

CONTENT OF PHOTOSYNTHETIC PIGMENTS IN *Sedum album* L. AND *Sedum reflexum* L. IN DRY WEATHER CONDITIONS OF THE STEPPE ZONE OF UKRAINE

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Abstract

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The climate changes in the steppe zone of Ukraine are associated with the rise in temperature and prolonged droughts, and the consequences of their stressful action depend on the stage of plant development, as well as duration and severity of stress. Species of the genus *Sedum* L. have long been cultivated; however, these unpretentious multifunctional perennials are of limited use in artificial cenoses of the region. The purpose of this study was to determine the content of photosynthetic pigments during the growing season in *S. album* and *S. reflexum* in dry weather conditions of the steppe zone of Ukraine. It was found that the content of basic photosynthetic pigments (1.1–3.5 mg/g of raw materials) was higher in the leaves of *S. reflexum* plants, with the predominance of Chl *a* in the total pigment amount at all phases of development. During flowering, the content of Chl *b* and of secondary peroxidation products in *S. album* increased significantly. In addition, the medium-strength direct correlation between the level of precipitation and the content of Chl *a* ($r = +0.58$) was found in *S. album*. In *S. reflexum*, the content of carotenoids increased during flowering, and correlation coefficients at the phase of completion of the vegetative growth indicated the strong inverse relationship ($r = -0.95$) of the content of all pigment forms with the air temperature. The study results revealed that the content of photosynthetic pigments and variation in their quantities in the leaves of *S. album* and *S. reflexum* were species specific, and these changes contributed to an increase in the protective mechanisms of the pigment system associated with the resistance to stress.

Key words: genus *Sedum* L., photosynthetic pigments, growing season, temperature, precipitation, stress.

Introduction

Research on the relationships between plants and their environment, as well as the plant adaptation to living conditions, is particularly relevant given the combination of negative impacts of urbanization and climate change. Global climate change often creates stressful conditions for the development of numerous plant species. Their survival, in response to fluctuations of the natural and anthropogenic factors, is predetermined by the plasticity of the plant organism, and the changes occurred at different levels of the structure of a specimen are adaptive in their nature and aimed at stabilizing the ontogenetic development (Musienko, Zhuk, 2009; Bano et al., 2019). The steppe zone of Ukraine, especially its southern part, where climate change is associated with the rise in temperatures and prolonged droughts, is characterized by unfavorable conditions for the vital activity of most plants used in the landscaping of settlements (Chypyliak et al., 2022; Strashok, 2022). Here, the plants are affected by a lot of different factors, but their survival and growth are determined by several critical causes, having a significant influence

on the biological productivity of the species. However, their fluctuations do not exceed the range of stability for the plant survival at any stage of ontogenesis (Loidi et al., 2012; Oishy et al., 2025; Alatalo, 2025). The extreme natural phenomena, such as the combination of droughts and high temperatures during the growing season, have a detrimental effect on the plants, limiting their growth and development, since they are among the most complex stressors of all abiotic factors that natural and artificial ecosystems currently face (Giordano et al., 2021; Krzyzak et al., 2023). Under their action, the plants experience dehydration of their cells and increased formation of the reactive oxygen species; the processes of transpiration, photosynthesis, chlorophyll synthesis, and respiration are disrupted, with the subsequent growth reduction and morphological changes. The consequences of stress because of drought and temperature factors vary depending on the species and genotype of plants, stage of their development, duration, and severity of stress (Wach, Skowron, 2022; Mishra et al., 2023; Kiriziy et al., 2024).

The city of Kryvyi Rih (where the research was conducted) is one of the largest industrial cities in the country, located in the

steppe zone of Ukraine. The anthropogenic landscapes of the city have an impoverished biotic component, which is outdated in the sense of modern landscaping; the plants in artificial phytocenoses are suppressed and cannot fully demonstrate the decorative qualities inherent in them (Chypyliak et al., 2022). The selection of new, hardy herbaceous ornamental perennials not widely spread in culture should be based on the scientific prediction of their adaptive capacity and viability in the urban landscapes of Kryvyi Rih.

