果　树　学　报　2024，41（6）：1170-1180
Journal of Fruit Science

DOI:10.13925/j.cnki.gsxb.20230564

避雨和补光对西番莲产量、果实品质及光合特性的影响

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摘　要：【目的】探讨避雨和补光对西番莲产量和果实品质的影响，为西番莲设施栽培提供参考。【方法】供试材料为甜果型黄果西番莲（*Passiflora edulis* f. *favicarpa*），观测避雨（RS）、补光（L）、避雨+补光（RSL）和露地栽培（CK）等不同栽培模式下西番莲结果枝生长、果实发育及产量，可滴定酸、总糖、总游离氨基酸、维生素C、总酚、总黄酮、β-胡萝卜素含量等果实品质指标，叶绿素a和叶绿素b含量，净光合速率、蒸腾速率、胞间二氧化碳浓度、气孔导度等光合特性指标。【结果】与CK相比，L能使结果枝粗度显著增加，果实转色加快3 d，果实营养物质含量平均增加13%，叶绿素含量略有增加，净光合速率提高20%，对果实纵横径和产量无显著影响；RS和RSL会使结果枝更细长，RS会延缓果实转色8 d，产量提高20%，果实营养物质含量平均减少26%，净光合速率降低50%，RSL会延缓果实转色4 d，产量提高23%，果实营养物质含量平均减少20%，净光合速率降低37%，RS和RSL叶绿素含量均显著增加，对果实纵横径无显著影响。【结论】避雨能增加产量，补光能提高果实品质，可根据实际需求使用。

关键词：西番莲；避雨；补光；产量；果实品质；光合特性

中图分类号：S667.9　　　**文献标志码：**A　　　**文章编号：**1009-9980(2024)06-1170-11

Effect of rain shelter and light supplement on yield, fruit quality and photosynthetic characteristics in passion fruit

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Abstract:【Objective】Passion fruit is native to South America, and because of its unique aroma and flavor, passion fruit is favored in the domestic fruit market in recent years. However, Guizhou and other provinces where the passion fruit is mainly cultivated generally use the open field cultivation, which is susceptible to environmental conditions, so the yield and quality performance of passion fruit is not stable, which affects the economic benefits of passion fruit seriously. As the auxiliary measures of cultivation, rain shelter and light supplement can effectively improve the yield or quality of many vegetables and fruit crops. In order to find the methods which can stabilize performance of passion fruit, in this study, we conducted the rain shelter cultivation and light supplement cultivation, to reveal the effect of the rain shelter and light supplement on the yield and fruit quality of passion fruit, and find the possible contributing causes, so as to provide reference for efficient cultivation of passion fruit.【Methods】The test material was sweet passion fruit, and four treatments were set, including Rain Shelter (RS), Light Supplement (L), Rain Shelter + Light Supplement (RSL) and open field cultivation as the control (CK). The surveyed indexes include: branch length, internode length and thickness, longitudinal fruit diameter

收稿日期：2024-01-02　　**接受日期：**2024-04-08

基金项目：黔科合基础-ZK[2024]一般625项目；国家重点研发计划课题（2021YFD1100303）后补助项目；贵州科学院青年基金（黔科院J字2023[16]号）

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and transverse fruit diameter, colour-changing period, average fruit number and weight of individual tree, yield, intrinsic quality of the fruit (titratable acid, total sugar, total free amino acids, vitamin C, total phenols, total flavonoids and *β*-carotene), content of chlorophyll-a and chlorophyll-b, photosynthetic properties (net photosynthetic rate, transpiration rate, stomatal conductivity and intercellular CO_2 concentration). 【Results】In contrast to the control, Light Supplement (L) indicated: there was no significant effect on the branch length and internode length, while it could significantly increase the internode thickness by 4%; there was no significant effect on the longitudinal fruit diameter and transverse fruit diameter, but it could accelerate the fruit color change by 3 d (5%); there was no significant effect on the yield, but it could increase the titratable acid content by 3% and the total sugar content by 2%, and the total free amino acids content significantly increased by 12%, the vitamin C content significantly increased by 9%, the total phenols content significantly increased by 13%, the total flavonoids content significantly increased by 38%, the *β*-carotene content significantly increased by 19%, and the chlorophyll-a content significantly increased by 11%; there was no significant effect on the chlorophyll-b content, but the net photosynthetic rate significantly increased by 20%, the transpiration rate significantly increased by 8%, the stomatal conductance significantly increased by 19%, and there was no significant effect on the intercellular CO_2 concentration. Rain Shelter (RS) indicated: the branch length significantly increased by 19%, the internode length significantly increased by 26%, the internode thickness significantly decreased by 20%, but ther was no significant effect on the longitudinal fruit diameter and transverse fruit diameter, and the fruit color change was delayed by 8 d (14%), yield significantly increased by 20%, the titratable acid content significantly decreased by 14%, the total sugar content significantly decreased by 11%, the total free amino acids content significantly decreased by 7%, the vitamin C content significantly decreased by 6%, the total phenols content significantly decreased by 64%, the total flavonoids content significantly decreased by 43%, the *β*-carotene content significantly decreased by 37%, the chlorophyll-a content significantly increased by 10%, the chlorophyll-b content significantly increased by 37%, the net photosynthetic rate significantly decreased by 50%, the transpiration rate significantly decreased by 62%, and the stomatal conductance significantly decreased by 55%, the intercellular CO_2 concentration significantly decreased by 7%. Rain Shelter + Light Supplement (RSL) indicated: the branch length significantly increased by 19%, internode length significantly increased by 7%, the internode thickness significantly decreased by 6%, while there was no significant effect on the longitudinal fruit diameter and transverse fruit diameter, and the fruit color change was delayed by 4 d (7%), yield significantly increased by 23%, the titratable acid content significantly decreased by 8%, the total sugar content significantly decreased by 10%, the total free amino acids content significantly decreased by 6%, the vitamin C content significantly decreased by 4%, the total phenols content significantly decreased by 50%, the total flavonoid content significantly decreased by 37%, the *β*-carotene content significantly decreased by 25%, the chlorophyll-a content significantly increased by 19%, the chlorophyll-b content significantly increased by 40%, the net photosynthetic rate significantly decreased by 37%, the transpiration rate significantly decreased by 46%, and the stomatal conductance significantly decreased by 51%, but there was no significant effect on the intercellular CO_2 concentration. 【Conclusion】Light Supplement (L) can significantly improve the leaf photosynthetic characteristics, increase the nutrient contents in fruit, and accelerate the time of fruit color change, but cannot effectively increase the yield. Rain Shelter (RS) and Rain Shelter + Light Supplement (RSL) can significantly increase the yield, but it may lead to the decline of the plant photosynthesis characteristics and the intrinsic fruit quality, and delay the time of fruit color change. All indicators of RSL were better than RS, indicating that light supplement can compensate for the influence of insufficient light, but the effect of light source in this test is apparently less than that of natural light. Rain shelter and light supplement should be used according to the actual requirements.

