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SELECTED ELEMENTS OF BIOLOGY AND MORPHOLOGY OF ROSEROOT IN SOUTH-EASTERN POLAND

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Abstract. *Rhodiola rosea* is a valuable, perennial plant with important pharmaceutical activity. Its raw material – rhizomes and roots are collected from nature, however due to the intensive collecting, natural populations are highly threatened. Therefore, this is important to understanding the biology and variability of roseroot and introduction of this species to the culture is very important. The objective of this study was to acquaint the biology and morphology of *Rhodiola rosea* L. plants during seven following years of cultivation in south-eastern part of Poland. Results of our experiment indicate that the rate of growth and development of roseroot in a south-eastern Poland did not differ from that observed in other parts of Europe, but was faster than observed wild growth in the Altai Mountains. The life cycle of plants from bud to fruit production takes place within one growing season. Starting from the second year of vegetation throughout next following vegetation periods plants produced shoots of second or from the third vegetation period – of third generation, so the period of accumulation of biologically active substances extended to five months, causing a rapid increase in weight of rhizomes. Weight and dimensions of the aerial and under ground parts of plants have changed in subsequent years of vegetation. In the first year of cultivation plants produced one to three stems and under ground parts with average air dry matter of 2.38 g plant^{-1}. In the next following vegetation periods weight of rhizomes and roots systematically increased, reaching the highest value from fourth to sixth year of vegetation.

Key words: *Rhodiola rosea*, growth stages, plant characteristics, plant age

INTRODUCTION

Roseroot, *Rhodiola rosea* L. (syn: *Sedum rosea* (L.) Scop), also commonly known as golden root or arctic root, has been used in the traditional Asian, Scandinavian and Eastern European medicine for centuries. That herbaceous perennial plant (from Crasul-

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laceae family) is a arctic-alpine plant that occurs in the vast area of Eurasia and North America in the polar tundra and high mountains, starting from western Europe – Pyrenees, the Vogues and the Alps, through the Carpathian Mountains, Kola Peninsula, Siberia, Far East Russia – Kamchatka, Sakhalin, and ending in Alaska [Nukhimovskii 1974, 1976; Nukhimovskii et al. 1987; Kovaleva et al., 2003; Galambosi 2006; Krukowski et al. 2009; Ampong-Nyarko 2010].

Traditional folk medicine used *Rhodiola rosea* to increase physical endurance, longevity, resistance to high altitude sickness, and to treat fatigue, depression, anemia, impotence, gastrointestinal ailments, infections, and nervous system disorders [Brown et al. 2002; Galambosi 2006; Panossian et al. 2010]. Phytochemical studies carried out on the rhizomes and roots of *Rhodiola rosea* shows the presence of different groups of important pharmaceutical substances: phenylpropanoids, phenylethanol derivates, flavonoids, monoterpenes, triterpenes and phenolic acids [Revina et al. 1976; Saratikov 1977; Kiryanov et al. 1989; Furmanowa et al. 1999; Galambosi 2006; Panossian et al. 2010]. Cinnamic glycosides, such as rosin, rosavin, and rosarin, as well as salidroside and its aglycon *p*-tyrosol are considered the major active substances responsible for most of the pharmacological activities [Saratikov 1977; Ganzera et al. 2000; Platikanov and Evstatieva 2008; Panossian et al. 2010; Kucharski et al. 2011]. Modern phytotherapy considered this species as a vegetal source of an antioxidant and antistress-adaptogene action, due to influence of some of its compounds on the level of monoamine and peptide (ß-endorphine type) in the human body [Furmanowa et al. 1999; Panossian et al. 2010]. This action is mainly due to rosavine and salidroside.

Roseroot is a dioecious species, developing male and female specimens, very variable (variation in leaf-shape shows some geographical consistency) [Costica et al. 2007]. Its rhizome is thick, fleshy, bulbous thickened, and after drying, emits the distinctive rose fragrance. At the upper side there are many buds generating new aerial stalks, which could be used for new plantation establishment (in a form of tips) [Platikanov and Evstatieva 2008]. The stalks are erect, cylindrical, straight, thick, leaved, sometimes – less red colored in upper part. Leaves are alternatively disposed, orbicular-ovate to linear-oblong, usually dentate, broad-based, planed, fleshy, hair-loss. Leaves and stems sometimes take on the characteristic bluish color. The inflorescence is a dense corymb (occurs in June) with 4 types of flowers: functionally staminate, bisexual, functionally pistil and pistil [Przybył et al. 2004]. The female flowers are often without petals, or with significantly smaller petals, while male are yellowish to slightly reddish. The fruit is a follicle with intense red color with brown seeds with thousand seed weight 0.2 g [Nukhimovskii 1974, 1976; Nukhimovskii et al. 1987; Revina et al. 1976; Galambosi 2006; Costica et al. 2007; Krukowski et al. 2009].

