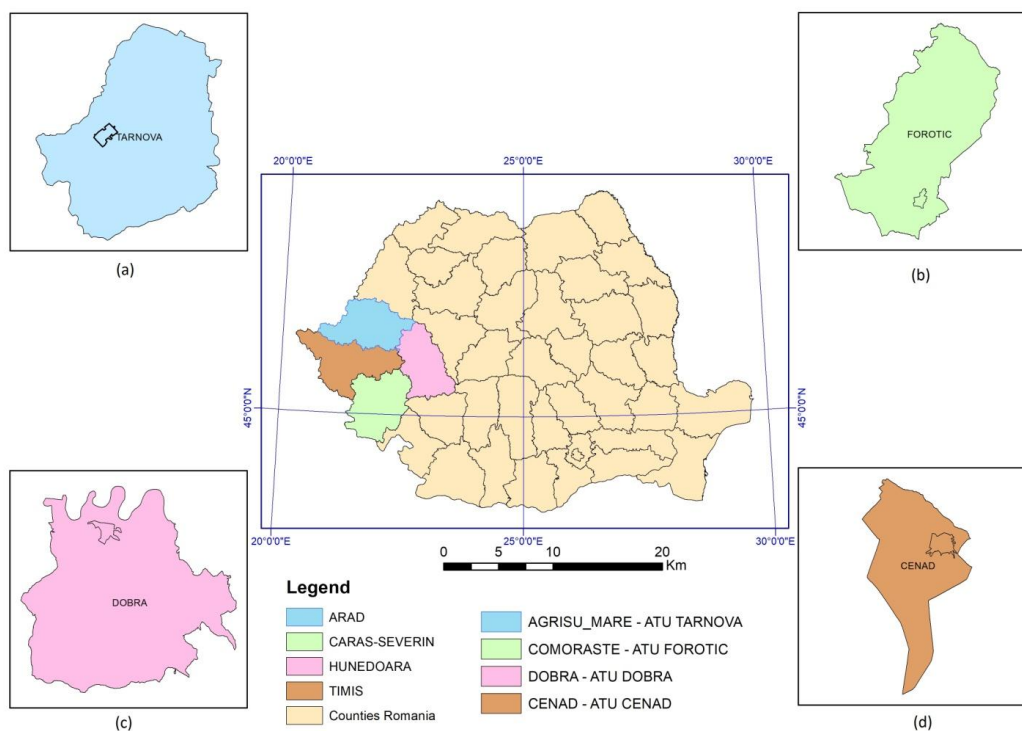


Figure 1. The source of the studied garlic landraces; Central image – Romania map; (a) Arad County, Agrisu Mare (AR-AM); (b) Caras Severin County, Comoraste (CS-Co); (c) Hunedoara County, Dobra (HD-Do); (d) Timis County, Cenad (TM-Ce). Original figure based on ESRI (2011)

Biological material (garlic cloves) has been planted in autumn, in September month, 2022. Planting spacing was 25 cm between rows, and 15 cm per row, planting depth 3 cm. The landraces were planted side by side with 180-190 cloves from each garlic landraces, transplantation was not practiced. Plant emergence was recorded starting November 1. No organic or mineral fertilizers were applied. During the growing season, the garlic crop was maintained by hoeing and weeding, as necessary. No other treatments were applied. A way of cultivation, as practiced by local farmers, was ensured. Aspects during the growing season and at harvest are shown in *Figure 2*.

Cytometry analysis

A genetic characterization of the four landraces was performed by flow cytometry method by analyzing the distribution of cells within the cell cycle.

For the cytometry analysis, leaf samples (5 leaves) were randomly sampled from young plants on each experimental variant. Sampling was done in April. The leaf samples were put in sterile, sealable bags and transported to the Genetics Laboratory of ULS “King Mihai I” from Timisoara. For each garlic landraces, from the plant samples, young leaves, an amount of ca. 0.5 cm² of leaf tissue was used.

The samples were finely crushed very well in 0.5 ml Nuclei Extraction Buffer (Sysmex Partec GmbH, Arndtstraße 11 a-b 02826 Goerlitz Germany) for 30-60 s.

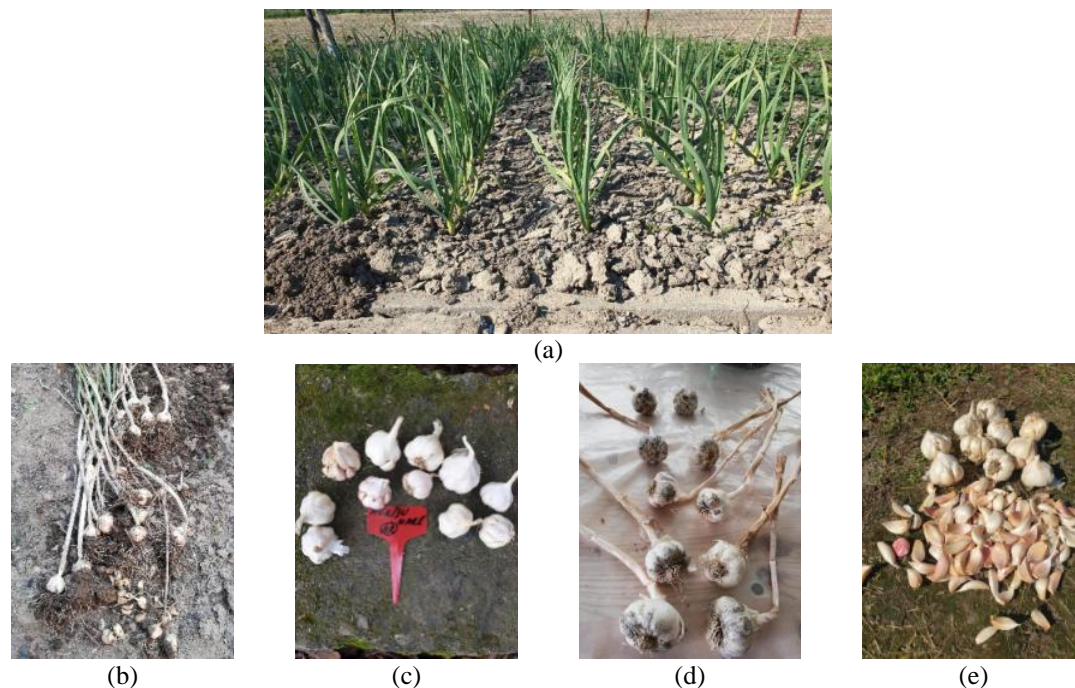


Figure 2. Study period pictures: Vegetation period (a), Collecting period (b), (c), (d) (e); (a) – Aspect from vegetative period, TM-Ce; (b) – Collected plants, CS-Co; – Garlic bulbs, AR-AM; (c) – Dried plants HD-Do; (d) – Galic bulbs and cloves AR-AM (Original photos and figure)

This was followed by incubation of the samples in this buffer for at least another 30-90 s at room temperature. The mixture was poured into a 50 μm filter, after which 2 ml sample⁻¹ Staining Solution was added.

Staining Solution was prepared according to the specific protocol. For the analysis of a sample, 2 ml Staining Buffer is mixed with 12 μl PI (propidium iodide) stock solution and 6 μl RNA-ase stock solution. This staining solution is valid for 24 h under storage conditions at 4°C. Preparation of RNA-zyme stock solution: 5 mg RNA-zyme (S.C. Biozyme S.R.L., Street George Valentin Bibescu, nr. 31A, Cluj-Napoca, Romania) in 1.5 ml H₂O is added to an Eppendorf tube and mixed thoroughly (IKA lab dancer vortex shaker, 2800 RPM). The resulting solution can be stored at -20°C.

