

# 稀土叶面肥对荔枝光合作用和成花坐果的影响

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**摘要:**【目的】探究稀土元素叶面肥对荔枝的光合作用、成花、坐果和果实品质等方面的影响。【方法】以桂味、糯米糍和井岗红糯荔枝为材料, 在花期、果实发育期和秋梢老熟期叶面喷施稀土元素, 测定光合作用参数、光合相关酶活性, 并进行坐果和果实品质分析。【结果】稀土元素叶面肥处理可显著提升荔枝叶片的净光合速率, 特别是对老叶的作用更明显, 提升的幅度为10%~20%;稀土元素处理对荔枝叶片的叶绿素水平和光合作用关键酶的活性均无显著的影响, 但明显增加了气孔导度, 说明稀土元素提高净光合速率的途径主要是增加气孔导度。成花和坐果是决定荔枝产量和经济效益的瓶颈问题, 冬季进行2次的叶面肥处理在显著提升光合作用的同时, 极显著提高了成花枝率, 提升幅度达50%;在雄花开放和花后2周叶面喷施则可显著提高坐果率, 增加产量, 增产幅度接近60%, 显著增加经济效益。【结论】稀土元素可以提高荔枝叶片的净光合速率, 进而提高荔枝的成花枝率和坐果率, 显著提高产量和经济效益。

**关键词:**荔枝;稀土元素;光合作用;成花;坐果;产量

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## Effects of foliar rare earth fertilizer on photosynthesis, flowering and fruiting in *Litchi chinensis*

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**Abstract:**【Objective】In this experiment, the effects of foliar rare earth fertilizer on the photosynthesis, flowering, fruit setting and fruit quality of litchi were studied to provide references for increasing efficiency in litchi industry.【Methods】Guwei and Nuomici litchi trees grown in the orchard of South China Agricultural University were selected as test materials. The flowering rate in 2019 was extremely low due to the warm winter in 2018. The unfruiting Guwei and Nuomici trees were sprayed with rare earth fertilizer on 29<sup>th</sup> April. Two weeks after the treatment, the photosynthetic parameters were analyzed, and the activities of key photosynthetic enzymes were determined. Single tree was used as one replicate and 5 biological replicates were set up. In late October of 2019, another Nuomici and Guwei trees with relatively consistent tree vigor and development state were sprayed with rare earth fertilizer, and leaf photosynthetic parameters were measured at two weeks after spraying. Rare earth element was sprayed again after photosynthesis measurement, and the flowering rate was investigated in April, 2020. Single tree was used as one replicate and 8 biological replicates were set up by using random block design. Jingganghongnuo was selected to investigate the effects of rare earth element on the fruit set and fruit quality of litchi. Rare earth fertilizer was sprayed twice at male flowering and two weeks after anthesis around mid-March and early April in 2020, respectively. Eight trees of each treatment and thirty clusters from each tree were analyzed. The clusters were used to investigate the fruit retention rate. The