The largest populations of *R. rosea* L. are situated in the Altai area of South Siberia [Polozhii and Pevyakina 1976; Galambosi 2006]. Rapidly growing demand and high prices paid for its raw material by the industry caused increased pressure on natural habitats. Due to the intensive collection, natural populations are highly threatened and this plant has been included in the list of endangered plant species in many countries. The species has become a threatened plant in Russia, Great Britain, the Czech Republic, Bosnia and Herzegovina, Slovakia and in Bulgaria and its collection is strictly forbidden [Platikanov and Evstatieva 2008]. Despite of this, an estimated 20–30 t of dried rhizomes and roots are traded annually in Russia alone [Galambosi 2006]. In Poland, this species was found in national parks of the Giant Mountains, the Tatras, on Babia Góra, and the Bieszczady Mountains, only. Roseroot is not Red Listed in Poland, nevertheless, this species is no longer found on some natural habitats where it used to grow or the number of individuals is extremely low [Przybył et al. 2004; Krukowski et al. 2009]. Therefore, cultivation could be only one solution to produce raw material in sufficient quantities and quality for industrial purposes. There is a need for understanding the biology and variability of *Rhodiola*, and on that basis determine, important from an economic point of view, possible recommendation for a time of raw material harvesting. In the available literature dominate those, that focus on the phyto-chemical evaluation of raw material obtained (among other examining various plant origins). The few studies on roseroot field culture have been carried out in several parts of the former Soviet Union, in Poland, Bulgaria, and Canada [Nukhimovskii 1976; Kiryanov et al. 1989; Elsakov and Gorelova 1999; Przybył et al. 2004, 2005, 2008; Platikanov and Evstatieva 2008; Ampong-Nyarko 2010; Kucharski et al. 2011]. In Finland roseroot can be grown successfully using organic growing methods with compost application [Galambosi 2006]

The objective of this study was to acquaint the biology and morphology of *Rhodiola rosea* L. plants through seven following years of cultivation in south-eastern part of Poland.

MATERIAL AND METHODS

In the years 2005–2011 an experiment was conducted on experimental fields at the University of Agriculture in Lublin (N 51 09'06.81", E 22 28'23.42"), located on luvisols, slight acid in reaction (pH 5.2), medium in phosphorus (61.9 mg kg^{-1} of soil) and potassium (174.3 mg kg^{-1} of soil), low in magnesium content (56 mg kg^{-1} of soil).

In the experiment, every year in the first decade of April, seeds of roseroot obtained from Botanical Garden of Maria Curie-Sklodowska University in Lublin were sown in 50 × 30 cm distance. A few seeds stratified for 1 month in 0°C were seeded to a depth of 0.5 cm on the plots with the area of 4 m^2 (in four replications, 21 plants per plot). After germination (on an average – 85% of germination capacity), the plants was thinned, leaving one in a place. Plants were authenticated by Prof. Anna Rysiak, taxonomist of the University of Maria Curie-Skłodowska in Lublin (Poland). Mustard plowed up as a green manure was a forecrop for roseroot. In 2011 at experimental objects there were found annual, two-, three-, four-, five-, six- and seven-year old roseroot plants. On the plots, phosphorus-potassium fertilization was applied every year at the following doses: 24.0 kg P and 66.4 kg K per hectare, whereas 40.0 kg of nitrogen were applied in two equal doses: in the spring, before the beginning of vegetation, and in full blooming phase. Every year during vegetation, the plants were three times weeded (by hand), and interrows were loosening. During the vegetation in 2011 there was carried out observations of the phases of roseroot development as well as growth rate and stems appearance. At the end of vegetation period (15^{th} of September 2011) 10 randomly chosen plants from each plot were dug out. After digging and cleaning underground parts of plants, the raw material was subjected to thermal drying – at 80ºC and detailed measurements (e.g. diameter of rhizomes and roots, the total length of roots, number of roots, buds and tips, number and height of shoots, fresh and air-dry weight of shoots and roots).

Numerical results concerning content of different morphological parts of plants were subjected to analysis of variance and t-Duncan's multiple range test (p = 0.05% of significance level) was used for means separation. The results of the analyses of the roseroot parts of plants at different age were analyzed also by Multivariate Statistical Package (MVSP 3.1). Cluster analysis was performed by using UPGMA (Unweighted Pair Group Method Using Arithmetic Averages) complete linkage to group the plants by the similarity of morphological parameters and weight of plants. Mean values of features under study are listed in Table 1–4. The result of the clustering was plotted as a hierarchical tree or dendrogram (fig. 2, 3).

RESULTS AND DISCUSSION

During seven following vegetation periods the appearance and size of *Rhodiola rosea* plants have changed (tab. 1–5, fig. 3–6). However, as in nature, the life cycle of plants from bud to fruit production took place within one vegetation period [Krukowski et al. 2009].

The results obtained indicate that the development of roseroot grown in south-eastern Poland was faster than those of plants growing wild in the Altai Mountains and was comparable with noted in Moscow region, in central Poland and in Bulgaria [Nukhimovskii 1974, 1976; Nukhimovskii et al. 1987; Przybył et al, 2008; Platikanov and Evstatieva 2008]. In spring 2011 the first plant emergence was recorded at the end of March (plants over the age of two), while in the first year emergence was observed at the beginning of the second decade of May (tab. 1). This was in accordance with reports of Nukhimovskii [1976], Polozhii and Pevyakina [1976] and Revina et al. [1976], who discovered that roseroot plants start its vegetation just after snow melting.