Samples were incubated in the dark for at least 1 h before analysis by flow cytometer. The samples thus prepared were stable for 12 h at 4°C. The determination was done within the shelf life of the samples.

Flow Cytometer analysis of garlic samples was performed on “The Partec CyFlow SL flow cytometer (Partec GmbH, Munster, Germany) complies with the European IVD Directive 98/79/EC and is therefore marked with the CE sign.” cytophotometric analysis for the characterization of garlic landraces was done by using the manufacturer’s software (FloMax - Software for Cytometry, Version 2.4 (29.08.2005) by Partec GmbH, Munster, Germany) which allowed the calculation of the percentage of cells in different phases of the cell cycle.

Collection of plant samples for quantitative parameters

Harvesting of garlic plants (whole plant with bulb, Fig. 2b) was done in early June 2023, at the first signs of physiological maturity, marked by yellowing of leaves Meier (2001). It

was not waited until the leaves were definitively dry (pre-harvest), as the twisted bulbs shed their parchment leaves and the stalks disintegrated, leading to crop losses.

Harvesting was done by hand in dry weather. Garlic bulbs were shaken off the soil avoiding mechanical damages. The thus harvested plants (bulbs with leaves) were placed on the soil surface for drying for 7-8 days (traditional harvesting method; *Fig. 2b*). After drying, quantitative (biometric and productivity) parameters were determined.

Determination of quantitative parameters

The biometric analysis considered quantitative traits, and was based on measurements on random samples from the four garlic landraces. For quantitative traits, determinations were made on 160 plants within each garlic landraces.

To characterize the four garlic landraces based on quantitative parameters, the following were determined: plant height (PH, cm), garlic bulbs height (GBH, cm), garlic bulbs diameter (GBD, cm), garlic bulbs weight (GBW, g), and garlic bulbs clove number (GCN). Based on the recorded data, the average weight of a garlic clove (GCW, g) was calculated. Plant height was measured with a ruler, accuracy ± 0.5 mm. The height and diameter of garlic bulbs were measured with an electronic caliper, accuracy ± 0.001 mm. The weight of garlic bulbs was determined with a KERN EG220-3NM balance (Kern & Sohn GmbH, D-72336 Balingen, Germany).

In order to characterize the shape of garlic bulb, Garlic bulb shape index (GbsI) (*Eq. 1*) was proposed by the authors, and calculated as the ratio between GBH and GBD for the garlic landraces considered in the study.

$$GbsI = \frac{GBH}{GBD} \quad (\text{Eq.1})$$

where: GbsI - Garlic bulb shape index; GBH - garlic bulb height; GBD - garlic bulb diameter; GbsI = 1, globular shape; GbsI > 1, tall shape; GbsI < 1, flattened shape.

Statistical data analysis

The data series were analyzed in relation to the objectives of the study. Descriptive Statistical Analysis was applied for the general characterization of the data series.

For each quantitative parameter, the comparative statistical analysis was done between the garlic landrace with the highest mean value of a parameter, and the other three landraces. Each garlic landrace was independent of the others, and there was no control group, in the concept of the experiment, against which to compare the studied landraces. For these reasons, different tests were used, based on parametric and nonparametric hypotheses, that evaluated the mean value of the data series (t-test), the median value (Wilcoxon test), and the null hypothesis (Mann-Whitney test).

In all cases the standard thresholds of statistical reliability ($p < 0.05$; $p < 0.01$; $p < 0.001$) were considered. Multivariate analysis (PCA) was applied to obtain the distribution plots of genotypes in relation to genetic parameters (FCM) and productivity parameters, and to explain the presence of the variance in the data series.

Correlation analysis was performed between cytometry data and quantitative parameter data to evaluate the interdependence relationships between quantitative and genetic parameters. PAST software v. 4.02 (Hammer et al., 2001), and JASP software v. 0.16.4 were used to analyze the data and generate graphs.

Results and discussion

Flow cytometry analysis

The recorded values in this study, based on cytophotometric analysis (FCM), are presented in *Table 1*, and the resulting cytograms are presented in *Figure 3a* for the AR-AM garlic landraces, in *Figure 3b* for the CS-Co garlic landraces, in *Figure 3c* for the HD-Do garlic landraces, and in *Figure 3d* for the TM-Ce garlic landraces, respectively.

Table 1. Results of flow cytometry analysis of garlic leaf samples, of garlic landraces

Garlic population	Csp	G1	S	G2M	CVG1	CVG2	MnG2	MnG1	G2M/G1	ChiSqu
	(%)									
AR-AM	6.84	74.24	6.84	18.92	7.96	7.53	194.06	104.64	1.85	1.17
CS-Co	2.00	46.08	2.91	51.00	7.40	27.09	199.03	102.00	1.95	0.76
HD-Do	3.88	76.96	3.88	19.16	10.15	10.14	182.47	98.62	1.85	1.33
TM-Ce	11.14	57.05	11.14	31.81	7.75	7.40	183.22	98.00	1.87	1.30

AR-AM, landraces from Arad county, Agrisu Mare locality; CS-Co, landraces from Caras Severin county, Comoraste locality; HD-Do, landraces from Hunedoara county, Dobra locality; TM-Ce, landraces from Timis county, Cenad locality. Csp - cells in the synthetic phase, G1 - pre-synthetic period, S - synthetic period, G2M - postsynthetic period, CVG1 - coefficient of variability presynthesis, CVG2 - coefficient of variability postsynthesis, postsynthetic mean, MnG1 - presynthetic mean, G2M/G1 - cells in the G1/G2 period of mitosis, ChiSqu - chi-squared test (Pearson's chi-squared test)

