Effects of greenhouse 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 in 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 metabolite, salidroside in...
its roots. In order to investigate the effects of light intensity and light quality on plant growth and salidroside content in roots of *Rh. sachalinensis*, a controlled environmental study was conducted in a greenhouse in April 2000. Four light intensity levels (relative light intensities were 100%, 67.75%, 44.71% and 31.96% of full sunlight, respectively) were created by using neutral shading cloth, and four different light qualities were done by red, yellow, blue and green films (relative light intensities were 51.76%, 60.69%, 26.96% and 24.80% of full sunlight, respectively). On April 27, 3-year-old plants grown at a nursery in Daxinganling Mountain (124°02' E, 50°30' N), were transplanted to pots (diameter 25 cm, depth 25 cm) in a greenhouse at Northeast Forestry University, Harbin, P. R. China (126°38' E, 45°43' N). Light controlled treatments were performed after 1 week of shoot development. Aboveground and root biomass, the contents of chlorophyll a and chlorophyll b in leaves, and salidroside content in roots of *Rh. sachalinensis* were measured after 45 days of treatment, and whole plant biomass, root/shoot ratio, total chlorophyll content, chlorophyll a/b ratio and salidroside yield in roots (the product of salidroside content and root biomass) were calculated.

Results revealed that the biomass of *Rh. sachalinensis* was affected by light intensity. The biomasses of the whole plant and roots tended to decrease as light intensity declined, though whole plant biomass was not influenced apparently when light intensity was 44.71% of full sunlight or higher. The biomasses of the whole plant were 87.82%, 84.95% and 37.46% with light intensities of 67.75%, 44.71% and 31.96% of full sunlight to the control of 100% full sunlight, and those of roots were 83.08%, 76.12% and 53.23%, respectively. Root/shoot ratio with light intensity of 31.96% of full sunlight was significantly larger than under other light intensity conditions. The contents of chlorophyll a, chlorophyll b and total chlorophyll in leaves of *Rh. sachalinensis* slightly decreased with the descent of light intensity.

Shaded by red, yellow, blue and green films, whole plant and root biomasses were significantly less than that of the control without shading. To define the real effect induced by light quality, based on the effect of light intensity on biomass, the theoretical biomasses of the whole plant and for the control with the corresponding relative light intensities to that under different shading films were calculated. Thereby, whole plant biomasses under red, yellow, blue and green films would be 80.73%, 76.11%, 60.96% and 71.28% to the respective calculating values, and that of roots would be 90.24%, 76.80%, 52.83% or 52.00%, respectively. Thus, blue and green films would induce more root biomass loses of *Rh. sachalinensis* than would red and yellow films. Versus the control, root/shoot ratio was apparently enlarged under red, blue and green film treatments. Color film treatments positively affected on the contents of chlorophyll a, chlorophyll b and total chlorophyll, but only blue film caused a significant effect.

When light intensities were 67.75% and 44.71% of full sunlight, though *Rh. sachalinensis* salidroside content lightly lowered to the control, salidroside yield was down significantly. Both the content and yield of salidroside in roots of *Rh. sachalinensis* under light of 31.96% of full sunlight declined remarkably to that under other conditions.

Compared to the control, red film conducted an increase of 83% in salidroside content and of 35% in salidroside yield, whereas yellow, blue and green films did decreases of 56.95%, 72.22% and 31.94% in salidroside content and 70.43%, 92.35%, and 82.34% in salidroside yield, respectively, which suggested that red film enhanced the production and accumulation of salidroside in *Rh. sachalinensis* roots but not the other three. Eliminated the influence of light intensity, salidroside contents would be 242% and 244%, and salidroside yields would 150% and 357% higher in plants in red and green lights than in the control. Hence, if we could remain a higher light intensity in green light, it would also do favor to the production of salidroside.
salidroside in *Rh. sachalinensis*, either.

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

In the life activities of various plants from low to high, light is an important environmental factor. Plants convert light energy into chemical energy through photosynthesis and use it for growth. Light also acts as environmental information to regulate plant differentiation, growth, and development, allowing them to better adapt to their surroundings. Many studies have shown that differences in light intensity and quality not only affect the initial phases of plant metabolism but also influence many secondary metabolic processes. Discussing the effects of light intensity on plant growth and development, as well as secondary metabolism, is crucial. These studies, especially those focusing on the effects of light quality, are relatively rare. Most research has been conducted on plant tissue culture materials. However, understanding how light quality affects the production of secondary metabolites can provide theoretical support and practical guidance for the efficient production of certain important drugs and economically valuable secondary metabolites.

