光强和光质对野外栽培高山红景天生物量和红景天甙含量的影响

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摘要：为探讨野外条件下光强及光质对高山红景天（*Rhodiola sachalinensis*）生物量和红景天甙含量的影响，于 2001 年 5 月 8 日至 9 月 16 日在大兴安岭加格达奇的高山红景天种植圃地，利用纱布及红色、蓝色和绿色的滤光膜遮光处理，对生长 3a 和 4a 的高山红景天进行了光强、光质控制实验。与温室实验类似，遮荫显著抑制高山红景天根的生长，并使红景天甙的含量略有提高。红膜处理使光强大约降低一半，但仅从光质的角度而言，红膜处理对根的生长影响不大，却显著增加了根中的红景天甙含量和产量，不过效果不如温室实验明显。绿膜处理未表现出对红景天甙积累的促进作用，这与温室实验结果不同。红膜处理不同天数的结果表明，处理时间对红景天甙含量提高的程度影响很小。这意味着在野外种植的情况下，可以在临近收获的最后一段时间用红膜对高山红景天进行处理，这样既可避免红膜处理对高山红景天根生长的抑制（由于减弱了光照），又可显著提高根的红景天甙含量，从而达到大幅度提高红景天甙产量的目的。

关键词：高山红景天；光强和光质；生物量；红景天甙含量

Effects of field light intensity and quality on biomass and salidroside content in roots of *Rhodiola sachalinensis*

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Abstract: *Rhodiola sachalinensis* A. Bor, a perennial herb, belonging to the family Crassulaceae, is mainly distributed at mountains of 1700～2500 m above sea level. It is a very important medicinal plant with high activities of anti-fatigue, anti-senescence and anti-radiation, due to the secondary product salidroside in its roots.

Our previous research in a greenhouse has testified that shading can reduce biomass, salidroside content and yield in roots of *Rh. sachalinensis*, and shading with red film promotes salidroside content observably with a little negative effect on biomass, thereby results in a higher yield of salidroside in roots of *Rh. sachalinensis*. In the present paper, the effects of light intensity and light quality on plant growth and salidroside content in roots of *Rh. sachalinensis* in the field were investigated. Controlled experiments were performed on 3- and 4-year-old *Rh. sachalinensis* in 2001 at a nursery of Daxinganling Mountain (124°02′E, 50°30′N). Herbs were treated under red, blue and green films (relative light intensities were 51.76%, 26.96% and 24.80% of full sunlight, respectively), together with a control (CK) of no shading. All experiments started on May 8 and stopped on September 16, 2001 and *Rh. sachalinensis* roots were cropped on September. In treatment Ⅰ, *Rh. sachalinensis* plants were shaded by neutral cloth to achieve a same intensity as red-film-shading did during the experimental process. In Treatment Ⅱ, Red-film-shading was conducted all the time. In treatment Ⅲ, Ⅳ, Ⅴ or Ⅵ, plants were covered with neutral shading cloth from May 8, and then changed to red film on June 3, July 4, August 4 and September 2 (for 105, 74, 43 and 14 days of red-film-shading) respectively. In treatment Ⅶ or Ⅷ, blue- and green-film-shading were performed from the beginning to the end.

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In treatment Ⅸ, shading materials were shifted from neutral cloth to green film on September 2. Biomass and salidroside content were measured at the end of experiment, and salidroside yield (the product of salidroside content and biomass of root) was calculated.

Shaded by neutral cloth positively affected salidroside content, but negatively did root biomass of 3- and 4-year-old *Rh. sachalinensis* (treatment Ⅰ) in the field, and synthetically resulted in a negative effect on salidroside yield in both 3- and 4-year-old *Rh. sachalinensis* with no significant difference to CK, which were similar to those results in a greenhouse.