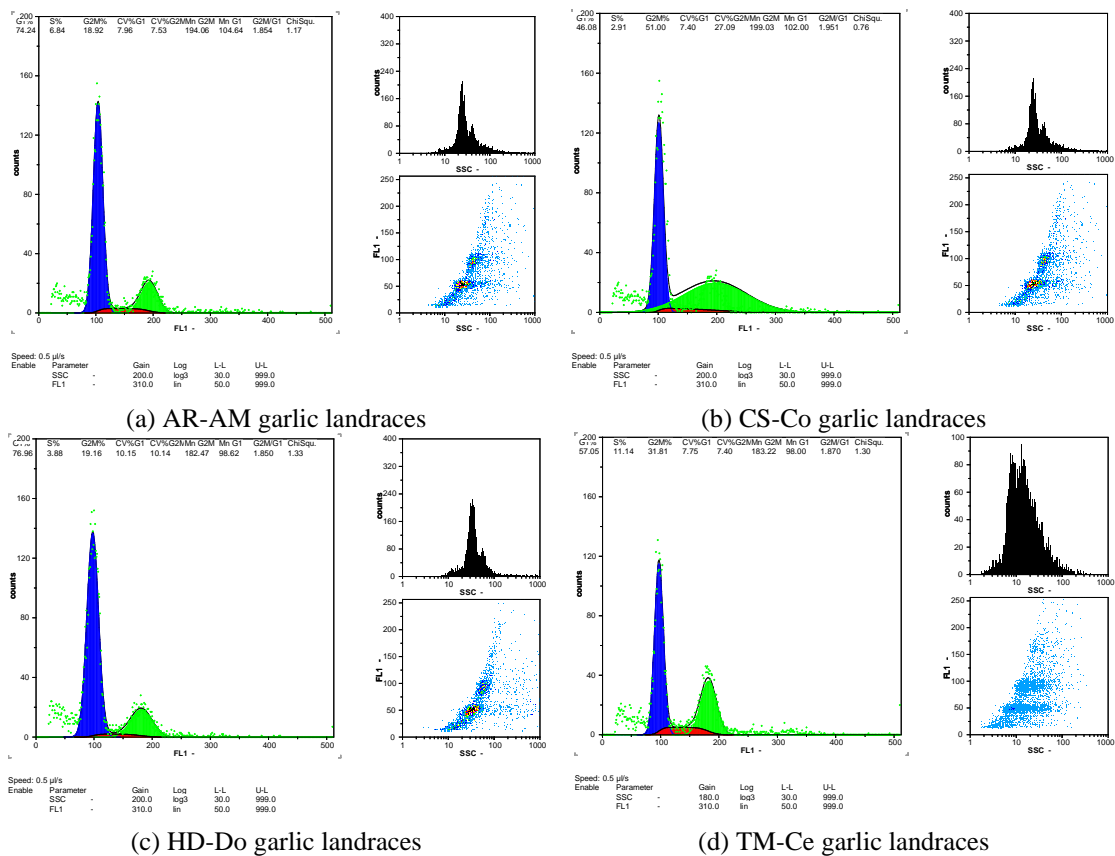


Figure 3. Cytograms of cells distribution in the cycle of the garlic landraces studied (original figure based on cytometry analysis)

The number of cells analyzed with the flow cytometer showed that the distribution of cells in the different phases of the mitotic division does not show an abnormal evolution, which reveals the stability of the genome. Regarding ploidy, no other degree of ploidy was noted. They contain the number of complete sets of chromosomes in the somatic cells, that is, no different degree of ploidy was observed depending on the number of copies of the homologous chromosomes (e.g. triploid, hexaploid) which shows the stability of the genome with a role in the continuity of the species.

The cell cycle analysis of leaf samples, AR-AM garlic landraces, showed 6.84% cells in the synthesis phase of the mitotic cell cycle, and 1.85% cells in G2M/G, out of the total of 1854 cells analyzed (*Table 1; Fig. 3a*).

In the third stage of the interface, i.e. in G2, only 18.92% particles were found. This demonstrated that the cells were captured in the mitosis stage proper, and will divide. In the garlic landraces CS-Co, it was observed that out of the total 1951 cells analyzed, only 2% were found to be in the synthesis stage, which is favorable for mitotic division (*Table 1; Fig. 3b*). This indicated that the cells were already captured in the proper division phases of the mitotic cell cycle from somatic cells.

Particle analysis of the HD-Co garlic landraces showed a rather high variability, possibly due to the fact that single cells appeared, which were quantified as singlet, and led to a high variability of the analyzed cells.

Out of the 1850 cells analyzed, the percentage of 3.88% of cells in the synthetic phase also indicated a rather high variability coefficient value for the first stage of the interface, CV = 10.15%. To the same extent, a high percentage of cells in mitosis proper were also recorded at 19.16% (*Table 1; Fig. 3c*). In the TM-Ce garlic landraces, a percentage of 11.14% of cells under synthesis was recorded. The coefficient of variability in G1 was CV = 7.75%, and the coefficient of variability in G2 was CV = 7.40%, a rather high value, exceeding the maximum standard cutoff of 5% (*Table 1; Fig. 3d*).

Analysis of quantitative characters

The recorded data series were analyzed for quantitative parameters considered in the characterization of the four garlic landraces. The results obtained, according to Statistical Analysis, are presented synthetically in *Table 2*.

According to the results generated by the Descriptive Statistical Analysis (*Table 2*), based on the mean values of the quantitative parameters, a certain differentiation of the studied garlic landraces was observed. The CS-Co landraces stood out for the parameter GCW (1.127 ± 0.034 g). The HD-Do landraces was evident for the GBW (2.2708 ± 0.039 cm) and GBD (3.031 ± 0.038 cm) parameters. The TM-Ce landraces was evident for the PH parameter (33.089 ± 0.589 cm), the GBW parameter (13.008 ± 0.218 g) and the GCN parameter (11.575 ± 0.182).

The ANOVA test was applied to comparatively analyze the data recorded for quantitative parameters, in the garlic populations studied. The results for Test for equal means, and Kruskal-Wallis test for equal medians are presented in *Table 3*.

The results for Mann-Whitney pairwise, and Dunn's post hoc, are presented in *Table 4*. The recorded results, based on the applied tests, indicated significant differences between the garlic populations, in the case of the evaluated parameters.

The comparative analysis was made between the garlic landrace with the best value for each quantitative parameter, and the other garlic landraces. The results of the comparative analysis, including statistical safety parameters, are presented in

Tables 5–10. In the case of the PH parameter, the TM-Ce garlic landrace presented quantitative advantages in relation to the other garlic landraces (PH = 33.089 ± 0.589 cm, Table 5). In the case of the GBH parameter, the HD-Do garlic landrace presented quantitative advantages in relation to the other landraces (GBH = 2.708 ± 0.039 cm, Table 6). In the case of the GBD parameter, the HD-Do garlic landrace presented quantitative advantages in relation to the other garlic landraces (GBD = 3.031 ± 0.038 cm, Table 7). In the case of the GBW parameter, the TM-Ce garlic landrace presented quantitative advantages in relation to the other garlic landraces (GBW = 13.008 ± 0.218 g, Table 8). In the case of the GCN parameter, the TM-Ce garlic landrace presented quantitative advantages in relation to the other landraces (GCN = 11.575 ± 0.182, Table 9). In the case of the GCW parameter, the TM-Ce garlic landrace presented quantitative advantages in relation to the other landraces (GCW = 1.128 ± 0.010 g, Table 10).

Table 2. Results of descriptive statistical analysis for quantitative parameters, garlic landraces studied

Statistical parameters	PH	GBH	GBD	GBW	GCN	GCW	GBH/GBD
Valid*	160	160	160	160	160	160	160
Missing*	0	0	0	0	0	0	0
AR-AM							
Median	33.400	2.520	2.710	10.165	9.000	1.031	0.925
Mean	32.959	2.437	2.627	9.491	9.231	1.030	0.928
Std. Error of Mean	0.401	0.039	0.041	0.215	0.148	0.019	0.004
Minimum	17.400	1.430	1.320	4.130	6.000	0.583	0.813
Maximum	43.700	3.560	3.830	18.400	15.000	1.712	1.205
CS-Co							
Median	30.300	2.410	2.680	9.740	9.000	1.052	0.892
Mean	30.887	2.442	2.717	10.647	9.494	1.127	0.898
Std. Error of Mean	0.540	0.041	0.043	0.382	0.186	0.034	0.005
Minimum	17.000	1.190	1.370	3.270	5.000	0.358	0.753
Maximum	46.200	3.920	4.310	23.860	16.000	1.902	1.215
HD-Do							
Median	31.200	2.705	3.100	12.005	11.000	1.131	0.903
Mean	31.210	2.708	3.031	12.020	10.813	1.118	0.896
Std. Error of Mean	0.383	0.039	0.038	0.124	0.115	0.009	0.008
Minimum	20.300	1.200	2.060	7.760	8.000	0.812	0.360
Maximum	42.900	3.960	4.300	17.080	14.000	1.492	1.181
TM-Ce							
Median	32.210	2.610	2.860	12.465	11.000	1.117	0.917
Mean	33.089	2.626	2.962	13.008	11.575	1.128	0.925
Std. Error of Mean	0.589	0.035	0.111	0.218	0.182	0.010	0.011
Minimum	11.000	1.740	1.360	7.850	7.000	0.872	0.091
Maximum	52.000	3.640	19.220	19.490	19.000	1.535	1.647