Key words: Passion fruit; Rain shelter; Light supplement; Yield; Fruit quality; Photosynthetic characteristic

西番莲是原产于热带地区的西番莲科（Passifloraceae）西番莲属（*Passiflora* Linn.）草本或常绿攀缘木质藤本多年生植物，国外一般称“Passion fruit”[1]，并根据口味的酸甜分为酸果型西番莲（sour passion fruit）[2]和甜果型西番莲（sweet passion fruit）[3]。国内则习惯根据果皮颜色将可食用西番莲分为“紫果”和“黄果”两大类，也常将二者统称为“百香果”，甜果型黄果西番莲（*P. edulis* f . *favicarpa*）因甜度高、香气多样而成为当前主栽的鲜食品种[4]。

西番莲在贵州和国内其他主栽省份的种植模式主要是露地栽培，贵州西番莲的花果期集中在6—9月，此时贵州正值多雨夏季[5]，受雨水及高温影响，存在传粉昆虫减少、病虫害高发、花粉活力降低及落花落果等问题，制约了贵州西番莲产业的发展。避雨设施栽培可避免雨水机械损伤、调节棚内小气候环境、降低病虫害发生率并提高果树开花坐果率[6-7]，是减轻环境不利影响的有效措施，但对避雨栽培的研究发现，避雨棚膜对光照的抑制率为25%~50%[6]，植物长期处于弱光环境下会导致光合效率降低从而出现生长发育迟缓、枝条细长、开花延迟、果实小、果实营养物质积累下降等现象[8-10]。补光作为提高植物光合效率的有效手段之一，在番茄和葡萄等果蔬栽培上已有广泛应用，例如补光能使番茄叶面积指数提高43.42%，产量提高24.14%[11]，叶绿素（a+b）含量提高8.93%、净光合速提升率93.69%[12]，使葡萄叶片净光合速率提高45.66%，显著提高葡萄单粒质量和纵横径、可溶性糖和可滴定酸含量等[13-14]。因此，通过避雨设施和补光来提高西番莲的产量和品质，对贵州西番莲提质增效具有重要意义。

笔者在本试验中以贵州当前主栽品种甜果型黄果西番莲为研究对象，观测西番莲在避雨（Rain Shelter，RS）、补光（Light supplement，L）、避雨+补光（Rain Shelter+Light supplement，RSL）和露地栽培（CK）等不同栽培模式下结果枝生长、果实发育及产量，可滴定酸、总糖、总游离氨基酸、维生素C、总酚、总黄酮、*β*-胡萝卜素含量等果实品质指标，叶绿素a和叶绿素b含量，净光合速率、蒸腾速率、胞间二氧化碳浓度、气孔导度等光合特性指标，探讨不同栽培模式对西番莲的影响，以期为西番莲设施栽培提供参考。

1 材料和方法

1.1 试验地与材料

试验在贵州科学院植物种质资源保育基地（26°55′22″ N，106°49′25″ E，海拔1 051.3 m）进行，棚内设4个小区，采用4 mm钢丝搭建单层双向垂帘架，架高1.8 m。基地年均温15.3 ℃，极端高温37.8 ℃，极端低温−2.9 ℃，土壤pH 6.5，0~20 cm土层全氮含量（*w*，后同）2.42 g · kg^{-1}，全磷含量1.25 g · kg^{-1}，全钾含量12.86 g · kg^{-1}，有机质含量6.01%。

