Review Article

RHODIOLA ROSEA L. – A VALUABLE PLANT FOR TRADITIONAL AND FOR THE MODERN MEDICINE

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Abstract: Rhodiola rosea (golden root, rose root, arctic root) is a species whose medicinal properties are well known since antiquity; the plant is used for centuries in the folk medicine of Scandinavia and Russia. Its medicinal properties lead to its thorough phytochemical and pharmacological analysis and its capitalization for therapeutical purposes. The massive exploitation of this species lead to its extinction in several areas of its native habitats, that imposed special environmental protection regulations or its entrance on the red list of the endangered species. In this view, and to supply the necessary amount of R. rosea raw material for the pharmaceutical use, this species was grown in conventional cultures; several in vitro breeding methods were elaborated, as well. This paper is a synthesis of all the data on Rhodiola rosea gathered in many years, comprising the botanical description, its spread, the chemical composition, its utility in traditional and in modern medicine, its reaction in conventional and in vitro cultures etc.

Keywords: Rhodiola rosea, taxonomy, spreading, chemical composition, medicine use, cultivation

Introduction

Rhodiola rosea L., synonymous with Sedum rhodiola DC, and Sedum rosea (L.) Scop., known as Rhodiola, rosroot, ronenroot, golden root, arctic root, orpin rose, Rhodiola rougeâtre (Panosian et al., 2010) is a herbaceous perennial plant with a thick rhizome, that belongs to the Crassulaceae family. It was named „the golden root” due to its exquisite pharmacological properties of the root compounds, the rose root due to its rose scent emanated by the freshly sectioned roots, and arctic root because it is spread in the arctic area. It is known since antiquity by the name of rodia riza; the Greek physician Dioscoride (B.C.) recommended it for curative purpose in his paper „De Materia Medica”.

The species is used for centuries in the traditional medicine from Scandinavia and Russia. Between 1725 and 1960 (the moment of rising interest due to some specific active compounds) several data on this species’ medicinal use were published in Sweden, Norway, France, Germany, Russia, and Iceland (Brown et al., 2002). In 1755, R. rosea was included in the Pharmacopoea of Sweden (first edition), although the species was known and used previously, the vikings used it to increase physical strength and resistance. In his 1755 paper named „Flora Svecia”, Linné (cited by Kylin, 2010) displayed that R. rosea emits a very pleasant scent, and it is recommended to cure headaches. The pharmaceutical importance of this species lead to its thorough study in many countries (other than Russia and Scandinavia).
Systematics, spreading and botanical description

The *Rhodiola* genus originates in the mountain areas of South-Eastern China and Himalaya (Darbinyan et al., 2000). It grows in the alpine rocky abyss tundra regions. The species of the *Rhodiola* genus display a natural circumpolar spread. In the Middle and Northern Asia this genus ranges from the Altai mountains over Mongolia, Kazakhstan, Uzbekistan, and in many regions of Siberia; in Europe it was encountered in Iceland and British Islands, Scandinavia, Pyrenees, Alps, Carpathians, and other peaks from the Balkan area. The Table 1 displays the geographical range of the *Rhodiola* species.

Table 1. The geographical spreading of the species included in the *Rhodiola* genus
(http://rhodiolarosea.org/rhodiola-rosea-taxonomy-rhodiola-geographical-distribution)

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*R. rosea* may be found in the mountain areas of 28 European countries. Some species range in North America, Alaska, Canada, in the Northern mountains from USA, as well (Brown et al., 2002; Galambosi, 2005; Kylin, 2010; Rohloff, 2002). In Norway, *R. rosea* ranges from coast regions (sea level) up to 2,280 m in the mountains (Alm, 2004; Galambosi, 2005), whereas in other areas it ranges in the mountains from 1,000 to 5,000 m in altitude (Rohloff, 2002). In Romania, *R. rosea* may be found in the sub-alpine and alpine areas of the Călimani, Rodnei, Ceahlău, Rarău, Bucegi, Făgăraș Mountains, in Maramureș etc. (Răvăruț, 1956)

The taxonomic status of the *Rhodiola* genus had an intricate path. Before the second World War, the taxonomists gathered some *Rhodiola* species in an independent group, separated from the *Sedum* genus, that they included in the subfamily *Sedoideae*. The *Rhodiola* group was subsequently classified as a subgenus of the *Sedum* genus and
comprised about 10 species; in 1963 Hegi, based on some morphological characteristics, considered this genus a stable one, with more than 50 species. There are still contradictory opinions regarding the taxonomical inclusion in the Rhodiola genus for several new species, although the separation main criteria remain controversial (Brown et al., 2002). The species within the Sedum genus have hermaphrodite flowers, whereas many species of the Rhodiola genus, including R. rosea, are dioic (Lippert, cited by Alm, 2004).

The systematic classification of the Rhodiola rosea L. species is (according to: www.gwannon.com/species/Rhodiola-rosea):

**Regnum:** Plantae  
**Phylum:** Magnoliophyta  
**Class:** Magnoliopsida  
**Order:** Rosales  
**Family:** Crassulaceae  
**Genus:** Rhodiola  
**Species:** Rhodiola rosea  
**Subspecies:** R. rosea, ssp. atropurpurea  
R. rosea, ssp. borealis  
R. rosea, ssp. elongata  
R. rosea, ssp. integrifolia  
R. rosea, ssp. krivochizhinii  
R. rosea, ssp. neomexicana  
R. rosea, ssp. polygama  
R. rosea, ssp. roanensis  
R. rosea, ssp. sachalinensis  
R. rosea, ssp. tachiri  
**Varieties:** R. rosea, var. alaskana  
R. rosea, var. alpina  
R. rosea, var. integrifolia  
R. rosea, var. scopolii  
R. rosea, var. subalpina  
**Forms:** R. rosea, form purpurascens

*R. rosea* has a circumpolar mountaneous/alpine spreading, and is a hemycryptophyte with thick rizomes. In 1958 Hultén (cited by Alm, 2004) considered *R. rosea* as: „A collective species comprising many races that differ from each other by size, shape, crenate leaves and flower colour”. There are certain opinions according to which the species *R. rosea* may comprise two subspecies: *R. rosea* ssp. *rosea* (L.) – the common roseroot, and *R. rosea* ssp. *arctica* (Boriss.) A. and D. Löve – the arctic roseroot (Galambosi, 2005). In Norway, for instance, the *R. rosea* plants from the lower regions belong to the *rosea* subspecies, and the ones from the high mountains to the *arctica* subspecies (Alm, 2004). Despite its succulent, fleshy appearance, the species is in a constant need for water supply.

