邻株竞争对低磷环境杉木幼苗光合特性及生物量分配的影响

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摘要 选择同一杉木(*Cunninghamia lanceolata*)无性系幼苗为研究对象, 通过设计邻株竞争处理和3个供磷水平的室内沙培模拟试验, 采用破坏性收获方式, 分别于试验初期、中期和末期测定不同竞争与供磷水平条件下杉木幼苗光合特性和生物量分配的变化规律, 综合分析邻株竞争对低磷环境杉木响应行为的影响。结果表明: 竞争处理、供磷水平和胁迫时期三者对杉木幼苗4个光合特性指标的影响均存在明显的交互作用($p < 0.05$), 而对生物量分配的交互作用未达显著水平($p > 0.05$)。低磷和不供磷处理条件下杉木幼苗叶片的净光合速率、蒸腾速率和气孔导度均明显较低, 其中缺磷胁迫和邻株竞争对叶片气孔导度的降低具有叠加效应。随着竞争和低磷处理时间的延长, 杉木幼苗叶片蒸腾速率逐渐降低, 但气孔导度和胞间CO₂浓度呈先下降后上升的趋势, 而根系生物量和根冠比均显著增加。

关键词 同化物运输; 杉木; 竞争策略; 低磷胁迫; 根冠比

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Effect of neighboring competition on photosynthetic characteristics and biomass allocation of Chinese fir seedlings under low phosphorus stress

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Abstract

Aims To explore the effects of neighbor competition on photosynthetic characteristics in needles and biomass accumulation and allocation of Chinese fir (*Cunninghamia lanceolata*) seedlings under low phosphorus (P) environment, and to investigate the complex adaptive responses of Chinese fir to available P limitation and intraspecific competition.

Methods The experiment was performed in a greenhouse at Fujian Agriculture and Forestry University with a Chinese fir clone named ‘YANG-020’. The specially designed glass pots of 30 cm length, 30 cm width and 40 cm height were made for the P stress and competition simulation. Two seedlings were planted in each pot, except the control with a single seedling in the center of pot. All the competition treatments were involved three P supply levels: no P supply (0 mg·kg⁻¹ KH₂PO₄), low P supply (6 mg·kg⁻¹ KH₂PO₄) and normal P supply (12 mg·kg⁻¹ KH₂PO₄). The seedlings of each treatment were harvested to determine shoot biomass, root biomass and root: shoot ratio at the prime stage (9th September, 2013), interim stage (30th October, 2013) and last stage (19th December, 2013), separately, after determining the intercellular CO₂ concentration, net photosynthetic rate, transpiration rate and stomatal conductance in needles over the experimental period.

Important findings There were significantly three-way interactive effects among competition treatment, P supply level and stress stage on the photosynthetic indexes of Chinese fir seedlings, including intercellular CO₂ concentration, net photosynthetic rate, transpiration rate and stomatal conductance ($p < 0.05$), but no significantly interactive effect was exhibited among the three factors on the biomass allocation ($p > 0.05$). Compared to the normal P supply, all of the values (*i.e.*, net photosynthetic rate, transpiration rate and stomatal conductance) decreased markedly in Chinese fir needles. The factors of low P supply and neighboring competition additively

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affected stomatal conductance of needles. Over the course of the stress experimental period, the value of transpiration rate in needles gradually decreased, but both root biomass and root:shoot ratio sharply increased. For the stomatal conductance and intercellular CO₂ concentration, both of them gradually declined from the prime stress stage to the interim stage, while increased during the last stress stage.

Key words assimilate transport; *Cunninghamia lanceolata*; competitive strategy; low phosphorus stress; root:shoot ratio