Representatives of the Crassulaceae J.St.-Hil. family have long been cultivated in culture. These multifunctional perennials are unpretentious to soil conditions and quite tolerant to drought (Pushka et al., 2019; Zhang et al., 2024). The family Crassulaceae includes 36–50 genera and 1500 species of plants, widely distributed in the world, but with the greatest diversity in the Northern Hemisphere and South Africa (Genera, 2007; Plants, 2023). One of the most numerous genera in the family Crassulaceae is the genus *Sedum* L., distributed in Asia, Europe, South America, Central and South Africa, the Mediterranean, and Madagascar. In the natural flora of Ukraine, the genus is represented by 17 species (Fedoronchuk, 2023), which are found on sandy soils, rocky and stony slopes, and limestone substrate. The introduction of *Sedum* species in various ecologo-geographical conditions is due to their wide ecological amplitude and a wide range of decorative qualities (Pérez et al., 2020; Cotoz et al., 2024; Fabian, Talhouk, 2025). However, despite the obvious potential for use in various types of landscape gardening, only a few species of stonecrop are used in our region. Therefore, the purpose of this study is to determine the content of photosynthetic pigments during the growing season in *S. album* L. and *S. reflexum* L. in dry weather conditions of the steppe zone of Ukraine.

All-round study of the plant biology at the regional level will allow developing the ways to improve the plant resistance and increase phytodiversity owing to new fast-growing species, tolerant to anthropogenic impacts. In addition, the results of our study give an opportunity to develop the practical measures aimed at reducing the negative impact of climate change on the functioning of the artificial plant communities.

Material and methods

Research area

Kryvyi Rih located in the steppe zone of Ukraine is part of the arid, very warm agro-climatic zone. The landscapes with the natural flora are fragmented and occupy 1–1.5% of the total area (Lykholat et al., 2019). The largest mining and processing enterprises of Ukraine are concentrated on the territory of the city. Over the past 30 years, the average annual air temperature in the city has increased by more than 2.5, from +8.7 °C (1987) to +10.0–12.7 °C (2014–2024). The average daily temperature in January–February increased from –4.4 to –5.1 °C (1987) to –0.8 to –2.1 °C (2024) and in July–August from +19.4 to +21.1 °C (1987) to +24.6 to +27.4 °C (2024). The yearly precipitation is 260–450 mm, and during the summer months, the moisture balance is characterized by a deficit—100–150 mm only falls during the growing season. Summer is marked by abnormally high air temperatures (+36.7–39.2 °C) and frequent hot winds (Paranko, Shypunova, 2015; Meteopost, 2025).

Table 1. Characteristics of meteorological conditions in 2024 in the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (steppe zone of Ukraine).

Month	Air temperature, °C		Average monthly precipitation, mm
	Average monthly	Max	
January	–0.8	8.8	26.0
February	3.6	12.8	16.3
March	5.2	25.1	26.4
April	15.1	29.8	14.6
May	16.4	30.2	13.6
June	23.2	35.8	9.0
July	27.4	39.2	2.0
August	24.6	36.4	1.2
September	20.9	33.2	6.6
October	12.0	26.9	8.8
November	3.3	15.6	23.2
December	1.5	11.2	18.4
Average annual air temperature 12.7			Annual precipitation 166.1



Fig. 1. General view of plants of the species *Sedum album* L. (up) and *Sedum reflexum* L. (bellow) during flowering when introduced to the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine.



Fig. 2. Distribution of *Sedum album* L. (light green) and *Sedum reflexum* L. (blue) in Ukraine in natural habitats and in areas of introduction (pink).