According to Răvăruț (1956) *Rhodiola rosea* L. belongs to the Crassulaceae family, its height ranges from 10 to 30 cm, it has a bushy appearance, a thick fleshy cylindrical rhizome with a persistent rose scent, many buds on the rhizome that develop aerial stems. The stems are erect, simple, densely arranged leaves, that sometimes appear slightly coloured in red at the top. The upper stem leaves are densely arranged, alterne, narrow ovate
or lanceolate, sessile, base cuneate, pointed, rarely obtuse, up to 3 cm in length, dentate on margins, flat, fleshy, hairless. The lower stem leaves are wider, reverse ovate, elongated. The inflorescence is a dense terminal corymbus, flowers unisexual-dioic, 4-merous, rarely 3- or 5-merous. The male flowers bear 4 lanceolate short purple sepals, 4 linear yellowish or reddish petals of 3-4 mm in length, 8 stamina longer than the petals and 2-4 ovaries, usually aborted. The female flowers comprise 4 sepals, 4 petals up to 2 mm in length (frequently absent), 4 ovaries, each bearing a nectariferous flake at the base, ovate-elongated, bilobate to the tip. The fruits are erect follicles of 6 to 12 mm in length, sharp pointed, the seeds brown, up to 1.5 mm in length. *Rhodiola rosea* is a perennial hemi-cryptophyte, saxicolous, mesohygrophyle, chionophile (Sârbu et al., 2013).

The recent papers display an approach on the genetic diversity in *R. rosea* and its preservation (Elameen et al., 2008; György et al., 2013; Kylin et al., 2010; Soni et al., 2010). These type of studies in *R. rosea*, conducted by Elameen et al. (2008) in Norway evinced a wide span of genetic variability for this species. Among the 97 clones analyzed by means of AFLP, the author identified 82.3% polymorphic bands, the degree of genetic similarity ranged between 0.440 and 0.950 – with an average value of 0.631. The genetical analysis acknowledged there is no close similitude between the clones depending on their origin. The analysis of molecular variance (AMOVA) revealed a significantly higher variation inside the regions (92.03%) whereas between the regions (7.97%).

Soni et al. (2010) studied the phylogenetic relations for 30 genotypes of *R. rosea* originating in Ladach district (India), from three valleys (Changla, Khardungla and Khalse), using 10 PCR markers: 5 specific to SSR genes (*simple sequence repeats*) and 5 CAPS (*cleaved amplified polymorphic sequences*). The results pointed out that the 30 genotypes belong to 3 clusters: the Changla genotypes formed a separate cluster, whilst the clusters Khardungla and Khalse overlayed. The analysis of the dendrograms evinced a very low genetic differentiation, that indicated a high level of the gene flow, a fact that significantly influenced the genetic structure of the populations. The authors considered that this high gene flow among the populations of *R. rosea* is a result of seed spread more than of cross pollination.

Using 4 SSR markers and 4 ISSR markers (*inter simple sequence repeats*) in a study of genetic diversity in *R. rosea* collection of the Northern Centre for Genetic Resources in Sweden (the biological material came from Sweden, Greenland, and Faroe Islands), Kylin (2010) observed that 12 polymorphic bands resulted by means of SSR method, and 37 using ISSR. The percentage obtained by polymorphic bands corresponded to the ISSR - 83.78% for the material collected from Sweden, 94.59% for the one in Greenland, and 48.65% for the one originating in Faroe Islands. The author specified he was not able to identify specific population primers.

György et al. (2013) accomplished a similar study to assess the genetic diversity of 10 *R. rosea* habitats from Finnmark region (Norway). Using the 8 SSR markers developed by Zini et al. (2009), the authors established that only four of them (RRC10, RRD6, RRE2 and RRF2) were successful, and the degree of genetic variation in the 10 studied habitats was rather low. The observed heterozygosity was of 1.0 for each locus, and the expected one ranged between 0.60 and 0.65. The obtained results pointed out that the analyzed populations of *R. rosea* present genetic differences among them, that are increased by the distance between them.
The chemical composition of the *Rhodiola rosea* species

In the years 1970s’ it was thought that the pharmacological effects of the *R. rosea* preparates were due to salidroside (rodiolozid); this is the reason for which the first generation of extracts/tinctures were standardized at a minimum of 0.6% amount of salidroside (approved by the Russian Pharmacopoea Committee). The intense use of the *R. rosea* preparates caused a massive exploitation of this species from the spontaneous flora of USSR, that at a certain moment was not able to fulfill the market demand (late 1980s). That was the moment of obvious and inexplicable decline in the quality and efficiency of the preparates based on *R. rosea* (Ramazanov et al., 2004). This observation lead to the analysis of this phenomenon and to the fact that another species, besides *R. rosea*, supplied the high demand of raw material on the sovietic market - *R. crenulata*, that comprises salidroside as well. A mixture of the two species, or the use of *R. crenulata* solely lead to lower effects of the phyto-pharmaceutical products. As it was initially considered that the salidroside is responsible for the positive effects of the preparates containing the arctic root (at first regarded as a kind of ”marker” for the preparates of golden root), a new hypothesis was issued – that probably *R. rosea* comprise, along with salidroside, other compounds that contribute to the higher pharmacological action of the pharmaceutical preparates made from this plant solely.

Ramazanov pointed out that the research of over a decade performed by Zapesochnaya et al. (1983, 1985), Kurkin et al. (1985, 1986), Dubichev et al. (1991) on the chemical composition of the roots/rhizomes of *R. rosea* proved that it obviously differs from other species of *Rhodiola*. It was noticed that *R. rosea* is the only of all the studied *Rhodiola* species that contain phenyl-propanoids in their roots (cinnamyl - alcohol-glycosides): rosavin, rosin and rosarin (all three named *rosavins*).

The rosavins (Fig. 1) are specific solely to *R. rosea*, whilst the salidroside also characterises other species of the *Rhodiola* genus, other plant species, and some bacteria and yeasts (Ramazanov and Abidoff, 2000). The tyrosol and the salidroside (Fig. 1) were identified in *Salix triandra* as well (the name salidroside derives from this species; this chemical compound was depicted in this species by Bridel and Beguin in 1926), *Vaccinium vitis-idaea* and *Rhododendron* sp. (Thieme et al., 1969; Tieme and Winkler, 1971 – cited by Ramazanov, 2002). Moreover, the amount of salidroside and of tyrosol in some species, such as: *Salix alba, Olea europaea*, is even higher than in *R. rosea*. As a consequence, the basic chemical markers to verify the vegetal product golden root are represented by rosavins, and by the ratio rosavin/salidroside, that has to be about 3:1 (Ramazanov et al., 2004).

