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Evaluation of phenotypic variability of seedlings obtained from open pollination of three varieties of the genus *Hylotelephium*

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ABSTRACT

This article reflects on the conventional open pollination breeding method of the genus *Hylotelephium*. Six-year-old seedlings were evaluated and compared with the mother plants for 3 years. A total of 1 063 seedlings were evaluated (54 in the *H.* 'Red Cauli', 90 descendants in the *H.* 'Xenox', 919 descendants in the *H.* 'Purple Emperor'). This study deals with six evaluated characters of vegetative parts of plants (habit, height and width of plants, length and width of leaves and the colour of the upper side of the leaves). The most significant phenotypic variability was confirmed for habit, plant height, leaf colour in summer and leaf length in population *H.* 'Xenox' and for spring colouration of lower leaves in population *H.* 'Red Cauli'. The highest degree of variability was found for plant height, where the monitored populations split into a total of seven different sizes. On the contrary, the lowest degree of variability was demonstrated for the length and width of leaves, where all populations showed shorter and narrower leaves compared to the mother plants, with minimal differences.

Keywords: biological variation, Crassulaceae, *Hylotelephium*, open pollination, phenotype, plant breeding, seedlings

Abbreviations: *H., Hylotelephium;* M1, mother plant *Hylotelephium* 'Red Cauli'; M2, mother plant *Hylotelephium* 'Xenox'; M3, mother plant *Hylotelephium* 'Purple Emperor'; P1, offsprings from mother plant *Hylotelephium* 'Red Cauli' M1; P2, offsprings from mother plant *Hylotelephium* 'Xenox' M2; P3, offsprings from mother plant *Hylotelephium* 'Purple Emperor' M3; PCA, principal component analysis; RHS CCH, Royal Horticultural Society colour chart.

INTRODUCTION

The genus *Hylotelephium* (Family: Crassulaceae) is a relatively young genus. Plants belonging to this genus were formerly part of the large genus *Sedum* and are still cultivated under this name in many places (Uher, 2011). In 1977, the Japanese botanist H. Ohba singled out a group of plants whose morphological features and seed structure differed from other representatives of the then-extensive genus *Sedum* (Ohba, 1977, 1978). Currently, the genus *Hylotelephium* includes >30 natural species, originating from North America, Europe and Asia (Grulich, 1992). Ohba (2005) divided the current genus *Hylotelephium* into three sections: 1. *Hylotelephium*, 2. *Sieboldii* (H. Ohba) and 3. *Populifolium* (A. Berger). Representatives of the genus *Hylotelephium* are

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perennial herbs, rarely semi-shrubs. Most of the species are hemicryptophytes (during the winter season, they have buds on the surface of the soil). The roots can be fibrous or tuberous similar to beets or carrots. The position of the leaves can be alternate, opposite or whorled. The leaf blade is often amplexicaul, elliptical, ovate, thick, glabrous, fleshy, green, greyish green, sometimes reddish. The edges of the leaves can be regularly or irregularly toothed or serrated with different depth of cuts. Inflorescences are corymbose with varying densities. Individual flowers are on short stalks, bisexual, usually pentamerous. The petals range in colour from white, yellowish, greenish, light purple to dark purple but are never bright yellow ('t Hart and Eggli, 1995; Ohba, 2005; Gontcharova and Gontcharov, 2007; Thiede and Eggli, 2007).

Representatives of the genus *Hylotelephium* were and still are widely used in gardening, and their popularity continues to grow, especially nowadays, when low-maintenance and drought-tolerant plants are in demand (Hanzelka, 2018). They have a wide range of applications, owing to not only their succulent body structure but also their diversity in terms of habit, height, shape and edge of the leaf blade, as well as colour of leaves, stems and flowers. During the flowering period, they attract many insect species. Many species/varieties are popular for rockeries, walls, perennial beds, as well as for greening of roof gardens and vertical walls or for beautifying various containers. Upright-growing plants with greater height can be used as singular plants or for cut flowers (Uher, 2007; Baroš and Martínek, 2018).

The varietal composition of the genus *Hylotelephium* has grown considerably in recent years (Hanzelka, 2015). There are varieties not only from the *H. spectabile* group, but also from the *H. telephium* group. The last-mentioned group has undergone a real big change. Various colour variations of not only flowers but also vegetative parts have begun to appear. While mainly natural species were offered during the 19th century, dozens of other very interesting varieties have been added since the beginning of the 20th century to the present day. In the 19th century, natural species and their colour variations were offered from contemporary catalogues, in the form of either variegation or reddish colouring of the leaves. If they were red-leaved plants, they were very often offered under the name *Sedum maximum* 'Atropurpureum'. Of the variegated varieties, *Sedum maximum* 'Variegatum' and *Sedum maximum* 'Versicolor' were often grown under the horticultural names. The last mentioned was often offered as *Sedum rodigasii* (Uher and Sotolářová, 2018). From the beginning of the 21st century to the present, many interesting varieties have appeared. Contemporary breeders are trying to enrich the assortment with completely new habitual types, as well as colour combinations of leaves and flowers. Breeding goals in the genus *Hylotelephium* are in two directions. The first direction is to obtain ground cover-type cultivars with compact, mounding plant habits without the tendency to flop (Hansen, 2019a). The second direction is to obtain strong and healthy cultivars with numerous attractive flowers (Oudshoorn, 2010a). From 2003 to August 2022, 72 varieties that belong to the current genus *Hylotelephium* were patented. The variegated 'Lajos' was the first patented variety in 2003. This variety is a sport or mutation of *Sedum* 'Autumn Joy' (Horvath, 2014a). Current varieties were created by crossing *H. spectabile*, *H. telephium* with dark foliage, *H. cauticola*, *H. tatarinowii* and *H. ussuriense*. Among the varieties known to be cultivated, *H.* 'Purple Emperor', *H.* 'Xenox' (*H. telephium* × *H. telephium*) and *H.* 'Sunkissed' (*H. telephium* × *H. telephium*) are used for crossing. Even non-patented varieties are still popular. The origin of non-patented varieties is often uncertain due to nonavailability (Uher, 2011). Not much is known about the varieties that were created in the distant past through open pollination. The most famous varieties of the 20th century include the following: *H.* 'Vera Jameson', *H.* 'Matrona' and *H.* 'Joyce Henderson'. *H.* 'Vera Jameson' was named after its discoverer, who found it as an unknown plant in a garden in Gloucestershire, England, in the 1970s, probably a cross between *H.* 'Ruby Glow' × *H.* 'Atropurpureum' (Ellis, 2022). *H.* 'Matrona' was discovered in 1986 by Ewald Hügin in Germany as a seedling of *H. telephium* subsp. *maximum* 'Atropurpureum'. Further, *H.* 'Joyce Henderson' originated as a random seedling from *H.* 'Matrona' (Hügin, 2014; Horvath, 2014a). From 2003 to August 2022, 72 varieties of stonecrops, which belong to the current genus *Hylotelephium*, were patented. From the patent documents, it was found that >20 varieties arose from open pollination: 'Cloud Walker' (Gossett, 2007a), 'Crystal Pink' (Gossett, 2011), 'Desert Black' (Egger, 2014a), 'Desert Blonde' (Egger, 2014b), 'Desert Red' (Egger, 2014c), 'Dolseb' (Doll, 2022), 'Eline' (Dijkstra, 2014), 'Hot Stuff' (Gossett, 2006), 'Chocolate Cherry' (Noort, 2014), 'Lemonjade' (Hurd, 2016), 'Marina' (Egger, 2015a), 'Mr. Goodbud' (Gossett, 2007b), 'Pillow Talk' (Horvath, 2017), 'Plum Perfection' (Horvath, 2012), 'Pool Party' (Heims, 2012), 'Pure Joy' (Horvath, 2014b), 'Rainbow Xenox'(Oudshoorn, 2010a), 'Raspberry Truffle' (Egger, 2012), 'Sunset Boulevard' (Horvath, 2020), 'Thundercloud' (Horvath, 2011), 'Touchdown Breeze' (Egger, 2015b), 'Touchdown Jade' (Egger, 2015c) and 'Touchdown Teak' (Egger, 2015d).

