Rhodiola kirilowii – the present status and perspectives of medicinal use
Part I. In vivo and in vitro cultivation as well as phytochemical investigations of extracts of roots and callus tissues

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S u m m a r y

\textit{Rhodiola kirilowii} (Regel) Maxim (Crassulaceae family) is used in traditional East Asian medicine, mainly in China, to prevent damages due to hypoxic environment of high altitude. On the basis of own achievements and wide review of the published articles the authors describe the status of field cultivation as well as phytochemical and biotechnological investigations carried out on \textit{R. kirilowii} (callus tissue cultures, micropropagation \textit{in vitro}, somatic seeds production, hairy roots cultures). The identified chemical constituents of the extracts of roots and callus tissues of \textit{R. kirilowii} are presented and divided according to chemical groups.

\textbf{Key words:} \textit{Rhodiola kirilowii}, traditional medicine, hypoxia, field cultivation, \textit{in vitro} cultures, micropropagation, hairy roots, somatic seeds, phytochemical investigations, salidroside, rosvins

\textbf{RHODIOLA SP. – TRADITIONAL MEDICINAL PLANT}

\textit{Rhodiola} plants belong to herbs used in traditional medicine in China, in Russia and in Northern Europe. The best known is \textit{Rhodiola rosea} L. – goldenroot. \textit{R. rosea} grows
in many places in Europe, in opposite to *R. kirilowii*, growing widely only in Asia. Tor the first time, *R. rosea* was described by Dioscorides, the Greek physician, in *De Materia Medica* in 77 CA. In the 17th century the medical properties of *Rhodiola* were cited by Linne in his elaborates on Scandinavian flora: in the Flora Lapponica [1], the Flora Suecica [2] and in the Materia Medica Holmiae [3] (fig. 1). Linne described *Rhodiola rosea* as a remedium for treatment rupture, vaginal discharges, headache and hysteria [3]. In Asia, especially in China and Tibetan traditional medicine as well as in Siberian folk medicine *Rhodiola* was used as a plant adapting a human body to disadvantageous environmental conditions and improving physician and mental abilities. Other disorders treated in ethnomedicine with *Rhodiola* are as follows: fatigue, depression, anemia, alleviate nervous disorders. It is also used in treatment of high altitude sickness and to enhance fertility. In China divers, astronauts, pilots and mountaineers use *Rhodiola* to enhance their abilities. The positive properties of extracts from *Rhodiola* plants in adaptation to environmental conditions caused that nowadays *R. rosea* extracts become serving as constituents of modern medicines of plant origin used to enhance physician and human abilities, also in European countries.

**BOTANICAL CHARACTERISTICS**

*Rhodiola* genus (*Crassulaceae* family) consists of more than 50 species. For the first time *Rhodiola kirilowii* (Regel) Maxim. was described under this name in 1859 in Russia in the article published by Imperial Academy of Science in Saint Petersburg in the journal entitled “Mémoires présentés á l’Académie Impériale des Sciences de St.-Petersburg par Divers Savants et lux dans ses assemblées” (according to Flora of China [4]). Other synonyms of *Rhodiola kirilowii* are *Sedum kiriolwii* Regel and *Sedum elongatum* Kar. [4, 5]. *R. kirilowii* belongs to *Linearifoliae* A. Bor. group of *Rhodiola* genus [5]. In Chinese is called *xia ye hong jing tian* [4].

*R. kirilowii*, a perennial plant, has erect, thick root and rhizomes with lanceolate or ovate scalelike leaves. The stems are up to 60 (max. 90) cm high, density leafy. Leaves are alternate or subverticillate, linear to linear-lanceolate, on the margin sparsely serrulate. Flowers are bi- or unisexual 4- or 5-merous, with green, greenish yellow or red petals. Seeds are oblong-lanceolate, ca. 1.5 mm. *R. kirilowii* flowers at May-September. The plant grows in mountains at the altitude of 2000-5600 m in Asia: mainly Tien Shan, Altaj, Pamir. The natural sites of *R. kirilowii* are forest margins, grassy slopes, often in partial shade [4, 5].