In the field, red film slightly decreased root biomass of 3- and 4-year-old *Rh. sachalinensis* (treatment Ⅱ, Ⅲ, Ⅳ, Ⅴ and Ⅵ) to their relative control of treatment Ⅰ, and a little severer biomass losses were showed while the treatment time prolonged. Similar to the results in a greenhouse, salidroside contents in roots of *Rh. sachalinensis* were improved significantly by red film, which were 57.13%～67.57% and 45.45%～55.27% higher than did neutral cloth in 3- and 4-year-old plants, respectively, and as a result, the enhancement of salidroside yields of 43.90%～73.02% in 3-year-old plants, and of 43.84%～47.46% in 4-year-old plants were observed. The difference among treatment Ⅱ～Ⅵ was of no significance which implied that the improvement of the accumulation of salidroside induced by red film did not depend on the spell of time, suggesting that we could treat *Rh. sachalinensis* plants under red film for a couple of days before harvest to yield more salidroside and less biomass losses.

Long-term treatments (for 131 days) under blue and green films (treatment Ⅶ, Ⅷ) observably inhibited the growth of *Rh. sachalinensis* roots, whereas short-term treatment (14 days) with green film (treatment Ⅸ) affected root growth insignificantly. Though the results in a green house suggested that green film would also do favor to the production of salidroside in roots of *Rh. sachalinensis* as did red film, it did not show a corresponding result in the field. The content and yield of salidroside in roots of *Rh. sachalinensis* with short-term green light treatment were comparable to their control of treatment Ⅰ.

Key words: *Rhodiola sachalinensis*; light intensity and light quality; biomass; salidroside content

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高山红景天(*Rhodiola sachalinensis* A. Bor)是景天科(Crassulaceae)的一种多年生草本植物,主要分布在日本、朝鲜、中国和俄罗斯,在中国主要分布于东北地区吉林省的长白山和黑龙江省张广才岭东南部部分高山区,多生长在海拔 1700～2500 m 之间,是一种典型的高山植物[1,2]。高山红景天根中所含的以红景天甙为主的次生代谢产物具有抗疲劳、抗缺氧、抗衰老及抗辐射等显著功效,是在军事医学、航天医学及运动医学上有十分重要应用价值的环境适应药物[3]。对于高山红景天的生物学特性、生长生殖特征、红景天甙的提取和含量测定以及通过组织和细胞培养生产红景天甙等方面已有一些研究工作[4～14],但有关光强和光质对高山红景天的生长特别是对其次生代谢影响的工作尚未见到。为此,通过温室栽培和野外栽培实验,利用滤光膜进行处理,研究了光强和光质对高山红景天生物量和次生代谢产物红景天甙含量的影响。

已有研究报告了温室栽培处理实验的结果[15]。中度以下的遮荫(光强大于 45%的全光照)导致高山红景天根的红景天甙含量降低,但与全光照的差异并未达到显著水平,而根的生物量则显著低于全光照的,因而根的红景天甙产量(根的红景天甙含量与生物量乘积)明显比全光照的要低。而光质的实验表明,红膜处理对高山红景天根生物量的影响最小,却使红景天甙的含量显著增高;绿膜处理虽然使红景天甙含量增高,但却严重抑制根的生长;蓝膜处理使红景天甙含量提高甚微,也严重抑制根的生长;黄膜处理则使根的红景天甙含量降低。这些是在温室中处理 45 d 的实验结果,那么更长或更短时间的处理效果会如何?另一方面,高山红景天的自然生境通常气候恶劣、气温较低,与温室的环境有很大的区别,那么在野外条件下光强和光质又如何影响高山红景天的生长和红景天甙积累?为此,在 2000 年温室栽培处理实验的基础上,于 2001 年在大兴安岭加格达奇的高山红景天人工种植圃地进行了野外栽培处理实验。

1　研究方法

1.1　栽培处理实验

野外处理实验在大兴安岭加格达奇的高山红景天人工种植圃地进行。加格达奇位于东经 124°02′,北纬 50°30′,年均气温 −2.1℃,1 月份平均气温 −24.4℃,7 月份平均气温 18.2℃。这里有类似于高山红景天自然生境的高寒气候。实验材料为生长 3a 和 4a 的高山红景天,用透明膜和纱布遮荫改变光照强度,用红色、蓝色和绿色的滤光膜进行光质处理,其相对光强分别为全光照的 51.8%～52.9%和 24.8%,3 种滤光膜的吸收光谱见图 1。