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yield was calculated, and fruits were harvested to determine the fruit quality at maturity. Li6400 portable photosynthesis meter (Li-Cor, USA) was used to measure leaf photosynthetic parameters. Sixteen mature shoots with similar growth status were randomly selected from different directions of the canopy. In the summer of 2019, the photosynthesis of autumn shoots of last year and spring shoots of current year were determined, respectively. In the winter of 2020, autumn shoots of that year were selected to measure the photosynthetic parameter. Leaf SPAD value was measured by SPAD-502 Plus chlorophyll meter. The numbers of terminal shoots and flowering shoots in the selected branches were recorded. The flowering rate was calculated using a formula ( $\text{flowering rate}/\% = \text{number of flowering shoots}/\text{number of terminal shoots} \times 100$ ). **【Results】**The net  $\text{CO}_2$  assimilation of newly mature leaves from spring shoots was much higher than that on old leaves of autumn shoots in the previous year. Accordingly the stomatal conductance of the old autumn leaves in the previous year was significantly less than that of the new mature spring leaves in the current year. The net  $\text{CO}_2$  assimilation rate of mature leaves significantly increased after spraying with amino acid rare earth fertilizer (GM) and rare earth fertilizer (XT), especially on the old autumn leaves. At the same time, the treatments also increased the stomatal conductance and transpiration rate of the leaves, and the effect on the old leaves was more significant than that on the newly mature leaves. The increase of net photosynthetic rate may be related to the increase of chlorophyll content or photosynthetic enzyme activity. In this study, the leaf chlorophyll level and photosynthetic key enzyme activity with rare earth treatment and control were measured. The results showed that there were no significant differences in SPAD value, Rubisco, GAPDH and PRK activities between the two treatments, indicating that rare earth elements did not increase net photosynthetic rate by increasing photosynthetic pigment content or photosynthetic key enzyme activities. Foliar spraying with rare earth elements in winter significantly increased the net photosynthetic rate of mature leaves on autumn shoots, and also significantly increased the percentage of flowering shoots. The percentage of flowering shoots was only  $(37.1 \pm 6.9)\%$  and  $(29.2 \pm 7.9)\%$ , while that of treatments was  $(64.8 \pm 5.8)\%$  and  $(49.0 \pm 6.7)\%$  in Guiwei and Nuomici, respectively. The increment was more than 50%. There was no significant difference in the average number of fruits per cluster between the treatment and the control at 10th day after anthesis, but with the development of fruits, the average fruit number of the clusters from trees treated with foliar rare earth fertilizer was significantly higher than that of the control. The average yield per tree was  $(53.0 \pm 6.2)$  kg with the treated trees, but only  $(33.9 \pm 5.6)$  kg with the control trees. The increment was around 60%. Compared with the control, the average fruit size with the treatment was 22.5 g, which was slightly smaller than that of the control (23.6 g), but it did not reach a significant level. The smaller fruit size may be related to the significant increase of yield. There was also no difference in fruit color parameters and fruit recovery rate. The total soluble solids content in fruits with treated trees was 16.2%, which was significantly less than that of the control (16.8%). However, sucrose, glucose, fructose and thus total sugar contents in the aril with treatment and control displayed no significant difference. **【Conclusion】**Rare earth elements can enhance the flowering and fruit setting rate of litchi and thus increase the yield by improving net  $\text{CO}_2$  assimilation rate mainly due to an increase in stomatal conductance.

**Key words:** Litchi; Rare earth element; Photosynthesis; Flowering; Fruit setting; Yield

荔枝(*Litchi chinensis* Sonn.)为热带亚热带常绿木本果树,是南方特色大宗果树,我国面积近55万hm<sup>2</sup><sup>[1]</sup>。荔枝果实外形美观,色彩艳丽,果肉高甜微酸,肉质细腻并有特殊香气,营养丰富,是滋补佳品,深受消费者喜爱,被称为岭南佳果。除了鲜食,还可制成荔枝干、荔枝酒、罐头、果汁、浓缩汁等加工产品,具有较高的经济价值。成花和坐果是荔枝产量形成的关键因素,成花不稳和坐果率低是限制荔枝产业可持续发展的2个问题。自20世纪80年代以来,国内外学者对荔枝花果发育生理与调控技术的研究取得了长足进步,荔枝产量的年度波动幅度明显降低,产量明显提升,然而,大年年份平均单产每666.7 m<sup>2</sup>仍不到500 kg<sup>[1]</sup>。说明荔枝与其他大宗果树如苹果、柑橘等相比,产量还有很大的提升空间。树体的碳水化合物储备影响荔枝的成花和坐果<sup>[2-5]</sup>,因而是影响荔枝产量的重要因素。

绿色植物通过光合作用,利用光能将二氧化碳和水转化为碳水化合物,光合作用是作物产量形成的基础。荔枝属于净光合速率低下的作物种类,新成熟叶的净光合速率一般5~6 μmol·m<sup>-2</sup>·s<sup>-1</sup>,老叶的净光合速率更低,一般只有2~3 μmol·m<sup>-2</sup>·s<sup>-1</sup><sup>[6]</sup>。远低于净光合速率大于15 μmol·m<sup>-2</sup>·s<sup>-1</sup>的毛叶枣<sup>[6]</sup>、苹果<sup>[7]</sup>和葡萄<sup>[8]</sup>等果树。提高荔枝叶片的净光合速率,进而提高树体的碳素营养水平可能是当前解决荔枝产量低问题的有效手段。刘建峰等<sup>[9]</sup>研究发现一些荔枝保果剂可显著提高净光合速率,同时促进荔枝的坐果。但具体的保果剂配方和提高光合作用的内在机制未知。

