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RESEARCH ON THE VARIABILITY OF PHENOLOGICAL CHARACTERISTICS IN GARLIC GENOTYPES AND THE INFLUENCE OF ENVIRONMENTAL FACTORS ON DIFFERENT VEGETATIVE STAGES

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Abstract

The objective of this study was to analyse the variability of phenological characteristics in garlic genotypes over two vegetation years and to assess the influence of environmental factors on different growth stages across 36 genotypes and two garlic varieties. The primary phenological development stages were examined according to BBCH standards, considering the specific environmental factors of the experimental location (44°21'55"N, 23°48'18"E). For autumn varieties, the vegetative period of garlic genotypes was longer during the 2022/2023 season (253.79 days) compared to 2021/2022 (224.99 days). Conversely, in spring varieties, the vegetative period was shorter in 2023 (108.99 days) than in 2022 (130.5 days). This reduction was attributed to abundant precipitation, influencing the growth and development of the crop and reducing the plant's lifespan. The results underscore the significant impact of environmental factors, particularly temperature and precipitation, on the developmental stages of garlic plants.

Key words*: Allium sativum L., climatic impact, crop phenology.*

INTRODUCTION

The phenology of plants represents the recurrent annual sequence of developmental stages, crucial for the functioning of plants and ecosystems (Piao et al., 2019). This sequence undergoes alterations in response to global climate changes, which have the potential to desynchronize ecological interactions and threaten ecosystem functioning (Thackeray et al., 2016). Factors influencing plant growth and development include variations in temperature and soil moisture, nutrient availability, light, and increased CO_2 concentration (Nord & Lynch, 2009). These changes have significant consequences for ecosystem productivity, the carbon cycle, competition, trophic networks, and other ecosystem functions and services (Tang et al., 2016). Field observations provide a method offering direct evidence of phenological changes, accurately recording the timing of phenological events in specific locations and species and providing valuable information on climate change (Piao et al., 2019). Field observation must yield consistent information, even when recorded by different individuals in diverse locations, considering genetic diversity (Popa et al., 2023). In this context, the BBCH system is frequently employed, providing a standardized definition of plant developmental stages (Meier et al., 2009). An extended BBCH scale for garlic, comprising seven main growth stages divided into secondary stages, has been detailed and represented by a code of two or three digits by Lopez-Bellido et al. (2016). Morphological studies, correlated with phenology, have been conducted by other researchers to better understand processes and key traits in the development and growth of garlic plants and their implications for final crop yield simulations (Hsiao et al., 2019) or to analyse phenotypic plasticity and functional responses to water availability (Sanchez-Virosta et al., 2021). Considering these aspects, this work aimed to analyse the variability of phenological

characteristics in garlic genotypes over two vegetation years and to examine the influence of environmental factors on different growth stages.

MATERIALS AND METHODS

Biological Material and Research Location
A comprehensive examination involved 36 garlic genotypes (16 autumn varieties: CR14, IZ6, RC12, PV8, SS4, GH2, DB11, CN7, PL1, DG3, GR5, OR10, BR9, M15, DB13, and 20 spring varieties: CR9, CR12, IZ10, RC13, RC14, RC15, SS3, SS19, DB20, CN7, DN8, CZ5, CZ16, C17, PC4, RB11, GL18, BL6, CT1, OT2, FC21), along with 2 approved varieties ('Benone' and 'Cucerdea 80'). Observations were conducted in an experimental plot located in the northern part of Craiova (44°21'55"N, 23°48'18"E). Climatic conditions during the research period (October 2021 - July 2022) were as follows: accumulated precipitation reached 517.6 mm, with an average temperature of 12.7°C; the monthly average minimum temperature was 3.6°C in January 2022, and the monthly average maximum temperature was 26.68°C in July 2022. For the period October 2022 - July 2023, total precipitation accumulated to 717.6 mm, and the average temperature was 13.3°C. Soil characteristics were determined as follows: pH - 6.31, humus content 1.8% (m/m), nitrogen content: nitrites - <0.25 mg/kg, nitrates - 96.6 mg/kg; chemical elements content: P - 496 mg/kg, K - 5410 mg/kg, Mg-4310 mg/kg, Na - 260 mg/kg, Fe - 23700 mg/kg, Zn - <50 mg/kg. Soil analyses were performed by WESSLING Romania SRL. The cultivation scheme, in rows, had the following distances: 25 cm row spacing, 6-8 cm plant spacing within rows, and a planting depth of 2-3 cm for spring varieties, while for autumn varieties, the planting depth was 5 cm.