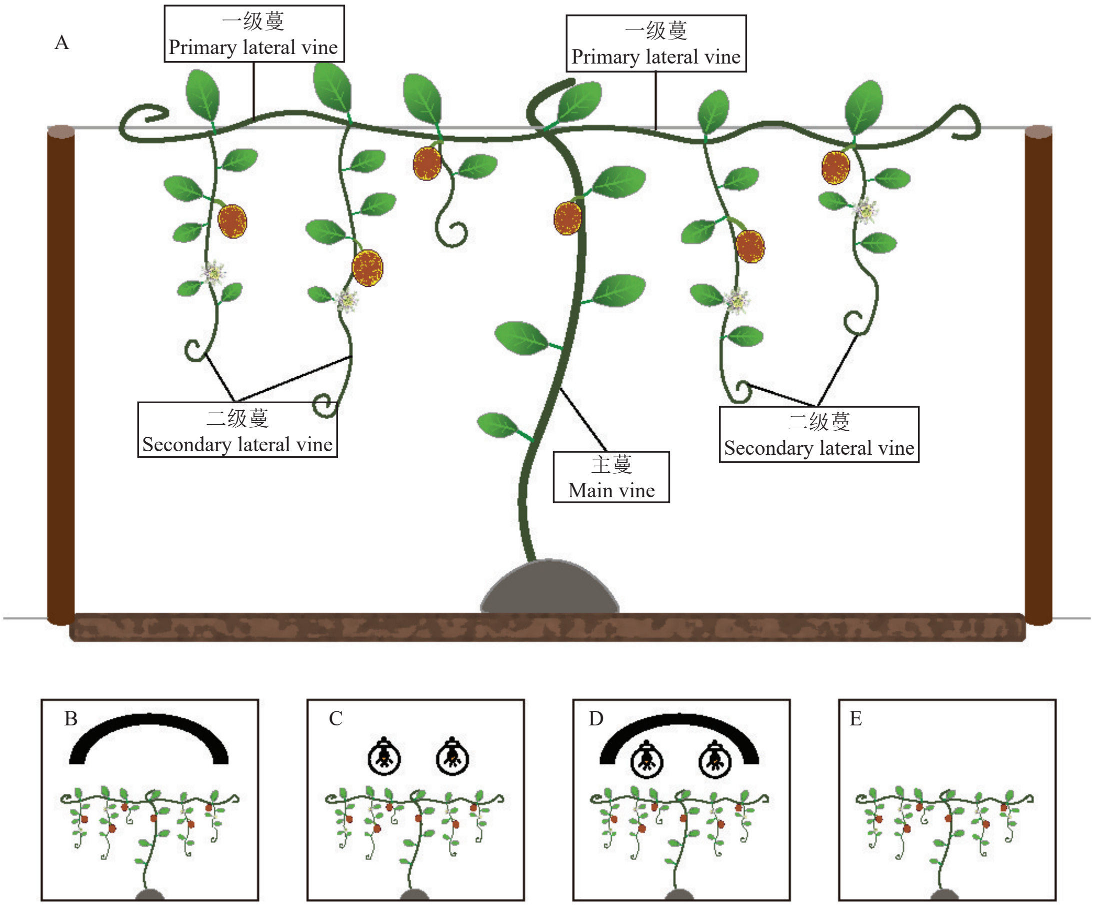
供试材料为甜果型黄果西番莲5月龄嫁接苗，苗高80~100 cm，每小区种植2行，行距4 m，每行15株，株距1.5 m，种植密度为110株•666.7 m^{-2}（1650株•hm^{-2}）。所有试验材料于2023年3月定植，每株施农家肥5 kg，栽培模式如图1-A所示，所有小区均采用相同农艺管理。

1.2 试验设计

设置避雨和补光2个因素，共3个处理和1个对照，分别为避雨（Rain shelter，RS，图1-B）、补光（Light supplement，L，图1-C）、避雨+补光（Rain Shelter + Light Supplement，RSL，图1-D）和露地栽培（open field cultivation，CK，图1-E）。避雨棚膜为聚乙烯薄膜，厚15 S（0.15 mm），顶高5 m，大棚侧面薄膜全部打开。补光灯为LED灯，功率30 W，设置在植株上方1 m，白光（410 nm）∶蓝光（450 nm）∶红光（660 nm）=1∶1∶1，光照度设置为西番莲适宜光照度2800 lx[15]，根据西番莲适宜光周期16∶8[16]设置补光时间为5:00—21:00，其间当光照度低于2800 lx时补光灯自动开启。

1.3 指标及测定方法

1.3.1 结果枝长度、节间长度及粗度 5月初，每个处理随机选取10株，每株随机选取1个二级蔓新萌发嫩梢，每隔5 d测量枝条长度，共测7次，并在35 d将结果枝打顶，同时测量第3~8节[17]节间平均长度



A. 西番莲栽培模式；B. 避雨；C. 补光；D. 避雨+补光；E. 对照。

A. Diagram of the cultivation mode; B. Rain shelter; C. Light supplement; D. Rain shelter + light supplement; E. CK.

图1　西番莲栽培模式（A）及不同处理（B、C、D和E）示意图

Fig. 1　Diagrams of the cultivation mode (A) and different treatments (B, C, D and E) of passion fruit

和粗度。

1.3.2　果实纵径、横径及转色时间　6月底，每个处理随机选取10朵花，在同一日进行人工授粉，每隔5 d用电子游标卡尺测量果实纵横径，共测7次，并观察记录果实成熟所需转色时间。

1.3.3　单果质量、单株结果数及产量　各处理于9月中旬（记为S1期，下同）采集主蔓和一级蔓成熟果实，10月中旬（记为S2期，下同）采集二级蔓成熟果实，在两个时期分别随机取10个果实测定单果质量，并计算平均单果质量。每个处理随机选择5株，收集首次采摘到11月底全部成熟果实，计算平均单株结果数。根据平均单果质量、平均单株结果数和种植密度计算产量。

1.3.4　果实内在品质　于S1和S2时期，各处理随机取10个成熟果实可食部分混样，3次重复。用酸碱滴定法测定总有机酸含量，采用酸水解苯酚-硫酸比色法测定总糖含量，采用茚三酮显色法测定总游离氨基酸含量，采用2,6-二氯靛酚滴定法测定维生素C含量，采用福林酚比色法测定总酚含量，采用硝酸铝盐比色法测定总黄酮含量，采用乙醇-石油醚提取直接比色法测定β-胡萝卜素含量。