During emergence in the 1st year plants produced two elliptical leaves with a diameter of 4–6 mm (staying for relatively long time) and growth of young seedlings after sprouting was very slow – the first leaves appear in 25 to 35 days, which was comparable with Nukhimovskii [1976], Nukhimovskii et al. [1987], Kovaleva et al. [2003] and Platikanov and Evstatieva [2008] findings. During the first year, the seedlings develop only 1–3 thin stems and small underground parts, which was similar as in Nukhimovskii et al. [1987] studies. In following vegetation periods already in the autumn of the previous year plants formed the buds with the beginnings of new shoots, which began its development just after soil warming (fig. 4). About 4 weeks later (first year) immediately after snow melting, plants began to develop assimilation shoots – the first generation shoots, which remained on the plants for further 18–20 weeks. We observed that in plants that have evolved shoots followed rapid growth of rhizome diameter and biomass. At the earliest flowering reached plants found in 3, 4 and 5 years of the vegetation (second half of June), a bit later the oldest plants (6 and 7 year old), while at the latest flowering was observed in the case of annual plants. As in

Table 1. Growth stages of roseroot plants in following seven years of vegetation
Tabela 1. Fazy rozwojowe roślin różeńca w kolejnych siedmiu latach wegetacji

Growth stages Fazy rozwojowe	Plants age (year) – Wiek roślin (lata)						
	1	2	3	4	5	6	7
Emergence Wschody	15 V	25 III	24 III	22 III	21 III	21 III	21 III
Start of flowering Początek kwitnienia	14 VI	24 IV, 5 VII	22 IV, 2 VII	20 IV, 2 VII	20 IV, 3 VII	25 IV, 5 VII	27 IV, 3 VII
Fruits ripening Dojrzewanie owoców	25 VIII – 15 IX	22 V – 25 VII	20 V – 30 VII	16 V – 30 VII	16 V – 30 VII	26 V – 10 VIII	29 V – 15 VIII
I[st] generation period of life Okres życia pędów I generacji	10 VI – 15 IX	1 IV – 1 IX	1 IV – 1 IX	1 IV – 1 IX	1 IV – 1 IX	1 IV – 1 IX	1 IV – 1 IX
II[nd] generation period of life Okres życia pędów I generacji	-	18 V – 20 IX	1 VI – 1 IX	10 VI – 15 IX	10 VI – 15 IX	15 VI – 15 IX	15 VI – 10 IX
III[rd] generation period of life Okres życia pędów I generacji	-	-	10 VIII – 15 IX	5 VIII – 15 IX	5 VIII – 15 IX	10 VIII – 15 IX	10 VIII – 15 IX
Dying out of plants Obumieranie części nadziemnej	20 IX	20 IX	15 IX	15 IX	15 IX	15 IX	10 IX

Table 2. Characteristics of aboveground parts of *Rhodiola rosea* depending on plants age
Tabela 2. Charakterystyka części nadziemnych różeńca w zależności od wieku roślin

Plants age (year) Wiek roślin (lata)	Stems number (unit per plant) Liczba pędów (szt. roślina^{-1})	Average height Średnia wysokość (cm)	Stem diameter Średnica pędu (mm)	Fresh weight of stems (g per plant) Świeża masa części nadziemnej (g·roślina^{-1})	Air dry matter of stems (g per plant) Powietrznie sucha masa części nadziemnej (g·roślina^{-1})
1	1.25 ± 0.3[b] a	8.2 ± 4.0 a	1.98 ± 1.01 a	8.29 ± 0.79 a	1.082 ± 0.34 a
2	4 ± 1.8 a	9.3 ± 2.3 a	2.40 ± 0.75 a	17.47 ± 3.90 a	4.117 ± 1.55 a
3	5.6 ± 1.0 a	15.4 ± 4.5 b	4.04 ± 1.49 a	28.25 ± 3.75 b	11.693 ± 4.53 b
4	23.4 ± 9.0 b	16.4 ± 3.0 b	4.10 ± 0.61 a	52.1 ± 9.31 b	23.520 ± 4.24 b
5	58.2 ± 4.9 bc	29.8 ± 2.9 bc	4.64 ± 1.314 ab	221.17 ± 14.99 bc	91.508 ± 6.05 bc
6	64.6 ± 8.8 bc	38 ± 1.7 bcd	5.38 ± 0.95 b	279.26 ± 13.11 bcd	118.600 ± 12.06 bcd
7	46.8 ± 9.5 bcd	26.7 ± 1.7 bc	3.58 ± 1.38 a	191.08 ± 10.81 bcde	62.120 ± 1.82 bcde

Values within columns followed by the same letter are not significantly different from each other (ANOVA. Duncan multiple range test. $P \leq 0.01$)
Wartości w kolumnach oznaczone różnymi literami nie różnią się istotnie. test t-Duncana. ($P \leq 0,01$)

Table 3. Characteristics of rhizomes of *Rhodiola rosea* depending on plants age
Tabela 3. Charakterystyka kłączy różeńca w zależności od wieku roślin

