温室栽培光强和光质对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 2000 年 4 月至 6 月在东北林业大学温室内以移栽于大兴安岭加格达奇圃地人工种植生长 3a 的高山红景天为材料，通过纱布遮荫及遮以不同颜色的滤光膜分别进行了光强、光质控制实验（处理 45 d）。随着光强的降低，高山红景天全株生物量、根生物量、根的红景天甙含量和产量以及叶中叶绿素 a、叶绿素 b、总叶绿素的含量均有降低的趋势，但叶绿素含量变化很小，不同光强及对照之间的差异均未达到显著水平。相对光强为 67.75％和 44.71％的两种处理下的全株生物量、根生物量、根的红景天甙含量和产量差异不显著，它们的全株生物量和红景天甙含量与对照（全光照）的差异也不显著，但根生物量和红景天甙产量与对照的差异显著。当相对光强减弱至 31.96％，全株生物量、根生物量、根的红景天甙含量和产量均大幅度下降，根冠比显著增加。4 种滤光膜处理均使高山红景天的全株生物量及根生物量显著降低，蓝膜和绿膜处理的降低幅度大于红膜和黄膜处理的。红膜处理的红景天甙的含量和产量均高于对照，但黄膜、蓝膜和绿膜处理的红景天甙含量和产量则低于对照。通过计算去除 4 种滤光膜的光强因素，仅从光质的作用看，4 种滤光膜处理仍是减小了全株生物量和根生物量，红膜和绿膜处理提高了红景天甙的含量和产量，而黄膜处理降低了红景天甙的含量和产量，蓝膜处理几乎没有效果。4 种滤光膜处理均使叶绿素含量增加，但只有蓝膜处理的与对照差异显著。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 90.24％），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会有一定的实践意义。

关键词：高山红景天；光强和光质；生物量；叶绿素含量；红景天甙含量

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

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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 biomasses, 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%, 70.11%, 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 in *Rh. sachalinensis*, either.

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

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在低等至高等的各种植物的生命活动中,光是重要的环境因子之一。植物通过光合作用把光能转化成为化学能贮存起来,为其生长提供能量。同时,光还以环境信息的形式作用于植物,调节植物的分化、生长和发育,使其更好地适应外界环境。许多研究工作表明,光强的差异和光质的不同,不仅影响植物的初生代谢过程和生长状态[1~11],而且会影响许多植物的次生代谢过程[3,12~17]。这其中,探讨光强对植物生长发育及次生代谢影响的工作较多,而有关光质的研究工作特别是对次生代谢的影响则相对较少,而且这些工作多数是以植物的组织培养材料为研究对象的[13~16]。但是,对于光质影响植物次生代谢产物的探讨,常常可以为某些具有重要药用和经济价值的次生代谢产物的高效生产提供理论依据和实践指导,因而这方面的研究工作显得尤为重要[15,17]。

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,在中国主要分布在东北地区吉林省的长白山和黑龙江省张广才岭东南部的部分高山区,多生长在海拔 1700~2500 m 之间,是一种典型的高山植物[18,19]。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[20]。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[21~31],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。本文是温室栽培处理实验的结果。

1　研究方法

1.1　栽培处理实验

2000 年 4 月 27 日,在大兴安岭加格达奇(东经 124°02′,北纬 50°30′)高山红景天人工种植圃地,挖取即将萌芽的生长 3 年的高山红景天,移到哈尔滨(东经 126°38′,北纬 45°43′)后用普通花土栽植于直径 25 cm、深 25 cm 的花盆中,每盆 3 株,在东北林业大学阳光温室中培养。温室为自然采光,培养期间的昼间温度 23~26 C,夜间温度 17~20 C,昼夜温度自然过渡。湿度为 50%~60%。萌出地上部分 1 周后分组进行光强和光质处理。

光强处理分为 3 组,采用医用纱布进行遮荫,其相对光强分别为全光照的 67.75%、44.71%和 31.96%。光质处理分为 4 组,分别遮以红色、黄色、蓝色和绿色的滤光膜,其相对光强分别为全光照的 51.76%、60.69%、26.96%和 24.80%,4 种滤光膜的吸收光谱见图 1。处理 45 d 后取样测定各项指标。