The research was conducted on the territory of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (the KBG) (coordinates of the location: 48°10' north latitude, 33°40' east longitude). The natural and climatic conditions of the botanical garden show the indicators common to the steppe zone. Soils are represented by heavy loamy, moderately eroded ordinary black soil. The research during the seasonal ontogenetic development was conducted in 2024, which was the driest in the last 10 years, and the period of active growth and development of the plants under study was distinguished by rather difficult meteorological conditions (Table 1).

Studied species

For the study, we chose *Sedum album* L. and *S. reflexum* L., since these species are not found in nature in the Steppe of Ukraine, but for more than 20 years, they have been undergoing introductory research in the KBG, which is located in the steppe zone. They differ in the morphological structure of their vegetative and reproductive spheres, seasonal development, and decorative qualities (Fig. 1).

S. album is a Eurasian species that is also found in Asia Minor and North Africa. In Ukraine, under natural conditions, it grows mainly in the Crimea and the Carpathians (Fig. 2) on rocky slopes and cliffs (Fedoronchuk, 2023). In the Forest-Steppe zone (Kyiv and Zhytomyr regions), *S. album* has naturalized on

roadsides and rocky soils (Davydov, 2021; Orlov et al., 2022).

The range of *S. reflexum* covers almost all of Europe, but in most parts of it, the species is listed from culture (allochthonous). In Ukraine, the species occurs in natural cenosis of the Carpathian Foothills (Lviv, Ternopil), Right-Bank Polissya, and Forest-Steppe (Zhytomyr, Kyiv, Vinnytsia regions) in pine forests and on rocky slopes (Orlov et al., 2022; Fedoronchuk, 2023).

The climatic conditions of the distribution area of both species in Ukraine are significantly different from those in the steppe zone – lower air temperatures and more precipitation. Thus, in the Carpathians, the average monthly temperatures in January are -3 to -5 °C and in July +13–18 °C, and in Crimea, in winter, they are -1.2 to +0.3 °C and in summer +21.0–22.5 °C (Kostenyuk et al., 2024; Babin et al., 2024; Regional, 2025). In addition, the highest annual precipitation falls in the mountainous areas of Ukraine (800–2000 mm in the Carpathians and 1000–1500 mm in the Crimea). In other localities (Polissya, Forest-Steppe), an average of 530–648 mm of precipitation falls per year, with a maximum in the summer months (Patseva et al., 2023; Osadchuk et al., 2024; Maksymova, Andriychuk, 2025).

Methods

We studied five specimens of each species *Sedum album* and *S. reflexum*, which were grown in the open ground at the same

Table 2. Seasonal changes of the chlorophyll content in leaves of plants of *Sedum* L. genus in the conditions of Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (steppe zone of Ukraine).

Species	Pigment content, mg/g of raw materials		
	Chl <i>a</i> M±m	Chl <i>b</i> M±m	Car M±m
V – the stage of completion of spring development			
<i>Sedum album</i> L.	0.71 ± 0.01*	0.38 ± 0.01*	0.40 ± 0.01*
<i>Sedum reflexum</i> L.	0.96 ± 0.02*	0.49 ± 0.01*	0.48 ± 0.02*
Fl – the stage of mass flowering			
<i>Sedum album</i> L.	0.86 ± 0.13*	1.15 ± 0.03*	0.73 ± 0.06*
<i>Sedum reflexum</i> L.	2.32 ± 0.18*	1.18 ± 0.09*	1.60 ± 0.12*
V2 – the stage of completion of vegetative growth			
<i>Sedum album</i> L.	1.58 ± 0.02*	1.08 ± 0.01*	0.80 ± 0.01*
<i>Sedum reflexum</i> L.	1.97 ± 0.01*	1.44 ± 0.03*	0.90 ± 0.02*
V3 – the stage of completion of seasonal development.			
<i>Sedum album</i> L.	0.23 ± 0.01*	0.12 ± 0.01*	0.13 ± 0.01*
<i>Sedum reflexum</i> L.	0.24 ± 0.01*	0.11 ± 0.01*	0.12 ± 0.01*

Note: *Significance more than 95%.

place for the last 3 years in the conditions of the natural moisture supply and in conditions as close to natural as possible. For the physiological and biochemical analysis, the leaves from the middle part of one-year vegetative shoots were taken from the species under study. The sample size (n) for each species was 125 leaves.