Plants age (year) Wiek roślin (lata)	Rhizome diameter Średnica kłącza (cm)	Buds number (unit per plant) Liczba pąków pędowych (szt. ·roślina^{-1})	Tips number (units per plant) Liczba kopułek (szt. ·roślina^{-1})	Fresh weight of rhizome (g per plant) Świeża masa kłącza (g·roślina^{-1})	Air dry matter of rhizomes (g per plant) Powietrznie sucha masa kłącza (g·roślina^{-1})
1	1.88 ± 0.5[b] a	5.5 ± 1.9 a	1.5 ± 0.7 a	4.52 ± 5.75 a	1.498 ± 1.94 a
2	3.62 ± 0.3 a	10.7 ± 4.9 a	2.2 ± 0.9 a	16.993 ± 1.45 a	4.541 ± 1.07 a
3	4.14 ± 0.8 a	12.6 ± 3.2 a	3.6 ± 2.2 a	19.094 ± 4.53 a	8.928 ± 1.94 a
4	9.41 ± 3.0 b	116.4 ± 40.9 ac	22.5 ± 3.8 b	30.280 ± 17.13 a	12.830 ± 1.37 b
5	17.00 ± 1.3 bc	522.0 ± 70.5 b	35.8 ± 3.9 bc	484.129 ± 42.98 b	120.960 ± 10.40 b
6	19.96 ± 1.7 bc	252.0 ± 55.3 bd	40.2 ± 5.0 bc	334.584 ± 56.85 bc	79.473 ± 7.43 bc
7	17.36 ± 2.3 bc	220.2 ± 74.2 bd	43.2 ± 13.7 bc	158.632 ± 30.79 bcd	45.440 ± 3.54 bcd

Note: see Table 2
Objaśnienia: patrz tabela 2

Table 4. Characteristics of roots of *Rhodiola rosea* depending on plants age
Tabela 4. Charakterystyka korzeni różeńca w zależności od wieku roślin

Plants age (year) Wiek roślin (lata)	Roots diameter Średnica korzeni (mm)	Average roots length Średnia długość (cm)	Number of roots per plant Liczba korzeni (szt. ·roślina^{-1})	Fresh weight of roots (g per plant) Świeża masa korzeni (g·roślina^{-1})	Air dry matter of roots (g per plant) Powietrznie sucha masa korzeni (g·roślina^{-1})
1	1.68 ± 0.3^{b} a	7.2 ± 1.5 a	8.5 ± 3.3 a	1.02 ± 1.51 a	0.485 ± 0.39 a
2	1.69 ± 0.3 a	13.8 ± 2.6 a	9.0 ± 2.7 a	14.77 ± 2.88 a	5.750 ± 2.25 a
3	6.14 ± 2.8 a	16.8 ± 1.5 b	10.6 ± 14.2 a	34.56 ± 15.01 a	14.232 ± 5.93 a
4	8.51 ± 2.0 b	17.7 ± 1.9 b	19.2 ± 8.6 b	70.05 ± 32.96 b	30.476 ± 18.99 b
5	10.44 ± 2.7 b	18.4 ± 5.1 b	55.6 ± 5.1 b	222.70 ± 21.39 b	88.914 ± 17.15 b
6	10.79 ± 3.0 bc	18.0 ± 4.2 b	53.4 ± 7.4 b	256.90 ± 6.49 bc	87.620 ± 14.45 bc
7	10.67 ± 0.7 b	18.5 ± 4.1b	39.6 ± 2.4 b	221.02 ± 65.60 bc	86.660 ± 11.77 bc

Note: see Table 2
Objaśnienia: patrz tabela 2

Nukhimovskii et al. [1987] an Platikanov and Evstatieva [2008] experiments, starting from the second year male plants flowered at the end of April, whereas female plants begin flowering a week later than male plants. Plants from plots in third, fourth and fifth year of cultivation produced fruits the earliest, followed by the oldest plants and plant during the first year of vegetation. In the first year of roseroot cultivation there was observed a creation of first shoots generation, while during the following six vegetation periods also shoots of second generation (fig. 5) and beginning from the third vegetation period – third generation of shoot was recorded which was in accordance with Nukhimovskii et al. [1987] findings in Moscow region, whereas in Altai Mountains plats created only one shoot generation. Similarly as in Przybył et al. [2008] studies, from the third year of vegetation the plant created three generations of shoots, so the period of accumulation of biologically active substances is extended to six months, causing a rapid increase in weight of rhizomes. Plants creating second shoots generation flowered again at the beginning of July. At the latest plant vegetation ended the youngest plants (late September), while in the case of the oldest ones signs of dying off was observed earlier (tab. 1). The vegetation period of roseroot lasted from 127 days in the first year to 174–180 in six following years of cultivation and was comparable with Revina et al. [1976] results.

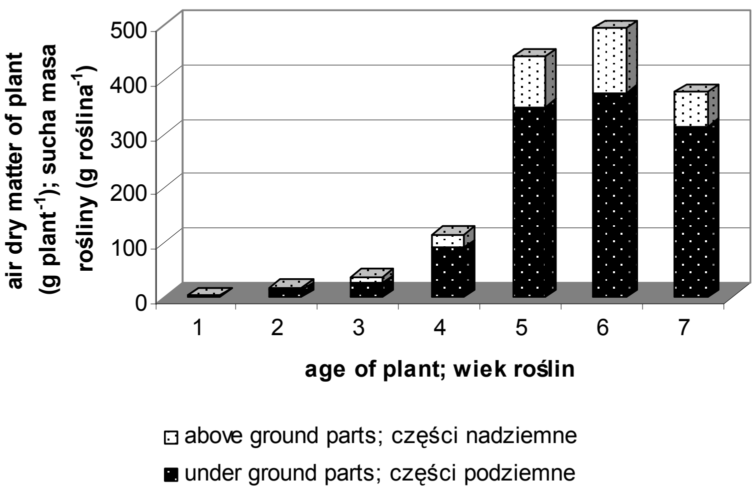

Fig. 1. Air dry matter of above and under ground parts in total biomass of roseroot plants depending on the age

Rys. 1. Powietrznie sucha masa części nadziemnych i podziemnych w ogólnej masie roślin różeńca w zależności od wieku roślin

Weight and dimensions of the aerial and under ground parts of plants have changed in subsequent years of vegetation (tab. 2–5).