1.2　生物量、叶绿素含量和红景天甙含量测定

生物量采用烘干称重法测定。叶绿素含量按 Arnon[32]的方法测定。红景天甙含量按照王洋等[33]的方法测定。每一处理重复 5~8 株。

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叶绿素含量的影响

从表 1 的数据可以看出,通过遮光降低高山红景天的光照强度,导致高山红景天的生物量降低。相对光强为 67.75%和 44.71%的高山红景天,其全株生物量分别为全光照的 87.82%和 84.95%,与对照相比降低幅度不大,差异未达到显著水平。但当光强进一步下降时,全株生物量显著降低,相对光强为 31.96%的高山红景天的全株生物量仅为全光照的 37.46%。

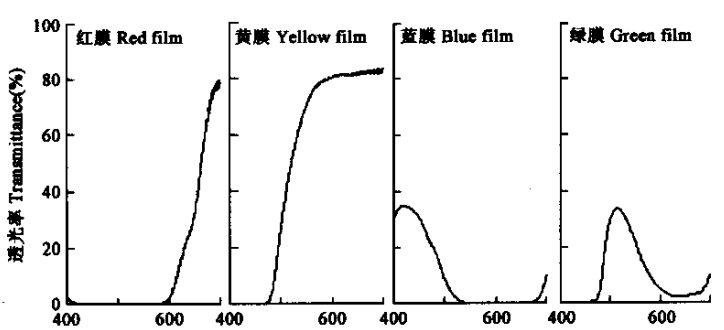

图 1 滤光膜的吸收光谱

Fig. 1 The absorption spectrum of films

表 1 不同光强下高山红景天的生物量和叶绿素含量

Table 1 The biomass and chlorophyll content of *Rhodiola sachalinensis* under different light intensity

相对光强(%) % of full sunlight	全株生物量 Biomass of plant (g/plant)	根生物量 Biomass of root (g/plant)	根冠比 Root/shoot ratio	总叶绿素含量 Total chlorophyll content (mg/gdw)	叶绿素 a 含量 Chlorophyll a content (mg/gdw)	叶绿素 b 含量 Chlorophyll b content (mg/gdw)	叶绿素 a/b Chlorophyll a/b
31.96	3.66 a	1.07 a	0.42 a	2.457 a	1.672 a	0.684 a	2.44 a
44.71	8.30 b	1.53 b	0.23 b	2.548 a	1.829 a	0.719 a	2.54 a
67.75	8.58 b	1.67 b	0.24 b	2.649 a	1.896 a	0.753 a	2.52 a
100	9.77 b	2.01 c	0.26 b	2.687 a	1.911 a	0.776 a	2.46 a

同一列数据中字母不同者表示差异性显著($p<0.05$) Data with different letters are significantly different($p<0.05$) in the same column

从根冠比的数据看,相对光强为 31.96%的高山红景天,其根冠比显著高于其他光强的。这意味着此光强下生长的高山红景天与对照相比,地上部分生物量的降低幅度大于地下部分。在 67.75%和 44.71%的相对光强下,高山红景天根的生物量分别为全光照的 83.08%和 76.12%,并且与全光照的差异达到了显著水平。这表明,在这两个光强下,虽然高山红景天全株生物量受到的影响不是很大,但地下部分所受的影响相对较大。

随着生长环境光照强度的减弱,高山红景天叶片中的总叶绿素含量、叶绿素 a 含量、叶绿素 b 含量均有逐渐降低的趋势,但不同光照强度之间均未达到显著水平。而且,叶绿素 a 与叶绿素 b 的比例也没有明显区别(表 1)。

2.2 光质对高山红景天生物量和叶绿素含量的影响

光质对高山红景天生物量的影响比较明显,4 种滤光膜处理的全株生物量和根生物量均显著低于对照水平(表 2)。滤光膜不仅改变了光质,同时也减弱了光强。为此,依据表 1 中光强处理的实验结果,将光强与生物量的关系进行数学拟合,并依据拟合方程计算了对应于 4 种滤光膜相对光强下的生物量。红膜、黄膜、蓝膜、绿膜对应光强下高山红景天的全株生物量分别为 7.94、9.00、3.33、2.82 g/plant,根生物量分别为 1.64、1.81、1.06、1.00 g/plant。以此为基础与表 2 的数据对比可知,红膜、黄膜、蓝膜、绿膜处理下,高山红景天的全株生物量分别为相同光强的阳光下的 80.73%、70.11%、60.96%、71.28%,而根生物量则分别为 90.24%、76.80%、52.83%、52.00%。可见,如果去除滤光膜对光强改变的因素,仅就光质的作用而言,在对高山红景天全株生物量的影响方面 4 种滤光膜之间的差别不是非常大。4 种滤光膜的光质差异对根生物量的影响则不同,红膜处理的影响最小,黄膜次之,而蓝膜、绿膜处理的几乎使根生物量减少了一半。