**Highland Rhodiola** is a perennial herb in the *Rhodiola* genus, distributed in Japan, Korea, China, and Russia. In China, it is mainly found in northeastern regions such as Jilin Province and Heilongjiang Province, particularly in high mountainous areas above 2000 to 2500 meters. Highland Rhodiola is a typical high-altitude plant. The root of this plant contains secondary metabolites such as salidroside, which具有显著的抗疲劳、抗缺氧、抗衰老和抗辐射等功效。这种药物在军事医学、航天医学及运动医学中具有重要应用价值。对于高原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经有了一些研究工作。但有关光强和光质对高原红景天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。本文是温室栽培处理实验的结果。

**Materials and Methods**

**Growth and Reproduction Characteristics**

Highland Rhodiola saplings were dug from an artificial planting plot in the study area and transplanted to a greenhouse in Harbin city. The greenhouse was naturally illuminated. The daytime temperature was 25°C and the night temperature was 17°C to 20°C. The plants were grown in pots with a diameter of 30 cm and a depth of 23 cm. Each pot contained 10 plants. The plants were divided into groups for light intensity and quality treatments. Light intensity treatments included shading with medical gauze to reduce light intensity by 50% of full sunlight and 10% of full sunlight. Light quality treatments included red, yellow, blue, and green filters, reducing light intensity by 50% of full sunlight and 10% of full sunlight.

**Biomass, Chlorophyll Content, and Salidroside Content Determination**

Biomass was determined by drying and weighing. Chlorophyll content was determined by the method of Porra et al. Salidroside content was determined according to the method of Wang et al. Each treatment had three replicates, and the data were analyzed using SPSS software.

**Results and Analysis**

**Effect of Light Intensity on Highland Rhodiola Biomass and Chlorophyll Content**

From the data in Table 1, it can be seen that reducing Highland Rhodiola's light intensity through shading reduces its biomass. The biomass of Highland Rhodiola with light intensity reduced by 50% of full sunlight is 67.75% and 44.71% of the full sunlight control, with a significant difference. When the light intensity is further reduced, the biomass is significantly lower, with the biomass of Highland Rhodiola with light intensity reduced by 10% of full sunlight being only 31.96% of the full sunlight control.

**Effect of Light Quality on Highland Rhodiola Biomass and Salidroside Content**

Highland Rhodiola exposed to red light has a significantly lower biomass than those under red and blue light, while the biomass under blue light is significantly lower than that under red light. Red light reduces the biomass of Highland Rhodiola by 64.99% compared to full sunlight, while blue light reduces it by 52.97%.

**Conclusion**

The results show that light intensity and quality significantly affect the growth and secondary metabolism of Highland Rhodiola. Reducing light intensity through shading and using red light for treatment significantly reduce the biomass and salidroside content of Highland Rhodiola compared to full sunlight. The effects of blue light are even more significant. Therefore, optimizing light intensity and quality can effectively control the growth and secondary metabolism of Highland Rhodiola, providing theoretical support and practical guidance for the efficient production of secondary metabolites, especially salidroside.
Table 1 The biomass and chlorophyll content of *Rhodiola sachalinensis* under different light intensity

<table>
<thead>
<tr>
<th>Relative light (%)</th>
<th>Biomass of plant (g/plant)</th>
<th>Biomass of root (g/plant)</th>
<th>Root/shoot ratio</th>
<th>Total chlorophyll content (mg/gd)</th>
<th>Chlorophyll a content (mg/gd)</th>
<th>Chlorophyll b content (mg/gd)</th>
<th>Chlorophyll a/b</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.96</td>
<td>3.66 a</td>
<td>1.07 a</td>
<td>0.42 a</td>
<td>2.457 a</td>
<td>1.672 a</td>
<td>0.684 a</td>
<td>2.44 a</td>
</tr>
<tr>
<td>44.71</td>
<td>8.30 b</td>
<td>1.53 b</td>
<td>0.23 b</td>
<td>2.548 a</td>
<td>1.829 a</td>
<td>0.719 a</td>
<td>2.54 a</td>
</tr>
<tr>
<td>67.75</td>
<td>8.58 b</td>
<td>1.67 b</td>
<td>0.24 b</td>
<td>2.649 a</td>
<td>1.896 a</td>
<td>0.753 a</td>
<td>2.52 a</td>
</tr>
<tr>
<td>100</td>
<td>9.77 b</td>
<td>2.01 c</td>
<td>0.26 b</td>
<td>2.687 a</td>
<td>1.911 a</td>
<td>0.776 a</td>
<td>2.46 a</td>
</tr>
</tbody>
</table>

(p < 0.05) Data with different letters are significantly different (p < 0.05) in the same column.