1.3.5　叶绿素含量　于7月中下旬和8月中下旬（S1和S2果实生长发育时期），各处理随机取10枚完整、健康叶片剪碎混样，5次重复。采用分光光度法[18]测定叶绿素a和叶绿素b含量。

1.3.6　光合参数　7月中下旬和8月中下旬选择某一晴天，于当天的09:00—11:00，各处理随机选择健康西番莲5株，在植株0.6、1.2、1.8 m处用LI-6800光合仪测定叶片净光合速率、胞间二氧化碳浓度、蒸腾速率和气孔导度。

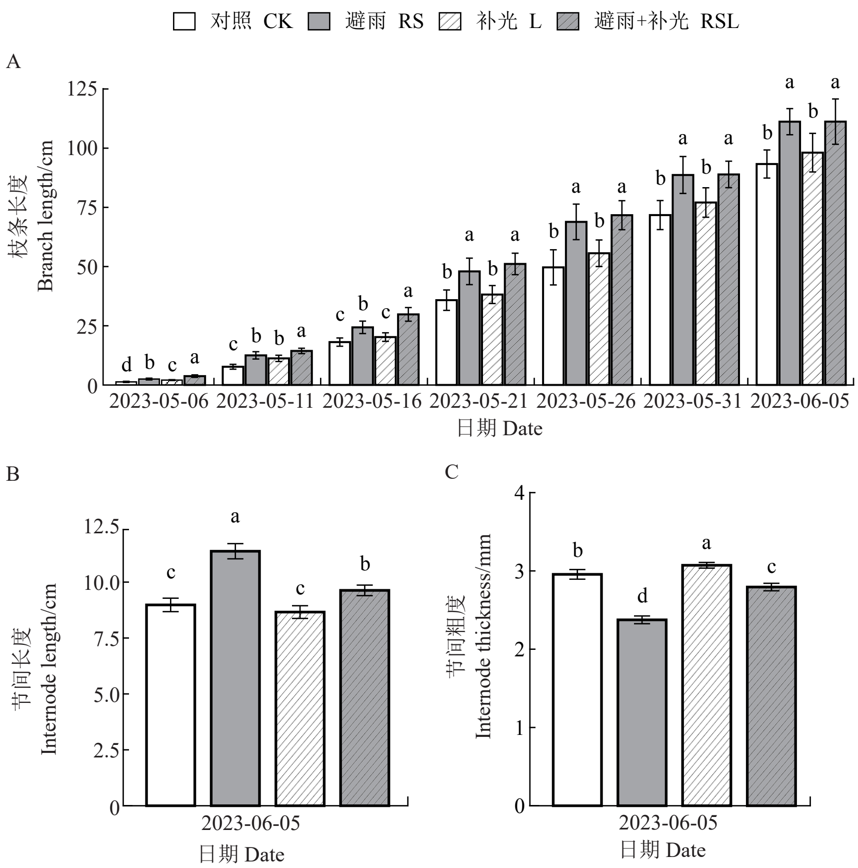
1.4　数据处理与分析

用WPS进行原始数据记录和整理，栽培模式采用Adobe Illustrator作图，用R语言进行数据分析统计，显著性检验通过t检验进行。

2 结果与分析

2.1 避雨补光对西番莲结果枝生长的影响

西番莲结果枝生长情况如图2所示，前15 d各处理的差异在不断变化，萌芽后20 d结果枝生长稳定，避雨组结果枝长度显著高于未避雨组（L和CK为未避雨组，RS和RSL为避雨组，下同），且补光对结果枝生长无显著影响（图2-A），节间平均长度在避雨组与未避雨组间有显著差异，RS显著高于RSL，节间平均长度表现为RS＞RSL＞CK＞L（图2-B）；节间平均粗度在4个处理间均有显著差异，最大为L，其后依次为CK、LRS、RS（图2-C）。西番莲结果枝生长情况说明，避雨能增加西番莲结果枝长度和节间长度，同时降低枝条粗度，而补光有利于枝条增粗。



不同小写字母表示在 $p<0.05$ 差异显著。下同。

Different small letters indicate significant difference at $p<0.05$. The same below.

图2 不同处理下西番莲枝条长度（A）、节间长度（B）和节间粗度（C）对比

Fig. 2 Comparison of branch length (A), internode length (B) and internode thickness (C) of passion fruit under different treatments

2.2 避雨补光对西番莲果实生长发育的影响

西番莲果实生长发育和转色时间如图3所示，果实在授粉后3周膨大基本结束，不同处理间果实纵径和横径在7个观测时间点均无显著差异，在授粉35 d后纵径呈现L＞CK＞LRS＞RS（图3-A）、横径呈现CK＞L＞LRS＞RS的趋势（图3-B）；果实转色平均所需时间最短为L（52.8 d），较CK、RSL、RS分别显著缩短2.6、6.4、10.7 d（图3-C）。观测结果表明，避雨和补光对果实纵横径无显著影响，但会影响果实转色时间。

2.3 避雨补光对西番莲产量的影响

避雨组和未避雨组间的平均单果质量、平均单株结果数和产量均存在显著差异，组内处理无显著差异，RS和RSL平均单果质量比CK分别降低23.2%和20.6%，单株平均结果数比CK分别高出56.7%和55.4%，产量比CK分别提高20.4%和23.4%（表1）。结果表明，补光对产量无显著影响，避雨能显著提高产量。