Method
The BBCH scale, as described by Meier (2001), was utilized for observations of garlic plant growth stages. Observations commenced from crop establishment (bulb planting), recording each developmental stage: germination phase (00-09), leaf apparatus development (10-19), bulb development (41-48) and senescence (92-99). Additionally, for autumn garlic genotypes developing a flowering stem, the flowering initiation stage (51-59) and full bloom (60-69) were recorded. Observations spanned two cultivation years (2021-2022, 2022-2023).

Statistical Analysis
The obtained data were statistically analysed using the Excel data analysis program.

RESULTS AND DISCUSSIONS

Substantial disparities in environmental conditions have been observed, encompassing average monthly temperatures, the seasonal mean temperature, monthly precipitation averages, total precipitation, and their distribution. The data delineated in Table 1 pertains specifically to the temperature factor, revealing an upward trend. In the cultivation season of 2022-2023, the monthly temperature mean surpassed the previous season by +0.60°C. Notably, the lowest value for monthly mean temperatures occurred in the inaugural cultivation season, with January recording 3.66°C. In contrast, the minimal mean value for December 2022, within the 2022-2023 season, was 4.6°C.

Table 1. Average monthly temperatures (°C) for the period October 2021 - July 2023

Period/ Average temperature (°C)			
October 2021	11.91°C	October 2022	15.58°C
November 2021	9.26°C	November 2022	11.21°C
December 2021	4.31°C	December 2022	4.6°C
January 2022	3.66°C	January 2023	6.03°C
February 2022	6.89°C	February 2023	5.35°C
March 2022	6.85°C	March 2023	10.7°C
April 2022	13.3°C	April 2023	12.44°C
May 2022	19.75°C	May 2023	17.69°C
June 2022	24.46°C	June 2023	22.2°C
July 2022	26.68°C	July 2023	27.25°C
Mean	12.70°C	Mean	13.30°C

For spring garlic varieties, the cultivation season spanning from March to July is notably shorter compared to that of autumn varieties. Within this timeframe, considering only the March to July interval, the monthly temperature mean was 18.20°C for the March - July 2022 season and 18.05°C for the March - July 2023 season, showcasing a marginal difference of a mere 0.15°C between the two seasons. Substantial distinctions are identified in October (3.67°C), November (1.95°C), January (2.37°C), and March (3.85°C). Table 2

delineates the monthly and total precipitation quantities for the two cultivation seasons. Data analysis reveals a heightened precipitation amount for the period October 2022 - July 2023, recording 717.5 mm, surpassing the October 2021 - July 2022 period by 199.9 mm (517.6 mm). Concerning the distribution of precipitation across calendar months, no consistent pattern is discerned, with each month exhibiting diverse tendencies annually. In the initial three months of 2023, precipitation amounts were notably higher compared to 2022. Moreover, the concluding months of June and July in the growing season exceeded the values of the corresponding months in the previous year (June 2022 - 63 mm, June 2023 - 111.2 mm; July 2022 - 41 mm, July 2023 - 67.6 mm). Regarding spring varieties, the initial cultivation season (2022) accumulates a total of 345 mm, representing over half of the total precipitation value recorded for the autumn variety cultivation season (2021-2022). The second growth season registers a total of 310 mm, a value proximate to the previous year. However, the distribution therein significantly differs (March 2022 - 5.8 mm; March 2023 - 95.2 mm; July 2022 - 41 mm; July 2023 - 67.6 mm).