Even at the turn of the 20th century, open pollination was a commonly used breeding method, especially for cereals and vegetables (Kutka, 2011; Bradshaw, 2022). It is generally used to sow seeds only from mother plants (the male plant is unknown). The advantage of this method is its simplicity and the creation of a large number of offspring with different phenotypic characteristics. Open pollination is used when the specific genotype of the resulting offspring does not matter so much, and on the contrary, we expect a greater dispersion of phenotypic traits (Brinch and Haghighi, 2022). From open pollination, seed is obtained either by self-pollination or by cross-pollination. The descendants will exhibit similar, identical or different characteristics. It is therefore an uncontrolled breeding method that can increase biodiversity (Anderson, 2007).

The aim of this work was to evaluate the phenotypic variability of seedlings obtained through open pollination from three varieties of the genus *Hylotelephium*. *Hylotelephium* is an important attractive plant for various pollinators, so a higher degree of phenotypic variability can be assumed.

MATERIALS AND METHODS

Characteristics of the trial site

The evaluation of seedlings and mother plants (*H.* 'Red Cauli', *H.* 'Xenox' and *H.* 'Purple Emperor') took place on the grounds of the Faculty of Horticulture, Mendel University, in the village of Lednice. The geographical location of the plot is 48°48′0″ N, 16°48′12 E″, and it is 173 m above sea level. The average temperature in the monitored period was 10.8°C. The average relative humidity during the monitored period was 73%. The average amount of precipitation in the monitored period was 410 mm. The average total duration of sunshine for the observed period was 1 910 hr (meteorological data were processed from the data obtained from the climatological station of the Czech Hydrometeorological Institute (ČHMI, 2022 [*Český hydrometeorologický ústav*]) Lednice, www.chmi.cz).

Plant material

Three varieties of the genus *Hylotelephium* H. Ohba were selected, which are part of the assorted collection of the Faculty of Horticulture in Lednice. The variety *H.* 'Red Cauli' (M1) was chosen because it does not have stamens. A higher difference in phenotypic variability can be assumed for this variety. The variety grows to a height of 60–70 cm, and the width of the plant can be >90 cm. In spring, the leaves may have a grey–green tinge and stems are bright red (Horvath, 2014a). The variety *H.* 'Xenox' (M2) is upright growing and has a compact habit. It can branch in the basal part. It grows to a height of 25 cm, and the width of the plant can be >29 cm. In the spring, the leaves can have an olive–green tint, and later, they turn dark purple. The leaves are massive, slightly toothed and almost clasp the maroon red stem. The position of the leaves is opposite. The length and the width of the leaves are 7.7 cm and 5.9 cm, respectively (Oudshoorn, 2006). The variety *H.* 'Purple Emperor' (M3) has an upright growth. It grows to a height of 45–60 cm, and the width of the plant can be >60 cm. In the spring, the leaves may have a grey tinge, but later, the leaves darken. The surface of the blade is semi-glossy. Leaf position is mostly opposite and can be alternate, usually 2.5 cm long and >5 cm wide (Horvath, 2014a).

Experimental design

The seeds were collected in September 2009 and sown in November 2009 in the teaching greenhouse of the Faculty of Horticulture, Mendel University. At the site, the grown seedlings were planted at the turn of May and June 2010 with a spacing of 0.50 × 0.70 m. They were grown in chernozem soil. In order to eliminate weeding of the experimental area as much as possible, black nursery foil was used (Figure 1). No fertiliser was used during the evaluation; irrigation was started only in the months of July and August. Year-round treatment consisted of weeding and removal of dry above-ground parts. From the variety *H.* 'Red Cauli'

Figure 1. Experimental area of Faculty of Horticulture, Mendel University in Brno (photo: July 2020).

(M1), 54 seedlings (P1) were grown and evaluated; from the variety *H.* 'Xenox' (M2), 90 seedlings (P2) were grown and evaluated; and from the variety *H.* 'Purple Emperor', 919 seedlings (P3) were grown and evaluated.