**RHODIOLA KIRILOWII IN FIELD CULTIVATION AND IN MICROPROPAGATION IN IN VITRO CONDITIONS**

The investigations on *R. kirilowii* in Poland started about 2000 and were carried out in cooperation in two laboratories: Department of Biology and Pharmaceutical
Figure 1. *Rhodiola* sp. in Caroli Linnaei publications – figures obtained by kindness of Anders Backlund, Division of Pharmacognosy, Department of Medicinal Chemistry, Uppsala University

a. Linnaei C. Flora Suecica, 1745 [2]

b. Linnaei C. Materia Medica Holmiae, 1749 [3]

c. Linnaei C. Flora Lapponica, 1737 [1]
Botany, Warsaw Medical University and the Research Institute of Medicinal Plants (RIMP), Poznań. These searching were supported by grants from Polish Committee for Scientific Research (No PBZ-KBN-092/PO5/2003) and from the Ministry of Science and High Education (project No N405 025 32/1687).

Plants were grown in the RIMP Garden of Medicinal Plants in Plewiska near Poznań (fig. 2). On the basis of these five-year investigations the instruction for the field cultivation of this species was elaborated [RIMP – unpublished data]. The obtained raw plant material was investigated for chemical constituents and served as the start material for callus tissue cultures. The getting results proved that the field cultivation of this species of Asian origin is possible in Polish climate. Phytochemical investigations of the obtained root extracts allowed to determine the main chemical constituents, widening the known chemical spectrum of the compounds. The results of these investigations are summarized in the chapter about phytochemical investigations of roots of R. Kirilowii.

Following the above-mentioned study on field cultivation the investigators from RIMP and Warsaw Medical university searched the micropropagation of R. kirilowii in in vitro conditions [6]. Micropropagation of R. kirilowii was studied for the first time by Chinese group in 2004 (Li et al. [7]), but their achievements were not widely distributed due to language barrier. Polish investigators from Warsaw Medical university elaborated the simple method of plants propagation from sterile seedlings connected with somatic seeds production [6, 8]. The group from Warsaw Medical University and the group from RIMP searched the encapsulation of axillary buds and differentiating callus tissue of R. Kirilowii using sodium alginate mixed with pure Murashige-Skoog medium [9] or medium supplemented with growth regulators. After encapsulation the somatic seeds were stored at 4ºC for 1 to 15 weeks and then their viability was tested on MS medium. The results showed that after six weeks of preservation 100% of somatic seeds were able to develop into plantlets. Authors suggest that not only axillary buds could be encapsulated. The small pieces of differentiating callus tissue can be used in somatic seeds production as well [6].

PHYTOCHEMICAL INVESTIGATIONS OF R. ROSEA ROOTS, THE BEST KNOWN MEDICINAL PLANT FROM RHODIOLA SP.

The modern chemical investigation on Rhodiola sp. started in the seventies of 20th century. It allows to determine the main active constituents of the extracts: salidroside (glycoside of p-tyrosol) [10, 11], occurring in many Rhodiola species, and ro-savins (phenylopropanoids derivatived from cinnamyl alcohol) treated like specific compounds of R. rosea [12]. Goldenroot belongs to more often investigated Rhodiola plants and about 100 compounds have been isolated and identified from roots and underground parts of this plant: rosavins [12], p-tyrosol, salidroside [10, 11], flavonoids [13], phytosterols (daucosterol and β-sitosterol) [14], chlorogenic acid, caffeic acid, gallic acid, hydroxycinnamic acid, coumaric acid [15, 16], cyanogenic glycoside – lotaustralin [17], essential oil [18], fatty acids [19].
Figure 2. *Rhodiola kirilowii* (Regel.) Maxim. cultivated in the Garden of Medicinal Plants, Research Institute of Medicinal Plants in Poznan

a. b. 5-year-old plantation  
c. 5-year-old flowering plant  
d. root of 5-year-old plant

**PHYTOCHEMICAL INVESTIGATIONS OF *R. KIRILOWII* ROOTS**

On the contrary to relatively well investigated extracts from *R. rosea*, *R. kirilowii* is searched mainly in China and the obtained results are not widely known, due to the fact that most of them are published in Chinese. According to Russian investigations carried out on *Rhodiola* sp. in the seventies of 20th century, *R. kirilowii*...
contains: salidroside, p-tyrosol, gallic acid, coumarins esculetin and umbelliferone, flavonoid herbacitrin [20]. Chinese searchers communicated that R. Kirilowii contains bergenin, identified by spectral methods by Zhang et al. [21]. β-sitosterol in R. Kirilowii was described for the first time in 1992 by Kang et al. [22]. The other phytosterol – daucosterol was found in R. Kirilowii rhizome by Peng and coworkers in 1994 [23]. They also identified lotaustralin, an toxic cyanogenic glycoside, in this plant material [23]. This compound was searched by GC methods by Kang et al. – according to their opinion, R. Kirilowii was the plant of the highest content of lotaustralin in ten investigated Rhodiola species [24, 25].