The chemical composition of the *R. rosea* rhizomes and roots was studied by many researchers, mainly effected in former USSR and Russia, that evinced some phenolic compounds, such as the salidroside and its aglycon – the tyrosol (Satsyperova et al., 1993), cinnamic glycosides such as: the rosin, the rosavin, and the rosarin (Kurkin et al., 1985; Kurkin and Zapesochnaya, 1986; Satsyperova et al., 1993; Youseff et al., 2006) flavonoids (Kurkin et al., 1982; Zapesochnaya and Kurkin, 1983), tannins (Revina et al., 1976), of the gallic acid and its esters (Dubichev et al., 1991; Satsyperova et al., 1993), of the essential oils (Kurkin et al., 1985) etc. Kelly (2001) stated that 28 chemical compounds were isolated from the roots and the aerial part of *R. rosea*, 12 of which are new compounds.
As it was aimed, the chemical content varies with the region the plant is harvested from, the harvesting moment, the year of vegetation, the analyzed organ etc. Fjelldal et al. (2010) effected a research study on *R. rosea* plants belonging to 10 populations from Finnmark region (Norway) that displayed significant variations of salidroside and of rosavins within the rhizomes and the roots: the amount of salidroside ranged between 0.46% and 2.61%, the amount of rosavins ranged between 0.67% and 2.7%. Several HPLC tests made by Hârțan (2009) on some rhizomes of *R. rosea* from Ceahlău mountain (1,750 m in altitude) revealed that the level of the rosavin and of the tyrosol varied (during 2003-2008) with the year and with the harvesting moment, between 0.2858 – 0.4937 mg/g d.s. rosavin and 0.2752 – 0.5679 mg/g d.s. tyrosol.

Although the most papers on *R. rosea* researched the phytochemistry of the rhizomes and of the roots, Kolodziej and Sugier (2013) investigated the chemistry of the aerial part of the cultured plants using the HPLC method and noticed that by the age of 3 years the plants display a much lower level of phenyl – ethanoids and of phenyl – propanoids, compared to the 4-6 years old plants. The total amount of these substances in roots augmented from 6.55 mg/g (in the roots of the first year of vegetation plants to 13.60 mg/g in the roots of the fourth vegetation year plants); it diminished gradually to 9.02 mg/g in the 7 year plants. In the aerial part of the plants, the amount of the analyzed substances was of about 2.40 mg/g in the first year plants, augmented to 6.12 mg/g in the four year plants, then it gradually decreased up to 2.37 mg/g in the 7 year old plants. As a conclusion, the rhizomes and the roots of the same age display a twice higher level of this compounds compared to the stems and to the leaves. Based on the obtained results, the authors considered that not only the rhizomes and the roots, but also the aerial part (the herba) might be a source of these pharmaceutically important substances.

In a study on the dynamics of the salidroside accumulation in the *R. rosea* plants that grow in the Rhodopi mountains (1,625 m altitude), Bozhilova (2011) observed that the level of this compound varied with the plant sex, the year of vegetation, and the development stage of the foliar system. The different amount of salidroside depending on sex might be caused by a various growth level, as the male plants stop growing after flowering, whilst the female plants continue their growth until the end of the vegetation season. It was ascertained as well that the amount of salidroside differs in the rhizomes compared to the roots, and also differs with the two sexes.

There were effectuated several phytochemical investigations on the callus in some species of *Rhodiola*. Therefore, Grysczynska et al. (2012) used ultraperformant liquid chromatography (UPLC), combined with mass spectroscopy (the UPLC-MS/MS method), to analyze the content of proanthocyanidins in the genetically modified callus and roots of *R. rosea* and *R. kirilowii*. These substances, that are flavan-3-ols, are antioxidant. The test results displayed that the *in vitro* calli of *R. rosea* may be a good source of catechins, mainly of epigallocatechin-galate.

Tolonen et al. (2003) depicted other 4 new phenylpropanoids within the methanol/water extracts of *R. rosea*: cinnamyl-(6'-O-β-xylopiranosil)-O-β-glucopiranozid; 4-metoxycinnamyl-(6'-O-α-aranopyranosil)-O-β-glucopiranozid; picein and benzyl-O-β-glucopyranosid. In another paper (from 2004), the authors studied the property of the *R. rosea* compact callus to transform cinnamal-alcohol into cinnamal-glycoside, noticing that there were provided large amounts of rosine, whilst the rosavin was produced in very small
amounts. By means of HPLC and MS there were identified 4 new biotransformation compounds in the callus.

There are scientific contributions that approached the chemical investigations both on *R. rosea* and other species of the *Rhodiola* genus, aiming to identify the species based on the plants’ chemical composition. Such a study on seed proteins soluble in alcohol was accomplished by means of HPLC (reversed-phase) by Wang et al. (2005) on 10 species (*R. coccinea, R. jungarica, R. heterodonta, R. linearifolia, R. pamiro-alacium, R. kaschgarica, R. litwinowii, R. gelida, R. rosea* and *R. quadrifida*), a study that evinced the fact that the species can be grouped into 4 clusters and the analyses provided general and unique biochemical markers for each species. The method RP-HPLC proved to be a rapid, repeatable and safe in the identification of *Rhodiola* species, and also to analyze their genetic diversity.

A comparative phytochemical study (Yousef et al., 2006) including 3 species of *Rhodiola* (*R. rosea, R. heterodonta, and R. semenovii*) lead to the isolation of two major groups of secondary metabolites: phenols and/or cyanogenic glycosides and proanthocyanidins; there were noticed both similarities and differences among the 3 species. Although the analyzed species comprise proanthocyanidins made of (−)-epigallocatechine and their esthers 3-O-gallate, the degree of polymerization was obviously different; compared to the other two species, *R. rosea* contained higher molecular weight polymeric proanthocyanidins.

Wiedenfeld et al. (2007) tested, by means of column chromatography, several extracts of *R. rosea* and *R. quadrifida*, and isolated more compounds, among which: the cinnamyl alcohol, the chlorogenic acid, the rodiooctanzid, the rosiridin, the rosavin, the salidroside, the rodiolin and the viridozid with an attached unit of arabinose (the mongrosid – a new compound). The chemical composition of the two *Rhodiola* species is similar, mentioning that *R. quadrifida* does not comprise cinnamyl alcohol and rosiridin. At the same time, the authors discovered (by means of HPLC analysis) that there is a wide range in the content and composition for the pharmacologically active compounds inside the biological material of various origins and depending on the harvesting moment, as well.