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自然环境中,植物无法像动物一样自由移动,在整个生命周期内持续不断遭受种内或种间对共有环境资源的竞争(Novoplansky, 2009)。当植物低密度种植时,植物间的竞争主要发生于地下(Di Iorio *et al.*, 2013)。植物可利用根系形态可塑性(Rolo & Moreno, 2012; Chen *et al.*, 2015)、根系分泌有机物(Kigathi *et al.*, 2013; Pierik *et al.*, 2013, 2014)等策略调整自身同化物在根冠间的分配格局,从而影响邻株植物间竞争关系(Schmid *et al.*, 2015)。而种植密度较大时,植物主要通过叶片红光(R, 波长655–665 nm)与远红光(FR, 波长725–735 nm)比值的变化来感受邻株植物的竞争强度(Ballaré *et al.*, 1990; Gundel *et al.*, 2014)。李建东等(2006)研究发现,光竞争优势植物的光合速率、蒸腾速率、气孔导度明显高于弱势植物,但低于非竞争环境下。黄顶菊(*Flaveria bidentis*)和藜(*Chenopodium album*)混种模式下,二者的净光合速率等均明显低于各自单植模式下,能有效地抑制黄顶菊的蔓延生长(杨晴等, 2014)。木质藤本植物也可通过改变表型特征,明显抑制需光植物的光合能力,从而增强自身竞争能力(陈亚军等, 2008)。然而,地上部分的竞争意味着根系对养分、水分等资源的竞争也逐渐增强(王平等, 2007)。特别是在养分不足的环境,邻株植物之间的竞争关系更为复杂(Mommer *et al.*, 2012; Wu *et al.*, 2014a)。因此,养分匮乏环境下植物的竞争行为是当前一个研究热点(Cheng *et al.*, 2014; Gundel *et al.*, 2014; Schmid *et al.*, 2015)。

磷是植物所需的大量元素,是植物光合作用、养分运输等生理生化过程的重要参与者(马祥庆和梁霞, 2004; 蔡丽平等, 2012)。我国约2/3的农林用地严重缺磷,极大地限制了植物的正常生长(李杰等, 2011)。杉木(*Cunninghamia lanceolata*)是我国特有的优质速生用材树种,土壤有效磷匮乏已明显抑制杉

木人工林的长期生产力(Chen, 2003; Zhang *et al.*, 2004; 盛炜彤和范少辉, 2005)。吴鹏飞等(2011)研究表明低磷胁迫下杉木叶片光系统II (PSII)光合反应中心破坏严重,光合效率明显受阻。不同植物或同种植物不同基因型对低磷胁迫的适应能力存在明显差异(马祥庆和梁霞, 2004; 吴鹏飞和马祥庆, 2009)。有些植物可通过降低光合和蒸腾速率、调节气孔大小等途径,有效地控制光合作用的同化物质运输,提高磷素利用效率,从而缓解缺磷对植物的伤害(曹翠玲等, 2010; 樊卫国和王立新, 2012)。近年来,有关高效利用土壤磷杉木基因型的筛选(Wu *et al.*, 2011b; 吴鹏飞等, 2012),以及试图通过挖掘并利用这些基因型对低磷胁迫的形态生理学响应机制,以维持杉木长期生产力的研究已有相关报道(梁霞等, 2005; Yu *et al.*, 2008; Wu *et al.*, 2011a; 赵中华等, 2014; Zou *et al.*, 2015)。然而,这些研究只是考虑单株栽植的情况,而有关邻株竞争对这些响应机制的影响研究甚少。

鉴于此,本文选择同一杉木无性系幼苗为研究对象,通过设计竞争处理和3个供磷水平的室内沙培模拟试验,采用破坏性收获方法,分别于盆栽的初期、中期和末期测定不同竞争与低磷胁迫条件下杉木幼苗叶片胞间CO₂浓度、净光合速率、蒸腾速率及气孔导度等光合特性参数的变化规律,结合不同试验时期杉木地上部分和根系的干物质分配量,综合分析邻株竞争对低磷环境杉木响应策略的影响情况,为揭示低磷胁迫下杉木光合同化产物积累与分配的调控机制和提高杉木林生产力提供科学基础。

1 材料和方法

1.1 试验材料

选择福建省洋口林场国家杉木良种基地培育的无性系(‘洋-020’)为研究对象。该无性系具有冠幅

小、树冠稀疏、生长快等特点, 初植密度为3 600–3 900株·hm⁻², 适于定向培育中小径材(李林源等, 2015)。参试材料为18个月生长健壮幼苗, 长势均一。