2.4 避雨补光对西番莲果实内在品质的影响

不同处理的西番莲果实营养物质含量情况如图

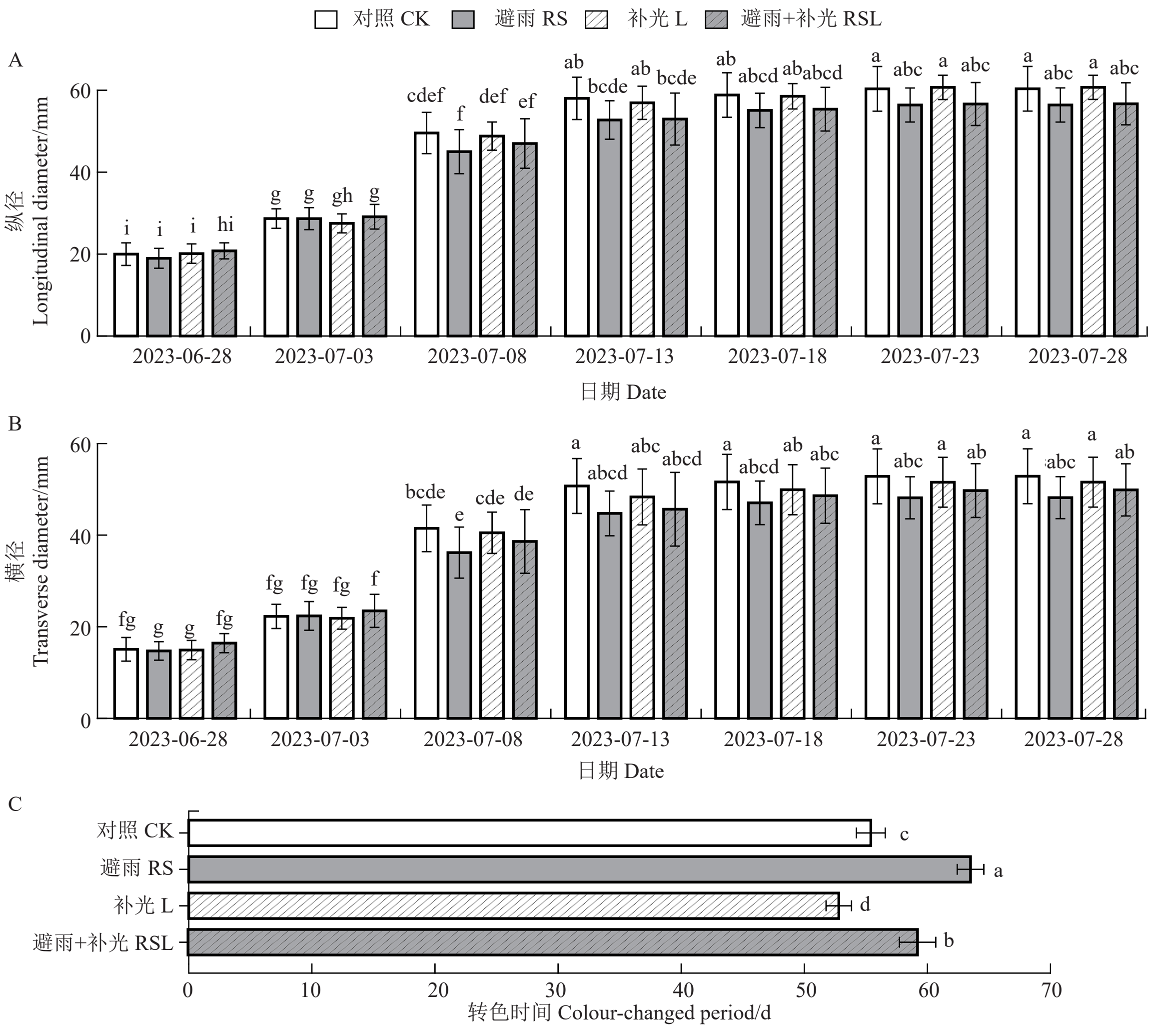


图3　不同处理下西番莲果实纵径（A）和横径（B）生长变化及转色时间（C）对比

Fig. 3　Comparison of fruit longitudinal diameter (A) and transverse diameter (B), colour-changed period (C) of passion fruit under different treatments

表1　不同处理下西番莲平均单果质量、平均单株结果数及产量

Table 1　Average weight of individual, average fruits number and yield of passion fruit under different treatments

处理 Treatment	平均单果质量 Average fruits mass/g	平均单株结果数 Average fruits number of individual	产量 Yield/（kg·hm^{-2}）
CK	80.82±15.78 a	60.7±11.10 b	8 094.5±2 604.6 b
RS	62.10±10.30 b	95.1±11.12 a	9 744.4±1 882.8 a
L	82.38±14.70 a	61.3±11.16 b	8 332.3±1 156.3 b
RSL	64.18±9.96 b	94.3±13.15 a	9 986.1±2 487.4 a

4所示，两个时期不同处理下可滴定酸、总糖、总游离氨基酸和总酚含量在避雨组和未避雨组间有显著差异，维生素C及β-胡萝卜素含量L高于CK且显著高于避雨组，S1期RS总黄酮含量显著低于其他处理，而S2期未避雨组总黄酮含量显著高于避雨组，营养物质含量差异主要体现在S2期总酚、总黄酮和β-胡萝卜素含量上，RS、RSL总酚含量比CK分别减少64%和50%，总黄酮含量分别减少43%和37%，β-胡萝卜素含量分别减少37%和25%，L总酚含量比CK高出13%，总黄酮含量高出38%，β-胡萝卜素含量高出19%。S1期至S2期，未避雨组主要营养物质含量有不同程度提高，避雨组则下降，各处理的总游离氨基酸均呈下降趋势。果实营养物质测定结果说明，避雨和补光对果实内在品质均有显著影响，补光L能促进西番莲果实营养物质积累，避雨处理则会降低果实营养物质积累。