In recent years the growing interest in R. Kirilowii searchings is observed with the use of modern identification and quantitative compounds analysis methods. The examples are Cui et al. investigations [26] carried out on R. Kirilowii and R. crenulata by capillary zone electrophoresis (CZE). This team elaborated the rapid method of simultaneous determination of p-tyrosol and salidroside in plant material with suggestion to use this method for bulky samples and quality control in pharmaceutical plants [26].

The results of first chemical investigations carried out in the Department of Biology and Pharmaceutical Botany of Warsaw Medical University and in the Research Institute of Medicinal Plants (RIMP) in Poznań on the material grown in the RIMP Garden of Medicinal Plants in Plewiska near Poznan were described in 2002 [27]. In next years the self-elaborated HPLC method allowed to determine next compounds in the hydroalcoholic extract of plant material from field cultivation: gallic acid – in higher concentration than in R. rosea [28-31], epigallocatechin gallate (also in the higher concentration than in R. rosea) [28, 29, 32], p-tyrosol, salidroside and – for the first time in this species – rosavins [31]. A new compounds, namely rhodiocyanoside A (cyanogenic glycoside), arbutin and fructopyrano-(1-4)-glucopyranose have been found recently by Wiedenfeld et al. [33] in the root extract from the plants cultivated in Poland (in RIMP).

Testing the extract activity against chronic hepatitis C virus the group of Chinese investigators has found for the first time some compounds in the extract from R. kirilowii: 3,3’-digalloylpropropdelphinidin B2 (rhodisin), 3,3’-digalloylprocyanidin B2, (-)-epicatechin-3-O-gallate (ECG), (-)-epigallocatechin, (-)-epicatechin, luteolin, tricetin, rhodiolinoxide [34]. They also confirmed, that in R. kirilowii extracts (-)-epigallocatechin-3-O-gallate (EGCG), gallic acid, tyrosol and salidroside are present [34].

Searching the anti-tuberculosis activity, another group of Chinese investigators separated and identified twelve compounds from R. kirilowii extracts. Among them a few compounds were isolated from this species for the first time, namely trans-hydroxycinnamic acic, hexyl-β-glucopyranoside, rhodiolgin, isolariciresinol-9-O-β-glucopyranoside, rhodiooctanoside, sacranoside B, geranyl-β-glucopyranoside and neryl-β-glucopyranoside. Moreover, they isolated β-sitosterol, p-tyrosol, gallic acid and -epigallocatechin gallate [35].
The constituents identified or searched in the roots of *R. kirilowii* are summarized in table 1. The structures of most of them are presented in figures 3–6.