Evaluation of seedlings and mother plants

The actual evaluation of every seedling and mother plant took place from spring 2015 to winter 2017, and it consisted of regular measurements every first week of each month. For the evaluation, a list of descriptive characteristics was first created, based on the National protocol "NP/HYL/2 rev." (Naktuinbouw, 2020; Table 1). A total of 53 descriptive characteristics with the corresponding point scale (1–9) were created and evaluated at the same time. Six traits with assigned numbers were selected for this report: habit; height and width of the plant; leaf length and width and leaf colour (Table 1).

Plant habit was assessed visually (Figure 2). Plant height was measured at the time of full bloom. Stem length was measured from the base to the imaginary border of the inflorescence. The width of the plant was measured at the time of full bloom at the widest point of the bunch. The evaluation of the length and width of the leaves, as well as the evaluation of the summer colour of the leaves, was carried out by taking three leaves from three random stems in a bunch from the middle part of the stems, due to the presence of various deviations in the colour, size and shape within the whole plant. Leaf length was measured from the top of the leaf blade to the leaf base. Leaf width was measured in the widest

Table 1. List of descriptions by Sotolářová (2022): selected descriptors.

Descriptor number	Number	Descriptor	Scale	Values	Note
2.	1.2.	Plant			
	1.2.1.	Plant – habit	1 Upright		
			2 Semi-upright		
			3 Spreading		
			4 Repens		
3.	1.2.2.	Plant – height (cm)	1 Very low	<10 cm	
			2 Very low–low	11–20 cm	
			3 Low	21–30 cm	
			4 Low–medium	31–40 cm	
			5 Medium	41–50 cm	
			6 Medium–high	51–60 cm	
			7 High	61–70 cm	
			8 High–very high	71–80 cm	
			9 Very high	>80 cm	
4.	1.2.3.	Plant –width (cm)	3 Narrow	<30 cm	
			5 Medium	31–65 cm	
			7 Wide	66–90 cm	
			9 Very wide	>90 cm	
16.	1.4.	Leaf			
	1.4.2.	Leaf – length (cm)	1 Very short	<2 cm	
			3 Short	3–5 cm	
			5 Medium	6–8 cm	
			7 Long	9–10 cm	
			9 Very long	>11 cm	
17.	1.4.3.	Leaf – width (cm)	1 Very narrow	<2 cm	
			3 Narrow	3–4 cm	
			5 Medium narrow	5–6 cm	
			7 Wide	7–8 cm	
			9 Very wide	>8 cm	

Continued

Table 1. Continued.

Descriptor number	Number	Descriptor	Scale	Values	Note
34. (a, b, c)		Leaf – primary			Colour codes (RHS CCH 2007)
		colour of adaxial	1 Yellow-green		144A
		leaf surface	2 Light green		138B, 138C
			3 Green		135C, 136B, 137A, 137C, 137D, N137A, 138A, 139C, 143A, 143B, 146B, 152A
			4 Grey-green		133B, 136A, 136B, 136C, N137D, 138B, N138B, 189A
			5 Dark green		-
			6 Burgundy		N77B, 136B, 183C, 185B, 185C, 186A, 186B, 187C, 187D
			7 Maroon		53A, 184A, 184B, N186D, 187B, 187C
			8 Dark maroon		59A, N77A, 183A, 183B, 185A, N186C, 187A
			9 Plum, damson		N77B, N79A, N79B, N92A, N186A, N186B, N187A

RHS CCH, Royal Horticultural Society colour chart.

Figure 2. Examples of plant habit for descriptor number 2 (scales 1–4 in Table 1).

part of the leaf blade (Figure 3). The characteristics described above were always evaluated from April to November. For the leaf, the primary colour of adaxial leaf surface was always evaluated from April to August. In spring, this trait was evaluated in both the upper part of the plant and the lower part of the plant (Figure 4). In summer, the colour was assessed from the middle part of the stem (Figure 5). A tape measure was used to obtain cardinal data for the morphometric characteristics (plant height and width; leaf blade length and width). To obtain nominal data regarding leaf primary colour, the colour scale for plants published by the Royal Horticultural Society (RHS) (2007) was used (Table 1).

Statistical analysis

Averages were first calculated for the following morphometric cardinal characteristics: plant height and width; leaf blade length and width. Average values were calculated in a Microsoft Excel spreadsheet. Basic statistical analyses (average, median, upper and lower quartiles 25%–75%, max–min) were used to determine the degree of variability in individual populations of mother plants. Principal component analysis (PCA) was used to determine the relationships between the assessed traits and individuals in the given population. Statistical processing was performed in Statistica 14.0.0.15 (Tibco Software Inc., 2020, 3307 Hillview Avenue, Palo Alto, CA 94304, USA).

RESULTS

Evaluation of phenotypic variability of selected traits in individual populations

Phenotypic variability was demonstrated to a greater or lesser extent for all observed traits. The degree of population variability was expressed as a percentage (Figure 6).

Descriptor **No. 2: Plant – habit.** The variability in M1/P1 was 96.3%, corresponding to 52 individuals differing in habit type (50% erect growth and 46.3% semi-erect growth, with M1 having prostrate growth). Moreover, from among a total of 90 individuals, 57.78% differed in M2/P2 (51.11% erect growth and 6.67% prostrate growth, M2 semi-erect). In M3/P3, 40.80% differed from among 919 (28.94% upright growth and 11.86% prostrate growth, M3 semi-erect) (see Table 2 and Figure 6 for the complete data).

Descriptor **No. 3: Plant – height.** Of the total number of already mentioned individuals, 66.8% in P1, 70% in P2 and 67.5% in P3 showed a different height. The average height of P1 was 5.39 cm higher than in M1, P2 was again higher by 2.81 cm compared to M2, but in P3, on the other hand, height was lower by 5.47 cm compared to M3 (see Table 2 and Figures 6 and 7).

Descriptor **No. 4: Plant – width.** For M1/P1, 24.1% of individuals showed a different width. The variability in M2/P2 was significant at 93.33%, where 84 individuals differed. For M3/P3, 42.9% of individuals differed. The average plant width in P1 was 6.57 cm wider than in M1; in P2, it was even 14.71 cm wider than in M2, and in P3, it was only 3.36 cm wider than in M3 (see Table 2 and Figures 6 and 7).