2.5　避雨补光对西番莲叶绿素含量及光合特性的影响

不同处理的西番莲叶片叶绿素含量如图5所示，7月，RSL、RS、L叶绿素a含量比CK分别提高

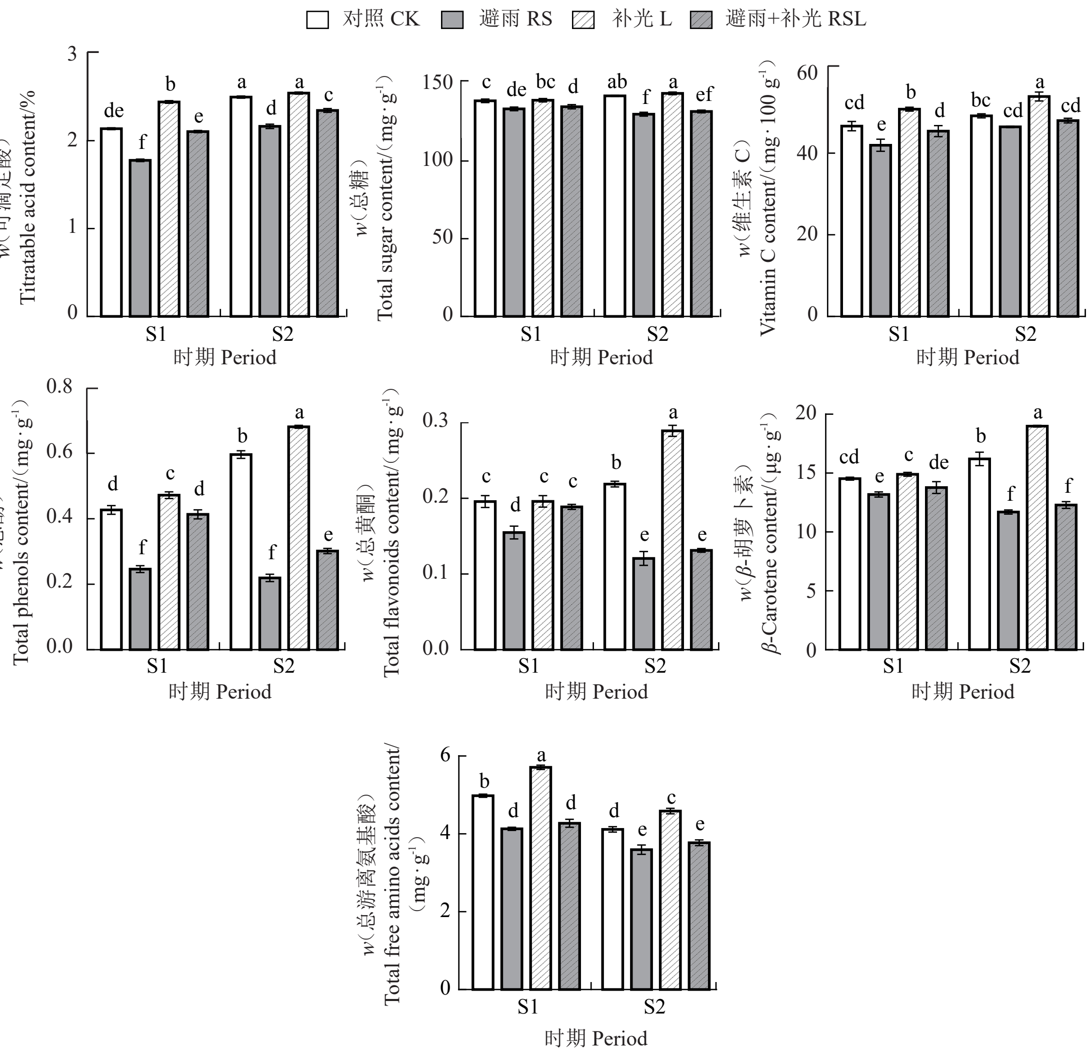


图 4 不同处理下 S1 期和 S2 期西番莲果实主要营养物质含量对比

Fig. 4 Comparison of main nutrient content during S1 and S2 under different treatments

23%、18%和5%，叶绿素b含量分别提高30%、24%和2%；8月，RSL、RS、L叶绿素a含量比CK分别提高19%、10%和11%，叶绿素b含量分别提高40%、37%和7%。7—8月，未避雨组叶绿素a含量升高，叶绿素b含量降低，叶绿素(a+b)含量基本无变化，叶绿素a/b值升高；避雨组叶绿素相关指标均有小幅下降，叶绿素a降幅大于叶绿素b。叶绿素含量测定结果说明，避雨和补光均能提高植株叶绿素含量。

不同处理下西番莲光合特性如图6所示，7月，未避雨组净光合速率(P_n)、蒸腾速率(T_r)和气孔导度(G_s)均显著高于避雨组，RS胞间二氧化碳浓度(C_i)显著低于其他处理；8月，未避雨组P_n、T_r和G_s仍显著高于避雨组，各处理C_i也有差异，L的P_n较CK提高20%，RS和RSL则比CK分别减少50%和37%。7—8月，未避雨组P_n、T_r和G_s仍有不同程度提高，避雨组P_n、T_r和G_s则小幅下降，C_i在各处理间均下降。光合特性监测结果说明，避雨和补光对西番莲植株光合特性均有显著影响，补光能提高植株光合效率，避雨则会降低植株光合效率。