Table 2. Amount of monthly precipitation (mm) for the period October 2021 - July 2023

Period/Monthly precipitation (mm)			
October 2021	44.6	October 2022	27.0
November 2021	56.4	November 2022	93.2
December 2021	35.0	December 2022	110.0
January 2022	76.2	January 2023	76.2
February 2022	77.8	February 2023	100.6
March 2022	5.8	March 2023	95.2
April 2022	117.8	April 2023	0.2
May 2022	117.4	May 2023	36.3
June 2022	63.0	June 2023	111.2
July 2022	41.0	July 2023	67.6
Total	517.6	Total	717.5

Table 3 illustrates the progression of phenological stages for autumn garlic genotypes across two cultivation seasons, highlighting variations arising from distinct environmental conditions. In the first year of the study (2021-2022), the initial phenological stage, germination, a period characterized from planting to the emergence of the first true leaf, averaged 30.75 days, with a range between 14 and 69 days, manifesting a 55 day difference among genotypes. In the year 2022/2023, the germination period was shorter than the preceding year, recording an average duration of 26.5 days. The variation limits were narrower compared to the previous year, with a lower limit of 21 days and an upper limit of 35 days, indicating a 14 day difference among genotypes. The duration of the germination period among genotypes was more closely clustered around the mean value for the 2022/2023 season, with the coefficient of variation (CV) at 18.3%, as opposed to the 2021/2022 season when the CV was 52.52%. This difference is attributed to varying environmental factors (Tables 1 and 2). According to specialized literature, factors influencing the garlic clove germination rate encompass planting time, cultivar, environmental factors (temperature), photoperiod, and harvest maturity (Kamenetsky & Okubo, 2012). The second stage, leaf development, spans from the emergence of the first visible true leaf, exceeding 3 cm (11-101 BBCH), to the appearance of the last leaf in the foliage apparatus (19-109 BBCH). For the study period 2021/2022, the leaf development phase lasted an average of 117.66 days. The statistically calculated minimum number of days was 72, while the maximum was 148. In the following growing season, 2022/2023, the vegetation period increased by approximately 20 days compared to the previous year, reaching 137.93 days. Regarding the range limits, the values were much closer to each other, with the minimum limit at 133 days and the maximum at 147 days. The coefficient of variation showed values of 22.03% in the 2021/2022 season and 3.93% in the 2022/2023 season. The onset of bulb formation is considered when the basal leaf begins to thicken or expand (41-401 BBCH). This phase is primarily influenced by genetic and environmental factors, especially photoperiod and increasing temperatures, correlated with the plant's phenological stage (Atif et al., 2019). The end of this phenological stage is recorded when growth is complete, leaves are dry, and bulb dormancy begins (49-409 BBCH). In the 2021/2022 growing season, this phase lasted 61.2 days, with variation limits between 54 and 69 days. In the second year, 2022/2023, the data were approximately similar, with values varying very little compared to the year 2021/2022. The average

period was 67.93 days, the range limits were 56 to 77 days, and the coefficient of variation was 9.80%. For genotypes with tall stems, exhibiting "hard neck," which develop a flowering stalk, the flowering phase (51-501 BBCH) occurs simultaneously with the bulb development phase, concluding with the end of flowering (69-609 BBCH). This phenological stage coincides with the final stage of bulb formation and involves the appearance of the flowering stalk, observed only in some autumn garlic genotypes. The phenomenon is influenced by the storage conditions of garlic bulbs and the duration of the photoperiod. Generally, it is considered that low temperatures and a long photoperiod favour the appearance of flowering stalks (Kamenetsky et al., 2004). Mathew et al. (2011) suggest that garlic florescence can be promoted through exposure to appropriate environmental stimuli during storage before planting and sprouting until subsequent growth stages. Regarding autumn garlic genotypes, specialized literature indicates three types: genotypes that do not produce flowering stems ("soft neck," *A. sativum* L. var. *sativum*), genotypes that produce flowering stems, form flowers, and sterile seeds (Kashmiri garlic - *A. schoenoprasum* L.), and genotypes that develop flowering stems and form aerial bulbils, such as Rocambole garlic ("hard neck" - *A. sativum* var. *ophioscorodon*). In the conditions of the 2021/2022 growing season, the flowering phase lasted an average of 53.73 days. The range limits for this phase were between 42 and 69 days, varying with the genotype. In the second growing season (2022/2023), the flowering period significantly decreased, reaching an average duration of 38.6 days. The range limits for this year were between 32 and 45 days.