Descriptor **No. 16: Leaf – length.** In M1/P1, only 9.26% of individuals showed a different leaf length. In P2, all observed individuals differed from M2, and in M3/P3, 15.23% (142 individuals) showed different leaf lengths. The average leaf length of P1 was 1.20 cm shorter than the M1 leaf length, that of P2 was 3.19 cm shorter than for M2, and that for P3 was 0.19 cm shorter than for M3 (see Table 2 and Figures 6 and 7).

Descriptor **No. 17: Leaf – width.** In M1/P1, 16.67% of individuals showed a different width; for M2/P2, 11.11% were different; similarly, for M3/P3, 11.64% showed difference. The average leaf width of P1 was 0.20 cm wider compared to the width of M1 leaves; in

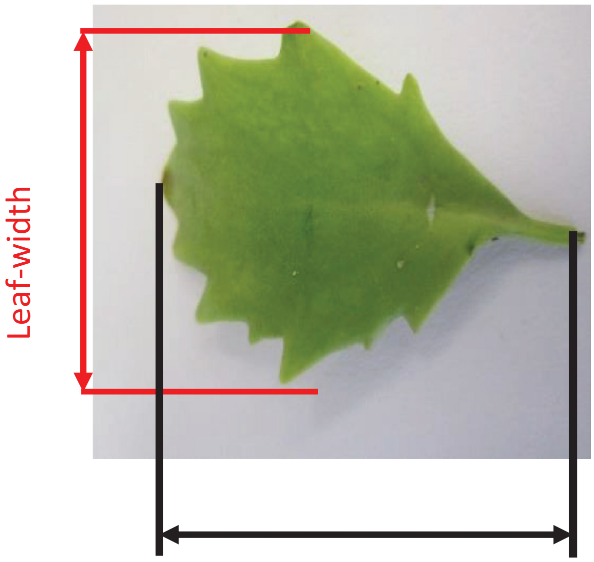


Figure 3. Leaf: length (Scale 1.4.2. in Table 1) and width (Scale 1.4.3. in Table 1).

Figure 4. Primary colour of the adaxial leaf surface: (A) spring colouring of the upper leaves; (B) spring colouring of the lower leaves.

Figure 5. Primary colour of adaxial leaf surface: summer colouring of upper leaves.

P2, it was 1.61 cm narrower compared to M2; and in P3, it was 0.20 cm narrower compared to M3 leaves.

Descriptor **No. 34: Primary colour of the upper side of the leaf.** The results of the evaluation of the colour of the spring foliage of the upper leaves (character 34b) are as follows: in M1/P1, 96.3%; for M2/P2, 90.0%; and for M3/P3, 97.1% showed the same colour (grey green). Evaluation of the colour of the spring foliage of the lower leaves (character 34c) showed a different colour in 96.3% for M1/P1, 46.7% for M2/P2, and 33.7% for M3/P3. For the results of leaf colour assessment in summer (character 34a), 92.6%, 91.0% and 86% showed a different colour in M1/P1, M2/P2 and M3/P3, respectively. As for the summer colouration of the leaves, most of the offspring in all populations had damson foliage (Scale 9). Among the individuals in P1, 35 individuals experienced lightening of the colour to scales 6 (burgundy), 7 (maroon) and 8 (dark maroon). In P2, the transition from spring to summer foliage colour was preserved by approximately the same number of individuals, with the difference that one individual was in Scale 2 (light green) and three individuals were in Scale 4 (grey–green). The colour of the leaves darkened to damson (Scale 9), dark maroon (Scale 8) and maroon (Scale 7). In P3, two individuals (0.20%) in Scale 3 (green) retained the same colour in the transition from spring foliage colour to summer, as was the case with scales 4 (grey–green) and 7 (maroon).

Correlation between the evaluated descriptors and individuals in the given populations

Analysis of interpopulation variability using PCA is shown by ordination plots (Figure 8). The individual graphs show the distribution of individuals in the space formed by the selected descriptors and the correlation of these descriptors with the first two axes. The scatterplot of the component score sorted the individual descendants in all evaluated populations into four clusters. Descendants were sorted based on the plant height-to-width ratio score. Clusters of tall to wide, intermediate tall to intermediate wide, tall to narrow, and short to wide plants were thus formed. The analysis showed strong correlations between plant height and width, leaf length and width, and spring and summer foliage colouration. Plant habit does not affect the height and width of the plants, nor does it affect the length and width of the leaves. Plots of component weights found that leaf colour was not related to plant habit, height and width, nor was it related to leaf length and width. A diagram of the component weights divided the evaluated features according to correlational significance. It follows from the graphs that the important indicators include the following: height-to-width ratio of the plant, length-to-width ratio of the leaf blade, and spring colouration of the lower leaves to summer colouration of the leaves.

DISCUSSION

Ornamental plant breeding is a profitable business worldwide. Before the discovery of Mendel's laws, new varieties were created by natural bud mutation or open pollination (natural hybridisation in cross-pollinated or partially cross-pollinated plants). The pollination system and the reproduction cycle of plants play very important roles in breeding. The common goal of all breeders is a variety that shows not only better properties but also good return on investment itself (Datta, 2022). The breeding method of open pollination is very simple, in which a large number of individuals with different degrees of variability can be obtained, as demonstrated by this study.

Recently, the importance of green roofs and green walls has been drawing attention, especially in large cities, with the use of unpretentious and drought-tolerant plants (e.g. *Geum triflorum*, *Viola sagittata*, *Andropogon gerardii*, *Sporobolus airoides* and, generally, plants with a succulent structure) (Hawke, 2015). Hozhabralsadat et al. (2022) dealt with the current problem of urban air pollution, assessing the accumulation of heavy metals and dust particles. They found that plants of the genus *Hylotelephium* contained 81% relative water content and high adsorbance of dust particles. High water content in plants helps maintain physiological balance under stressful conditions (Dedio, 1975; Meerabai et al., 2012). Among the most important plants for the cultivation of green roofs and walls are generally stonecrops (Hawke, 2015). It is, therefore, clear that this is a prospective genus, and the goal of breeding will be new varieties with a higher aesthetic value depending on the use (for beds, green roofs, cuttings, rockeries, containers).

This work follows on from the breeding programme of selected perennials carried out at the Faculty

Table 2. Summary results of evaluation of populations (P) and their mother plants (M).