The features of plant development were studied according to generally accepted methods for phenological observations (Nordt et al., 2021). We recorded the following phenological phases: V – phase of completion of spring development (formation of full-fledged monocarpic shoots), Fl – phase of mass flowering (more than 50% of flowers on one specimen are open), V2 – phase of completion of vegetative growth (no renewal shoots are formed), and V3 – phase of completion of seasonal development (plants partially lose their turgor and natural color).

The chlorophyll and carotenoid content was determined according to the method of Wellburn (1994): pigments were extracted in dimethyl sulfoxide (DMSO); optical densities of extracts were found using a CФ-2000 spectrophotometer by absorption maxima – for chlorophylls *a* (Chl *a*) and *b* (Chl *b*) – 665, 652, and 649 nm and for carotenoids (Car) – 480 nm. The concentration of photosynthetic pigments was calculated by the following formulas:

$$C_a = 12,19 \times A_{665} - 3,45 \times A_{649}, \quad (1)$$

$$C_b = 21,99 \times A_{649} - 5,32 \times A_{652}, \quad (2)$$

$$C_{car} = (1000 \times A_{480} - 2,14 \times C_a - 70,16 \times C_b) / 200, \quad (3)$$

where C is the pigment concentration, mg/ml.

The content of TBA-active compounds was determined by the method based on the formation of the colored complex during interaction of malonyldialdehyde with thiobarbituric acid (Musienko et al., 2001). The concentration of TBA-active compounds was determined in 20% homogenates prepared in 0.1 M potassium phosphate buffer containing 0.25 M sucrose. The resulting homogenate was centrifuged at 8000 g for 20 min. Af-

ter that, we took 0.5 ml of supernatant and added to it 2 ml of distilled H₂O, 1 ml of 17% trichloroacetic acid, and 1 ml of 0.8% thiobarbituric acid (TBA). The resulting mixture was heated in the boiling water bath for 20 min, cooled, and centrifuged at 8000 g for 10 min. Immediately after that, we measured the optical density of supernatant at 540 nm in cuvettes with the optical path length of 1 cm using a CФ-2000 spectrophotometer. Based on our findings, we calculated the concentration of malondialdehyde using the formula:

$$C = \frac{E_{540} \times V}{C_2 \times K}, \quad (4)$$

where C is the concentration of malondialdehyde (M MDA/mg of protein), E_{540} is the optical density, V is the total volume of the mixture (ml), C_2 is the protein concentration (mg/g of raw materials), and K is the molar extinction coefficient ($1.58 \times 10^5 \text{ M}^{-1} \text{ cm}^{-1}$).

The protein content in plant tissue homogenates was determined by the method of Greenberg and Gaddock (1982) by the reaction of protein with bromophenol blue. The calibration curve was constructed by the method of standard dilutions of bovine serum albumin.

Statistical data processing and correlation (degree of dependence of parameters under study) were carried out by parametric variational statistics methods according to Yegorshyn and Lisovyi (2005) and Pryluts'kyy et al. (2017) using the Microsoft Office Excel software package. Statistical significance was set at $p \leq 0.05$ taking into account the variance and Student's test. In order to determine the impact of ecological factors of the environment where the plants develop, we conducted the correlation analysis of dependence of photosynthetic pigments in leaves on the average monthly air temperature and amount of precipitation (Franklin, 2009). The dependence was calculated using the Pearson correlation coefficient (r) and the correlation error (m_r) at $p \leq 0.05$, where $0.2 < r \leq 0.5$ indicated weak correlation; $0.5 < r \leq 0.7$, medium-strength correlation; and $0.7 < r \leq 0.9$, strong correlation.