Rohloff (2002) analyzed the terpenes and volatile scents within the rhizomes of *R. rosea* from Norway and observed that the dry rhizomes comprised 0.05% ethereal oils made of: monoterpenes hydrocarbon (25.40%), monoterpenes alcohol (23.61%), and straight - chain aliphatic alcohols (37.54%). The most frequent compounds of the essential oil were: n-decanol (30.38%), geraniol (12.49%), and 1.4-p-metadien-7-ol (5.10%); the total number of compounds was 86. The geraniol was depicted as the most important rose - type compound. The floral traces of the rhizome scent come from the linalool and its oxides (nonanal, decanal and cinnamyl alcohol).

The chemical composition analysis of the essential oil from the *R. rosea* rhizomes (originating in Bulgaria, China and India) was studied by Evstatieva et al. (2010), stating that the main compound in the samples from Bulgaria and China was the geraniol, followed by myrtenol in the Bulgaria sample and octanol in the China sample. The main compound in the volatile oil from the India sample was phenethyl – alcohol, followed by myrtenol and octanol. The cinnamyl alcohol, depicted in a low concentration within the sample from Bulgaria, was not detected in the other analyzed samples.
The tyrosine-decarboxylase is a key enzyme in some species’ secondary metabolism. György et al. (2009) proved that it is a decisive enzyme in the salidroside biosynthesis within *R. rosea*.

Brown et al. (2002), the authors of a review on golden root, including the chemical composition of the plant, displayed that the specific secondary metabolites are included into 6 groups:

- **Phenylpropanoids**: rosavin, rosin and rosarin;
- **Phenyl-ethanolic derivatives**: salidroside (rodiolozid), tyrosol;
- **Flavonoids**: rodiolin, rodionin, rodiosin, acetilrodalgin, tricin;
- **Monoterpenes**: rosiridol, rosaridin;
- **Triterpenes**: daucosterol, beta-sitosterol;
- **Phenolic acids**: chlorogenic acid, hydroxy cynamnic acid, gallic acid.

Panossian et al. (2010) acknowledged that a number of about 140 compounds were isolated from the rhizomes and the roots of *R. rosea*, among which there were: monoterpenes, alcohols and their glycosides, cyanogenic glycosides, aryl-glycosides, phenylethanoids, phenylpropanoids and their glycosides, flavonoids, flavonlignans, proanthocyanidins, and gallic acid derivatives.

It is considered that the phenyl-propanoids and the phenyl – ethanolic derivatives are responsible for the positive antistress – adaptogene effects (Dragland, 2001 – cited by Kylin, 2010) (see Fig. 1). As it was previously mentioned, the specific chemical compounds in *R. rosea* are the phenyl - propanoids (the rosavins), that serve as chemical markers for the raw material to produce basic preparates of *R. rosea*, substances that are absent within the other species of Rhodiola (Kylin, 2010). The major compounds in golden root (from the pharmaceutical viewpoint) are at present the salidroside and the phenyl – propanoids: the rosavin, the rosin, the rosarin, as well as the rosaridin (the latest compound appears to be specific only to *R. rosea*, as the rosavins are). It was ascertained that the *R. rosea* extracts are superior due to their unique compounds, which proves that not only the above-mentioned glycosides are responsible with the pharmacological effects of this species, even though they serve as a marker in the diagnosis of the biological material (Wiedenfeld, 2007).

Recent scientific contributions aimed to detect the ability of the golden root to synthesize some specific compounds by means of *in vitro* cultures. Therefore, Kurkin et al., (cited by György, 2006) isolated 13 compounds from the *R. rosea* callus provided *in vitro*, among which the most important was the triandrin; the salidroside and the cinnamyl-alcohol-glycosides were absent. Nevertheless, Furmanova et al. (cited by György, 2006) analyzed the roseroot callus and traced the mentioned glycosides, as well as the triandrin and the caffeic acid. Specificity appears to be decisive in this case as well, because a keen species, *Rhodiola sachalinensis*, displayed a 3 to 6 times higher amount of salidroside (Xu et al.; Jianfeng et al., cited by György, 2006).

The research of Krajewska-Patan et al. (cited by Tasheva and Kosturkova, 2012) that spaned between 2002-2008 ascertained that the golden root callus cultures both on solid and liquid medium provide specific chemical compounds. By adding some yeast extracts within the culture medium, the synthesized amount of salidroside doubled. The callus generated by the axillary buds and the hypocotyls transformed the cinnamic alcohol – a precursor of the phenyl – propanoids (introduced in the nutritive medium) into rosin and rosavin.
In her doctoral thesis, György (2006) aimed the glycoside production in compact leaf callus clusters of *R. rosea* by glycosilation of the outer source aglycons. Cinnamyl – alcohol was added in the culture medium to provide cinnamyl – alcohol glycosides, and tyrosol was added to trigger the production of salidroside. The level of salidroside and of rosin was significantly higher than in the spontaneous flora plants. At the same time there were evinced 4 new cinnamyl – alcohol glycosides. By adding glucose within the culture medium, cinnamyl – alcohol glycosilation rate doubled, rosavin being provided as well. The researcher invented a culture system in a 2 litres air-lift reactor, in which there were placed compact callus cultures to obtain glycosides in two phases: during the first phase, the callus clusters were cultured until the highest biomass was provided, then the precursor was added, in order to be converted. The tests evinced the major role of tyrosin – decarboxylase in the synthesis of salidroside.

**The use of *Rhodiola rosea* in the traditional medicine**

*Rhodiola* species are well-known and used by the traditional Tibetan medicine for over 1000 years (Kylin, 2010). Linné stated (in his works from 1748 and 1749) that *R. rosea* is used as an astringent and also to cure hernia, leucorrhrea, hysteria and headaches. According to the data provided by some authors (Alm, 2004; Brown et al., 2002; Galambosi, 2005; Kylin, 2010; Panossian et al., 2010; Ramazanov and Abidoff, 2000), the plant is known and used in the various regions of its spreading area, to improve physical endurance, work productivity, longevity, resistance improve physical endurance, work productivity, longevity, resistance to altitude sickness, to remove fatigue, treat depression, anemia, impotence, infections, gastro-intestinal and nervous system disorders etc. There is a kind of legend in Siberia that says: “the people that drink *Rhodiola* tea will live more than 100 years” (Ramazanov and Abidoff, 2000).