Valid	N	Average	SE±	Scale								
				1	2	3	4	5	6	7	8	9
Descriptor number 2: Plant-habit												
M1	-	-	-	-	-	*	-	-	-	-	-	-
P1	54	-	-	27	25	2	0	-	-	-	-	-
M2	-	-	-	*	-	-	-	-	-	-	-	-
P2	90	-	-	46	38	6	0	-	-	-	-	-
M3	-	-	-	*	-	-	-	-	-	-	-	-
P3	919	-	-	266	544	109	0	-	-	-	-	-
Descriptor number 3: Plant-height (cm)												
M1	-	27.33	2.52	-	-	*	-	-	-	-	-	-
P1	54	32.72	8.57	0	5	18	19	11	1	0	0	0
M2	-	30.00	5.00	-	-	*	-	-	-	-	-	-
P2	90	33.81	5.62	0	9	27	33	17	3	1	0	0
M3	-	35.00	5.00	-	-	-	*	-	-	-	-	-
P3	919	29.53	9.41	10	153	346	298	100	11	1	0	0
Descriptor number 4: Plant-width (cm)												
M1	-	58.33	2.89	-	-	-	-	*	-	-	-	-
P1	54	51.76	14.81	-	-	3	-	41	-	10	-	0
M2	-	39.33	5.13	-	-	-	-	*	-	-	-	-
P2	90	54.04	19.62	-	-	9	-	53	-	24	-	4
M3	-	42.33	2.52	-	-	-	-	*	-	-	-	-
P3	919	45.69	20.76	-	-	236	-	525	-	137	-	21
Descriptor number 16: Leaf-length (cm)												
M1	-	5.43	0.81	-	-	*	-	-	-	-	-	-
P1	54	4.23	4.26	0	-	49	-	5	-	0	-	0
M2	-	7.33	1.6	-	-	-	-	-	-	*	-	-
P2	90	4.14	5.72	0	-	84	-	6	-	0	-	0
M3	-	4.83	0.21	-	-	*	-	-	-	-	-	-
P3	919	4.64	5.42	2	-	777	-	140	-	0	-	0
Descriptor number 17: Leaf-width (cm)												
M1	-	2.6	0.36	-	-	*	-	-	-	-	-	-
P1	54	2.82	1.19	9	-	45	-	0	-	0	-	0
M2	-	4.37	0.96	-	-	*	-	-	-	-	-	-
P2	90	2.76	1.01	10	-	80	-	0	-	0	-	0
M3	-	2.83	0.12	-	-	*	-	-	-	-	-	-
P3	919	3.07	1.16	94	-	812	-	13	-	0	-	0
Descriptor number 34a: Leaf-primary colour of adaxial leaf surface (summer foliage)												
M1	-	-	-	-	-	-	-	-	*	-	-	-
P1	54	-	-	0	0	0	0	0	4	14	17	19
M2	-	-	-	-	-	-	-	-	-	*	-	-
P2	90	-	-	0	0	0	0	0	4	8	29	49
M3	-	-	-	-	-	-	-	-	-	-	*	-
P3	919	-	-	0	0	2	8	0	14	20	129	746
Descriptor number 34b: Leaf-primary colour of adaxial leaf surface (spring-upper foliage)												
M1	-	-	-	-	-	-	*	-	-	-	-	-
P1	54	-	-	0	0	0	52	0	0	0	0	2

Continued

Table 2. Continued.

Valid	N	Average	SE±	Scale								
				1	2	3	4	5	6	7	8	9
M2	-	-	-	-	-	-	*	-	-	-	-	-
P2	90	-	-	0	0	4	81	0	0	0	0	5
M3	-	-	-	-	-	-	*	-	-	-	-	-
P3	919	-	-	2	3	17	892	0	0	0	2	3
Descriptor number 34c: Leaf-primary colour of adaxial leaf surface (spring-lower foliage)												
M1	-	-	-	-	-	-	-	-	-	*	-	-
P1	54	-	-	0	0	0	5	0	0	2	0	47
M2	-	-	-	-	-	-	-	-	-	-	-	*
P2	90	-	-	0	1	0	3	0	7	3	28	48
M3	-	-	-	-	-	-	-	-	-	-	-	*
P3	919	-	-	1	0	2	7	0	49	13	238	609

*Position of mother plants (M).

of Horticulture, Mendel University. The genus *Hylotelephium* was included in the programme for its attractiveness, unpretentiousness and usability in urban plantings. The aim of this work was to determine the phenotypic variability of seedlings from three mother plants. The work of Kopečná (2013) also dealt with the phenotypic variability of plant height and leaf colour. For the evaluated trait 'plant height' in the *H.* 'Red Cauli' population, Kopečná states that 91% of individuals had the same height as the mother plant and the variability was 9%. In this study, the variability of the assessed trait was much higher (66.8%). For the evaluated trait 'leaf colour', Kopečná states that 35% of individuals had the same green colour as the mother plant *H.* 'Red Cauli', 35% of individuals had bronze colour and 24% of individuals had red leaves. This study also looked at the change in leaf colour during the growing season. Only 7.40% of individuals had the same summer leaf colour (burgundy) as the mother plant *H.* 'Red Cauli'. Other leaf colours such as maroon, dark maroon to damson were present in the population. The difference in leaf colour assessment between this study and that of Kopečná was caused by the age of the plants and the different assessment period (spring/summer). For the evaluated trait 'plant height' in the *H.* 'Xenox' population, Kopečná states that 54% of individuals had the same height as the mother plant *H.* 'Xenox' and the variability was 46%. In this study, the variability of the evaluated descriptor was higher by 24%. For the evaluated trait 'leaf colour', Kopečná states that 41% of the individuals had the same bronze colour as the mother plant *H.* 'Xenox', 18% of the individuals had green colour and 41% of the individuals had red leaves. Summer evaluation of leaf colour in this study showed that 91% of individuals were different in colour. Burgundy, maroon and damson leaves were present in the population. Kopečná states that 53% of the individuals had the same height as the mother plant *H.* 'Purple Emperor' and the variability was 47%. In this study, the variability of the assessed descriptor was higher by 21%. For the leaf colour, Kopečná states that 53% of individuals had the same bronze colour as the mother plant *H.* 'Purple Emperor', 10% of individuals had green colour and 37% of individuals had red leaves. From the results of this study, it is clear that 14% of individuals had the same leaf colour as the mother plant *H.* 'Purple Emperor'. Green, grey–green, burgundy, maroon and damson leaves were present in the population.