Results

Our findings indicated that the content of the basic photosynthetic pigments (Chl *a* + *b*) in stonecrop leaves in April–October was within 1.1–3.5 mg/g of raw materials (Table 2). In absolute terms, the content of Chl *a*, Chl *b*, and carotenoids was higher in the leaves of *S. reflexum* plants, but during the seasonal development of species under study, their quantity and ratio changed. For example, in the flowering phase (in June), relative to spring indicators (in April), the content of Chl *b* in *S. album* increased significantly – three times, while the content of Chl *a* was 1.2 times higher and Car – 1.8 times higher.

That is, during that phase of development, Chl *b* prevails in the leaves of *S. album* plants, and its share in the total amount of pigments under study increases from 25.5% (in the initial phase) to 42%.

In contrast, in the leaves of *S. reflexum* plants during flowering, the Car content features greater intensity of increase (3.3 times), while Chl *a* and Chl *b* increase 2.4 times only. At the end of the vegetative growth (the end of September), the content of chlorophylls and carotenoids in the leaves of plants of both species exceeded the indicators determined in April by 2.0–3.0 times as well. However, in November, when the seasonal development of plants ended, the content of basic and auxiliary pigments decreased significantly – 3–3.2 times in *S. album* and 4–4.5 times in *S. reflexum*. But in terms of proportions of the content of Chl *a*:Chl *b*:Car, the pigments are distributed 2:1:1 as

in April. It should be noted that in the leaves of *S. reflexum* plants during each phase of development, Chl *a* comprises 45.5–51.1% of the total content of pigments under study. In *S. album*, Chl *a* also prevails in the content, but during the flowering period, the concentration of Chl *b* increases significantly – up to 42% of the total amount of pigments.

For determination of the balance of the photosynthesis process, we calculated the indices of ratios of the amount of Chl *a* to Chl *b* and Chl *a* + *b* to Car (Fig. 3). Changes in the amount of Chl *b* in stonecrops were confirmed by the index of Chl *a*/Chl *b*: in *S. album*, the index of Chl *a*/Chl *b* ranged from 0.75 to 1.92, where the lowest indicator corresponded to the flowering phase and the highest one to the phase of completion of seasonal development. For *S. reflexum*, the index limits were 1.37 (phase of completion of vegetative growth) to 2.18 (phase of completion of seasonal development). We recorded the species-specific increase in the carotenoid content, as shown by the index of Chl *a* + *b*/Car, having the lowest values in *S. reflexum* during flowering of plants.

We also investigated the seasonal dynamics of the content of secondary peroxidation products (TBA-active compounds) in the leaves of species of the genus *Sedum*, the content of which is considered a measure of the oxidative damage in plant tissues under abiotic stress. The results demonstrated that the content of TBA products in *S. album* increased 3.5 times during flowering and significantly decreased (6.8 times) at the end of the growing season (Fig. 4). The amount of TBA products in the leaves of