The physiological maturity of plants represents the necessary stage for further development or final maturity, aiming at the consumption, processing, or multiplication of garlic (Galgaye, 2023). As the ultimate phase, plant senescence initiates from the moment plants begin to discolour (92-902 BBCH) and concludes when they are harvested (99-909 BBCH). For the period 2021/2022, plant senescence lasted an average of 14.26 days, with variation limits between 8 and 19 days. For this phenological stage, the coefficient of variation recorded a value of 26.81%, indicating high variability among the genotypes under study. For the period 2022/2023, the duration of the garlic plant senescence phase was 21.43 days, longer compared to the previous year. The variation limits for this period were between 16 and 27 days.

Table 3. Evolution of phenological stages of autumn garlic genotypes

Phenological stages	Statistical indicators	Period	
		2021/2022	2022/2023
0. Sprouting	X±SD	30.75±16.15	26.5±4.85
	Range limits	14-69	21-35
	CV %	52.52	18.30
1. Leaf development	X±SD	117.66±25.92	137.93±5.43
	Range limits	72-148	133-147
	CV %	22.03	3.93
4. Bulbing phase	X±SD	61.2±6.73	67.93±6.65
	Range limits	54-69	56-77
	CV %	10.99	9.80
5. Flowering phase	X±SD	53.73±9.14	38.6±5.45
	Range limits	42-69	32-45
	CV %	17.01	14.14
9. Senescence	X±SD	14.26±3.82	21.43±3.28
	Range limits	8-19	16-27
	CV %	26.81	15.32

X - mean; SD - standard deviation; CV - coefficient of variability (%)

Table 4 provides a statistical analysis of the phenological stages in spring garlic genotypes. It is noteworthy that spring garlic genotypes do not produce flowering stems; hence, the flowering phase is absent in the study of phenological stages. Similar to autumn genotypes, the recording of phenological stages commenced at the establishment of the crop. In the first growing season, the year 2022, the average duration for the initial phase (sprouting) was 20.1 days. The range varied between 10 and 28 days for the same garlic genotypes. In the subsequent year, 2023, the germination period was shorter compared to the previous year, with an average duration of 13.65 days. The variation limits were narrower than those in 2022, with a lower limit of 10 days and an upper limit of 17 days. The coefficient of variation showed values of 23.99% in 2022 and 17.13% in the 2023 season. The second stage (leaf development) in 2022 spanned a period of 56.6 days, with a minimum of 36 days and a maximum of 68 days. For the next growing season, 2023, this stage recorded a decrease of approximately 9 days compared to the previous year, namely 47.80 days, likely due to higher temperatures in

that year. In terms of variation limits, the values were much closer to each other, with a minimum limit of 40 days and a maximum limit of 60 days. The coefficient of variation values was similar for both years, measuring 12.20% (2022) and 12.22% (2023). In the first year of cultivation (2022), the bulb formation phase lasted for 41 days. The range of variation was between 38 and 44 days, with a coefficient of variation of 3.87%. Similar to the previous stage, in the 2023 growing season, the duration of this phenological phase was shorter compared to 2022. The average period was 35.38 days, with variation limits of 30 to 42 days, and a coefficient of variation of 12.30%. The senescence stage of the plants averaged 12.8 days in 2022, with variation limits between 11 and 16 days. In 2023, the senescence period for garlic plants was 12.2 days. The coefficient of variation values was close, with 2022 having a value of 9.68%, and the subsequent year (2023) registering 12.29%