1.2 试验设计

于2013年7月采用长30 cm、宽30 cm、高40 cm的自制玻璃容器在福建农林大学温室大棚进行沙培盆栽试验。根据所有参试杉木幼苗的平均冠幅(5 cm)设置竞争处理: 邻株栽植2株杉木的茎间距均为5 cm, 并以单株栽植(非竞争处理)为对照(图1)。培养基质为洗净的河沙(总磷含量为(0.11 ± 0.004) mg·g⁻¹, 有效磷为痕量), 根据每盆河沙质量(30 kg), 设计3个供磷水平: 不供磷(0 mg·kg⁻¹ KH₂PO₄)、低磷处理(6 mg·kg⁻¹ KH₂PO₄)和正常供磷(12 mg·kg⁻¹ KH₂PO₄)。利用具有不含磷素、吸附性强、缓效释放养分、植物根系可自由穿透等特性的吸水树脂(water-absorbent resin) (Downie *et al.*, 2012), 在吸附KH₂PO₄之后与河沙混匀用于盆栽。为保证试验期间杉木幼苗对其他养分元素的需求, 每隔3天浇一次不含磷素的Hoagland营养液(Wu *et al.*, 2011a), 每盆每次浇100 mL。用KCl平衡不同供磷处理间K⁺含量的差异。每天午后浇纯净水100 mL。温室内温度为18–28 °C, 相对湿度>80%, 每天光照14 h, 光照强度约800 μmol·m⁻²·s⁻¹。分别在培养初期(2013年9月9日)、中期(2013年10月30日)和末期(2013年12月19日)测定杉木幼苗叶片的光合参数, 并采用破坏性收获试验测定生物量。每个处理重复4次。

1.3 测定方法

盆栽开始后, 每隔50天左右, 选择晴天(2013年9月9日、2013年10月30日、2013年12月19日) 9:00–11:00, 采用便携式光合测定系统(LCi-SD Ultra Compact Photosynthesis System, ADC Bio Scientific, Hertfordshire, UK)对杉木幼苗第1轮新生枝条上的健康成熟叶进行叶片胞间CO₂浓度、气孔导度、净光合速率和蒸腾速率等光合参数指标的测定。测定条件为: 环境CO₂浓度395 μmol·mol⁻¹、叶室温度(23 ± 0.5) °C、叶室流速500 μmol·s⁻¹, 光照强度为1 000 μmol·m⁻²·s⁻¹。并将收获后的杉木幼苗分为地上部分和根系, 分别用108 °C杀青后80 °C烘干至恒质量, 测定干物质质量。

1.4 数据统计

邻株栽植处理中每个数据表示相邻2株相同杉

图1 邻株竞争处理盆栽示意图。

Fig. 1 The design pot used for neighboring competition experiment.

木无性系同一测定指标的平均值。利用SPSS v.19.0 (SPSS, Chicago, USA)进行竞争处理(竞争和非竞争)、供磷水平(不供磷、低磷处理和正常供磷)和胁迫时期(初期、中期和末期)这3个因素对杉木幼苗光合特性、生物量等测定指标的交互作用进行多因素方差分析, 包括三因素方差分析和任意两个因素间的双因素方差分析。若各因素间无显著交互作用($p > 0.05$), 则进行单因素方差分析, 利用LSD多重比较方法进行检验($p = 0.05$), 分析3个因素之间对测定指标的叠加影响效应。所有数据结果以平均值±标准误差表示, 不同字母表示各处理间差异达显著水平($p < 0.05$)。

2 结果和分析

2.1 低磷胁迫条件下邻株竞争对杉木叶片光合特性的影响

三因素方差分析结果(表1)表明, 竞争处理、供磷水平和胁迫时期三者对杉木幼苗叶片胞间CO₂浓度、净光合速率、蒸腾速率和气孔导度等光合特性指标的影响均存在明显的交互作用($p < 0.05$)。其中

表1 竞争处理、供磷水平和胁迫时期对杉木幼苗光合特性的影响

Table 1 Effects of competition treatment, phosphorus supply level and stress stage on the photosynthesis characteristics of *Cunninghamia lanceolata* seedlings

	自由度 Degrees of freedom	F值F value			
		胞间CO ₂ 浓度 Intercellular CO ₂ concentration	净光合速率 Net photosynthetic rate	蒸腾速率 Transpiration rate	气孔导度 Stomatal conductance
竞争处理 Competition treatment (a)	1	53.9**	5.807*	11.181**	4.4*
供磷水平 Phosphorus supply level (b)	2	0.7 ^{ns}	16.698**	15.740**	20.9**
胁迫时期 Stress stage (c)	2	10.4**	0.698 ^{ns}	18.314**	3.3*
a和b组间交互作用 Effects between a and b	2	29.1**	6.984**	5.919**	0.9 ^{ns}
a和c组间交互作用 Effects between a and c	2	6.6**	9.382**	3.494*	8.2**
b和c组间交互作用 Effects between b and c	4	8.7**	4.323**	9.111**	10.5**
a、b和c组间交互作用 Effects among a, b and c	4	3.9**	3.522*	8.247**	8.4**
误差 Error	90				