在 2000 年的温室栽培处理实验中,红色滤光膜对红景天甙含量提高较多而对生物量影响较小,因此在 2001 年的野外栽培

处理实验中红色滤光膜处理较多。处理实验分为 9 组,对照组(CK)不加滤光膜。Ⅰ组用透明膜和纱布遮光,使其相对光强与遮红膜的一致。Ⅱ组从 5 月 8 日至 9 月 16 日一直遮红膜,处理时间为 131 d。Ⅲ、Ⅳ、Ⅴ、Ⅵ组从 5 月 8 日起遮透明膜和纱布,而后分别于 6 月 3 日、7 月 4 日、8 月 4 日和 9 月 2 日换为红膜,红膜处理的时间分别为 105、74、43 和 14 d。Ⅶ和Ⅷ组分别一直遮蓝膜和绿膜,处理时间为 131 d。Ⅸ组最初为透明膜和纱布,9 月 2 日换为绿膜,绿膜处理时间为 14 d(图 2)。遮膜处理的在四周靠近地面处留有通风空隙,并依照对照组的水分状况适时浇水。9 月 16 日,生长季结束,测定根的生物量和红景天甙含量。

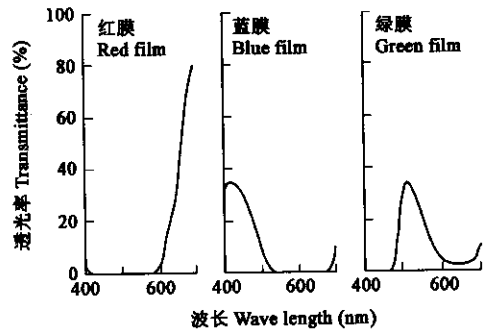

图 1 滤光膜的吸收光谱

Fig. 1 Absorption spectrum of films

1.2 生物量和红景天甙含量测定

生物量采用烘干称重法测定,红景天甙含量按照王洋等[16]的方法测定,每一处理重复 5～8 株。由根的生物量乘以红景天甙含量得出根的红景天甙产量。

所得数据用 SPSS 软件做统计分析。

2 结果与分析

2.1 光强对高山红景天生物量和红景天甙含量的影响

透明膜和纱布遮荫处理的光强大约为全光照的 51.76%。光照强度的减弱,导致根的生物量明显降低,无论是生长 3a 还是生长 4a 的高山红景天,其根的生物量与生长在全光照(不遮膜)下的相比,差异均达到显著水平(图 3)。

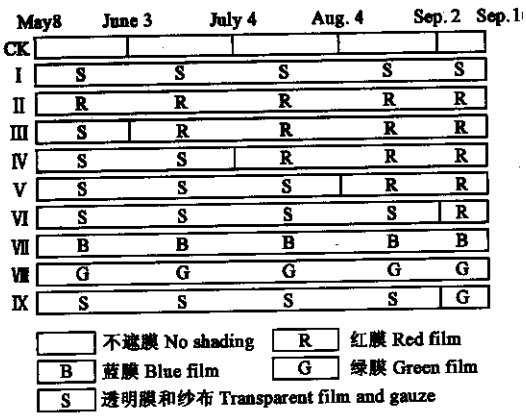

图 2 野外处理实验示意图

Fig. 2 Sketch of experimental treatment in field

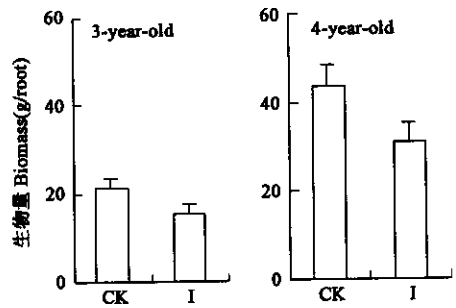

图 3 遮荫对高山红景天根生物量的影响

Fig. 3 Effect of shading on the biomass of roots of *Rhodiola sachalinensis*

CK,不遮膜 No shading;Ⅰ,遮透明膜和纱布 131d Shading for 131 days with transparent film and gauze;每一小图中,具有不同字母的柱体间差异显著($p<0.05$) In each panel, the bars with different letters are significantly different ($p<0.05$)