It is considered as a symbol of fertility in some mountain villages from Siberia. Even nowadays a cluster of *R. rosea* roots is offered to the couples that get married, to improve fertility and giving birth to healthy children (Saratikov, 1987 - cited by Brown et al., 2002). The benefits of this plant in the treatment of pain (including headaches), scurvy, hemorrhoids, as a stimulant and anti-inflammatory were described in Germany. In Middle Asia, the tea of *R. rosea* is the most efficient remedy to fight cold and influenza during very harsh winters characteristic to this region. In Mongolia it is recommended in the fight against cancer and tuberculosis (Khaidaiev and Menshikova, 1978 - cited by Brown et al., 2002).

Both the rhizomes and the herba are edible, therefore it was introduced into people’s nutrition, as it is the case of the Inuits in Greenland, the eskimos people in North America and the natives of Alaska. It appears that *R. rosea* is one of the 20 most frequently used plants in Alaska and Siberia. Alm (2004), quoting from Pontoppidan (1752) and Gunnerus (1766), related that the roots were a remedy against scurvy in Norway. The same author reported that, along the Western Coast of Norway, the *R. rosea* decoction was used to wash the human hair in a certain period of time (in the folk tradition, it stops hair fall), to stimulate hair growth, or in the treatment of various hair problems (such as dandruff). The same decoction was given to horned animals to treat some specific diseases and also intestinal parasites. In a certain age, in Norway, *R. rosea* was cultivated on roofs in order to
protect the house from fire, a system rarely used nowadays, and the cultivated plant is the turf.

*Rhodiola rosea* L. in the modern medicine

Since 1965 there are being studied the pharmacological effects of *R. rosea* by the Russian researchers; preparates of golden root are prescribed for athletes and cosmonauts (Hedman, cited by Kylin, 2010), as it is considered an adaptogene, due to its chemical compounds’ property to improve the resistance to several chemical, physiological, and biological stress factors (Soni et al., 2010). In 1975 it became a part of the official medicine from the former USSR – a tincture, this preparate was registered with the number 75/933/14, and named “liquid extract of *Rhodiola rosea*” (Ramazanov and Abidoff, 2000).

Ramazanov (2002) considered that *R. rosea* is the most studied of all the species included in this genus regarding its clinical, pharmacological and toxicological effects in humans and in animals. The chemical compounds of this species display many positive effects: adaptogene, antistress, antioxidant, antidepressive, anti-fatigue, enhance the brain’s bioelectric activity, improve memory and augment brain energy, speed the recovery after hard work, stimulate the synthesis of ATP within the muscles, the synthesis of glycogen in the muscles and liver, cardioprotective, stimulate CNS (including the cognitive processes – attention, memory, learning), stabilize the endocrine functions, facilitate lifespan growth etc (Brown et al., 2002; Hall, 2011; Panossian et al., 2010; Ramazanov et al., 2004; Saratikov et al., 1967). The *R. rosea* SHR-5 extract (a standard product traded in Sweden) displayed (by repeated intakes) several positive effects, such as: anti-fatigue, improvement of mental performance, mainly the concentration capacity (Olsson et al., 2009). The stress adaptation of the organisms treated with golden root is based on the augmented level of some brain neurotransmitters such as: serotonin, dopamine, etc; Saratikov and Marina (cited by Ramazanov and Abidoff, 2000) evinced that *R. rosea* enhanced their level by 30% and at the same time reduced the activity of catechol-O-methyltransferase (enzyme involved in the degradation of serotonin and dopamine) by 60%.

Overviewing the data of the scientific literature on this topic, Ramazanov (2002) showed that the tests on humans and on animals, and those on human and animal cell cultures evinced that the active principles from *R. rosea* determine complex effects in the organism: they reduce or prevent the cardiac lesions induced by stress, prevent arrhythmia, ameliorate the erectile dysfunctions in men, regulate the prostatic fluid and increase the level of 17-cetosteroids in urine (Gerasimova, 1970), activate the lipolytic processes (Dambueva, 1968; Salnik, 1970), reduce the toxicity level caused by anticancer drugs to liver, at the same time displaying anti-tumoral and anti-mutagene effects (they decrease the number of chromosomal aberrations and enhance DNA repair in the bone marrow cells after mutagene exposure (Salikova, 1997), stimulate the thyroid and the thymus function, increase adrenal glands reserves without causing their hypertrophy (Saratikov and Krasnov, 1987), decrease the peroxydation of the lipids, protect the small intestine mucus layer of the animals submitted to X-ray acute radiation (Bolshakova et al., 1997; Yakubovskyi et al., 1997). The tests ran by Darbinyan et al. (2007) on patients suffering from depression (aged 18 to 70 years old) proved that the standard extract SHR-5 from *R. rosea*, prescribed in doses of 340 mg or of 680 mg/day – for more than 6 weeks, is an antidepressive for the patients suffering from mild to moderate depression. The tests made on rats evinced that the
golden root extracts display an anxiolytic action; its efficiency depended on the administered dose and also on the anxiety test (Cayer et al., 2013).

Regarding the tests ran by Hillhouse et al. (2004), the alcoholic extract of golden root (10g/l) caused an inhibition of 42 ± 3.2% of acetylcholinesterase (AChE), which lead to a physiological explanation of the *R. rosea* extracts for the stimulation of mental capacity and of the memory, as well. Two flavonoid-glycosides were isolated from the extract (*gossypetin-7-O-L-rhamnopyranosid* and *rhodioflavonosid*) that, at a dose of 5g/l, inhibited AChE by 58 ± 15% and 38 ± 4.0%, respectively. The results made the authors to suggest this plant’s ability to cure the disorders in Alzheimer disease.

Research effected on rats displayed that the extracts from *R. rosea* exerted a hepatoprotector effect in the experimental toxic hepatitis, expressed by: the regulation in the activity of aspartate aminotransferase and alkaline phosphatase, of the average molecular mass peptides’ level, of the urea and the bilirubin, a low activity of alanin-aminotransferase and glutathione-S-transferase in rat plasma (Iaremyi and Grigorieva, 2002).

Other studies ascertained that the *R. rosea* rhizome extracts inhibit the division of HL-60 cells, preceded by the gathering of prophase cells, a fact that lead to apoptosis and necrosis of HL-60 cells and the obvious decrease of their survival rate (Majewska et al., 2006). The authors consider that the cytostatic and antiproliferative effect of golden root extracts has great perspective in their antitumoral use, as they increase the efficiency of cytostatics.