*Valid, and Missing parameters show the same values for each garlic landraces studied; PH – plant height; GBH – garlic bulb height; GBD – garlic bulb diameter; GBW – garlic bulb weight; GCN – garlic cloves number; GCW – garlic clove weight; GBH/GBD – ratio

Table 3. ANOVA Test, Test for equal means, and Kruskal-Wallis test

Statistical parameters	PH		GBH		GBD		GBW		GCN		GCW	
	Test for equal means											
	Sum of sqrs	Mean square	Sum of sqrs	Mean square	Sum of sqrs	Mean square	Sum of sqrs	Mean square	Sum of sqrs	Mean square	Sum of sqrs	Mean square
Between groups: (df = 3)	633.9	211.3	8.806	2.935	17.86	5.953	1141	380.5	588.5	196.2	1.084	0.361
Within groups: (df = 636)	24068	37.84	153.1	0.241	437.1	0.687	6484	10.19	2623	4.126	44.19	0.069
Total: (df = 639)	24702.5		161.942		454.961		7626.66		3212.49		45.2737	
F	5.584		12.19		8.663		37.32		47.55		5.203	
p (same)	0.000875		9.15E-08		1.22E-05		3.16E-22		9.74E-28		0.001481	
Components of variance (only for random effects):												
Var(group):	1.08418		0.016842		0.032915		2.31478		1.20043		0.001825	
Var(error):	37.8437		0.240779		0.687264		10.1965		4.12565		0.06948	
ICC:	0.0278511		0.065374		0.045704		0.185015		0.225387		0.025598	
omega2:	0.02103		0.04985		0.03467		0.1455		0.1791		0.01932	
Welch F test in the case of unequal variances:												
F	5.858		11.83		20.01		51.68		46.21		7.312	
df	348.5		352.7		344.1		331.8		346.6		331.9	
p	0.0006522		2.11E-07		5.64E-12		1.96E-27		3.80E-25		0.000118	
Kruskal-Wallis test for equal medians												
H (chi ²):	17.84		31.8		47.34		107		112.5		24.96	
Hc (tie corrected):	17.84		31.81		47.35		107		114.8		24.96	
p (same):	0.0004741		5.75E-07		2.93E-10		4.96E-23		1.00E-24		1.58E-05	
Significance of differences	There is a significant difference between the sample medians											

PH – plant height; GBH – garlic bulb height; GBD – garlic bulb diameter; GBW – garlic bulb weight; GCN – garlic cloves number; GCW – garlic clove weight

Table 4. ANOVA Test, Mann-Whitney pairwise, and Dunn's post hoc

Parameter and garlic landraces		Mann-Whitney pairwise				Dunn's post hoc			
		AR-AM	CS-Co	HD-Do	TM-Ce	AR-AM	CS-Co	HD-Do	TM-Ce
PH	AR-AM	0.00068	0.00068	0.00068	0.87330	0.00055	0.00055	0.00301	0.59020
	CS-Co	0.00068	0.44000	0.44000	0.00725	0.00301	0.62450	0.62450	0.00353
	HD-Do	0.00068	0.44000	0.44000	0.02276	0.00301	0.62450	0.62450	0.01518
	TM-Ce	0.87330	0.00725	0.02276	0.59020	0.00353	0.01518	0.01518	0.01518
GBH	AR-AM	0.43210	0.43210	2.68E-05	0.00160	0.58030	0.58030	1.95E-05	0.00427
	CS-Co	0.43210	0.43210	2.87E-06	0.00092	0.58030	0.58030	1.41E-06	0.00065
	HD-Do	2.68E-05	2.87E-06	0.10550	0.10550	1.95E-05	1.41E-06	0.00065	0.15770
	TM-Ce	0.00160	0.00092	0.10550	0.00427	0.00065	0.15770	0.15770	0.15770
GBD	AR-AM	0.47060	0.47060	3.70E-10	0.00015	0.36150	0.36150	5.74E-10	0.00024
	CS-Co	0.47060	0.47060	8.12E-08	0.01282	0.36150	0.36150	1.26E-07	0.00568
	HD-Do	3.70E-10	8.12E-08	0.01833	0.01833	5.74E-10	1.26E-07	1.26E-07	0.01175
	TM-Ce	0.00015	0.01282	0.01833	0.00024	0.00568	0.01175	0.01175	0.01175
GBW	AR-AM	0.16760	0.16760	1.79E-18	1.70E-21	0.00305	0.00305	1.08E-13	1.48E-20
	CS-Co	0.16760	0.16760	0.00011	9.74E-08	0.00305	0.00305	7.89E-06	2.43E-10
	HD-Do	1.79E-18	0.000105	0.00878	0.00878	1.08E-13	7.89E-06	0.06242	0.06242
	TM-Ce	1.70E-21	9.74E-08	0.00878	0.00878	1.48E-20	2.43E-10	0.06242	0.06242
GCN	AR-AM	0.39130	0.39130	1.31E-14	1.63E-18	0.20680	0.20680	1.16E-12	2.97E-19
	CS-Co	0.39130	0.39130	4.02E-09	4.19E-13	0.20680	0.20680	4.98E-09	1.29E-14
	HD-Do	1.31E-14	4.02E-09	0.01310	0.01310	1.16E-12	4.98E-09	0.06300	0.06300
	TM-Ce	1.63E-18	4.19E-13	0.01310	0.01310	2.97E-19	1.29E-14	0.06300	0.06300
GCW	AR-AM	0.20820	0.20820	8.97E-07	8.26E-07	0.01251	0.01251	2.19E-05	1.25E-05
	CS-Co	0.20820	0.20820	0.2757	0.1975	0.01251	0.01251	0.08052	0.06130
	HD-Do	8.97E-07	0.2757	0.88950	0.8895	2.19E-05	0.08052	0.08052	0.90160
	TM-Ce	8.26E-07	0.1975	0.88950	0.88950	1.25E-05	0.06130	0.90160	0.90160

AR-AM, landraces from Arad county, Agrisu Mare locality; CS-Co, landraces from Caras Severin county, Comoraste locality; HD-Do, landraces from Hunedoara county, Dobra locality; TM-Ce, landraces from Timis county, Cenad locality; PH – plant height; GBH – garlic bulb height; GBD – garlic bulb diameter; GBW – garlic bulb weight; GCN – garlic cloves number; GCW – garlic clove weight

Table 5. Statistical comparative analysis of garlic landraces in relation to TM-Ce, PH quantitative parameter

Statistical parameters	AR-AM	CS-Co	HD-Do
t test			
Given mean:	33.089	33.089	33.089
Sample mean:	32.959	30.887	31.21
95% conf. interval:	(32.167 33.75)	(29.82 31.953)	(30.454 31.966)
Difference:	0.13025	2.2021	1.879
95% conf. interval:	(-0.66142 0.92192)	(1.1355 3.2687)	(1.1231 2.6349)
t:	-0.32494	-4.0775	-4.9092
p (same mean):	0.74566	7.18E-05	2.25E-06
Significance of differences	ns	***	***
Wilcoxon test			
Given median:	32.21	32.21	32.21
Sample median:	33.4	30.3	31.2
W:	7895	7898	7906
Normal appr. z:	2.4789	2.484	2.4976
p (same median):	0.01318	0.012993	0.012503
Significance of differences	*	*	*