遮荫处理下的高山红景天,其根的红景天甙含量略高于全光照的,但两者的差异未达到显著水平,生长 3a 和生长 4a 的高山红景天均是如此。从根的红景天甙产量看,遮荫处理的略低于全光照的,但差异也不显著(图 4)。

2.2 红膜处理对高山红景天生物量和红景天甙含量的影响

在图 5 中,处理Ⅰ相当于红膜处理(Ⅱ、Ⅲ、Ⅳ、Ⅴ和Ⅵ)的对照,即用透明膜和纱布处理而与红膜处理具有相同的光照强度,而处理Ⅱ、Ⅲ、Ⅳ、Ⅴ和Ⅵ则是分别在测定前的不同天数(131、105、74、43 和 14 d)开始换为红膜。红膜处理致使高山红景天根的生长受到影响,红膜处理的天数越多,根的生物量与对照(遮荫)的差异越大,生长 3a 和生长 4a 的高山红景天都有这个趋势。但是各处理间的差异均未达到显著水平。

红膜处理使高山红景天根中的红景天甙含量显著提高,而处理天数对红景天甙含量提高的程度影响不是很大。生长 3a 的提高的幅度为 57.13%～67.57%,而生长 4a 的提高幅度为 45.45%～55.27%(图 6)。尽管红膜处理使高山红景天根的生物量有所降低,但根的红景天甙产量还是高于对照(遮荫)的。生长 3a 的高山红景天,红景天甙产量提高的幅度为 43.90%～73.02%,而生长 4a 的提高幅度为 43.84%～47.46%(图 6)。

2.3 蓝膜和绿膜处理对高山红景天生物量和红景天甙含量的影响

蓝膜和绿膜长期处理(131 d,处理Ⅶ和Ⅷ)的都严重地抑制了高山红景天根的生长,而短期的绿膜处理(14 d,处理Ⅸ)则对根的生长影响不是很大(图 7,图 3)。

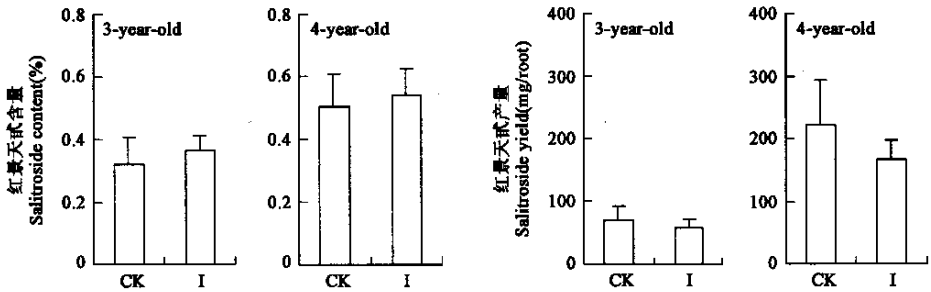

图 4　遮荫对高山红景天根中红景天甙含量和产量的影响

Fig. 4　Effect of shading on the content and yield of salidroside in roots of *Rhodiola sachalinensis*

CK、Ⅰ，**见图** 3 See Fig. 3；**各小图中** CK **和** Ⅰ **的差异均不显著**($p>0.05$) In each panel, no significantly different ($p>0.05$) between CK and Ⅰ