Due to the popularity of the genus *Hylotelephium*, the breeding goals are very different. It is clear from the Introduction section that many of the currently offered varieties arose precisely from open pollination, whether from *H. spectabile*, *H. telephium*, *H. ussuriense* or from another hybrids. The used cultivars *H.* 'Purple Emperor' and *H.* 'Xenox' are often used as parental components. Cross-pollination of *H.* 'Purple Emperor' (not patented) resulted in cultivars (e.g. 'Novem', 'Postaman's Pride') with shades of dark purple leaves and light-to-dark pink flowers. The cultivars derived from *H.* 'Purple Emperor' have an upright growth and the height varies from 20 cm to 50 cm (Oudshoorn, 2006, 2010; De Buck, 2006). Cross-pollination of *H.* 'Xenox' (patented) resulted in very well-known and currently offered varieties, such as *H.* 'Moonlight Serenade', *H.* 'Plum Dazzled', *H.* 'Razzleberry', *H.* 'Yellow and Orange Xenox' and others. The cultivars of this cross are very different. The plant habit is widely spreading or erect. The height of the plants varies from 18 cm to 50 cm. The colour of the leaves is very distinctive, from grey–green to dark purple to dark purple tones. The colour of the flowers varies, from pale pink, to yellowish with a slight hint of orange, to dark pink shades (Oudshoorn, 2010b, 2010c, 2012; Hansen, 2012, 2019b). In this study, the population from *H.* 'Red Cauli' showed the widest colour spectrum of leaves, probably due to the absence of male organs;

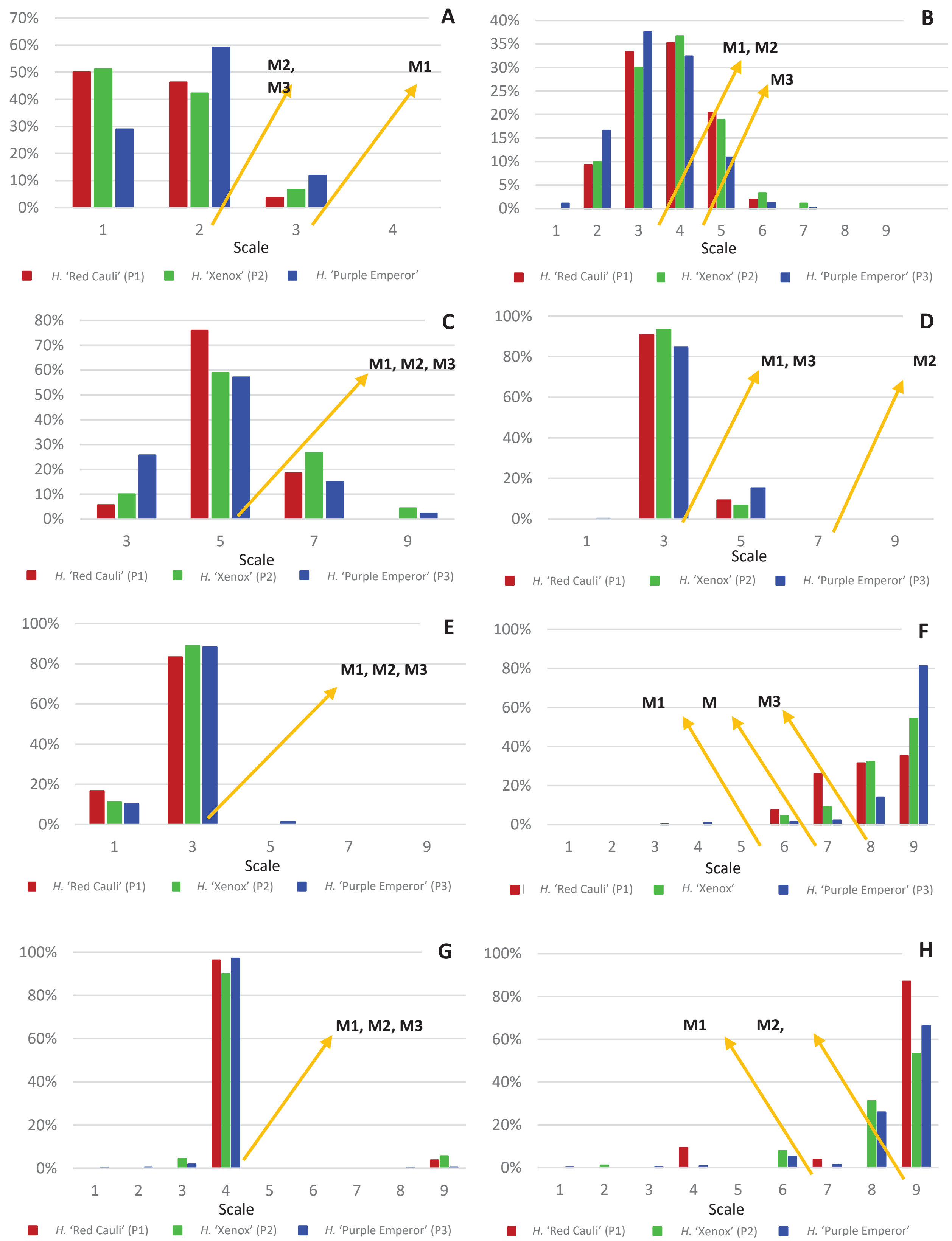


Figure 6. Comparison of the degrees of phenotypic variability of the evaluated populations (P) with their mother plants (M). (A) Descriptor No. 2: Plant-habit; (B) descriptor no. 3: Plant-height; (C) descriptor no. 4: Plant-width; (D) descriptor no. 14: Leaf-length; (E) descriptor no.17: Leaf-width; (F) descriptor no. 34a: Leaf-primary colour of adaxial leaf surface (summer); (G) descriptor no.34a: Leaf-primary colour of adaxial leaf surface (spring colouring of the upper leaves); (H) descriptor no. 34a: Leaf-primary colour of adaxial leaf surface (spring colouring of the lower leaves).