The antimutagen effect of the *R. rosea* extracts was observed during the *in vitro* tests on the mouse bone marrow cells; it was ascertained that they significantly decrease the number of cells with chromosomal aberrations and of micronuclei in the cells treated with cyclophosphamid and N-nitroso-N-methylurea (Salikhova et al., 1997). The research of De Sanctis et al. (2004) and of Batistelli et al. (2005) on human erythrocytes submitted to oxydative stress with hypochloric acid proved that the *R. rosea* roots aqueous extract prevented or removed some of the alterations induced by the oxidizing agent; this effect was thought to be caused by the tannin content more than the cinnamyl-glycoside content. The methanolic extracts of the underground organs in golden root displayed an inhibitory effect on *Staphylococcus aureus* (Ming et al., 2005).

In Sweden, *R. rosea* was acknowledges as a medicinal herbal product in 1985, and it was described as an antifatigue agent in the „Phytomedicine Manual for Pharmacists”. In another Swedish work, „The Pharmaceutical Book”, it is mentioned that *R. rosea* is characterized by the best stimulating effects of all the herbal medicinal products (Sandberg and Bohlin, cited by Brown et al., 2002). Several *R. rosea* preparates are widely used in Sweden and other countries from Scandinavia to improve the mental ability in stress, as psychostimulants and general tonic (Brown et al., 2002). Nevertheless, the *Rhodiola* tablets were marketed in this country since 1985; the tablets comprise an SHR-5 standard root extract.

The beneficial effects of the *R. rosea* phytopreparates were compared to the pharmacological action of some preparates made from other species, with similar properties, such as: *Eleutherococcus* sp., *Panax ginseng*, *Ginkgo biloba* etc. The adaptogene effects of the *R. rosea* compounds are explained by their influence on the synthesis, transport, and receptor activity of the monoamines and opioids. The best medicinal recommendation for *R. rosea* is its use in case of asthenia caused by overdosed
acute and chronic effort, leading to work performance decline, sleep disorders, low appetite, nervosity, hypertension, headaches and fatigue (Kelly, 2001).

A complex extract of \emph{R. rosea}, as Ramazanov et al. stated in 2004, must comprise all the marker compounds and/or the active compounds (the rosavins and the salidroside) in a 3:1 report, that is characteristic to the plant’s root in its native habitat; the Russian Pharmacopoeia Committee considered this report the standard one. The standardization of \emph{R. rosea} compounds based on many studies effected on humans implies a minimum of 3\% rosavins and 0.8-1\% salidroside (Brown et al., 2002). In order to take advantage of the \emph{R. rosea}’s positive effects on health, it is considered that a person should eat Siberian root extract, standardized for a minimum of 3\% rosavins, the optimal report between the active compounds - rosavins/rosaridins/salidroside is 3 : 1 : 1 (Hall, 2011; Ramazanov et al., 2004). The \emph{R. rosea} extracts are safe when applied to humans, with a very low toxicity level: it was acknowledged that the dose LD$_{50}$ is of about 3.36 mg/Kg in animals, the equivalent dose for a human person (weighing 70 Kg) was of about 235 mg. Usually, the clinically administered doses range between 200 and 600 mg/day, the lethal dose is 391 times higher than the clinical dose. The products based on this species are available as tablets, alcoholic extracts (pure or combined with other plant extracts) etc. (Galambosi, 2006).

Regarding the golden root’s perspective medicinal use, Ramazanov et al. (2004) stated the following: "We are certain that the 40 years of scientific research strongly support the fact that the \emph{Rhodiola rosea} extract, standardized for rosavins, is a medicinal phyto-product of unique importance to the global health of the 21th century".

The intense exploitation of natural habitats with \emph{R. rosea} endangers the species in certain areas

There is a growing interest in this species’ exploitation. The demand for raw - material of \emph{R. rosea} is constantly higher, and the market for this species is about to become as big as in the case of \emph{Ginkgo biloba} and \emph{Panax ginseng} (Kylin, 2010). The largest population of \emph{R. rosea} is situated in the Altai, South Siberia (Galambosi, 2006). The raw – material for the various products made of this species comes from the native populations, a fact that lead to the species’ decline in certain areas of the world. Therefore, Lei et al. (cited by Kylin, 2010) showed that the more intense reckless use of some \emph{Rhodiola} species in the South-West of China, during the 1980s, caused the extinction of the native habitats, a fact that imposed their entrance on the red list in the entire China. There is a similar case in Russia with the golden root, which limited the harvesting of this species (Galambosi, 2006). Regarding Europe, the species is endangered in Bulgaria (Platikanov and Evstatieva, 2010), in the Czech Republic and Bosnia and Herzegovina, and it is considered endangered in Slovenia (Lange, cited by Galambosi, 2005). Fortunately this threat is not present in Romania until now, because the therapeutical properties of this species are less known by the manufacturers of phyto-pharmaceutical products, therefore the native habitats of \emph{Rhodiola rosea} are still in good shape.
The introduction into conventional and in vitro cultures of *Rhodiola rosea* L. species

The higher demand for the rhizomes and roots of *R. rosea* in industry, on the one hand, and the exhaustion of the native habitats, on the other hand, imposed a series of research regarding its reaction in conventional and in vitro cultures. According to Galambosi (2005) informations, the experiences of plot growth were started at the end of the last century and the beginning of our century in some regions of Russia (Elsakov and Gorelova, 1999), in Sweden, in Poland (Furmanova et al., 1999), in Germany (Schittko, 2005), in Finland (Dragland and Galambosi, 1996), in Canada (Ampong-Nyarko, 2004, 2005), and in Bulgaria (Platikanov and Evstatieva, 2008).

In a paper published in 2005, Galambosi presented the main aspects of the cultivation technology for *R. rosea* in Finland’s environmental conditions. The author pointed out that due to the slow growth, the culture requires up to 5 years until harvesting. The seedlings should be grown in soil pots for one or two vegetative seasons, followed by the field cultivation for other 3 or 4 vegetative seasons. The soil should be profound, deprived of boulders, at shelter from dead- water, and without weeds. The seeds require natural layers (under the snow during winter) or must be kept in a cold room (2-4° C) in moist sand for two months. There are used some mature seeds, harvested during the months of July and August.