### Table 1.

Identified phytochemical constituents of *Rhodiola Kirilowii* plants

<table>
<thead>
<tr>
<th>class or group of compounds</th>
<th>compound name</th>
<th>identified or searched in plant’s extract by</th>
</tr>
</thead>
<tbody>
<tr>
<td>phenylethanoids</td>
<td>p-tyrosol</td>
<td>Krasnov et al. [20], Kang et al. [22], Peng et al. [23], Cui et al. [26], Krajewska-Patan et al. [31], Zuo et al. [34], Wong et al. [35]</td>
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<tr>
<td></td>
<td>salidroside</td>
<td>Krasnov et al. [20], Kang et al. [22], Peng et al. [23], Cui et al. [26], Krajewska-Patan et al. [31], Wiedenfeld et al. [33], Zuo et al. [34]</td>
</tr>
<tr>
<td>phenylpropanoids</td>
<td>rosavin, rosin, rosinarin trans-hydroxycinnamic acid</td>
<td>Krajewska-Patan et al. [31]</td>
</tr>
<tr>
<td></td>
<td>luteolin</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td></td>
<td>herbacitrin</td>
<td>Krasnov et al. [20]</td>
</tr>
<tr>
<td></td>
<td>tricetin</td>
<td>Zuo et al. [34]</td>
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<tr>
<td></td>
<td>rhodiolgin</td>
<td>Wong et al. [35]</td>
</tr>
<tr>
<td>flavonoids</td>
<td>epigallocatechin gallate</td>
<td>Miścisz et al. [28], Mielcarek et al. [30], Buchwald et al. [29], Krajewska-Patan et al. [31], Wiedenfeld et al. [33], Zuo et al. [34], Wong et al. [35]</td>
</tr>
<tr>
<td></td>
<td>(-)-epicatechin-3-O-gallate (ECG)</td>
<td>Zuo et al. [34]</td>
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<tr>
<td></td>
<td>(-)-epigallocatechin</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td></td>
<td>(-)-epicatechin</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td>hydroxycoumarins</td>
<td>esculetin, umbelliferone</td>
<td>Krasnov et al. [20]</td>
</tr>
<tr>
<td>isocoumarins</td>
<td>bergenin</td>
<td>Zhang [21]</td>
</tr>
<tr>
<td>phenolic acids</td>
<td>gallic acid</td>
<td>Krasnov et al. [20], Miścisz et al. [28], Mielcarek et al. [30], Buchwald et al. [29], Krajewska-Patan et al. [31], Zuo et al. [34], Wong et al. [35]</td>
</tr>
<tr>
<td>phytosterols</td>
<td>β-sitosterol</td>
<td>Kang et al. [22]</td>
</tr>
<tr>
<td></td>
<td>daukosterol</td>
<td>Wong et al. [31]</td>
</tr>
<tr>
<td>tannins</td>
<td>3,3’-digalloyl-proprodelphinidin B2 (rhodisin)</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td></td>
<td>3,3’-digalloyl-procyanidin B2</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td>cyanogenic glycosides</td>
<td>lotaustralin</td>
<td>Peng et al. [23], Kang and Wang [24], Kang et al. [25], Wiedenfeld et al. [33]</td>
</tr>
<tr>
<td></td>
<td>rhodiocyanoside A</td>
<td>Wiedenfeld et al. [33]</td>
</tr>
<tr>
<td>phenols</td>
<td>arbutin</td>
<td>Wiedenfeld et al. [33]</td>
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<tr>
<td>lignans</td>
<td>isolariciresinol-9-O-β-glucopyranoside</td>
<td>Wong et al. [35]</td>
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<tr>
<td>phenolic ketones</td>
<td>rhodiolinazole</td>
<td>Zuo et al. [34]</td>
</tr>
<tr>
<td>oligoglycosides</td>
<td>rhodiooctanoside</td>
<td>Wong et al. [35]</td>
</tr>
<tr>
<td>oligosaccharides</td>
<td>sucrose</td>
<td>Peng et al. [23]</td>
</tr>
<tr>
<td></td>
<td>fructopyranos-(1-4)-glucopyranosede hexyl-β-glucopyranoside</td>
<td>Wiedenfeld et al. [33]</td>
</tr>
<tr>
<td></td>
<td>sacranoside B</td>
<td>Wong et al. [35]</td>
</tr>
<tr>
<td></td>
<td>geranyl-β-glucopyranoside</td>
<td>Wong et al. [35]</td>
</tr>
<tr>
<td></td>
<td>neryl-β-glucopyranoside</td>
<td>Wong et al. [35]</td>
</tr>
</tbody>
</table>
Figure 3. The chemical structures of roots and/or biomass components identified in *R. kirilowii* – phenylethanoids and phenylopropanoids. Structures a), f) – h) according to Phytochemical Dictionary [36]. Structure b) according to Kir' anov et al. [10]. Structures c) – e) according to Zapesochnaya and Kurkin [12].
Figure 4. The chemical structures of roots and/or biomass components identified in *R. kirilowii* – flavonoids.  
structures a) and b) according to Phytochemical Dictionary [36]  
structures c) – f) according to Zuo et al. [34]
Figure 5. The chemical structures of identified in *R. kirilowii* roots and/or biomass components – hydroxycoumarins, isocoumarins, phenolic acids, tannins. 
structures a) – e) according to Phytochemical Dictionary [36] 
structures f) and g) according to Zuo et al. [34]
Figure 6. The chemical structures of identified in *R. kirilowii* roots and/or biomass components – cyanogenic glycosides, phenols, phenolic ketones, oligosaccharides. 
structures a), c), e) according to Phytochemical Dictionary [36] 
structures b) and f) according to Wiedenfeld et al. [33] 
structure d) according to Zuo et al. [34]

The main active compounds of the hydroalcoholic extract of roots of *R. kirilowii* can be detected by HPLC method elaborated in the Research Institute of Medicinal Plants in cooperation with Department of Biology and Pharmaceutical Botany of Warsaw Medical University (fig. 7).
PLANT TISSUE CULTURES IN VITRO OF *R. KIRILOWII* AND PHYTOCHEMICAL INVESTIGATIONS OF BIOMASS