*, $p < 0.05$; **, $p < 0.01$; ns, $p > 0.05$ 。

图2 竞争和非竞争处理下杉木幼苗叶片的光合特性(平均值±标准误差)。不同小写字母表示不同竞争处理间差异显著($p < 0.05$)。

Fig. 2 Photosynthetic characteristics of *Cunninghamia lanceolata* seedlings under neighboring competition treatment (mean ± SE). Different small letters indicate significant difference between two competition treatments ($p < 0.05$).

任意2个因素之间对叶片胞间CO₂浓度、净光合速率和蒸腾速率的交互影响作用均达显著水平($p < 0.05$, 表1); 但竞争处理与供磷水平这两个因素对叶片气孔导度的交互作用不显著($p > 0.05$, 表1)。

从单个因素对杉木叶片光合特性不同指标的影响情况来看, 竞争处理对4个光合特性指标的影响均达显著水平($p < 0.05$, 表1)。其中, 竞争处理中杉木幼苗叶片平均净光合速率、蒸腾速率和气孔导度均明显低于非竞争的单株种植处理(图2B–2D); 与之相反, 竞争处理中叶片的胞间CO₂浓度明显高于非竞争处理(图2A)。供磷水平对杉木幼苗叶片胞间CO₂浓度的影响不显著($p > 0.05$, 表1; 图3A), 但对净光合速率、蒸腾速率和气孔导度等3个参数的影响均达显著水平($p < 0.05$, 表1)。与正常供磷(12

mg·kg⁻¹ KH₂PO₄)相比, 低磷和不供磷处理条件下杉木幼苗叶片的净光合速率、蒸腾速率和气孔导度均明显较低(图3B–3D)。胁迫时期对杉木幼苗叶片胞间CO₂浓度、蒸腾速率和气孔导度这3个光合参数的影响具显著水平($p < 0.05$, 表1), 但对净光合速率的影响不显著($p > 0.05$, 表1; 图4B)。从图3A、3D可以看出, 杉木幼苗叶片胞间CO₂浓度、气孔导度随着胁迫时期的延长呈先下降后上升的趋势; 而蒸腾速率则随着胁迫时期的延长明显降低(图4C)。

2.2 低磷胁迫条件下邻株竞争对杉木生物量积累与分配的影响

竞争处理、供磷水平和胁迫时期三者对杉木幼苗地上部分生物量、根系生物量和根冠比的影响均无明显交互作用($p > 0.05$, 表2), 且任意2个因素之

图3 不同供磷水平下杉木幼苗叶片的光合特性(平均值±标准误差)。不同小写字母表示不同供磷水平间差异显著($p < 0.05$)。
Fig. 3 Photosynthetic characteristics of *Cunninghamia lanceolata* seedlings under different phosphorus supply levels (mean $\pm$ SE). Different small letters indicate significant difference among three phosphorus supply levels ($p < 0.05$).

图4 不同胁迫时期杉木幼苗叶片的光合特性(平均值±标准误差)。不同小写字母表示不同胁迫时期间差异显著($p < 0.05$)。
Fig. 4 Photosynthetic characteristics of *Cunninghamia lanceolata* seedlings at different stress stages (mean $\pm$ SE). Different small letters indicate significant difference among three stress stages ($p < 0.05$).

表2 竞争处理、供磷水平和胁迫时期对杉木幼苗生物量分配的影响

Table 2 Effects of competition treatment, phosphorus supply level and stress stage on the biomass allocation of *Cunninghamia lanceolata* seedlings