**Fig. 1** The absorption spectrum of films
### Table 2  The biomass and chlorophyll content of *Rhodiola sachalinensis* under different light quality

<table>
<thead>
<tr>
<th>Light quality</th>
<th>% of full sunlight (%)</th>
<th>Biomass of whole plant (g/plant)</th>
<th>Biomass of root (g/plant)</th>
<th>Root/shoot ratio</th>
<th>Total chlorophyll content (mg/gdw)</th>
<th>a</th>
<th>Chlorophyll a content (mg/gdw)</th>
<th>b</th>
<th>Chlorophyll b content (mg/gdw)</th>
<th>a/b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunlight</td>
<td>100</td>
<td>9.77 a</td>
<td>2.01 a</td>
<td>0.26 a</td>
<td>2.687 a</td>
<td>1.911 a</td>
<td>0.776 a</td>
<td>2.46 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red film</td>
<td>51.76</td>
<td>6.41 b</td>
<td>1.48 b</td>
<td>0.30 b</td>
<td>2.992 a</td>
<td>2.138 a</td>
<td>0.855 a</td>
<td>2.50 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow film</td>
<td>60.69</td>
<td>6.31 b</td>
<td>1.39 b</td>
<td>0.28 ab</td>
<td>2.900 a</td>
<td>2.022 a</td>
<td>0.878 a</td>
<td>2.30 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue film</td>
<td>28.96</td>
<td>2.03 c</td>
<td>0.56 c</td>
<td>0.38 c</td>
<td>4.951 b</td>
<td>3.534 b</td>
<td>1.417 b</td>
<td>2.49 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green film</td>
<td>24.80</td>
<td>2.01 c</td>
<td>0.52 c</td>
<td>0.35 c</td>
<td>3.124 a</td>
<td>2.172 a</td>
<td>0.952 a</td>
<td>2.28 a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data with different letters are significantly different ($p<0.05$) in the same column.

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**Fig. 2** The salidroside content and yield in roots of *Rhodiola sachalinensis* under different light intensity.

**2.3**

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**Fig. 3** The total chlorophyll content, a/b and relative photoperiod effects on root and shoot biomass of *Rhodiola sachalinensis*.

**2.4**
Fig. 3  The salidroside content and yield in roots of *Rhodiola sachalinensis* under different light quality

The column with shadow represents the value at same light intensity which calculated according to the results of Fig. 2

### 3

*...*
植物的次生代谢产物是植物适应环境的产物，同时对于人类也具有重要的经济价值。但关于光强和光质对次生代谢及其产物影响的研究工作很少，而且很大比例是以组织或细胞培养材料为研究对象的。

植物的次生代谢产物种类繁多，在与光强和光质相关的研究中已报道的有生物碱，黄酮，萜类内酯，挥发性成分等。

红景天甙属于糖苷类，冯敏等发现蓝光和绿光对毛地黄叶组织培养物中强心苷的产生和积累有促进作用，而红光则有抑制作用。

而冷平生等用3年生银杏幼苗所做的实验表明，光质对银杏黄酮苷的生物合成与积累影响较小，但遮荫处理显著降低银杏黄酮苷的含量，并且随着光照强度的减弱逐渐降低。

光照强度对高山红景天根中红景天甙含量的影响也是如此，弱光导致红景天甙含量急剧降低，在光质方面，红膜和绿膜处理的高山红景天红景天甙含量显著高于对照，而黄膜的抑制作用和蓝膜的促进作用均不明显。红膜处理不仅显著提高根中红景天甙的含量，为对照的3.42倍，而且对根生物量的影响较小，为对照的0.132倍，因而提高了高山红景天根的红景天甙产量，这意味着在生产上可能有一定的实践意义。

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\end{itemize}