稀土元素是当前农业生产较常使用的微量元素。应用较多的是镧系稀土,镧、铈等轻稀土能够促进农作物的生长,促进对氮、磷、钾等营养元素的吸收,缩短作物的生长周期,提升农作物叶片中的叶绿素含量,增强光合作用,促进干物质的积累,还能增强作物对病菌与干旱的抵抗能力,进而提高作物产量和质量<sup>[10-13]</sup>。早前有研究表明叶面喷施硝酸稀土能使荔枝显著增产<sup>[13]</sup>。低浓度的硝酸铈和硝酸镧促进拟南芥花穗抽生,并提高花穗数,增加开花数量<sup>[14]</sup>。硝酸镧和氨基酸-硝酸镧螯合物可通过降低氧化胁迫和增加叶绿素含量,有效改善水稻重金属胁迫,促进生长<sup>[15]</sup>。硝酸镧和氯化镧的La<sup>3+</sup>可在缺磷条件下增加红豆幼苗抗氧化保护酶的水平,包括超氧化物歧化酶(SOD)和过氧化物酶(POD),而显

著降低丙二醛(MDA)含量,显著增加叶片面积、气体交换能力、叶绿素含量和类胡萝卜素含量,并明显缓解因缺磷导致的光合效率下降<sup>[16-17]</sup>。氯化镧被证明可以提高中华魔芋的光合色素含量、叶绿素荧光参数、光合速率和气孔导度,从而提高魔芋的产量和葡甘露聚糖含量<sup>[18]</sup>。对处于生殖期的玉米,LaCl<sub>3</sub>可显著提高叶片的光合能力、叶面积和干物质含量,从而促进玉米穗部性状的改善和产量的提高<sup>[19]</sup>。稀土元素在提升大田作物的光合效率以及产量方面有了一定的研究,但是对木本果树的生物学效应以及发挥作用的具体途径目前研究较少。笔者在本研究中以荔枝为研究材料,在不同的物候期叶面喷施稀土元素,探讨处理对光合作用、成花、坐果以及产量与果实品质的影响,为荔枝提质增效栽培措施的研发提供重要的参考。

## 1 材料和方法

### 1.1 试验材料和田间处理

1.1.1 夏梢老熟期稀土元素处理对荔枝光合作用的影响 试验用树为广州华南农业大学果园的桂味和糯米糍荔枝,由于2019年是荔枝小年,华南农业大学果园的桂味和糯米糍荔枝几乎无花,于4月29日按照生产上叶面施肥常规方式进行整株喷施处理,处理后2周进行光合作用数据的采集,并取叶圆片进行光合作用相关酶活性测定。单株小区,随机区组设置,每处理5个重复。

1.1.2 秋梢期稀土元素处理对荔枝叶片光合作用和成花的影响 于2019年10月下旬选取树势和发育状态相对一致的糯米糍和桂味喷布稀土元素叶面肥,喷后2周测定叶面的光合作用参数,测定后再喷一次,于2020年4月调查成花枝率。单株小区,随机区组设置,每处理8个重复。

1.1.3 花期稀土元素处理对荔枝坐果、产量和果实品质的影响 于2020年3月中旬,井岗红糯雄花初开期树冠喷布稀土元素,并每株选择花穗大小相近的20个花穗挂牌,跟踪调查果穗的坐果情况,在果实成熟时采果进行产量的测定,每树随机取20个果进行果实品质测定。单株小区,随机区组设置,每处理8个重复。

### 1.2 光合作用和叶片SPAD测定

使用Li6400便携式光合作用测量仪(Li-Cor,美国)进行叶片光合参数的测定,选择晴朗无云的上

午,每棵树东南西北四个方向随机选择16枝生长状态相似的老熟秋(春)梢,测量第三复叶中间一对健康小叶的光合相关数据。夏季光合选择去年秋梢(老叶)和当年春梢(新成熟叶)分开统计,冬季光合选择当年秋梢的新成熟叶片进行测定。光合作用测定后采用SPAD-502 Plus叶绿素仪测定叶片SPAD值。

### 1.3 成花枝率和坐果情况调查

在每棵荔枝树的东南西北中五个方向各选取1个大于2 cm的大枝条,在选取的大枝条中调查末端枝条的个数以及其中的开花枝条的数目(简称花枝数目),并且记录下来。计算荔枝成花率,成花率/%=花枝数目/末端枝条数目×100。在第一次处理时,选择大小相对一致的花穗或果穗进行挂牌,在果实发育过程中跟踪调查穗的果数,以平均每穗果的挂果数来表示坐果的情况。