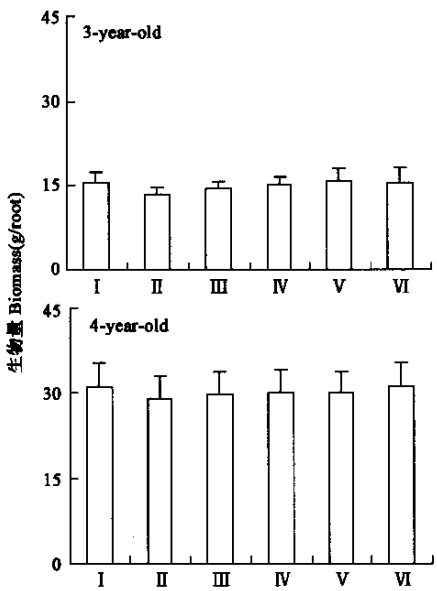

图 5　红膜处理对高山红景天根生物量的影响

Fig. 5　Effect of shading with red film on the biomass of roots of *Rhodiola sachalinensis*

Ⅰ，**遮透明膜和纱布** 131d Shading for 131 days with transparent film and gauze；Ⅱ，**遮红膜** 131d Shading for 131 days with red film；Ⅲ，**遮红膜** 105d Shading for 105 days with red film；Ⅳ，**遮红膜** 74d Shading for 74 days with red film，Ⅴ，**遮红膜** 43d Shading for 43 days with red film，Ⅵ，**遮红膜** 14d Shading for 14 days with red film；**各处理**(Ⅰ～Ⅵ)**间差异均不显著**($p>0.05$) No significantly different ($p>0.05$) between any two treatment (Ⅰ～Ⅵ)

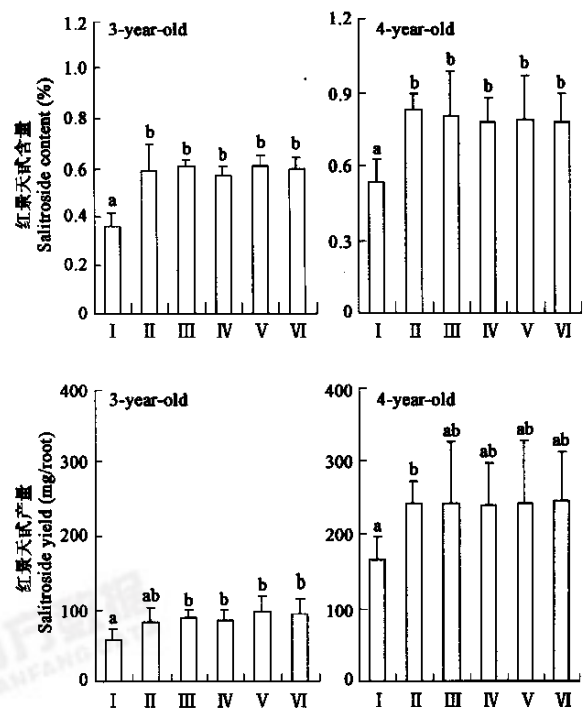

图 6　红膜处理对高山红景天根中红景天甙含量和产量的影响

Fig. 6　Effect of shading with red film on the content and yield of salidroside in roots of *Rhodiola sachalinensis*

Ⅰ、Ⅱ、Ⅲ、Ⅳ、Ⅴ、Ⅵ，**见图** 5 See Fig. 5；**每一小图中，具有不同字母的柱体间差异显著**($p<0.05$) In each panel, the bars with different letters are significantly different ($p<0.05$)

长期蓝膜和绿膜处理的高山红景天，根的红景天甙含量和产量都远低于遮荫处理的(处理Ⅰ)和对照的(CK)，而短期绿膜处理的高山红景天，根的红景天甙含量和产量则接近并略低于遮荫处理的(图 8，图 4)。

3　讨论

红景天甙具有重要的医疗和保健作用，对高山红景天的大规模利用已导致储量本就不丰的野生资源濒临枯竭，近年来在东北的高山和高寒冈开始有大量的高山红景天人工种植。但是，人工种植的高山红景天的红景天甙含量往往比野生的低很多。因此，如何提高人工种植高山红景天的红景天甙含量成为一个被关注的重要问题。