Table 6. Statistical comparative analysis of garlic landraces in relation to HD-Do, GBH quantitative parameter

Statistical parameters	AR-AM	CS-Co	TM-Ce
t test			
Given mean:	2.708	2.708	2.708
Sample mean:	2.4368	2.4418	2.6256
95% conf. interval:	(2.359 2.5147)	(2.36 2.5235)	(2.5568 2.6945)
Difference:	0.27119	0.26625	0.082375
95% conf. interval:	(0.19333 0.34904)	(0.18453 0.34797)	(0.013509 0.15124)
t:	-6.8793	-6.4351	-2.3624
p (same mean):	1.31E-10	1.39E-09	0.019366
Significance of differences	***	***	*
Wilcoxon test			
Given median:	2.705	2.705	2.705
Sample median:	2.52	2.41	2.61
W:	9702	9950	7748
Normal appr. z:	5.5575	5.9801	2.2285
p (same median):	2.74E-08	2.23E-09	0.025847
Significance of differences	***	***	*

Table 7. Statistical comparative analysis of garlic landraces in relation to HD-Do, GBD quantitative parameter

Statistical parameters	AR-AM	CS-Co	TM-Ce
t test			
Given mean:	3.031	3.031	3.031
Sample mean:	2.6273	2.7167	2.9623
95% conf. interval:	(2.5461 2.7086)	(2.6322 2.8012)	(2.744 3.1807)
Difference:	0.40369	0.31431	0.068687
95% conf. interval:	(0.32244 0.48493)	(0.2298 0.39883)	(-0.14965 0.28703)
t:	-9.8135	-7.3451	-0.62132
p (same mean):	4.55E-18	1.01E-11	0.53528
Significance of differences	***	***	ns
Wilcoxon test			
Given median:	3.1	3.1	3.1
Sample median:	2.71	2.68	2.86
W:	11445	10598	9278
Normal appr. z:	8.965	7.4945	4.8351
p (same median):	3.10E-19	6.66E-14	1.33E-06
Significance of differences	***	***	***

Table 8. Statistical comparative analysis of garlic landraces in relation to TM-Ce, GBW quantitative parameter

Statistical parameters	AR-AM	CS-Co	HD-Do
t test			
Given mean:	13.008	13.008	13.008
Sample mean:	9.4907	10.647	12.02
95% conf. interval:	(9.0661 9.9152)	(9.892 11.401)	(11.776 12.265)
Difference:	3.5173	2.3612	0.98769
95% conf. interval:	(3.0928 3.9419)	(1.6065 3.116)	(0.74325 1.2321)
t:	-16.363	-6.1791	-7.9803
p (same mean):	6.51E-36	5.20E-09	2.73E-13
Significance of differences	***	***	***
Wilcoxon test			
Given median:	12.465	12.645	12.465
Sample median:	10.165	9.74	12.005
W:	12288	9384	8491
Normal appr. z:	9.9621	5.0156	3.4942
p (same median):	2.23E-23	5.29E-07	0.00047544
Significance of differences	***	***	***

Table 9. Statistical comparative analysis of garlic landraces in relation to TM-Ce, GCN quantitative parameter

Statistical parameters	AR-AM	CS-Co	HD-Do
t test			
Given mean:	11.575	11.575	11.575
Sample mean:	9.2312	9.4938	10.813
95% conf. interval:	(8.9381 9.5244)	(9.1264 9.8611)	(10.585 11.04)
Difference:	2.3438	2.0812	0.7625
95% conf. interval:	(2.0506 2.6369)	(1.7139 2.4486)	(0.5354 0.9896)
t:	-15.791	-11.19	-6.6311
p (same mean):	2.19E-34	8.32E-22	4.94E-10
Significance of differences	***	***	***
Wilcoxon test			
Given median:	11	11	11
Sample median:	9	9	11
W:	9272.5	7972.5	4797
Normal appr. z:	8.609	6.7916	1.4637
p (same median):	7.37E-18	1.11E-11	0.14327
Significance of differences	***	***	ns

Table 10. Statistical comparative analysis of garlic landraces in relation to TM-Ce, GCW quantitative parameter

Statistical parameters	AR-AM	CS-Co	HD-Do
t test			
Given mean:	1.128	1.128	1.128
Sample mean:	1.0297	1.1274	1.1176
95% conf. interval:	(0.99189 1.0675)	(1.0593 1.1955)	(1.1005 1.1348)
Difference:	0.098281	0.00061875	0.010356
95% conf. interval:	(0.060457 0.13611)	(-0.067493 0.068731)	(-0.0068259 0.027538)
t:	-5.1317	-0.017941	-1.1904
p (same mean):	8.27E-07	0.98571	0.23567
Significance of differences	***	ns	ns
Wilcoxon test			
Given median:	1.117	1.117	1.117
Sample median:	1.0315	1.052	1.131
W:	9195.5	6639.5	6281.5
Normal appr. z:	4.6944	0.33988	0.001736
p (same median):	2.67E-06	0.73395	0.99861
Significance of differences	***	ns	ns

In addition, the nonparametric Mann-Whitney test was used. For each quantitative parameter, the best performing landraces was analyzed in comparison with each of the other garlic landraces considered in the study. The applied statistical tests (Mann-Whitney nonparametric test) led to certain statistical values (parameters U, and p), for each quantitative character, and comparative analysis between the garlic landraces.

In the case of PH parameter, the Mann-Whitney nonparametric test resulted in $U = 12668$, with $p = 0.873$ in the case of TM-Ce compared to AR-AM landraces; $U = 10578$, with $p = 0.0072$ in the case of TM-Ce compared to CS-Co landraces; $U = 10915$, with $p = 0.0227$ in the case of TM-Ce compared to HD-Do landraces. In the case of the GBH parameter, the Mann-Whitney non-parametric test resulted in U value = 9325, with $p < 0.001$ in the case of HD-Do compared to AR-AM landraces; U value = 8927 with $p < 0.001$, in the case of HD-Do compared to CS-Co landraces; U value = 11460 with $p = 0.105$ in the case of HD-Do compared to TM-Ce. In the case of the GBD parameter, the Mann-Whitney non-parametric test resulted in U-value = 7614.5 with $p < 0.001$, in the case of HD-Do compared to AR-AM landraces; U-value = 8360.5 with $p < 0.001$ in the case of HD-Do compared to CS-Co landraces; U-value = 10848 with $p = 0.0183$ in the case of HD-Do compared to TM-Ce. In the case of GBW parameter, the Mann-Whitney non-parametric test resulted in U value = 4920, with $p < 0.001$ in the case of TM-Ce compared to AR-AM landraces; $U = 8387.5$, with $p < 0.001$ in the case of TM-Ce compared to CS-Co landraces; $U = 10631$, with $p = 0.0087$ in the case in the of TM-Ce compared to HD-Do landraces. In the case of the parameter GCN, the Mann-Whitney non-parametric test resulted in U value = 5604 with $p < 0.001$ in the case of TM-Ce compared to AR-AM landraces; U value = 6851.5 with $p < 0.001$ in the case of TM-CE compared to CS-Co landraces; U value = 10777 with $p = 0.013$ in the case of TM-Ce compared to HD-Do landraces. In the case of GCW parameter, the Mann-Whitney non-parametric test resulted in U value = 8720.5 with $p < 0.001$, in the case of TM-Ce compared to AR-AM landraces; U value = 11733 with $p = 0.197$ in the case of TM-Ce compared to CS-Co landraces; U value = 12685 with $p = 0.889$ in the case of TM-Ce compared to HD-Do landraces.