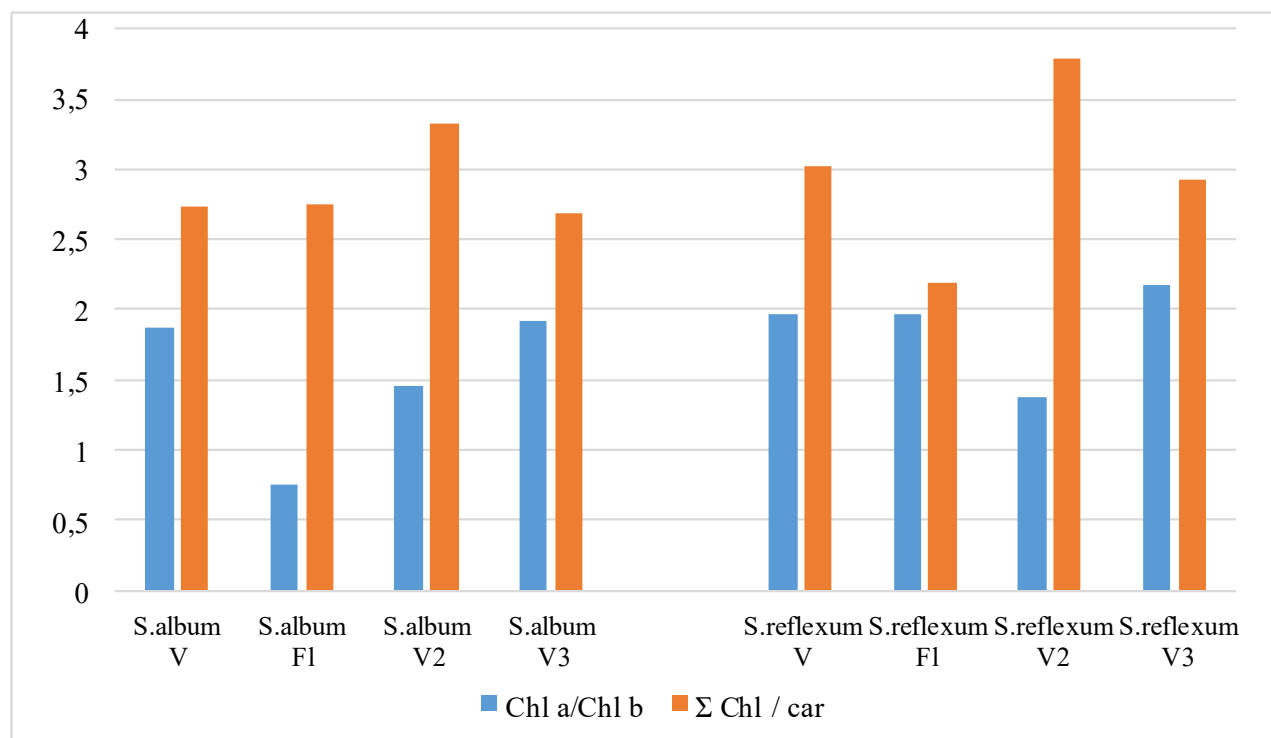


Fig. 3. The indices of the ratio of different forms of photosynthetic pigments in the leaves of plants of the genus *Sedum* L. during seasonal development in the conditions of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (steppe zone of Ukraine). Notes: V, the stage of completion of spring development; Fl, the stage of mass flowering; V2, the stage of completion of vegetative growth; V3, the stage of completion of seasonal development.

S. reflexum plants was significantly lower than that in the previous species, but changes in their content occurred in a similar way.

In order to determine the relationship between the pigment content and the level of air temperature and precipitation, we conducted the correlation analysis, which showed a positive strong relationship between the level of precipitation and content of Chl *b* ($r = +0.86$) and Car ($r = +0.85$) in *S. album* and Car ($r = +0.82$) only in *S. reflexum* (Table 3) at the phase of completion of spring development (in April).

The medium-strength correlation was determined for Chl *a* in *S. album* from April to the end of September, while in *S. reflexum*, it was evident only in September at the end of the vegetative growth. With regard to influence of the temperature factor on the content of photosynthetic pigments, we can state the strong inverse relationship characteristic of the end of the growing season (in September–November) in *S. album* for Chl *a* and Car, while in *S. reflexum* – for all pigments under study.

Note that during flowering of *S. reflexum*, no relationship was determined between the content of photosynthetic pigments and the level of precipitation and air temperature. Instead, in *S. album*, the medium-strength direct correlation between the content of Chl *a* and Chl *b* and climatic indicators was determined.

Discussion

As a result of our studies, it was found that the content of photosynthetic pigments and variation in their quantities in the leaves of stonecrops was species-specific and reflected the intensity of physiological processes occurring under the impact of stressful growing conditions.