### 1.4 果实品质测定

荔枝成熟后每株随机取20个果实进行品质分析。用Chroma Meter CR-400(日本)色彩色差计测量果实的色差参数,在果面中部的不同位置测3个

点,取平均值。用百分之一天平测单果质量、皮质量和种子质量,计算可食用率,可食用率/%=(果实质量-果皮质量-种子质量)/果实质量×100。用日本ATAGO pal-1数显糖度计测量单果可溶性固形物含量(TSS)。参照Wang等<sup>[20]</sup>利用高效液相色谱法测定假种皮的可溶性糖和总糖含量。

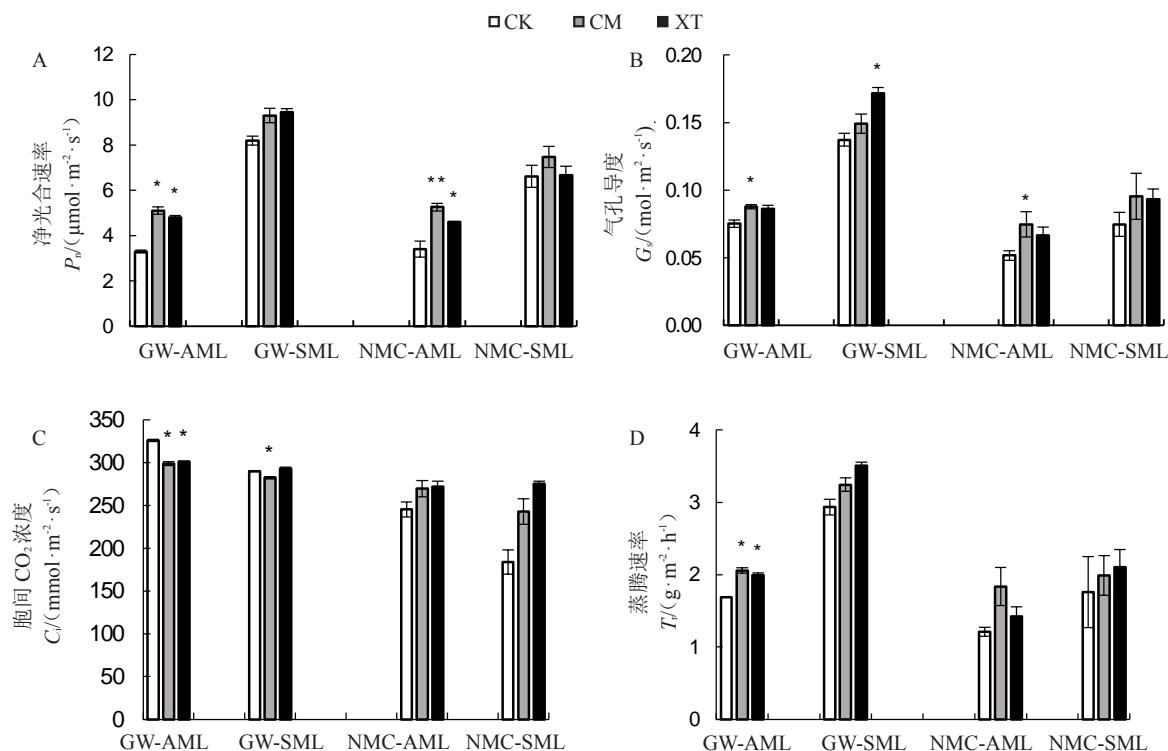
### 1.5 数据分析

使用Excel进行数据整理,学生氏t分布进行差异显著性检验,SigmaPlot 12.5进行图表绘制。

## 2 结果与分析

### 2.1 稀土叶面肥对荔枝叶片光合作用的影响

2.1.1 对上一年度秋梢老叶和本年度春梢新成熟叶光合作用的影响 处理后2周选取桂味(GW)和糯米糍(NMC)植株上一年度秋梢和当年春梢老熟叶片测定净光合速率、气孔导度、胞间二氧化碳浓度和蒸腾速率等光合作用参数,结果如图1所示。2个品种两趟枝梢叶片的光合作用有明显的差异,春梢新成熟叶净光合作用速率明显高于上一年度秋梢的老叶,这种差异的原因可能主要是上一年度秋梢老叶



GW. 桂味; NMC. 糯米糍; AML. 上一年秋梢老熟叶片; SML. 当年春梢老熟叶片; \*表示在  $p < 0.05$  差异显著。下同。

GW. Guiwei; NMC. Nuomici; AML. The leaves from last year autumn shoots; SML. The leaves from current year spring shoots; \* indicates significant difference at  $p < 0.05$ . The same below.

