The chemotaxonomic classification of *Rhodiola* plants and its correlation with morphological characteristics and genetic taxonomy

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**Abstract**

**Background:** *Rhodiola* plants are used as a natural remedy in the western world and as a traditional herbal medicine in China, and are valued for their ability to enhance human resistance to stress or fatigue and to promote longevity. Due to the morphological similarities among different species, the identification of the genus remains somewhat controversial, which may affect their safety and effectiveness in clinical use.

**Results:** In this paper, 47 *Rhodiola* samples of seven species were collected from thirteen local provinces of China. They were identified by their morphological characteristics and genetic and phytochemical taxonomies. Eight bioactive chemotaxonomic markers from four chemical classes (phenylpropanoids, phenylethanol derivatives, flavonoids and phenolic acids) were determined to evaluate and distinguish the chemotaxonomy of *Rhodiola* samples using an HPLC-DAD/UV method. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) were applied to compare the two classification methods between genetic and phytochemical taxonomy.

**Conclusions:** The established chemotaxonomic classification could be effectively used for *Rhodiola* species identification.

**Keywords:** *Rhodiola* plants, Morphological characteristic, Genetic taxonomy, Phytochemical taxonomy

**Background**

The genus *Rhodiola* L. (Crassulaceae) comprises approximately 96 species found in the alpine regions of Asia and Europe. A total of 73 species, 2 subspecies and 7 varieties are found in China [1,2]. *Rhodiola* species, historically used as adaptogens in Russia and northern Europe and as a traditional herbal medicine in China, are valued for their ability to enhance human resistance to stress or fatigue and to promote longevity [3-5]. *Rhodiola* plants are mainly distributed in southwest and northwest of China, with most species located in Tibet and in Sichuan province. In China, the *Rhodiola* species called Hongjingtian have been used as an important adaptogen, hemostatic, and tonic in traditional Tibetan medicines for thousands of years [6]. The phytochemical extracts of *Rhodiola* plants are widely used throughout Europe, Asia and the United States, with biological activities including anti-allergenic and anti-inflammatory effects and enhanced mental alertness, as well as a variety of other therapeutic applications [5]. Because of their commercial utility, *Rhodiola* plants are now cultivated in many locations in Europe and Asia. Most notably, the roots and rhizomes of *R. crenulata* (RC) have high activities and have been accepted by the Pharmacopoeia of China [7]. In addition, many *Rhodiola* plants, such as *R. sachalinensis* (RS), *R. himalensis* (D. Dons) S. H. Fu (RH), *R. serrata* H. Ohba (RSE), *R. rosea* L. (RR), *R. kirilowii* (Regel) Maxim (RK) and *R. fastigiata* (HK. F. et Thoma) S. H. Fu (RF), etc., are also used as Hongjingtian in China. However, the identification of the closely related species of *Rhodiola* plants is often difficult due to their generally similar morphology.

Phytochemical investigations show that there are six important classes of constituents in *Rhodiola* rhizomes, including phenylpropanoids, phenylethanol derivatives,