野外和温室的处理实验都表明,遮荫即光照强度的减弱会导致高山红景天根的生物量降低,但在根的红景天甙含量上,野外和温室的实验结果不尽一致。温室处理时红景天甙的含量随着光强的减弱而降低,而野外实验结果表明遮荫则使红景天甙含量略微升高。在红景天甙的产量上,野外和温室的结果又是一致的,即遮荫都使红景天甙的产量减少。不过,在大于 45% 的全光照下,这些差异都没有达到显著水平。

野外和温室的光质处理实验也都表明,红膜对根的生长抑制程度最小,而对红景天甙含量的提高最多。但是,红膜处理在改变光质的同时,也使光照强度降低了大约一倍,红膜处理对红景天甙含量的提高效果将被对根生长的抑制效果抵消一部分。在温室,红膜处理 45 d 的结果是红景天甙的产量比对照(无膜处理)的提高了 34.83%[15];而在野外,红膜处理 131 d 的结果是,生长 3a 和生长 4a 的高山红景天的红景天甙产量分别只比对照(遮荫处理,相同的光照强度)提高了 17.30% 和 8.35%。另一方面,野外实验中红膜处理不同天数的结果表明,处理时间对红景天甙含量提高的程度影响很小(图 6)。这意味着在野外种植的情况下,可以在临近收获的最后一段时间用红膜对高山红景天进行处理,这样既可避免红膜处理对高山红景天根生长的抑制(由于减弱了光照),又可显著提高根的红景天甙含量,从而达到较大幅度提高红景天甙产量的目的。

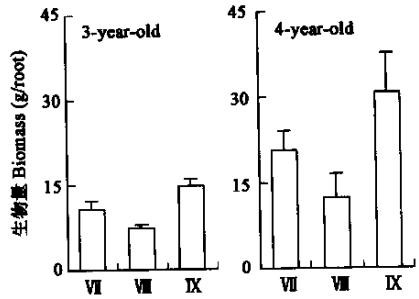

图 7 蓝膜和绿膜处理对高山红景天根生物量的影响

Fig. 7 Effect of shading with blue and green film on the biomass of roots of *Rhodiola sachalinensis*

Ⅶ, 遮蓝膜 131d Shading for 131 days with blue film; Ⅷ, 遮绿膜 131d Shading for 131 days with green film; Ⅸ, 遮绿膜 14d Shading for 14 days with green film

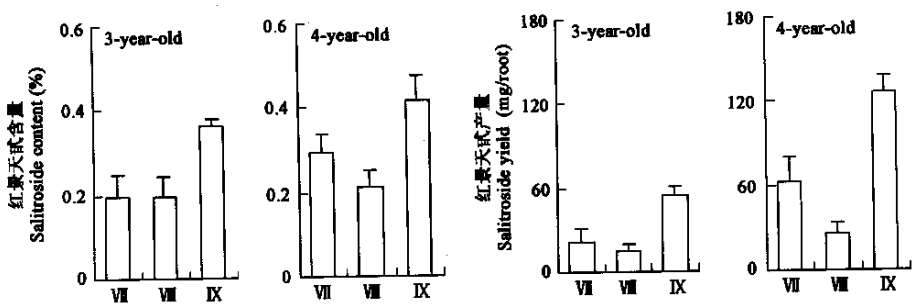

图 8 蓝膜和绿膜处理对高山红景天根中红景天甙含量和产量的影响

Fig. 8 Effect of shading with blue and green film on the content and yield of salidroside in roots of *Rhodiola sachalinensis*

Ⅶ、Ⅷ、Ⅸ, 见图 7 See Fig. 7

在温室实验中,绿膜处理也表现出对红景天甙含量提高的显著效果,只是由于对于高山红景天根生长的强烈抑制而导致最终的红景天甙产量低于对照的[15]。但是,在野外的实验中,无论是处理 131 d 还是处理 14 d,绿膜对红景天甙含量的提高效果均没有表现出来(图 4,图 8)。

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