3 讨 论

3.1 避雨补光对西番莲生长发育及产量的影响

结果枝的节间缩短和粗度增加有利于植物营养吸收和水分转运从而提高果实品质[19]，本研究结果表明，补光L处理能使西番莲结果枝节间粗度显著增加，这与设施葡萄补光的结果一致[20]，避雨模式RS和RSL则使结果枝更细长，这主要是因为避雨棚膜对光照的阻挡引起弱光胁迫[6]，导致植物产生更长、更细的茎以适应弱光环境[8]，这与烟草的研究结果一致[9]。总之，弱光胁迫并不利于西番莲生长发

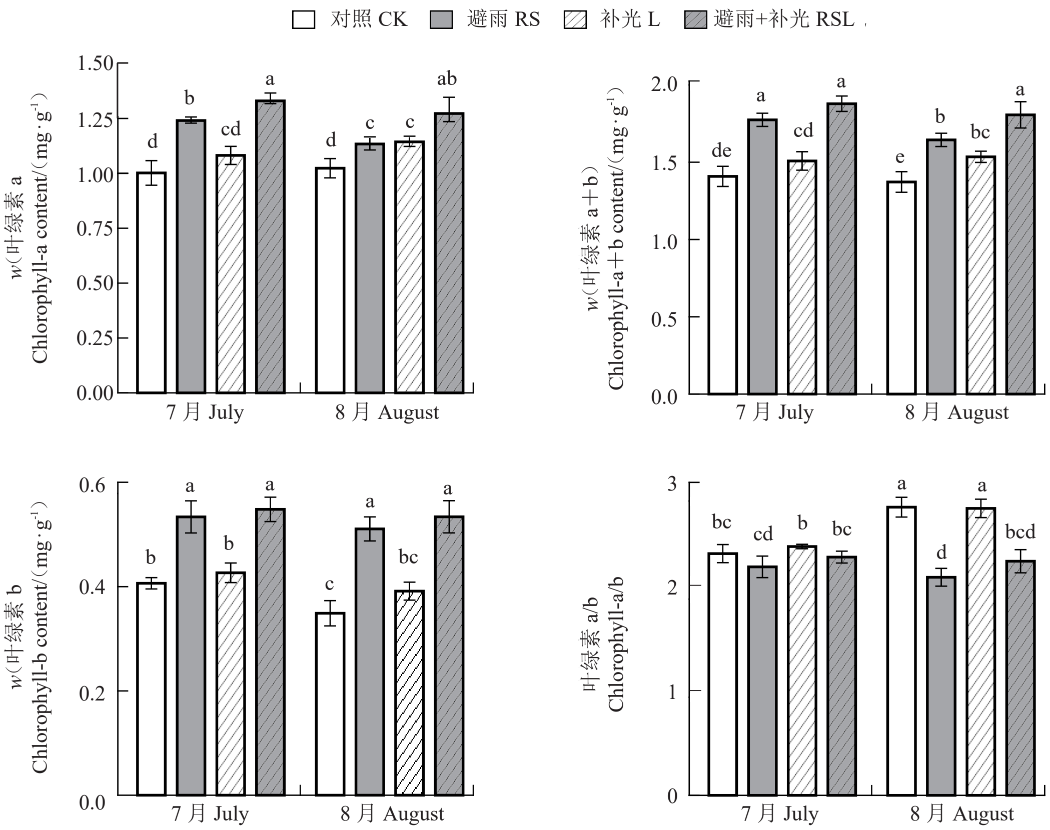


图 5　不同处理下 7 月和 8 月西番莲叶绿素含量对比

Fig. 5　Comparison of chlorophyll content during July and August under different treatments