The variability within each quantitative character and garlic landraces are comparatively discussed, based on the recorded CV values. In the case of the AR-AM landraces, moderate variability was recorded for the GBW parameter ($CV = 0.286$) and low variability for the PH parameter ($CV = 0.154$). In the CS-Co landraces, high variability was recorded for the GBW parameter ($CV = 0.454$) and low variability for the GBD parameter ($CV = 0.199$). In the HD-Do landraces, low variability was recorded for all productivity parameters, $CV = 0.098$ in the case of GCW to $CV = 0.183$ in the case of GBH. In the TM-Ce landraces, high variability was recorded for the GBD parameter ($CV = 0.472$) and low variability for the GCW parameter ($CV = 0.115$). According to the between-landraces analysis, for the PH parameter, low variability was recorded in the AR-AM landraces ($CV = 0.154$) and moderate variability in the TM-Ce landraces ($CV = 0.255$). For the GBH parameter, low variability was recorded in the TM-Ce landraces ($CV = 0.168$), and moderate variability in the CS-Co landraces ($CV = 0.214$). For the GBD parameter, low variability was recorded in the HD-Do landraces ($CV = 0.158$), and high variability was recorded in the TM-Ce landraces ($CV = 0.472$). For the GBW parameter, low variability was recorded in the HD-Do landraces ($CV = 0.130$) and high variability was recorded in the CS-Co landraces ($CV = 0.454$). For the GCN parameter, low variability was recorded in the HD-Do landraces ($CV = 0.135$) and moderate variability was recorded in the CS-Co landraces

(CV = 0.248). For the GCW parameter, low variability was recorded in the HD-Do landraces (CV = 0.098) and high variability was recorded in the CS-Co landraces (CV = 0.387).

PCA analysis of garlic landraces in relation to genetic and quantitative parameters

The multivariate analysis (PCA) was used to evaluate the behavior of the four landraces in relation to genetic parameters (FCM) and determined quantitative parameters. In relation to genetic parameters (FCM, mean values) the PCA resulted in the plot presented in *Figure 4a*. PC1 explained 60.62% of variance, and PC2 explained 35.098% of variance, based on PCM parameters. The differential positioning of garlic landraces in relation to the considered genetic parameters was observed (as biplot). The AR-AM landraces had a relatively independent position. The CS-Co landraces was positioned associated with G2, respectively intermediate between G2B and CVG2. The HD-Do landraces was positioned associated with CVG1. The TM-Ce landraces was associated with S.

In relation to quantitative parameters expressing productivity (GBW, GBN, GCW, mean values) PCA led to the diagram presented in *Figure 4b*. PC1 explained 66.323% of variance, and PC2 explained 33.403% of variance, based on quantitative parameters. From the analysis of the PCA plot in *Figure 5*, the independent positioning of the AR-AM landraces was found. The CS-Co landraces showed a positioning oriented towards the GCW parameter. The HD-Do landraces was balanced between GCW, GBW and GCN. The TM_Ce landraces showed a positioning oriented towards GBW and GCN.

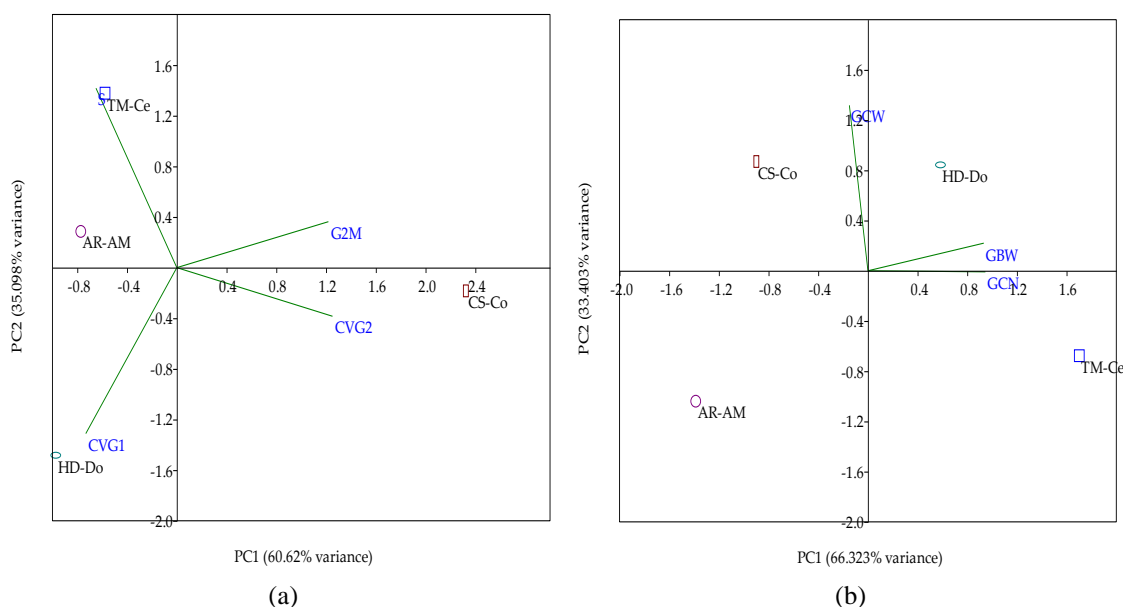


Figure 4. PCA diagram in relation to FCM genetic parameters (a), and productivity GBW, GCN, GCW parameters (b); original figures, based on PCA analysis

Interdependence analysis of quantitative and genetic traits

The correlation analysis was done on the mean values of quantitative parameters and genetic parameters (FCM) and the result is presented in *Figure 5*.

The PH parameter showed very strong positive correlation with CSP parameter ($r = 0.912$) and S parameter ($r = 0.901$). The GBH parameter showed very strong correlation with MnG2 ($r = -0.943$), strong correlation with MnG1 ($r = -0.89$) and moderate correlation with CVG1 ($r = 0.762$). The GBD parameter showed very strong correlation with MnG1 ($r = -0.961^*$) and strong correlation with MnG2 ($r = -0.898$). The GBW parameter showed very strong correlation with MnG1 ($r = -0.983$), and strong correlation with MnG2 ($r = -0.8$). The GCN parameter showed very strong correlation with MnG1 ($r = -0.948$), strongly correlated with MnG2 ($r = -0.89$) and weakly correlated with S ($r = 0.576$). GCW parameter strongly correlated with Csp ($r = -0.888$) and S ($r = -0.879$). GBH/GBD ratio strongly correlated with Csp ($r = 0.867$) and S ($r = -0.868$).