Research communications about *R. kirilowii* tissue cultures started to appear in 2004: Li and coworkers [37] described a method of rapid micropropagation of *R. Kirilowii*. Furthermore, Krajewska-Patan and coworkers from Research Institute of Medicinal Plants in Poznan described their investigations on callus elicitation methods [38]. The group from RIMP has obtained callus tissue from cotyledon, hypocotyle, epicotyle and roots of sterile seedlings on Murashige-Skoog’s medium [9] supplemented with benzyloaminopurine (BA), naphtylacetic acid (NAA), adenine hydrochloride or dichlorophenxyacetic acid (2,4-D) [38, 39]. In these investigations the conditions of callus culture were determined and optimized (fig. 8). Authors measured the tissue growth dynamics and growth parameters (fresh and dry weight, percent of dried weights, growth rate). According to these investigations, the fresh weights of callus obtained from cotyledons reached maximum values between days 35 and 42 of culture and approximated 14–21 g per one culture cultivated in 200 ml jar. It means that the fresh weights increased 5–8 times during the period of culture [38, 39].
Figure 8. *R. kirilowii* – callus tissue cultures according to Krajewska-Patan et al. [38] and Mrozikiewicz et al. [39]

a) callus originated from hypocotyl cultivated on MS medium supplemented with NAA, BA and adenine chloride

b) callus cultivated in dark condition on MS medium supplemented with 2,4-D

The data shown by Mrozikiewicz and coworkers from the Research Institute of Medicinal Plants in Poznań published in 2006 was the first report on phytochemical constituents of callus tissue from *R. Kirilowii* [39]. The callus tissue from cotyledon was able to synthesize the same biological compounds as those of *in vivo* plants but the contents of them were much lower [RIMP, unpublished data]. The authors identified some active components of extracts from callus tissue, namely salidroside, p-tyrosol, tannins, gallic acid, chlorogenic acid, caffeic acid [32, 39] and tested their contents *in vitro* during seven-week vegetation period. The content of salidroside varied from 0.08 mg/100 g to 1.56 mg/100 g of dry weight (it is worth expressing that salidroside content decreased rapidly between fourth and fifth weeks), p-tyrosol: 0.06-0.17 mg/100 g, tannins (expressed as pyrogallol) 0.20-0.73%, gallic acid 20.17–38.18 mg/100 g, caffeic acid 6.65–9.94 mg/100 g, chlorogenic acid up to 2.80 mg/100 g of dry weight [32]. Lotaustralin was not detected in the callus tissue. The callus tissue obtained from hypocotyle and from radicula of seedlings were able to synthesize the same components as described above: salidroside up to 3.29 mg/100 g, chlorogenic acid (up to 28.47 mg/100 g), p-tyrosol, tannins, phenolic acids, epigallocatechin gallate and rosavins, but their contents were lower than in the intact plant [32]. The latest two components were determined for the first time in callus tissue of *R. Kirilowii* [31].

Suspension culture of *R. kirilowii* was also tested but the contents of active components were lower than in callus tissue cultivated on solid medium [31].

The constituents identified or searched in *in vitro* cultivated plant material are summarized in table 2. The structures of most of components of biomass of *R. kirilowii* are presented in figures 4–6.
Table 2.

Identified phytochemical constituents of callus of *Rhodiola kirilowii*

<table>
<thead>
<tr>
<th>Group and names of the compounds</th>
<th>Identified or searched in callus extract by</th>
</tr>
</thead>
<tbody>
<tr>
<td>phenylethanoids – <em>p</em>-tyrosol, salidroside</td>
<td>Li et al. [37], Krajewska-Patan et al. [31, 32]</td>
</tr>
<tr>
<td>phenylpropanoids – rosavin, rosin, rosarin, chlorogenic acid, caffeic acid</td>
<td>Krajewska-Patan et al. [31, 32, 40]</td>
</tr>
<tr>
<td>phenolic acids – gallic acid</td>
<td>Krajewska-Patan et al. [31]</td>
</tr>
<tr>
<td>Tannins</td>
<td>Krajewska-Patan et al. [31, 32]</td>
</tr>
<tr>
<td>Flavonoids – epigallocatechin gallate</td>
<td>Krajewska-Patan et al. [32]</td>
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</table>

The process of biotransformation of exogenous added precursors in callus tissue of *R. kirilowii* was tested by Krajewska-Patan and coworkers in 2008 [40]. Callus tissue supplemented with *p*-tyrosol produced almost 70 times more of salidroside than the intact plants cultivated in Polish climatic conditions – up to 1100 mg/100 g. After supplementation with cinnamyl alcohol this type of callus tissue produced also a big amount of rosavins (mainly rosin) – up to 1200 mg/100 g [40]. This was the first report – according to the known literature – on artificial addition of precursors to *R. kirilowii* callus tissue [40].