The sowing can be manual or mechanical (in which case a mixture of sand and layered seeds of 20:1 is recommended). The seedlings may be kept inside into soil pots, and afterwards (depending on the growth rate) planted in field. The seedlings aged 1 to 2 years may be planted in field in raws during spring or autumn (in September). The density of plants on the plot is of 6-8 plants/m$^2$, and the distance between the raws is established depending on the mechanical control system for weeds. Another procedure is plant mulching with plastic black foil, of 0.9 m in width.

It is recommended that the weeds surrounding the plants should be manually removed during the first two years of culture. In between the raws they may be mechanically removed. As pests are concerned, there were not encountered problems until present. Starting with the 4th year in culture, and depending on the development of the rhizomes and roots, the roots can be harvested (manually or mechanically) in view of capitalization, during autumn or early spring. The shoots are removed, and the rhizomes and roots are washed and sliced for a more rapid drying. The crop of fresh roots in the 4-year old plants ranged between 1.8 and 2.8 Kg/m$^2$, and that of dry roots between 0.4 and 0.6 Kg/m$^2$ (Galambosi, 2005). It is estimated that in the end the task is not easy, the costs are high, because the cultures are started from seedlings, the timespan from cultivation until harvesting is of about 4 to 5 years, and the root harvesting and processing requires a hard work.

This type of data are stated by Platikanov and Evstatieva (2008) as well for the golden root grown in Bulgaria. In this case, the cultivation experiences took 5 successive years (2000-2005) in a greenhouse of the Botanical Institute in Sofia (situated at 670 m altitude) and in the „Beglica” experimental garden from the Rhodopi mountains (that lies at 1525 m altitude). The plant was propagated either by rhizome splitting or by seeds. The clonal breeding was effected by sectioning the male and female rhizomes into cuttings with 1-3 buds (0.5 - 4 cm in length; 1-5 grams of biomass). The splitting of rhizomes took place either at the beginning of the vegetative season (in May), or during autumn (in October)
before frosting. The cuttings were planted into soil on raws, at a 50-60 cm inbetween the raws, and 40 cm between the plants of a raw. The authors took into account the fact that the species prefers the sandy soil, well drained, with a sufficient amount of mold. The weeds were removed periodically, the plants were watered 2-3 times during the vegetative season. In case of starting the field cultures using seeds, the researchers either sowed them directly into soil, or they maintained them into a mixture of moist sand in controlled conditions (inside a container) at 2-5°C, for 30 days, or they were kept under snow for 2 months.

The tests were successful, therefore the authors recommend the breeding of this species on the hill-like regions of the Rhodopi mountains (up to 1,400 m altitude). The breeding by rhizome fragments appears to be successful, the cuttings’ survival rate was of 90-95%, and the time from breeding until harvesting in view of capitalization was of 3 years. The plants are in bloom during the consecutive year after planting. If the conventional cultures are started from seeds, the culture duration is one year longer, and the seedlings’ survival rate is low (about 10%). Regarding the amount of rosavins and of salidroside, the authors mention that the male plants of *R. rosea* are more valuable from the medicinal viewpoint, compared to the female plants.

In order to solve the issues of cultivation and capitalization of this species, such as: providing the necessary planting material, cloning some valuable genotypes, inducing the genetic variability, *in vitro* providing some chemical compounds specific to this plant etc.; the *in vitro* techniques are a great perspective in this species. There were reported many advances in this field during the last two decades. According to informations of György (2006), Aleksandrova et al. successfully provided roots from callus since 1981 but did not disclose info regarding callus induction and mainatenance, Kirichenko et al. (1993) and Ishmuratova (1998) succeeded to micropropagate this species, and Furmanova (1995) obtained the callus and several *in vitro* plants via callus.

Testing more than 10 variants of nutritive medium to micropropagate *R. rosea*, Dimitrov et al. (2003) observed that the best results were obtained by enriching the culture medium with 2 mg/l zeatin and 0.2 mg/l IAA, a medium variant that stimulated the growth of regenerants for 76.67% of the explants. These results were later confirmed by Tasheva and Kosturkova (2010), that pointed out the bet caulogenesis took place on a medium variant enriched with 2 mg l⁻¹ zeatin, and the enroting of the shoots was stimulated on half-strength Murashige-Skoog and by adding 2 mg l⁻¹ IBA and 0.2 mg l⁻¹ IAA. The *in vitro* regenerants’ transfer to their native habitats allowed a survival rate of about 70%. The best results for callus induction were registered from leaf explants harvested from the *in vitro* shoots grown on MS enriched either with 1 mg l⁻¹ BAP, or with 0.5 mg l⁻¹ 2.4-D, comprising 150 mg l⁻¹ glutamine and 1g l⁻¹ casein hydrolysate (Tasheva, 2011).

Tasheva and Kosturkova (2012) presented an *in vitro* micropropagation protocol for *R. rosea*, in which the explant source was represented by the plantlets grown from aseptically germinated seeds, inoculated on the MS medium supplemented with 5-100 mg/l; the shoots are micropropagated using nodes with leaves on the MS medium enriched either with 2 mg/l zeatin, 0.2 mg l⁻¹ IAA, or with 1 mg l⁻¹ BA and 0.1 mg l⁻¹ IAA; shoots are enrooted on MS supplemented either with 0.2 mg l⁻¹ IAA + 2 mg l⁻¹ IBA + 0.4 mg l⁻¹ GA₃, or with 0.2 mg l⁻¹ IAA + 2 mg l⁻¹ IBA + 0.1 mg l⁻¹ GA₃; the authors recommend for the *in vivo* acclimatisation the use of perlite, peat moss and soil in a 1:1:3 mix. The cytological observations effected on the regenerants’ root meristematic cells displayed that their
chromosome number was similar to the one identified in the plants from the spontaneous flora: 2n = 22 (Tasheva and Kosturkova, 2011).

In view of micropropagating this species, Debnath (2009) invented a bioreactor system, that comprised liquid medium, mixed with gelified medium. The *in vitro* culture was initiated using aseptically germinated seeds placed on ½ MS. By supplementing the culture medium with 2-4 μm TDZ shoot proliferation was induced, although their elongation did not occur. The bioreactor system caused the shoots’ vitrosis. The shoots affected by hyperhydria were transferred on solid medium, enriched with 1-2 μm zeatin, for their water rebalancing and were enrooted on the nutritive medium deprived of growth regulators.