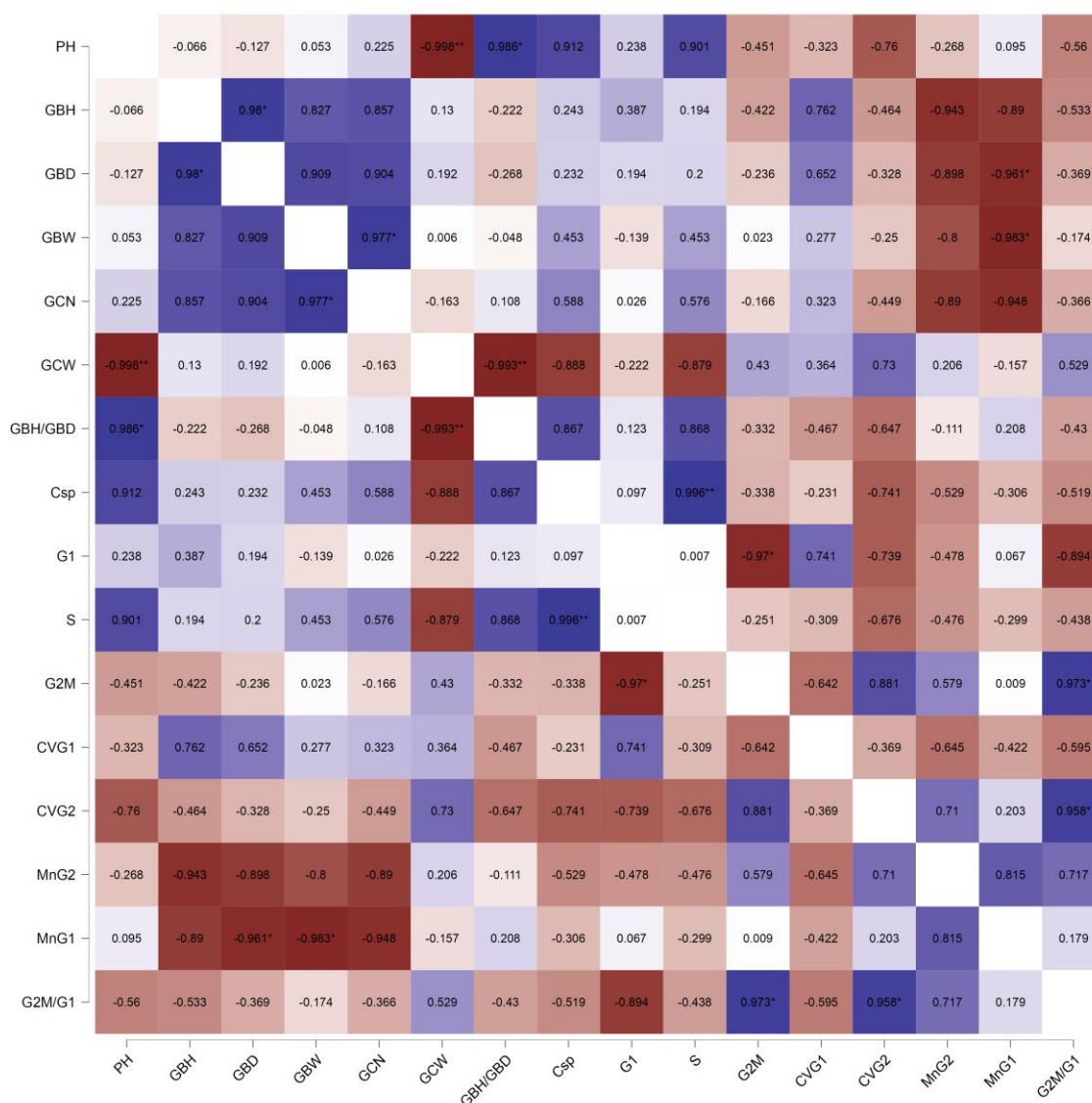


Figure 5. Graphic representation of the correlation between quantitative and genetic (FCM) parameters in the landraces garlic studied; original figure based on correlation analysis

At the level of genetic parameters, very strong correlations were found between CSp and S ($r = 0.996^{**}$), between G1 and G2M ($r = -0.97^*$), between G2M and G2M/G1

($r = 0.973^*$). Strong correlation was recorded between G1 and G2M/G1 ($r = -0.894$), between G2M and CVG2 ($r = 0.881$), between MnG2 and MnG1 ($r = 0.815$). There were also moderate correlations, or of lower intensity, between different quantitative parameters and genetic parameters, or at the level of genetic parameters.

The four garlic landraces behaved differently under uniform culture conditions, *ex situ*, in open field. Differences were recorded in both flow cytometry (FCM) and productivity parameters. Flow cytometry analysis showed differences on cell division flux within the four garlic landraces studied. The recorded results are comparatively discussed and analyzed, between the garlic landraces studied.

Different values recorded for FCM parameters may suggest differences in vegetation stages (precocity) between the garlic landraces studied. With cellular maturity, i.e. with increasing age, cells divide much less frequently, and this could be one of the explanations for the fact that in the presynthetic there was a high percentage of cells, and in the postsynthetic the doubling rate of DNAs was low. It is also possible that due to the fact that some garlic landraces showed more pronounced stability and expressivity of the genome, it was possible that cell division was present in a higher percentage.

The threshold was applied, on the scatter signal of 5%, with the possibility to modify this threshold, but the threshold of 5% was established by trial and error, because it was observed that, for this threshold, the data of interest were highlighted, i.e. only mononuclear cells. If the change of the 5% threshold is chosen, attention must be paid to the range of variation, because it is possible to lose data, and not to record useful data (for DNA analysis only cells with a single nucleus are of interest), which wanted to be analyzed. So, in sorting experiments, the threshold must be kept as low as possible, so that what is desired can be visualized, in relation to the purpose of the study. Sample preparation is extremely important in all cytometry experiments.

Similar results based on garlic flow cytometry have been reported in other studies. By flow cytometry, Sukias et al. (1990) determined the same nuclear DNA content in three garlic cultivars grown under New Zealand conditions. The varieties studied showed unique band patterns (the largest bands), exhibited some bands in terminal positions, and a limited number of bands were exhibited in interstitial positions (Sukias et al., 1990). On the basis of FCM, Xie et al. (1992) recorded decreased cell number in S phase and increased cell number in G1 phase under the influence of garlic oil treatments (experimental treatments in mice, S180 tumor cells). The authors concluded that garlic oil may block the transition of cells from G1 to S phase, lead to the accumulation of cells in G1, and inhibit AND synthesis and cell cycle (Xie et al., 1992).

Within each quantitative character, as a productivity parameter, different values were recorded in relation to the garlic landraces considered. The recorded results are discussed comparatively, between the garlic landraces, highlighting the significance of the differences, as appropriate. The four garlic landraces, in *ex situ* conditions, benefited from uniform crop conditions, with an accessible technology, similar to the farmers in the areas of origin of the garlic landraces. In these conditions, the garlic landraces expressed their genetic and biological growth and production potential. It was quantified based on quantitative characters, and two garlic landraces presented agronomic advantages. The HD-Do garlic landrace presented advantages for the GBH and GBD quantitative characters, while the TM-Ce garlic landrace presented advantages for the PH, GBW, GCN, and GCW quantitative characters. This may suggest the adaptability, and the different ecological plasticity of these garlic landraces.

Similar results were reported in other studies, regarding the contribution of some quantitative characters (e.g. cloves) to bulb formation in different garlic landraces. Significant positive contribution (genotypic and phenotypic) in the yield of garlic bulbs, were associated with certain plant characters, with the exception of plant height and harvest index (Tesfaye et al., 2021). Leišová-Svobodová et al. (2024) studied productivity parameters in garlic and found that the weight of cloves had a higher contribution to bulb weight compared to the number of cloves. The authors recorded a high correlation between genotype, phenotype and quantitative characters analyzed in the biological material studied (Leišová-Svobodová et al., 2024). In Belltall garlic, clove size strongly influenced bulb size (Casals et al., 2023).