表 2　不同光质下高山红景天的生物量和叶绿素含量

Table 2　The biomass and chlorophyll content of *Rhodiola sachalinensis* under different light quality

光质 Light quality	相对光强(%) % of full sunlight	全株生物量 Biomass of whole plant (g/plant)	根生物量 Biomass of root (g/plant)	根冠比 Root/shoot ratio	总叶绿素含量 Total chlorophyll content (mg/gdw)	叶绿素 a 含量 Chlorophyll a content (mg/gdw)	叶绿素 b 含量 Chlorophyll b content (mg/gdw)	叶绿素 a/b Chlorophyll a/b
阳光 Sunlight	100	9.77 a	2.01 a	0.26 a	2.687 a	1.911 a	0.776 a	2.46 a
红膜 Red film	51.76	6.41 b	1.48 b	0.30 b	2.992 a	2.138 a	0.855 a	2.50 a
黄膜 Yellow film	60.69	6.31 b	1.39 b	0.28 ab	2.900 a	2.022 a	0.878 a	2.30 a
蓝膜 Blue film	26.96	2.03 c	0.56 c	0.38 c	4.951 b	3.534 b	1.417 b	2.49 a
绿膜 Green film	24.80	2.01 c	0.52 c	0.35 c	3.124 a	2.172 a	0.952 a	2.28 a

同一列数据中字母不同者表示差异性显著($p<0.05$) Data with different letters are significantly different($p<0.05$) in the same column

另一方面,从根冠比的数据看,4 种滤光膜处理均使高山红景天的地下部分相对于地上部分增多了。除黄膜外,红膜、蓝膜和绿膜处理的与对照的差异均达到了显著水平(表 2)。

4 种滤光膜处理的高山红景天,叶片中总叶绿素含量、叶绿素 a 含量、叶绿素 b 含量均高于对照的,但只有蓝膜处理的达到了显著水平。而在叶绿素 a 与叶绿素 b 的比例上,各处理间的差异均不显著(表 2)。

2.3　光强对高山红景天根中红景天甙含量的影响

高山红景天为多年生植物,次生代谢产物红景天甙主要在根中积累。光照强度对根中红景天甙含量的影响与对生物量的影响规律类似。相对光强 67.75%和 44.71%处理下的红景天甙含量虽然均低于对照的,但差异却未达到显著水平,而相对光强 31.96%处理的红景天甙含量则大大低于前三者,与它们的差异达到了极显著水平(图 2A)。

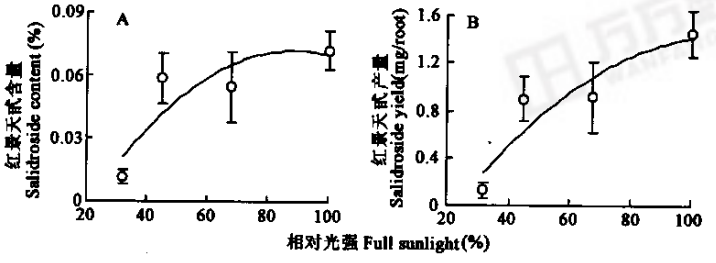

图 2　不同光强下高山红景天根中的红景天甙含量和产量

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

同时考虑根中的红景天甙含量和根的生物量,即得到高山红景天的红景天甙产量。生长环境的光照强度对红景天甙产量的影响类似于对红景天甙含量的影响,但又不相同。相对光强 67.75%和 44.71%处理下的红景天甙产量与对照的差异也达到了显著水平(图 2B)。

2.4　光质对高山红景天根中红景天甙含量的影响

光质对高山红景天根中红景天甙含量的影响也很明显。红膜处理的高山红景天,其根中的红景天甙含量达到对照的 1.83 倍,而黄膜、蓝膜和绿膜处理的则分别为对照的 43.05%、27.78%和 68.06%(图 3A)。依据 4 种滤光膜的相对光强和图 2 光强处理实验的结果,计算了对应于 4 种滤光膜光强的对照红景天甙含量(图 3A 中的阴影柱)。仅从光质的作用而言,红膜处理的红景天甙含量达到对照的 3.42 倍,绿膜处理

的为 3.44 倍,蓝膜处理的为 1.09 倍,而黄膜处理的红景天甙含量低于对照,为对照的 70.73%。可见红膜和绿膜处理有利于高山红景天根中红景天甙含量的提高。