As in Galambosi [2006] studies, in the first year of vegetation plants created 1–3 stems with an average height of 8.2 cm and diameter at the base of 1.98 mm. The average fresh weight of stems ranged from 4 to 13 g and air dry matter from 0.8 to 1.3 g. Under ground parts of plant (with average air dry matter of 2.383 g plant^{-1}) consisted of rhizomes with 3–9 buds and 5–10 roots with average length of 7.2 cm (representing 16.2% of total under ground biomass) – (tab. 3–4, fig. 6). Similar plants size, but with smaller under ground organs weight were found in the Moscow region, whereas in at high altitudes in the Altai plants had only 1or 2 buds [Nukhimovskii 1976; Kiryanov et al. 1989]. In Polish conditions during the first year of cultivation 30.7% of plants flowered, which was not comparable with Revina et al. [1976] findings, who stated that during the first year of culture roseroot did not flowering. Under the high-mountain conditions, roseroot plants flower and bear fruit at the year 7 to 40, whereas in the field stand of the introduced plants, the number of plants in flower increased gradually, from single plants at the year 1 to 53.3 to 86.7% at the fifth year [Nukhimovskii et al. 1987; Kovaleva et al. 2003].

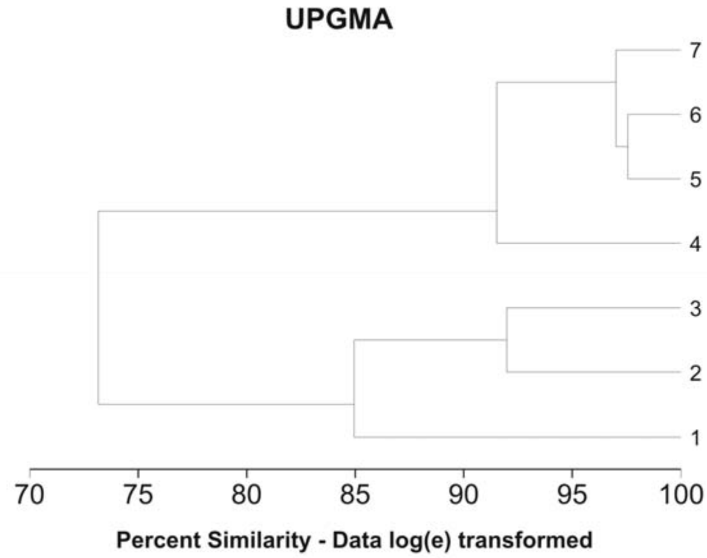

Fig. 2. Cluster analysis of morphological parameters of roseroot parts of plants depending on their age: 1 – one year old plants, 2 – two year old plants, 3 – three year old plants, 4 – four year old plants, 5 – five year old plants, 6 – six year old plants, 7 – seven year old plants

Rys. 2. Analiza klastrowa cech morfologicznych roślin różeńca w zależności od ich wieku: 1 – rośliny jednoroczne, 2 – rośliny dwuletnie, 3 – rośliny trzyletnie, 4 – rośliny czteroletnie, 5 – rośliny pięcioletnie, 6 – rośliny sześcioletnie, 7 – rośliny siedmioletnie

In the second year of cultivation total weight of under ground parts of plant increased almost five-fold and number of buds increased up to 11 units per plant, but number and dimensions of roots remained unchanged (tab. 2–3, fig. 1, 6). Higher plant weight noted Galambosi [2006] in Finland and Nukhimovskii et al. [1987] in Russia.

Share of rhizomes in total under ground biomass decreased to 58.8% (tab. 4). As far as above ground parts of plant is concerned its weight increased four-fold and its number increased to 2–6 units per plant in comparison to the first year of culture (tab. 2). In the Moscow region roseroot created 1–6 stems with height of 10–22 cm and under ground organs weight ranged from 0.13 to 47.7 g (mean 12.47 g) [Nukhimovskii 1976]. On field in Tomsk under ground parts of plant increased almost ten-fold compared to the first year [Revina et al. 1976], while in photoculture conditions 245-days-old plants reached comparable weight [Kovaleva et al. 2003]. Similarly as in Nukhimovskii [1976] study some of the plants remained in the immature phase, but 67.5% developed inflorescences. Obtained results were different from Nukhimovskii et al. [1987], who noted that in Moscow region only 0–15% of plants flowered.

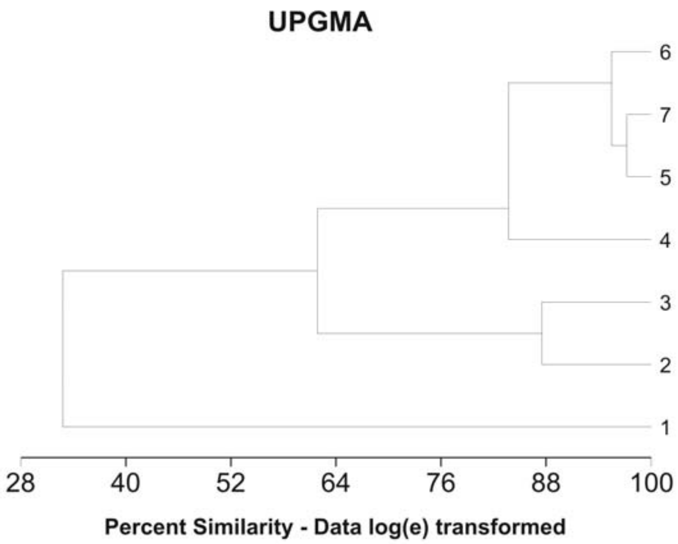

Fig. 3. Cluster analysis of roseroot weight of plants depending on their age: 1 – one year old plants, 2 – two year old plants, 3 – three year old plants, 4 – four year old plants, 5 – five year old plants, 6 – six year old plants, 7 – seven year old plants