Table 4. Evolution of phenological stages of spring garlic genotypes

Phenological stages	Statistical indicators	Year	
		2022	2023
0. Sprouting	X±SD	20.1±4.82	13.61±2.33
	Range limits	10-28	10-17
	CV %	23.99	17.13
1. Leaf development	X±SD	56.6±6.90	47.80±5.84
	Range limits	36-68	40-60
	CV %	12.20	12.22
4. Bulbing phase	X±SD	41±1.58	35.38±4.35
	Range limits	38-44	30-42
	CV %	3.87	12.30
9. Senescence	X±SD	12.8±1.23	12.2±1.23
	Range limits	11-16	11-14
	CV %	9.68	12.29

X - mean; SD - standard deviation; CV - coefficient of variability (%)

Regarding the duration of the vegetation period, Figure 1 illustrates the phenological stages' duration for autumn garlic genotypes, from crop establishment to plant senescence, for the two cultivation years 2021/2022 and 2022/2023. Differences between the two cultivation years in terms of the period and duration of these stages are observed. It is noted that during the first cultivation season (2021/2022), the progression through phenological phases occurred much faster compared to the following season (2022/2023). In 2021/2022, the crop was established in the third decade of October to the first decade of November. In this case, the end of the vegetative period took place in the last decade of June to the first decade of July, spanning, on average, 7-7.5 months. In 2023, the end of the vegetative period occurred in the first and second decades of July.

Comparatively analysing the two garlic genotypes' cultivation seasons, the following stand out: (1) A difference regarding the flowering period, specifically the absence or presence of the flowering phenological stage. Genotypes that did not emit a flower stem in both cultivation years were: CR14, IZ6, PV8, SS4, DB11, DB13, BR9. There were genotypes that developed the flowering phenological stage in both the 2021/2022 and 2022/2023 years: RC12, GR5, M15. For the three genotypes (RC12, GR5, M15), even though they developed the phenological stage in both cultivation years, the flowering period was shorter in 2022/2023 compared to 2021/2022: RC12 – 53 days (2021/2022) and 45 days (2022/2023); GR5 – 45 days (2021/2022) and 40 days (2022/2023); M15 – 50 days (2021/2022) and 45 days (2022/2023). (2) In 2023, for genotypes that emitted flower stems, aerial bulbils did not develop as expected, having reduced sizes and not reaching the required maturity state for harvesting. According to the literature, flowering and bulb formation in geophyte plants are energy-intensive processes, and the competition for internal resources limits their ability to fully develop (Michael et al., 2018).

Analysing the two study years, the number of days for phenological stages varied even within the same genotype, depending on the climatic conditions of each year. The number of days for the germination stage ranged from 14 days for the 'IZ6' genotype in 2021/2022 to 69 days for the 'M15' genotype in the same year. For the leaf development stage, the number of days ranged from 72 days for 'M15' (2021/2022) to 148 days for 'RC12' (2021/2022). The bulb development phase had a minimum limit of 46 days for 'Benone' (2021/2022) and a maximum limit of 84 days for 'M15' (2022/2023). The flowering stage ranged from a minimum of 32 days for 'BR9' (2022/2023) to a maximum of 68 days for 'PV8' (2021/2022). The senescence stage varied between 8 days for 'PV8', 'SS4' (2021/2022), and 27 days for 'SS4' (2022/2023).

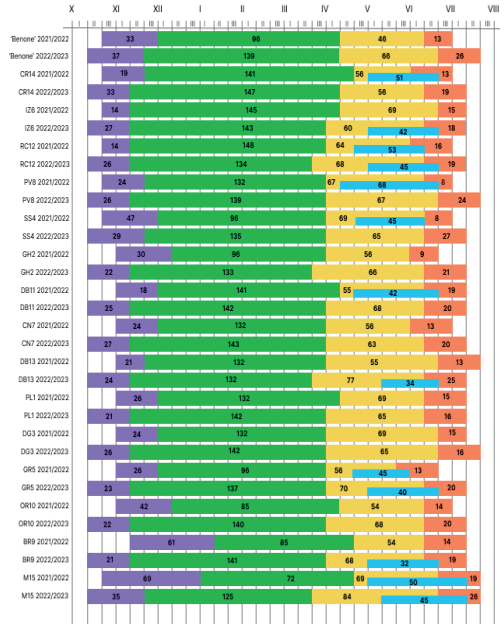

Figure 1. Phenogram of sprouting - senescence of autumn garlic genotype (purple: 00-09; green: 10-19; yellow: 41-48; blue: 51-69; red: 92-99)