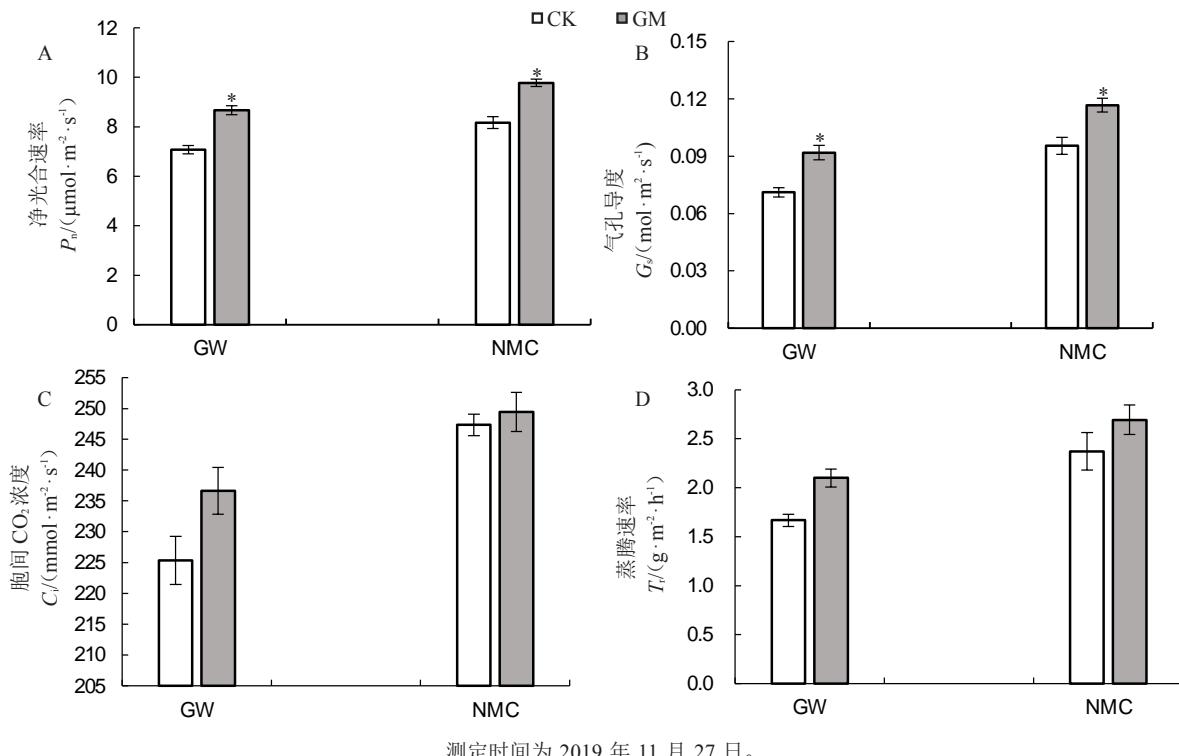
图1 夏季稀土元素叶面肥处理对荔枝上一年度秋梢老叶和本年度春梢新成熟叶光合作用的影响

Fig. 1 Effects of rare earth foliate application in summer on the photosynthesis of litchi leaves

的气孔导度明显小于本年度春梢的新成熟叶;氨基酸稀土叶面肥(GM)和稀土叶面肥(XT)树冠喷布后可明显提高两趟梢老熟叶片的净光合速率,其中提高上一年度秋梢老叶的效果更明显,2种叶面肥均显著提高2个品种上一年度秋梢老叶的净光合速率;同时处理也提高了叶片的气孔导度,增加了蒸腾速率,对老叶的影响较新熟叶片显著;与提高桂味叶片净光合速率相对应,胞间二氧化碳浓度显著降低,

而处理对糯米糍叶片胞间二氧化碳浓度则无显著的影响。2种叶面肥处理的效果大致相同,说明稀土元素是发挥作用的主要组分。

**2.1.2 对秋梢新成熟叶光合作用的影响** 冬季稀土元素叶面肥喷施处理对秋梢成熟叶片的光合作用参数也有显著的影响(图2),2个品种均表现为处理叶片净光合速率和气孔导度显著高于对照,与气孔导度提高相一致,叶片蒸腾速率也有增加的趋势,但没



测定时间为 2019 年 11 月 27 日。

The determination carried out on Nov. 27<sup>th</sup>, 2019.