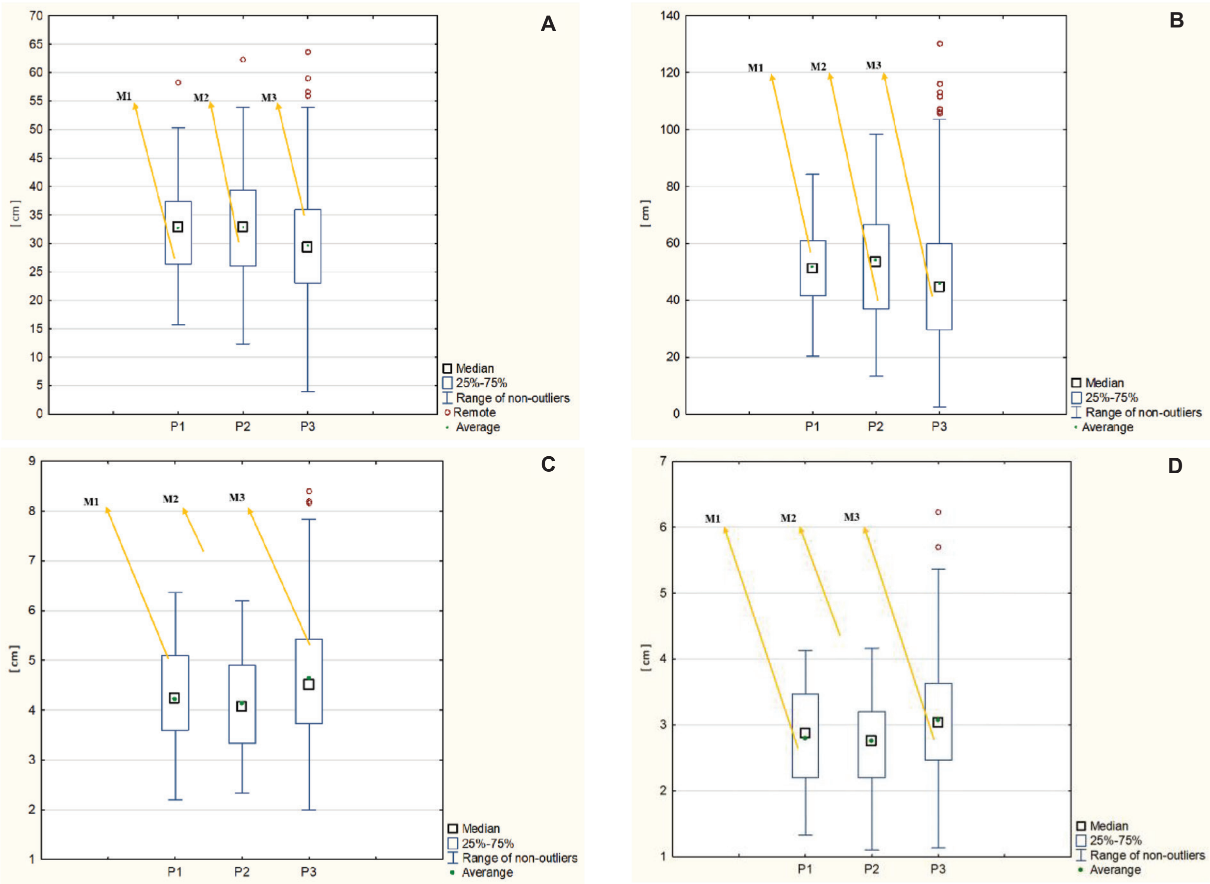


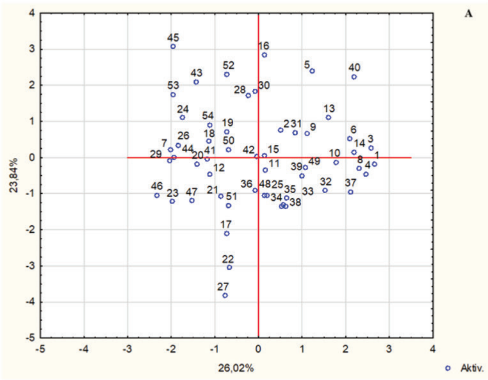
Figure 7. Comparison of quantitative variables between populations (P) and their mothers (M). (A) Descriptor No. 3: Plant-height. (B) Descriptor No. 4: Plant-width. (C) Descriptor No. 14: Leaf-length. (D) Descriptor No. 17: Leaf-width.

therefore, this variety appears promising for open pollination.

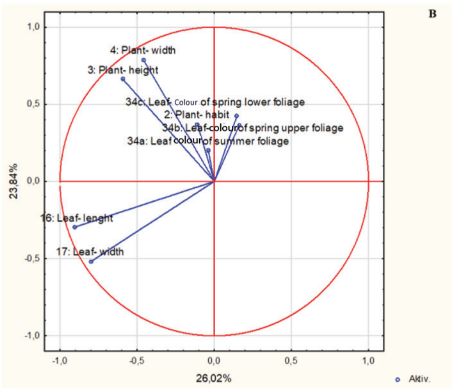
CONCLUSIONS

The subject of the experiment was to determine the degree of phenotypic variability in three populations from three mother plants. Our results pointed to the phenotypic variability of individuals using the traditional breeding method of open pollination. PCA analysis divided the individuals into foru clusters based on the ratio between plant height and width. The analysis found that the significant indicators include height-to-width ratio of the plant, length-to-width ratio of the leaf blade and spring colouration of the lower leaves to summer colouration of the leaves. The habit of the plants showed a split into three types of growth in the populations. The plant height in the populations was divided into a total of seven groups (P1/5 groups, P2/6 groups, P3/7 groups). The results of the evaluation show that the width of the plants did not show such significant splitting. Most individuals in all populations were rated on the same scale of '5' (intermediate) as their parent plants. The same was the case with the leaf width of the blade. Most progeny in all populations studied were rated on the same scale of '3' (narrow to intermediate) as their parent plants. Only a few individuals were rated as variants '1' (very narrow) and '5' (very narrow-medium narrow).