This group of investigator from RIMP and Warsaw Medical Academy tested also the process of elicitation using yeast extract (YE) and methyl jasmonate (JAME) in 1–10 mg/culture and 100 μM–1 mM/culture concentrations, respectively. They tested biomass changes and the influence on the content of bioactive components [38].

INVESTIGATIONS ON THE TRANSFORMED HAIRY ROOTS OF *R. KIRILOWII*

The research team from the Department of Biology and Pharmaceutical Botany of Warsaw Medical Academy elaborated the method of obtaining the hairy roots of *R. kirilowii* by infection of the plantlets with *Agrobacterium rhizogenes* LBA 9402 (with using acetylsyringone - 2 mg/l - in the incubation medium). It was the first report on transformation process of this species using *Agrobacterium rhizogenes*. Moreover, according to known literature it was the first obtaining of the hairy roots in the *Rhodiola* genus [41]. This achievement is worth of notice because transformation of *R. kirilowii* plants using bacterial vector is very difficult. Hairy roots cultures grew the best on hormone free DCR medium. The best plantlet fragments to obtain hairy roots are internodal segments of shoots. The process of transformation was confirmed in the Research Institute of Medicinal Plants genetic laboratory using polymerase chain reaction (PCR). DNA analysis showed that rol B gene and aux 1 gene from Ri plasmid of *A. rhizogenes* were incorporated into the plant genome of *R. kirilowii* [41]. The phytochemical analysis and biological activity of the obtained hairy roots are in progress.
CONCLUSIONS

The above presented agricultural investigations showed that it is possible to obtain valuable plant material in Polish climatic conditions. The results of phytochemical investigations carried out mainly in China and in Poland allowed to find certain chemical constituents of the extracts, but precise determination of chemical spectrum of that plant is needed. Above-mentioned phytochemical investigations show that chemical constituents of extracts from *R. kirilowii* roots are in most cases similar to the components isolated from *R. rosea* roots, with exception of the content of rosavins which presence in some plant material of definite origin was not detected. The future investigations may be allow to answer on the question whether production of rosavins may be connected with certain climatic or soil conditions.

The results of presented biotechnological investigations clearly documented that *R. kirilowii* callus tissues are able to produce characteristic active compounds and could be in taken into consideration as a source of important pharmaceutical constituents.

The summary of pharmacological and clinical investigations on *R. kirilowii* extracts will be shown in part II.

ACKNOWLEDGEMENTS

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**RHODIOLA KIRILOWII – STAN BADAŃ I PERSPEKTYWY ZASTOSOWANIA W LECZNICTWIE CZĘŚĆ I. UPRAWA W GRUNCIE ORAZ W WARUNKACH IN VITRO ORAZ BADANIA SKŁADU CHEMICZNEGO KORZENI I TKANEK KALUSOWYCH**

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**Streszczenie**

Różeniec Kiryłowa (*Rhodiola kirilowii* (Regel) Maxim. (rodzina gruboszowatych *Crassulaceae*) jest rośliną stosowaną w tradycyjnej medycynie w Azji Wschodniej, głównie w Chinach,
jako środek zapobiegający niekorzystnym zmianom w organizmie człowieka na skutek hipoksji związanej z przebywaniem na dużych wysokościach (choroba wysokogórksa). Na podstawie własnych prac oraz szerokiego przeglądu piśmiennictwa autorzy przedstawiają obecny stan badań nad *R. kirilowii* w dziedzinie upraw w gruncie, badań fitochemicznych i badań biotechnologicznych (kultury kalusa, mikrorozmnażanie *in vitro*, produkcja nasion somatycznych, kultury korzeni transformowanych). Dzieląc substancje chemiczne na grupy, w artykule przedstawiono zidentyfikowane składniki wyciągów z korzeni oraz tkanek kalusowych.

*Słowa kluczowe: Rhodiola kirilowii, medycyna tradycyjna, hipoksja, uprawy w gruncie, kultury in vitro, mikrorozmnażanie, korzenie transformowane, nasiona somatyczne, badania fitochemiczne, salidrozyd, rozawiny*