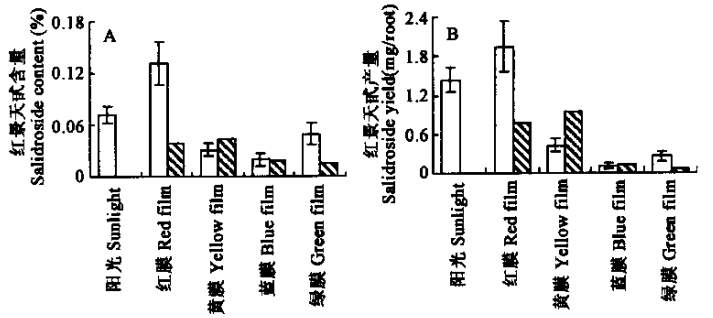

图 3 不同光质下高山红景天根中的红景天甙含量和产量

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

阴影系列为依据图 2 计算得出的相应光强下的数值 The column with shadow represents the value at same light intensity which calculated according to the results of Fig. 2

如果考虑高山红景天根生物量的因素即从根的红景天甙产量角度看,4 种滤光膜处理的效果稍有变化(图 3B)。红膜处理的红景天甙产量仅为对照的 1.35 倍,差异接近显著水平。黄膜、蓝膜和绿膜处理的红景天甙产量分别为对照的 29.57%、7.65%和 17.66%。仅从光质的作用而言,红膜处理的红景天甙产量达到对照的 2.50 倍,绿膜处理的则达 4.57 倍,而黄膜和蓝膜处理的红景天甙产量低于对照,分别为对照的 44.60%和 88.59%。

3 讨论

光照强度对植物生长的影响规律通常比较一致,对于阳性植物而言,一般情况下是随着光强的降低,植物的生长受到抑制,表现为生物量降低[1~3,5,6,11,17]。当然,也有些阳性植物在幼苗期需要避免过强的光照,而在高光强下表现为生长抑制[10]。高山红景天多生长于高山苔原的开阔地带,对强辐射有很强的适应能力和生长需求[18],是典型的阳性植物。本实验的结果也反映了高山红景天的生长对强光的依赖性,随着生长环境光强的降低,高山红景天的生物量特别是根的生物量随之降低。不过,生物量与光强的对应关系并不是线性的,当相对光强高于 45%时,光强的变化对高山红景天全株生物量的影响并不显著。一般而言,随着光强的减弱,植物为更好地利用环境光能以对生长进行补偿,通常叶绿素含量会增加,而且在弱光环境下叶绿素 a 和叶绿素 b 的比例也会发生改变[17,34,35]。本实验中,不同光强下生长的高山红景天的总叶绿素、叶绿素 a、叶绿素 b 虽有随光强减弱而含量趋低的趋势,但差异并未达到显著水平,叶绿素 a 与 b 的比例也没有显著差异。这种结果很可能与处理时间相对较短(45 d),叶绿素尚未产生明显的变化有关。

相对于光强而言,光质对植物生长的影响则较为复杂。不同波长的光的能量不同(在相同的光强下),对于植物生长必需的代谢过程——光合作用的有效性也不一样,而且一些特殊波长的光如红光、远红光、蓝光等还作为环境信号直接调节植物的生长发育进程即光形态建成[36]。一些有关光质对植物生长影响的研究工作,由于研究目的、处理方式、受试植物材料等的差异,结果也不一致[4,5,7~9,11]。有实验表明蓝光促进菊花和水稻幼苗的生长以及水稻幼苗的初级氮同化过程,而红光则对这些过程有抑制作用[7,9]。本实验所用的 4 种滤光膜处理,高山红景天的生长均受到抑制,而且红膜、黄膜的抑制程度相对较轻,蓝膜、绿膜的抑制程度较重。去除光照强度的因素,仅从光质的作用来看,4 种滤光膜处理也还是表现为抑制作用。从根生物量看,红膜的抑制程度最低(为对照的 90.24%),而蓝膜、绿膜的抑制程度较重(分别为对照的 52.83%、52.00%)。蓝膜处理的高山红景天的叶绿素含量显著高于红膜、黄膜、绿膜处理和对照的,这与蓝光促进水稻幼苗和菊花叶绿素合成的研究结果是一致的[7,9],但他们也报道红光降低叶绿素含量,本实验中红膜对高山红景天则未体现出相应的效果。

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、光质相关的研究中已报道的有生物碱[3,12,37]、黄酮[15,17]、萜类内酯[17]、挥发性性成分[38]等。红景天甙属于糖苷类,冯敏等发现蓝光、绿光和黄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[13],而冷平生等用 2 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,而且随着光强的减弱逐渐降低[17]。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 90.24%),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会有一定的实践意义。

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