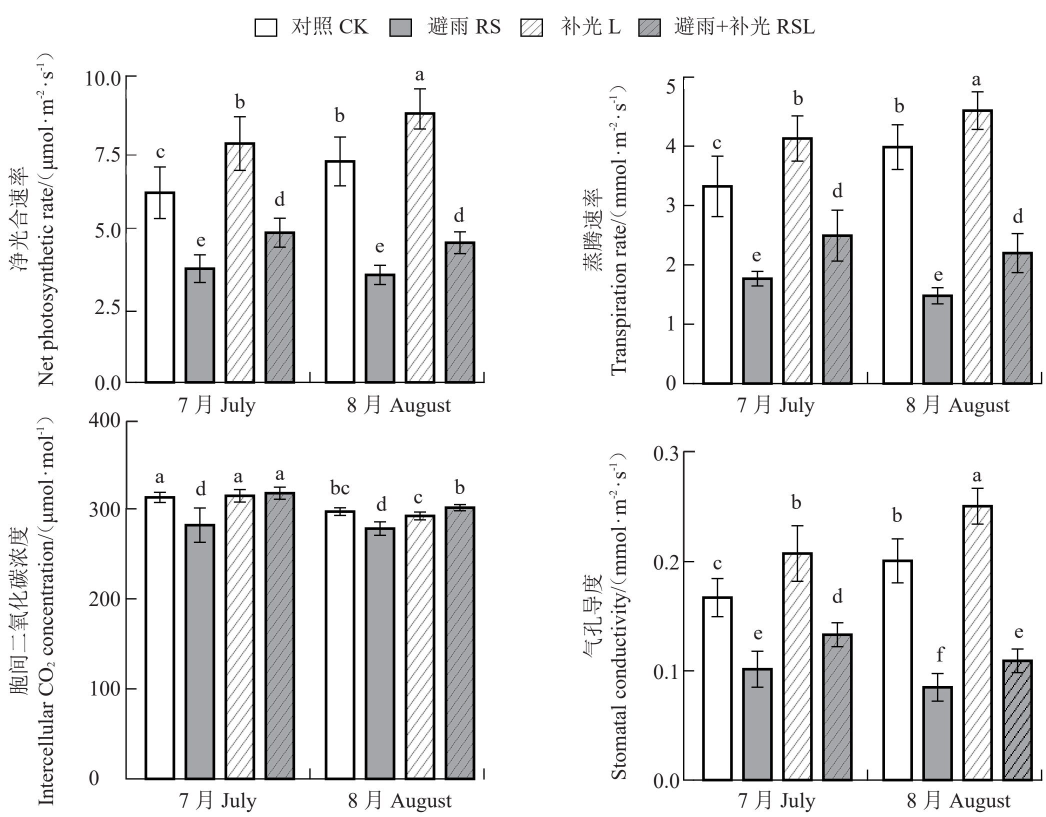


图 6　不同处理下 7 月和 8 月西番莲光合特性对比

Fig. 6　Comparison of photosynthetic characteristics during July and August under different treatments

育与营养物质积累。

试验中各处理间西番莲果实纵横径没有显著性差异，说明光照条件对西番莲果实纵横径生长影响不显著，西番莲果实生长发育主要与水肥供给差异有关[21-22]；补光能够加快西番莲果实转色，主要表现在光照能促进植物色素合成与积累[23-24]。综合来看，西番莲果实从生长到完成转色的最快处理为L处理，需80 d左右，生长周期比相关文献报道结果[15,22]慢10~30 d，主要原因是西番莲在整个生长发育周期较依赖合适的温度和相对湿度[17]，笔者在本试验中未监测环境因子，且避雨棚内小气候变化在不同研究中结论不同[6,25]，避雨栽培模式下西番莲生长发育的适宜环境条件另需详细研究。

避雨栽培的产量显著高于CK和L的原因要结合西番莲生长特性和气候条件来分析：夏季高温和强光会抑制西番莲花芽形成[17]，同时西番莲花果期与雨季同期，雨水会冲刷花粉、诱发病虫害等，避雨栽培则最大限度地避免了雨水与植株接触从而保证开花坐果，所以未避雨组单株结果数显著低于避雨组。西番莲在生长发育过程中，茎、叶生长和花芽、幼果发育同时进行，必然存在养分竞争[17]，更多的果实数量意味着植株养分供给分散，因此避雨组果实纵横径及单果质量低于CK。避雨栽培产量较露地栽培可显著提高20%以上，但在本试验中，西番莲的产量仍低于其他文献报道[14,21-22]，除前述环境因素外，与种植密度、水肥利用和修剪管护等都有关系[26-27]，生产中应兼顾各种因素。

3.2 避雨补光对西番莲果实内在品质、叶绿素含量及光合特性的影响

维生素C、酚、黄酮等西番莲果实所含抗氧化活性物质是当下研究的热点[28]，试验结果显示，补光能增加西番莲主要营养物质含量，提高果实内在品质，避雨则反之。研究表明，植物营养物质积累主要受光合作用强弱影响，净光合速率（P_n）可以反映植物对光能的利用效率，P_n提高能使植物产生更多光合产物参与代谢运输，促进营养物质积累[29-30]，而P_n与叶绿素（a+b）含量和叶绿素a/b值有密切关系，叶绿素（a+b）含量或叶绿素a/b值提高表示植物P_n愈高，反之P_n则愈低[31]。7月至S1期，L处理相较于CK能给植株提供更多光照，刺激植物合成更多叶绿素来捕获光能[32]，使L处理的植株叶绿素含量和P_n升高，进而促进营养物质积累，弱光胁迫也会刺激植物产生更多叶绿素来捕获光能[8]，但由于有效光合辐射减弱，RS缺少可利用的光能，导致P_n显著低于CK，果实品质也因此低于CK，RSL主要营养物质含量和P_n高于RS但仍显著低于CK。8月至S2期，植物会根据不同生长时期来调节自身叶绿素含量和P_n[33-34]，L叶绿素总量基本不变，但叶绿素a/b值升高，P_n高于前期L和同期CK，能积累更多营养物质，RS和RSL则可能受弱光环境下光合酶、叶绿体超微结构和激素变化等因素综合影响导致叶绿素含量较其下降[8,34-35]，P_n也低于各自前期和同期CK，同时随着果实数量不断增加，养分竞争加剧，最终导致单个果实营养物质积累减少，果实品质下降。T_r和G_s与P_n的变化趋势相同，这与烟草的研究结果一致[9]，L的C_i下降是因为P_n上升使CO_2利用率提高，RS和RSL的C_i下降则是因为植株总体光合特性减弱。

综上，补光L处理可以促进西番莲结果枝生长和果实转色，能提高叶绿素含量和净光合速率，促进果实营养物质积累，提高品质，但无法有效增加产量；避雨RS通过避免雨水与植株接触来提高花果数量，进而显著提高产量，但同时避雨棚膜会降低有效光合辐射，使果实转色时间延长及品质下降；避雨补光RSL处理的各项观测指标均略优于RS，证明试验光源能一定程度上弥补自然光照的不足。受限于试验条件，如能采取适时揭膜、增加避雨棚膜透光率、设置红蓝光比例及补光时长、调整光照度等措施，应能进一步提高西番莲的产量和品质，为西番莲设施栽培提供参考。

4 结 论

避雨能使西番莲产量提高20%以上，补光能使西番莲营养物质含量平均提高13%以上，在实际生产中可根据气候条件、建园成本和管护措施等因素选择使用方式。

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