Rys. 3. Analiza klastrowa masy roślin różeńca w zależności od ich wieku: 1 – rośliny jednoroczne, 2 – rośliny dwuletnie, 3 – rośliny trzyletnie, 4 – rośliny czteroletnie, 5 – rośliny pięcioletnie, 6 – rośliny sześcioletnie, 7 – rośliny siedmioletnie

In the third year of cultivation golden root stems number per plant ranged from 3 to 7, its average height was higher by 6.1 cm and average diameter was increased by 1.64 mm compared to the previous year. As a result air dry matter increased above six-fold in comparison to the first year (tab. 2), which was in accordance with Kiryanov et al. [1989] and Kucharski et al. [2011] findings. Higher differences were stated in Revina et al. [1976] experiments, where three-year-old plants created under ground parts almost 30-fold higher than in the first year. Similarly, Galambosi [2006] stated in the third year of vegetation almost 50-fold differenced between plants in this age. Plants formed under ground mass almost two times higher than in the case of 2-year-old plants and above of eleven times greater than in the first year (fig. 6). Share of rhizomes in the total under ground parts biomass was 43.7%. Rhizomes weight was lower than in obtained in central Poland on clayey soil [Przybył et al. 2005] and in Bulgaria [Platikanov and Evstatieva 2008]. During the third year of vegetation 88.2% of plants created inflorescences, and it was higher amount than in and Nukhimovskii et al. [1987] studies.

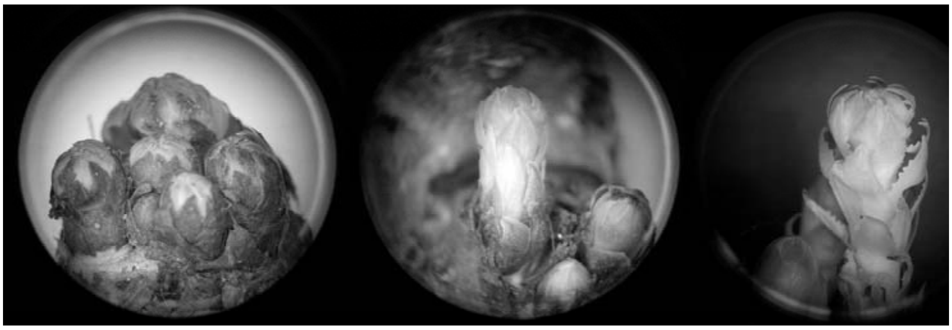

Fig. 4. The development of beginnings of shoots located on the buds of rhizome-shoot cuttings (tips) during germination of roseroot

Rys. 4. Rozwój zaczątków pędów znajdujących się na pączkach sadzonek kłączowo-pędowych (tipsach) podczas kiełkowania różeńca

Fig. 5. Four-year plant – shoots of I – 1 and II – 2 generation. Visible fruit on the shoots of the first generation (1) and inflorescences on shoots of second generation (2)

Rys. 5. Roślina czteroletnia – pędy I – 1 i II – 2 generacji. Widoczne zawiązane owoce na pędach I generacji (1) i kwiatostany na pędach II generacji (2)

Table 5. Above- and underground of plants share in total biomass of plant and flowering plants share depending on plants age
Tabela 5. Udział części nadziemnych i podziemnych w ogólnej masie roślin oraz roślin kwitnących w zależności od wieku roślin

Plants age (year) Wiek roślin (lata)	Share of aboveground parts in total plant biomass (%) Udział części nadziemnej w ogólnej masie roślin (%)	Share of rhizomes in total underground biomass (%) Udział kłącza w ogólnej masie części podziemnej (%)	Share of flowering plants (%) Udział roślin kwitnących (%)
1	52.6 ± 5.0 a	83.7 ± 7.9 a	30.7 ± 9.7 a
2	32.7 ± 4.7 b	58.8 ± 3.8 b	67.5 ± 18.7 b
3	33.1 ± 3.9 b	43.7 ± 17.9 b	88.2 ± 6.5 bc
4	21.7 ± 6.9 b	65.8 ± 8.3 bc	94.2 ± 3.3 bc
5	18.1 ± 1.0 b	77.4 ± 3.2 a	98.2 ± 1.9 bc
6	21.0 ± 1.8 b	75.5 ± 1.9 a	97.8 ± 2.0 bc
7	21.3 ± 3.3 b	69.7 ± 5.7 a	93.4 ± 4.4 bc

Note: see Table 2 – Objaśnienia: patrz tabela 2

In the following year of vegetation plants created 11–33 stems (mean 23.4 units per plant) with a height of 16.4 cm and diameter measured at the base of 4.1 mm. The average fresh weight of stems ranged from 39 to 65 g (mean 52.1 g plant^{-1}) and air dry matter from 17 to 30 g (mean 23.52 g plant^{-1}). Plants formed under ground mass almost three times higher than in the case of 3-year-old plants and above of thirty times greater than in the first year (fig. 6). Under ground parts of plant (with average air dry matter of 91.26 g plant^{-1}) consisted of rhizomes with 76–169 buds (mean 116 units per plant) and 7–30 roots with average length of 17.7 cm (similarly as in Galambosi [2006] experiments, representing 34.1% of total underground biomass) – (tab. 3, 4). In the fourth year of vegetation number of tips (adventitious buds with part of rhizome that could be used for vegetative propagation of roseroot plants) increased up to 22.5 units per plants, so 4-year-old rhizomes could be effectively used for clonal propagation and new plantation establishment (for example in the case of liquidation of the plantation).