Figure 2 illustrates the phenogram of spring garlic genotypes, highlighting all phenological stages for the years 2022 and 2023. A significant decrease in the durations of phenophases is observed for all garlic genotypes in the 2023 growing season. This is caused by a delay in crop establishment due to unfavourable weather conditions. Abundant and frequent precipitation was recorded in the months of February (100.6 mm) and March (95.2 mm), preventing adherence to the planting season, specifically the last decade of March and the first two decades of April. Del Pozo et al. (1994) suggest that the duration of the planting-emergence of shoots and emergence-initiation of bulbs is shorter when sowing is late. The sowing date and varieties are among the critical factors determining garlic yield and quality (El-Zohi et al., 2014). Unfavourable environmental factors affect the vegetation period. Such events were recorded in 2023 in the form of abundant precipitation and hail. Significant amounts of precipitation were recorded in June (111.2 mm) and July (67.6 mm), corresponding to the phenological stage of bulb development. The leaf apparatus of the plants was irreversibly affected, and at this point, the senescence phase of garlic plants occurred in the first and second decades of July. In 2022, garlic plants went through a longer vegetative period, with genotypes planted in the first decade of March, in the first urgency. The end of the vegetation period occurred in the second decade of July.

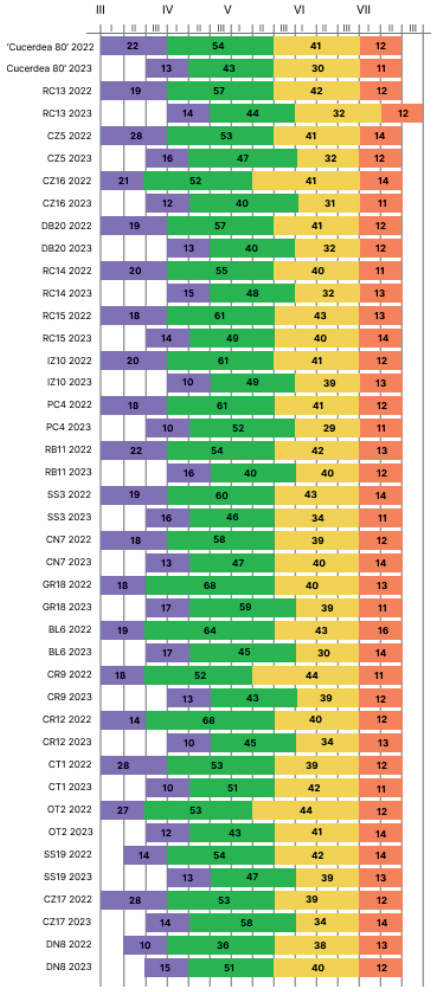

Figure 2. Phenogram of sprouting - senescence of spring garlic genotypes (purple: 00-09; green: 10-19; yellow: 41-48; red: 92-99)

Similar to autumn genotypes, the number of days for phenological stages varied. The number of days for the sprouting stage ranged from 10 days for genotypes 'PC4', 'IZ10', 'CR12,' and 'CT1' in 2023 to 28 days for genotype 'CZ5' in 2022. For the leaf development stage, the number of days ranged

from 36 days for 'DN8' (2022) to 68 days for 'GR18' (2022). The bulb development phase had a minimum duration of 29 days for 'PC4' (2023) and a maximum of 44 days for 'CR9' (2022). The senescence stage varied between 11 days for 'Cucerdea 80' (2023) and 16 days for 'BL6' (2022).

CONCLUSIONS

The obtained results emphasize that environmental factors, notably temperature and precipitation, wield a significant influence on the developmental stages of garlic plants.

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