In absolute terms, the pigment content was higher in the leaves of *S. reflexum* plants, with the predominance of Chl *a* pigments in the total amount. This may indicate higher efficiency of light absorption, which was associated with the activity of Chl *a* and more intensive photosynthesis process, characteristic of the species (Baguz, 2014; Kiriziy et al., 2024). During flowering of the species (in June), when the air temperature began to increase and the amount of precipitation decreased, we recorded a significant increase in the level of Chl *b* in *S. album* and Car in *S. reflexum*. It reflected the primary response of plants to stress, when the defense systems were

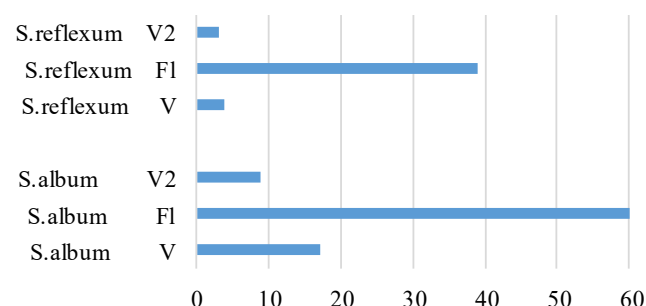


Fig. 4. Seasonal dynamics of the content of secondary peroxidation products in the leaves of *Sedum* L. species in the conditions of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (steppe zone of Ukraine), 10⁻⁶ M MDA/mg protein.

Notes: V, the stage of completion of spring development; Fl, the stage of mass flowering; V2, the stage of completion of vegetative growth.

Table 3. Dependence of pigment content in some species of the genus *Sedum* L. on air temperature and precipitation per month in the conditions of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (steppe zone of Ukraine) in 2024.

Phase of development	Chl <i>a</i> $r \pm m_r$		Chl <i>b</i> $r \pm m_r$		Car $r \pm m_r$	
	Average air temperature per month (°C)	Precipitation per month (mm)	Average air temperature per month (°C)	Precipitation per month (mm)	Average air temperature per month (°C)	Precipitation per month (mm)
<i>Sedum album</i> L.						
V (April)	-0.35±0.01	+0.51±0.04	+0.17±0.07	+0.86±0.04	+0.17±0.03	+0.85±0.02
Fl (June)	-0.44±0.05	+0.58±0.01	+0.52±0.04	+0.45±0.02	-0.20±0.27	+0.26±0.07
V2 (September)	-1.0±0.02	+0.56±0.06	+0.42±0.01	+0.37±0.03	-0.98±0.06	+0.26±0.01
V3 (November)	-0.62±0.02	-0.05±0.08	+0.08±0.02	-0.08±0.05	-0.62±0.12	-0.05±0.03
<i>Sedum reflexum</i> L.						
V (April)	+0.25±0.04	+0.11±0.09	+0.09±0.04	-0.05±0.02	-0.03±0.03	+0.82±0.16
Fl (June)	+0.13±0.07	+0.19±0.07	+0.18±0.07	-0.23±0.07	+0.06±0.02	-0.12±0.08
V2 (September)	-0.91±0.11	+0.45±0.05	-0.72±0.19	-0.49±0.04	-0.95±0.09	-0.21±0.01
V3 (November)	+0.23±0.02	-0.11±0.02	-0.10±0.08	-0.13±0.07	+0.39±0.06	-0.09±0.03

Notes: V – the stage of completion of spring development; Fl – the stage of mass flowering; V2 – the stage of completion of vegetative growth; V3 – the stage of completion of seasonal development; r – correlation coefficient (correlation error at $p \leq 0.05$).