As in Nukhimovskii et al. [1987] and Przybył et al. [2008] studies in the fifth year of vegetation total weight of under ground parts of plant increased almost four-fold in comparison to the previous year and number of buds increased up to 522 units per plant (also number of tips increased up to 35 units· plant^{-1}) – (fig. 1, 6). As in Kiryanov et al. [1989] studies five-year-old plants biomass was comparable to 30–50-year-old plants from wild Altai. Similarly, also number, dimensions and weight of roots increased, however its share in total under ground biomass decreased to 26.5% (tab. 4). As in Galambosi [2006] and Przybył et al. [2008] studies, in the fifth year of roseroot culture plants created the heaviest rhizomes constituting of 74.8% of total under ground biomass. As far as above ground parts of plant is concerned its weight increased four-fold in comparison to the fourth year of culture and its number increased to 51–66 units per plant with average height of 29.8 cm, but was smaller than in Moscow region [Nukhimovskii et al. 1987] (tab. 2, fig. 1).

Fig. 6. Comparison of the underground part of roseroot: 1 – one-year-old, 2 – two-year-old, 3 – three-year-old, 4 – four-year-old, 5 – five-year-old, 6 – six-year-old, 7 – seven-year-old
Rys. 6. Porównanie części podziemnych różeńca: 1 – jednorocznych, 2 – dwuletnich, 3 – trzyletnich, 4 – czteroletnich, 5 – pięcioletnich, 6 – sześcioletnich, 7 – siedmioletnich

Similarly as in Nukhimovskii et al. [1987], Kiryanov et al. [1989] and Przybył et al. [2008] studies, starting from the sixth year of vegetation under ground parts of plants destruction and disintegration was observed (rhizomes were fragmented, not so compacted, with visible necrosis and decay) and its weight began to decline systematically (tab. 3–4). Nukhimovskii [1974] stated, that first symptoms of plants aging in wild (Altai region) could be visible in the 15–20th and sometimes even 40th year of vegetation. However, in our studies in the sixth year of culture *Rhodiola* plants created the highest above ground biomass, which decreased rapidly in the following year of vegetation (share of above ground parts in a total plant biomass stayed at the level of an average of 21% – fig. 1, tab. 5). Weight and dimension of plants were smaller than obtained by Polozhii and Pevyakina [1976] in Altai conditions (however there was not known the age of roseroot harvested from the natural state). Cluster analysis of morphological parameters and weight of plants depending on its age showed that among the plants of all ages can be distinguished two separate groups: from one to three-year-old and from four to seven years old, supporting our observation that plants from the second group gave satisfactory yields and could be sourced from field plantations (fig. 2–3). Platikanov and Evstatieva [2008] recommended to harvest roseroot raw material after three years of vegetation in Bulgarian condition, whereas Galambosi [2006] concluded that roseroot should be harvested after four or five years of vegetation.

COCLUSIONS

Results of the experiment indicate that the rate of growth and development of roseroot in a south-eastern Poland did not differ from that observed in other parts of

Europe. Due to significant increases in plant weight its raw material should be obtained after four or five years of field cultivation.

REFERENCES

Ampong-Nyarko K., 2010. *Rhodiola rosea*: a high value crop. Agri-Facts, March 2010, Practical Information for Alberta's Agriculture Industry, Government of Alberta, 1–3.

Brown R.P., Gerbarg P.L., Ramazanov Z., 2002. *Rhodiola rosea*: a phytomedicinal overview. HerbalGram, 56, 40–52.

Costica M., Costica N., Toma O., 2007. Phytocoenological, histo-anatomical and biochemical aspects in *Rhodiola rosea* L. species from Romania. Analele Stint Univer "Alexandru Ioan Cuza" sec. Genet. Biol. Molec. VIII, 119–121.

Elsakov G.V., Gorelova A.P., 1999. Fertilizer effects on the yield and biochemical composition of rose-root stonecrop in North Kola region. Agrokhimiya, 10, 58–61.

Furmanowa M., Kedzia B., Hartwich M., Kozlowski J., Krajewska-Patan A., Mscisz A., Jankowiak J., 1999. Phytochemical and pharmacological properties of *Rhodiola rosea* L. Herba Pol. 65(2), 108–113.

Galambosi B., 2006. Demand and Availability of Rhodiola rosea L. Raw Material. Bogers R. Craker L.. Lange D. (eds.) Medicinal and Aromatic Plants. Springer, 223–236.

Ganzera M., Yayla Y., Khan I., 2000. Analysis of the marker compounds of *Rhodiola rosea* L. (golden root) by reversed phase high performance liquid chromatography. Arch Pharm Res 23(4), 349–52.