Based on the coefficient of variation (CV) values determined for the quantitative characters considered, variability within each landraces and between landraces was assessed. Genetic diversity and morphological variability for some productivity characters in garlic were also reported in other studies, which confirmed the importance of these approaches. Analyzing the genetic diversity in a garlic collection García-Lampasona et al. (2012) found different phenotypic classifications connected with genotype in response to genetic origins by ecophysiological groups. Jo et al. (2012) studied the genetic diversity in 120 garlic accessions, recorded high variability for phenotypic diversity (bulb size and color), and correlation of genetic diversity with geographic region. Groups with significant variation in agro-morphological traits were identified by analyzing genetic diversity in a collection of 39 garlic accessions (Chen et al., 2014). Raja et al. (2017) reported lower values of the coefficient of genotypic variation compared to phenotypic variation for 12 traits in a collection of 80 garlic genotypes studied. Significant diversity was recorded between quality parameters and bulb morphology in garlic, both among landraces from different regions of Greece and within the same region (Petropoulos et al., 2018). In a study on 260 garlic germplasm collected from different areas in India (13 traits analyzed), Jethava et al. (2018) found higher values for PCV (phenotypic variance coefficient) compared to GCV (genotypic variance coefficient). Higher values of GCV and PCV were recorded for pseudostem diameter and leaf width (Jethava et al., 2018). Genetic diversity was quantified at 16% within landraces and 84% associated with inter-landraces based on a survey of 53 garlic accessions in India (Kumar et al., 2019). Bonasia et al. (2020) reported high variability in the local garlic landraces studied (six landraces, Puglia region, Italy). At the same time, the authors of the study recorded decreasing interest in landraces, associated with genetic erosion in landraces, in favor of the promotion of modern garlic varieties. From the analysis of 28 garlic accessions, Tesfaye (2021) reported genetic progress and high variability in some morphological parameters studied. Tesfaye et al. (2021) reported high heritability combined with genetic advance for morphological and productivity parameters (bulb, cloves, and yield) based on a study of 49 garlic accessions (garlic growing areas in Ethiopia). Through genetic analysis (SSR markers, InDel) of the Belltall garlic landraces (16 accessions), Casals et al. (2023) reported low genetic and phenotypic diversity within the landraces. Higher overall diversity (genotypic and phenotypic) was recorded in the bolting garlic genetic landraces ($I = 0.94$) compared to the nonbolting garlic genetic landraces (Leišová-Svobodová et al., 2024). Multivariate analysis showed the differential orientation and correlation of garlic landraces in relation to FCM parameters (flow cytometry), and in relation to quantitative characters (biometric parameters in garlic bulbs and cloves). The recorded results showed interdependence between PCA values and correlation

values, regarding the behavior of the four garlic breeds in the study conditions. The association between FCM parameters and quantitative characters shows the connection between them. This was noted by PCA analysis and by Correlation analysis. According to the PCA and correlation data, some quantitative characters showed correlations with FCM parameters, with advantages for certain garlic landraces, under the study conditions.

The concordances between the results of PCA and cluster analysis were reported by Chen et al. (2014) based on their study on a collection of 39 garlic accessions. According to PCA, the identified clusters showed significant variation in agro-morphological traits. Multi-criteria analysis (PCA) facilitated the formation of garlic clusters (three clusters, 417 accessions as the study base) in relation to variety and geographical origin of provenance (Egea et al., 2017). The results were obtained and supported by genotyping by sequencing (GBS) technology, such as DArTseq, according to the authors (Egea et al., 2017). Hierarchical cluster analysis, the main coordinates analysis, and structure, have highlighted the general consistency, and in relation to the geographical origin and the genotype, they have generated three main groups of garlic (Egea et al., 2017).

The recorded correlations expressed the interdependence between the FCM parameters, determined on the leaf samples from the vegetation period of the garlic plants, and the quantitative characters, recorded at the end of the vegetation period. Associated with the correlation levels, between garlic landraces and quantified parameters, expressed in the PCA analysis, as well as between parameters (Figs. 4 and 5), it resulted that two garlic breeds presented certain advantages in some quantitative characters.

Correlation analysis is an appropriate statistical analysis tool, and it was used to describe the interdependence of different productivity parameters, agronomic and genetic characters in garlic. The correlation of genetic diversity with region of origin in garlic was reported based on a study of 120 garlic accessions (Jo et al., 2012). Correlations between certain agronomic traits and genotype were reported by Egea et al. (2017) based on a study of 417 garlic accessions. Tesfaye (2021) communicated positive, significant correlations between some quantitative characters analyzed on a collection of 28 garlic accessions. The author explained the results based on variability and genetic advance for certain characters. The author concluded that certain characters require attention (e.g. leaf length, plant height, number of cloves, bulb diameter and weight), because they are correlated and have a major contribution to yield formation (Tesfaye, 2021). Genetic progress was recorded in the number of leaves, bulb diameter, clove weight, and bulb yield (Tesfaye, 2021). Tesfaye et al. (2021) reported significant positive correlations (genotypic and phenotypic), of garlic bulb yield, with the analyzed traits, except plant height and harvest index. Leišová-Svobodová et al. (2024) reported high correlation between genotype and phenotype ($R = 0.88$, $p \leq 0.01$) in the studied garlic landraces (Garlic Collection, Olomouc Genebank). The average weight of garlic cloves contributed more to bulb weight than the number of garlic cloves (Leišová-Svobodová et al., 2024). The recorded results recommend further research, conducting similar studies for other garlic landraces, broadening the genetic base of analysis by including new garlic landraces, comparative analysis with commercial genotypes, and identification of valuable germplasm for breeding programs. In addition to the genetic and quantitative parameters used in the present study, it would be appropriate to consider economic indicators, analyzing the perspective of local landraces in relation to the market and consumer preferences.

Conclusions

In the present study, flow cytometry parameters (FCM) and quantitative characters were quantified in four garlic landraces (AR-AM, CS-Co, HD-Do, and TM-Ce) from the western part of Romania. FCM parameters (S, G1, G2M) showed differences between the garlic landraces, as a result of the differentiated flow of activity in the cell division process. This fact can be associated with differences in vegetation between garlic breeds (precocity). The distribution of cells in the different phases of mitotic division did not show an abnormal evolution, which revealed the stability of the genome.

The quantitative characters showed differentiated variability at the level of the garlic landrace, as well as between the garlic landraces. The HD-Do garlic landrace presented low variability for all determined quantitative characters. The AR-AM garlic landrace showed low variability for the PH character and moderate variability for the GBW character. CS-Co and TM-Ce garlic landraces showed low variability for GBW and GCW characters, respectively, and high variability for GBW and GBD characters, respectively.

Correlation of different intensity was recorded between quantitative parameters and FCM parameters, with possible advantages for certain quantitative and agronomic characters in the garlic landraces studied. The main components explained the presence of variance in the experimental data, in relation to FCM parameters (PC1 = 60.61%, and PC2 = 35.098%), respectively in relation to quantitative characters (PC1 = 66.323%, PC2 = 33.403%). Based on the recorded results for the quantitative characters, two garlic landraces stood out in comparison with the other two, through differences in statistical safety conditions. The HD-Do garlic landrace presented advantages for the GBH and GBD quantitative characters. The TM-Ce garlic landrace showed advantages for the PH, GBW, GCN, and GCW quantitative characters.

This study highlighted the behavior of the four garlic landraces in ex situ crop conditions, the differences between the FCM parameters and the analyzed quantitative characters, and identified two garlic landraces with agronomic advantages in the study conditions.

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