	自由度 Degrees of freedom	F值 F value		
		地上部分 Shoot	根系 Root	根冠比 Root to shoot ratio
竞争处理 Competition treatment (a)	1	1.767 ^{ns}	0.017 ^{ns}	0.659 ^{ns}
供磷水平 Phosphorus supply level (b)	2	0.240 ^{**}	38.689 ^{**}	38.096 ^{ns}
胁迫时期 Stress stage (c)	2	1.624 ^{ns}	0.710 ^{**}	4.927 ^{**}
a和b组间交互作用 Effects between a and b	2	1.225 ^{ns}	1.411 ^{ns}	0.007 ^{ns}
a和c组间交互作用 Effects between a and c	2	2.539 ^{ns}	0.438 ^{ns}	1.343 ^{ns}
b和c组间交互作用 Effects between b and c	4	0.412 ^{ns}	0.908 ^{ns}	1.075 ^{ns}
a、b和c组间交互作用 Effects among a, b and c	4	0.813 ^{ns}	1.571 ^{ns}	0.861 ^{ns}
误差 Error	90			

*, $p < 0.05$; **, $p < 0.01$; ns, $p > 0.05$.

间对上述生物量指标的交互作用亦均不显著($p > 0.05$, 表2)。

从单个因素的影响情况来看, 竞争处理对杉木幼苗地上部生物量、根系生物量和根冠比的影响不显著($p > 0.05$, 表2)。其中竞争处理下杉木地上部分和根系生物量均明显高于非竞争处理(图5A、5B), 但两个处理间的幼苗根冠比差异不明显(图5C)。供

磷水平对杉木幼苗根冠比的影响不显著($p > 0.05$, 表2; 图6C), 但对地上部分和根系生物量的影响均达到显著水平($p < 0.05$, 表2)。与正常供磷相比, 不供磷条件下杉木幼苗地上部分和根系生物量均明显较低(图6A、6B)。胁迫时期对杉木幼苗根系生物量和根冠比的影响均达到显著水平($p < 0.05$, 表2), 这两个指标均随胁迫时期的延长明显增大(图7B、7C),

图5 竞争和非竞争处理下杉木幼苗生物量的分配(平均值±标准误差)。不同小写字母表示不同竞争处理间差异显著($p < 0.05$)。
Fig. 5 Biomass allocation of *Cunninghamia lanceolata* seedlings under neighboring competition treatment (mean $\pm$ SE). Different small letters indicate significant difference between two competition treatments ($p < 0.05$).

图6 不同供磷水平下杉木幼苗生物量的分配(平均值±标准误差)。不同小写字母表示不同供磷水平间差异显著($p < 0.05$)。
Fig. 6 Biomass allocation of *Cunninghamia lanceolata* seedlings under different phosphorus supply levels (mean $\pm$ SE). Different small letters indicate significant difference among three phosphorus supply levels ($p < 0.05$).

图7 不同胁迫时期杉木幼苗生物量的分配(平均值±标准误差)。不同小写字母表示不同胁迫时期间差异显著($p < 0.05$)。
Fig. 7 Biomass allocation of *Cunninghamia lanceolata* seedlings at different stress stages (mean $\pm$ SE). Different small letters indicate significant difference among three stress stages ($p < 0.05$).

但胁迫时期对地上部分生物量的影响不显著($p > 0.05$, 表2; 图7A)。

3 讨论

在影响植物叶片光合特性的参数中, 气孔导度

的变化是植物感受竞争者是否存在的策略, 当两者形成竞争关系时, 优势植物可通过减少气孔导度, 以调节光合固碳量, 巩固其竞争地位(Vysotskaya *et al.*, 2011)。Kropp和Ogle (2014)研究报道种间竞争可导致灌木 *Larrea tridentata* 的气孔导度明显减小, 且

不同邻株竞争植物对其影响的程度大小存在明显差异。特别是人工林分培育过程中, 同种植物往往处于同一生态位, 当发生种内竞争时, 植物可通过调节气孔导度, 增强各自的光能利用效率以适应竞争环境(Niu *et al.*, 2015)。张永强等(2015)研究发现种内竞争可导致大豆(*Glycine max*)叶片气孔导度明显降低, 且不同种植密度对其影响的程度大小存在明显差异。本文研究表明, 竞争处理中杉木幼苗叶片气孔导度均明显低于非竞争的单株种植处理(图2D), 平均净光合速率和蒸腾速率表现出相似的规律(图2B、2C)。这是由于植物可通过调节气孔导度来控制CO₂和水汽进出叶片的浓度, 从而影响光合和蒸腾速率(Hetherington & Woodward, 2003)。竞争处理还导致杉木叶片的胞间CO₂浓度明显增加(图2A), 由于CO₂是光合作用碳同化的底物, 它的浓度高时有利于增强植物光合速率。但陈根云等(2010)认为胞间CO₂浓度取决于叶片周围空气的CO₂浓度、气孔导度、叶肉导度和叶肉细胞的光合活性等因素的变化, 故而光合速率和胞间CO₂浓度关系较为复杂。但植物胞间CO₂浓度较高一定程度上可加剧叶片气孔导度的降低(王建林和温学发, 2010)。