Kiryanov A., Bondarenko L., Kurkin V., Zapesohnaya G., 1989. Dinamika nakopleniya rozavidina i salidrozida v syrie rodioly rozowoy. kultiviruyemoy v podmoskvie. Khimiko Farmac. Zhurnal 23, 449–452.

Kovaleva N.P., Tikhomirov A., Dolgushev V., 2003. Specific characteristics of *Rhodiola rosea* growth and development under the photoculture conditions. Rus. J. Plant Phys. 50 (4), 527–531.

Krukowski M., Krakowski K., Malicki M., Szczęśniak E., 2009. Rozmieszczenie i biologia różeńca górskiego *Rhodiola rosea* L. w polskich Karkonoszach. Przyroda Sudetów 12, 3–8.

Kucharski W., Mordalski R., Buchwald W., Mielcarek S., 2011. Roseroot – the comparison of tillage in conventional and ecological system. J. Res. Appl. Agric. Eng. 56(3), 232–235.

Nukhimovskii E., 1974. Ekologicheskaja morfologija nekotorykh rastenii w estestvennykh uslovijakh ikh proizratanija. 2. *Rhodiola rosea* L. Rastitel´nye-resursy. 10(4), 499–516.

Nukhimovskii E., 1976. Initial stages of biomorphogenesis in *Rhodiola rosea* grown in the Moscow region. Rastitel´nye Resursy 12(3), 348–355.

Nukhimovskii E., Yurtseva N., Yurtsev V., 1987. Biomorphological characteristics of *Rhodiola rosea* L. cultivation (Moscow district). Rastitel´nye-resursy. 23(4), 489–501.

Panossian A., Wikman G., Sarris J., 2010. Rosenroot (*Rhodiola rosea* L.): traditional use, chemical composition, pharmacology and clinical efficacy. Phytomed. 17, 481–493.

Platikanov S., Evstatieva L., 2008. Introduction of wild golden root (*Rhodial rosea* L.) as a potential economic crop in Bulgaria. Economic Botany 64(4), 621–627.

Polozhii A., Pevyakina N. 1976. Developmental biology of *Rhodiola rosea* in the Katun'range (Altai). Rastitel´nye Resursy 12(1), 53–59.

Przybył J., Węglarz Z., Pawełczak A., 2004. Zmienność w obrębie populacji różeńca górskiego (*Rhodiola rosea* L.) pod względem plonu surowca i zawartości związków biologicznie czynnych. Zesz. Probl. Post. Nauk. Roln. 497, 525–31.

Przybył J., Węglarz Z., Geszprych A., 2005. Development of roseroot (*Rhodiola rosea* L.) plants cultivated in diverse climatic and soil conditions. Herba Pol. 51 suppl., 98–99.

Przybył J., Węglarz Z., Geszprych A., 2008. Quality of roseroot (*Rhodiola rosea* L.) cultivated in Poland. Acta Hort. (ISHS), 765, 143–150.
Revina T.A., Krasnov E.A., Sviridova T.P., Stepanyuk G.Y., Surov Y.P., 1976. Biological characteristics and chemical composition of *Rhodiola rosea* grown in Tomsk. Rastitel´nye Resursy 12(3), 355–360.
Saratikov A., 1977. Rose-root stonecrop (*Rhodiola rosea* L.). Khimiko Farmac. Zhurnal 11, 56–59.

WYBRANE ELEMENTY BIOLOGII I MORFOLOGII RÓŻEŃCA GÓRSKIEGO W POŁUDNIOWO-WSCHODNIEJ POLSCE

Streszczenie. *Rhodiola rosea* jest wieloletnią rośliną leczniczą o cennym działaniu frmakologicznym. Jego surowiec – kłącza i korzenie zbierane są ze stanu naturalnego, jednak ze względu na intensywny zbiór, populacje naturalne są bardzo zagrożone. Dlatego też poznanie biologii i zmienności cech różeńca i wprowadzenie tego gatunku do uprawy jest bardzo ważne. Celem niniejszych badań było przedstawienie biologii i morfologii roślin w ciągu siedmiu kolejnych latach uprawy w południowo-wschodniej części Polski. Wyniki badań wskazują, że tempo wzrostu i rozwoju różeńca w południowo-wschodniej Polsce nie różniły się od obserwowanych w innych częściach Europy, ale był szybsze niż obserwowane w stanie dzikim w górach Ałtaju. Pełny cykl rozwojowy roślin odbywał się w każdym badanym okresie wegetacji roślin. Począwszy od drugiego roku wegetacji przez kolejne lata rośliny wytwarzały pędy drugiej, a od trzeciego okresu wegetacyjnego – trzeciej generacji, tak więc okres akumulacji substancji biologicznie czynnych przedłużał się do pięciu miesięcy, co powodowało szybki wzrost masy kłącza. Masa i wymiary części nad- i podziemnych roślin uległy zmianie w kolejnych latach wegetacji. W pierwszym roku uprawy rośliny tworzyły od jednego do trzech pędów i część podziemną o średniej powietrznie suchej masie 2,38 g roślina^{-1}. W następnych latach wegetacji masa kłączy i korzeni systematycznie wzrasta, osiągając najwyższą wartość od czwartego do szóstego roku wegetacji.

Słowa kluczowe: *Rhodiola rosea*, stadia rozwojowe, charakterystyka roślin, wiek roślin

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