The scientific papers previously mentioned described that the seeds of *R. rosea* germinated aseptically were used to initiate the *in vitro* cultures and for the micropropagation of this species. This method represents a proper way to provide the planting material necessary for breeding. Only top-quality biological material will be micropropagated and further cultivated in field. Therefore, the *in vitro* regenerants should be the clones of such individuals, either identified in the spontaneous flora, or of the cultivated plants. During our research on *Rhodiola rosea* L., we took into account this major aspect and we initiated the *in vitro* culture with plants harvested from the Ceahlău mountain (of an altitude of about 1,750 m) (Fig. 2).

Several individuals of golden root were cultivated in Piatra Neamț where they were transferred into soil pots (the soil came from the species’ native habitat). Our attempts to initiate the *in vitro* culture using shoot tips, uninodal stem fragments, rhizome buds (harvested in early spring or in autumn at the end of the vegetative season) took 2 years, though the tests failed, as the microbial load on the explants was big, and the plant was highly sensitive to explant disinfestation. To overcome this situation, a pot with *R. rosea* shoots was kept under special environmental conditions, in a closed room, with a temperature under 10°C (for about 6 weeks) – in order to diminish the plants’ microbial load, intended to allow the use of lower concentration disinfection agents and reduced time of explant rinsing. The experiments were successful; the *in vitro* regenerants were the explant source to test the morphogenetic reaction depending on the explant type, the breeding conditions, the content of the nutritive medium, the identification of some efficient hormonal variants for clonal multiplication.

Our research (Ghiorghiță et al., 2008, 2011a, 2011b) ascertained that the main reaction of the shoot tips and stem uninodal fragments inoculated on different hormonal variants of the MS medium was the caulogenesis and the growth of neoplantlets; the formation of callus was a less intense process. The regenerants’ growth from this type of explants was not inhibited on the medium variants in which MS was only enriched in auxins (IAA, NAA, IBA, or 2.4-D). The caulogenesis was better expressed starting the culture from internode parts placed on the MS medium supplemented either with 2.4-D (2 mg l⁻¹), or with BAP (1mg/l) + 2.4-D (0.5 mg l⁻¹); these medium variants provided callus (compact, of different colours) from leaf fragments and roots, a callus that was slowly proliferative compared to the stem callus. The auxins added to the culture medium stimulated the rhyzogenesis, regardless of the type of explant, even if root fragments were used. The growth of shoots and neoplantlets from callus was a rare process, regardless of the callus’ origin (Ghiorghiță et al., 2011a).
During an incipient experimental phase, we noticed that the most efficient hormonal variants for micropropagation starting from shoot tips and stem uninodal fragments were, as it follows: N (2.0 mg/l NAA), free hormone MS, KN (1 mg l⁻¹ Kin + 0.5 mg l⁻¹ NAA), AZ (0.2 mg l⁻¹ IAA + 2 mg l⁻¹ Zt) (Ghiorghiță et al. 2008, 2011a). Later on, after the analysis of several morpho-physiological indices of the regenerants (mainly the average number of shoots/explant and the average number of nodes/shoot), we observed that the medium variants KD (1 mg l⁻¹ Kin + 0.5 mg l⁻¹ 2.4-D), BA (1 mg l⁻¹ BAP + 0.5 mg l⁻¹ IAA), and BB (1 mg l⁻¹ BAP + 0.5 mg l⁻¹ IBA) assure a very good turnover for the *in vitro* micropropagation of golden root (Ghiorghiță et al., 2011b).

The *in vitro* regenerants were acclimatised to the septic environment took place in a hydroponic system for approximately 10 days; their survival rate was of about 90%. In 2007, the *in vitro* regenerants (over 70 individuals) completely acclimatised to the septic environment were first transfered into small soil pots (Fig. 3) and subsequently grown in their native habitat (Ceahlău mountain) during spring (Fig. 4). One year after their transplantation (during the summer of 2008) their survival rate was of 73.5%, noticing that it was diminished to 57% in 2009.

The histo-anatomical tests effectuated on golden root plants harvested from their native habitat (Ceahlău mountain) and on the *in vitro* regenerants (Maftei, 2012) ascertained that there are mainly quantitative differences in the anatomical structure of the vegetative organs belonging to the two categories of plants. Nevertheless, the plants harvested from the spontaneous flora display a more developed vascular system compared to the *in vitro* regenerants; regarding the foliar system, the individuals grown in the spontaneous flora have fleshy, sessile leaves, densely arranged on the stem, oblong-ovate, pointed, whilst the *in vitro* regenerants are endowed with small petiolated round-lamina leaves. Regarding the fresh biomass of the *in vitro* regenerants, the highest individual values were registered on the following variants of the MS medium: N (2 mg l⁻¹ NAA) and AZ (0.5 mg l⁻¹ IAA + 1 mg l⁻¹ Zt) (Ghiorghiță et al., 2011b; Maftei, 2012).

Our research was also focussed on the *in vitro* reaction of two other species related to the golden root, meaning *Sedum hybridum* and *S. fabaria* (Ghiorghiță et al., 2003, 2007), and it was obviously a comparative research. The *in vitro* morphogenetic reaction of the explants and also the shoots and neoplantlets’ appearance for the three investigated species, provided on the tested hormonal medium variants (that were identical) was very similar, considered another argument for their kinship. A very interesting fact was that in *S. fabaria* and in *R. rosea* we succeded to sporadically provide neoplantlets by means of indirect organogenesis, via calus, starting from some root fragments inoculated either on the MS medium enriched with 2.4-D (2 mg l⁻¹), or on BD variant (1 mg l⁻¹ + 0.5 mg l⁻¹ 2.4-D), fact that be another argument to enhance their kinship. There were evinced several differences concerning the *in vitro* reaction of these three species. Unlike *S. hybridum* and *S. fabaria*, the *in vitro* growth processes of *R. rosea* (at a temperature of 20⁰C) are much slower, a fact that allows a very long period of time inbetween the subcultivations (even more than 240 days), without any deterioration of the biological material, that is a major advantage for the micropropagation, and to a longer preservation of the biological material than usual; as a consequence, there are lower costs implied to transit the unfavourable vegetative season.
REFERENCES


Figure 1. The molecular structure of some active compounds from *Rhodiola rosea* L. (Brown et al., 2002)
Figure 2. *Rhodiola rosea* L. individuals (the source of explants for the *in vitro* culture initiation) in their native habitat (Ceahlău mountain)

Figure 3. Several *in vitro* regenerants of *Rhodiola rosea* (acclimatised in a hydroponic system), grown into soil pots

Figure 4. The *in vitro* regenerants of *Rhodiola rosea* transferred in their native habitat (Ceahlău mountain)