许多研究表明, 低磷环境对农作物或林木的气孔导度、蒸腾速率等光合特征参数均具显著影响(周建朝等, 2009; 曹翠玲等, 2010; Wu *et al.*, 2014b), 施用磷肥可明显提高植物的光合特性(李跃娜等, 2010)。本文试验表明, 低磷和不供磷处理条件下杉木幼苗叶片的净光合速率、蒸腾速率和气孔导度均明显较低(图3B–3D), 但不同供磷处理间胞间CO₂浓度的差异未达显著水平($p > 0.05$, 图3A)。从竞争处理与供磷水平这2个因素之间的交互影响显著性来分析, 竞争处理与供磷水平对叶片胞间CO₂浓度、净光合速率和蒸腾速率的交互影响作用均达显著水平($p < 0.05$, 表1), 但对叶片气孔导度的交互作用不显著($p > 0.05$, 表1), 说明缺磷和邻株竞争对叶片气孔导度的降低具有叠加效应。随着试验处理时间的延长, 杉木幼苗叶片蒸腾速率明显降低(图4C), 但气孔导度呈先下降后上升的趋势(图4D)。这可能与低磷环境中具有竞争关系的邻株植物的根系延伸觅养、同化产物分配与调控等行为的适时调整策略有关(Mommer *et al.*, 2012; 李琦等, 2014; Kropp & Ogle, 2014; Wu *et al.*, 2014a)。

植物通常会根据养分胁迫程度不同向根系分配

大部分的生物量, 以保证植物体内部养分平衡和磷素吸收能力(曹翠玲等, 2010)。廉满红等(2011)研究发现, 不论低磷胁迫时期多长, 熊猫豆(*Phaseolus coccineus*)的根系生物量和根冠比均比对照有明显增加。本文中, 不供磷条件下杉木幼苗地上部分和根系的平均生物量均明显较低(图6A、6B), 而根冠比与正常供磷处理的差异未达显著水平(图6C)。从供磷水平、竞争处理和胁迫时期对杉木幼苗生物量指标的综合影响来看, 三者无明显交互作用($p > 0.05$, 表2)。总体上, 杉木根系生物量和根冠比均随处理时间的延长明显增大(图7B、7C)。虽然低磷环境下杉木幼苗的光合效率明显受阻(图3B), 降低了苗木的同化能力和碳水化合物的积累, 而且竞争处理对幼苗的地上部分生物量、根系生物量和根冠比3个指标的影响均无显著影响(图5A–5C); 但由于邻株竞争能够明显促进低磷环境下杉木幼苗根系长度、表面积等形态指标的可塑变化, 以促进苗高的生长(李琦等, 2014), 使得在相同的处理时间内, 竞争处理杉木幼苗地上部分和根系生长量大于非竞争处理。因此, 低磷环境下杉木幼苗生物量增加很可能是光竞争和营养竞争存在的互补作用导致。Schmid等(2013)认为植物在公共养分资源耗竭形成低养胁迫之前, 已通过体内蛋白的变化对邻株植物做出了反应。因此, 相邻植物之间的竞争关系复杂, 竞争行为多样化, 且与植物的不同发育阶段关系密切, 难以用统一的响应机制对其进行描述(Pierik *et al.*, 2013; Schmid *et al.*, 2015)。

植物在对邻株竞争做出响应之前必先通过某些特定途径来感受邻株植物的存在。近年来, 许多学者分别从植物对光竞争信号(R:FR)、根际养分浓度、根系分泌物、挥发性植物激素以及菌根释放化学信号等方面试图阐明邻株竞争的响应机制(Fang *et al.*, 2011; Pierik *et al.*, 2013, 2014; Schmid *et al.*, 2015), 但仍无法阐明邻株杉木间竞争策略的内在机理。而蛋白组学技术有望成为揭示竞争植物相互影响时, 植物通过体内蛋白合成的调控从而诱导生理形态响应变化的最重要的一种研究手段(Schmid *et al.*, 2013; Depuydt, 2014)。

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