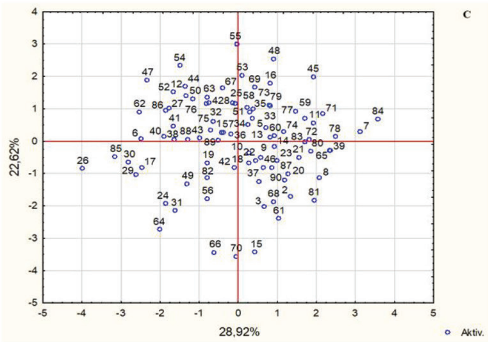
The colour of the leaves, which changed during the vegetative phase, brought very interesting results. A very significant colour contrast in the colour of the leaves was found in the spring, when some individuals had different colours of the lower and upper leaves. Most of the plants in the summer season started to show colours from light to dark purple shades. The most significant variability in leaf colour was for P1. The colouring of the spring top leaves was the same colour as their mother plants in >90% of all monitored populations (Scale 4: grey–green). Damson colour was present in P1. In P2, the colours green and dark purple were present. There were five colours in P3 (yellow–green, light green, green, magenta and dark magenta). The colour of the spring lower leaves in most P2 and P3 individuals was the same as that of their mother plants (Scale 9: damson). In P2, the colours light green, grey–green and burgundy were present. The colours yellow–green, green, grey–green, burgundy and maroon were present in P3. The change in the colours of the leaves during the year is an important feature that increases the aesthetics of modern cultivars, which is also demonstrated by this study. During the evaluated years, six promising hybrids different from the current offered assortment were selected. The study confirms that a simple breeding technique such



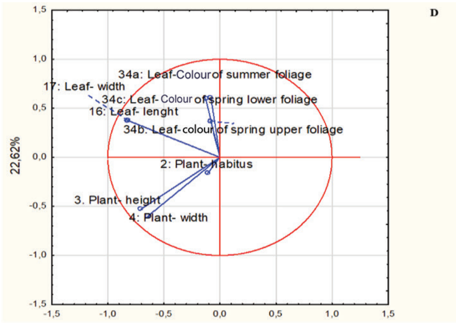
A. Scatter diagram showing the distribution of selected characteristics in the *H.* ´Red Cauli´ population in the space of the first two axes. The first two axes explain 26.02% and 23.84% of the total variability, respectively.



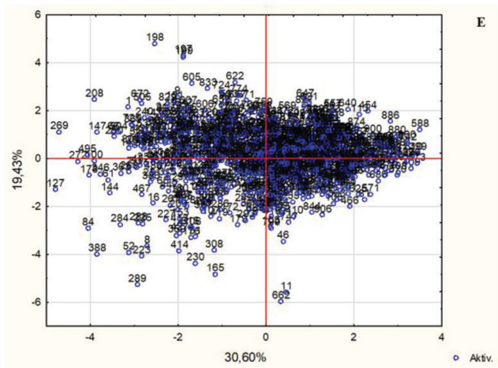
B. Diagram of component weights showing the correlation of selected characteristics in the *H.* ´Red Cauli´ population. The first two axes explain 26.02% and 23.84% of the total variability, respectively.



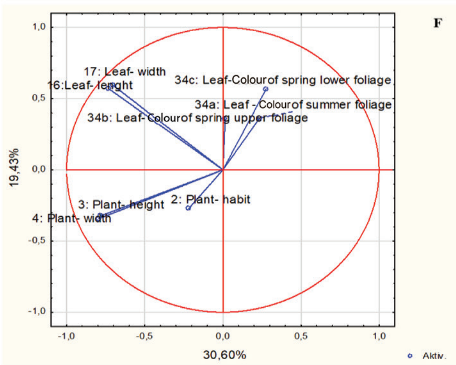
C. Scatter diagram showing the distribution of selected characteristics in the *H.* ´Xenox´ population in the space of the first two axes. The first two axes explain 28.92% and 22.62% of the total variability, respectively.



D. Diagram of component weights showing the correlation of selected characteristics in the *H.* ´Xenox´ population. The first two axes explain 28.92% and 22.62% of the total variability, respectively.



E. Scatter diagram showing the distribution of selected characteristics in the *H.* ´Purple Emperor´ population in the space of the first two axes. The first two axes explain 30.60% and 19.43% of the total variability, respectively.



F. Diagram of component weights showing the correlation of selected characteristics in the *H.* ´Purple Emperor´ population. The first two axes explain 30.60% and 19.43% of the total variability, respectively.

Figure 8. Correlations between the evaluated descriptors and individuals in a given population (P). (A) Scatter diagram showing the distribution of selected characteristics in the *H.* 'Red Cauli' population in the space of the first two axes. The first two axes explain 26.02% and 23.84% of the total variability, respectively. (B) Diagram of component weights showing the correlation of selected characteristics in the *H.* 'Red Cauli' population. The first two axes explain 26.02% and 23.84% of the total variability, respectively. (C) Scatter diagram showing the distribution of selected characteristics in the *H.* 'Xenox' population in the space of the first two axes. The first two axes explain 28.92% and 22.62% of the total variability, respectively. (D) Diagram of component weights showing the correlation of selected characteristics in the *H.* 'Xenox' population. The first two axes explain 28.92% and 22.62% of the total variability, respectively. (E) Scatter diagram showing the distribution of selected characteristics in the *H.* 'Purple Emperor' population in the space of the first two axes. The first two axes explain 30.60% and 19.43% of the total variability, respectively. (F) Diagram of component weights showing the correlation of selected characteristics in the *H.* 'Purple Emperor' population. The first two axes explain 30.60% and 19.43% of the total variability, respectively.

as open pollination in the genus *Hylotelephium* can produce many offspring with different characteristics. In the study, regarding the colouring of these leaves, the variety *H.* 'Red Cauli' showed itself most prominently.

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AUTHOR CONTRIBUTIONS

O.S. and R.S. performed and evaluated the experiments. They created a list of descriptive characteristics and drafted the manuscript. M.V. performed statistical analysis and drew tables. J.U. and R.P. corrected the article. All authors read the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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