actively working and the synthesis of protective pigments was enhanced. Nevertheless, at this phase of development, the peak of the content of Chl *a*, Chl *b*, and Car in *S. reflexum* occurs, whereas in *S. album* – Chl *b* only. On the other hand, the significant impact of stressful summer conditions is also indicated by the highest levels of secondary peroxidation products, determined during the plant flowering. However, the lower content of TBA-active compounds in *S. reflexum* indicates that the species has a greater ability to remove the reactive oxygen species compared to *S. album* (Sharma et al., 2020; Giordano et al., 2021; Wach, Skowron, 2022; Zhang et al., 2024). The different levels of hardiness of the species are also proven by the fact that no correlation dependence between the level of precipitation and the amount of pigments is found in *S. reflexum*, whereas in *S. album*, the medium-strength direct correlation with the content of Chl *a* ($r = +0.51 - 0.58$) is determined.

During the phase of completion of the vegetative growth (V2), the level of Chl *a* and Car in the leaves of *S. album* plants increased, and the correlation coefficients indicated a strong inverse relationship between their content and air temperature, which was still quite high in early autumn. The similar trend was characteristic of *S. reflexum* as well, but high inverse values of the correlation coefficient were determined for all forms of pigments under study. In our opinion, with the increase in air temperatures and duration of drought, the photosynthetic apparatus suffered damage manifested at different levels of the structural and functional organization of the plant (protein denaturation, impaired membrane permeability, accumulation of toxic metabolites in cells, etc.). At the same time, response reactions allowing plants to adapt to the impact of stressors were activated (Kožmińska et al., 2019; Sharma et al., 2020; Liu et al., 2021; Wach, Skowron, 2022; Krzyzak et al., 2023). The researchers showed that higher content of chlorophyll, which is part of the protein-lipid complex, increased the hydration and water-holding capacity of plastids and cells as a whole (Kosakivska, 2003; Bajguz, 2014; Al-Tawaha et al., 2017; Xu et al., 2020). Probably, increase in photosynthetic pigments in the leaves of these stonecrop species also contributed to their ability to induce Crassulaceae-type metabolism in response to stress – switching from C_3 to CAM photosynthesis, that is, adaptation allowing plants to survive in very hot and other adverse conditions (Castillo, 1996; Winter et al., 2008; Herrera, 2009; Koźmińska et al., 2019; Guidi et al., 2019; Liu et al., 2021). In November, when stonecrop plants completed their ontogenetic seasonal development, the pigment content decreased significantly to the same levels in both *S. album* and *S. reflexum*, and half of the total amount of pigments was Chl *a*. The index of Chl *a*/Chl *b*, which is considered as one of the signs of photosynthetic activity, used as a marker of hardiness under stressful conditions, was the highest at the end of the growing season. In our opinion, it indicates greater hardiness of Chl *a* in the species under study and rather high level of efficiency of their pigment system, owing to changes aimed at maintaining a certain level of metabolic processes which occurred in the seasonal ontogenesis (Rong-hu et al., 2006; Guidi et al., 2019; Karimpour, 2019; Foyer, Hanke, 2022).

Conclusion

Stonecrop species are unpretentious succulents demonstrating wide adaptation to various conditions and good esthetic qualities. Our studies show that the content of photosynthetic pigments (chlorophylls and carotenoids) and variation of their

quantity in the leaves of *S. album* and *S. reflexum* are species specific, and the changes occurring in the quantitative structure of photosynthetic pigments contribute to increase in the protective mechanisms of the pigment system associated with the resistance to stress. That is, the physiological adaptation occurs when the plants are exposed to adverse factors at the level of metabolic processes at certain phases of development, but their growth and development do not stop, which generally does not affect the phenotype strategy. The induction of CAM by drought and plant protection by antioxidant enzymes can be considered the ecological advantages for the species studied, which grow in the conditions of the steppe zone of Ukraine with prolonged dry periods.

We believe that the results of our study will both contribute to the development of landscape programs aimed at selecting plants adapted to the specific growing conditions and be used to better understand the plant response to stress.

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