图 2 冬季稀土元素叶面肥处理对荔枝叶片光合作用参数的影响

Fig. 2 Effects of rare earth foliate application in winter on the photosynthesis of litchi leaves

有达到显著水平。

**2.1.3 对叶片叶绿素水平和光合作用酶活性的影响** 净光合速率的提高可能与叶绿素含量增加或者光合作用酶活性的提高有关,测定了能显著提高净光合速率的稀土处理和对照叶片的叶绿素水平和光合作用关键酶活性,结果如图3所示,处理与对照叶片SPAD值以及1,5-二磷酸核酮糖羧化/加氧酶(Rubisco)、磷酸甘油酸激酶(GAPDH)和磷酸核酮糖激酶(PRK)活性均无显著差异,说明稀土元素不是通过增加光合色素含量或光合关键酶活性提高净光合速率。

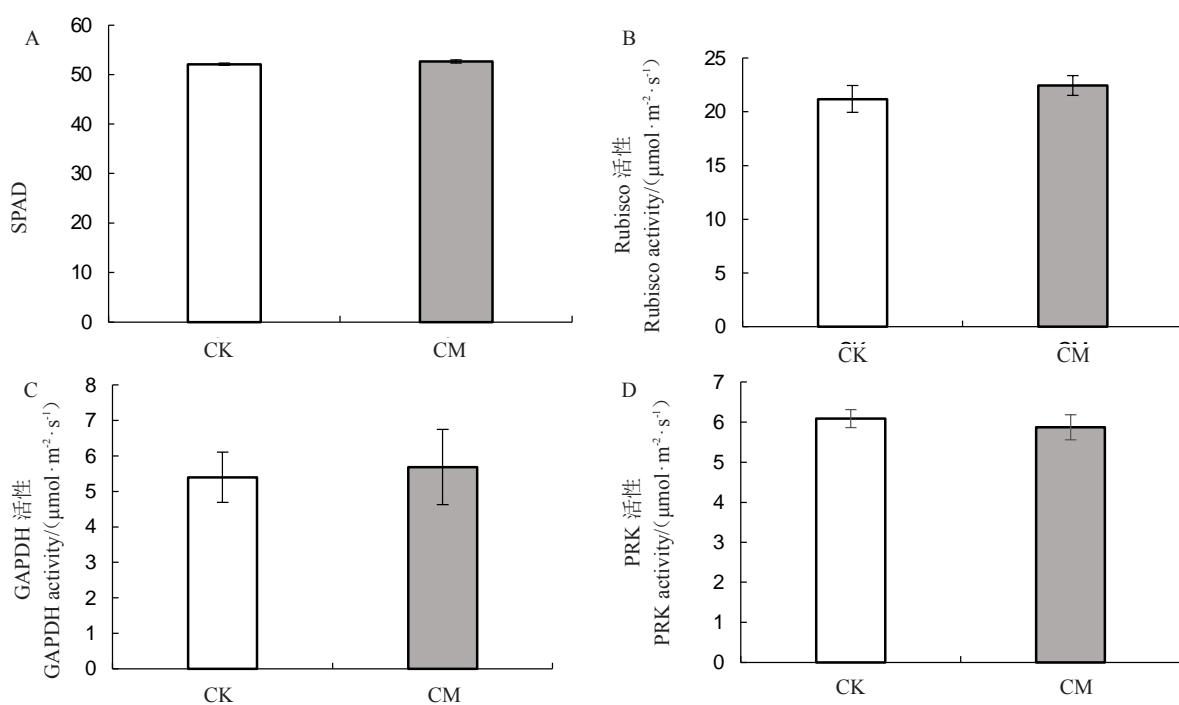
## 2.2 稀土元素叶面肥处理对荔枝成花的影响

冬季稀土元素叶面喷施在显著提高秋梢成熟叶

片净光合速率的同时,极显著提高了成花枝率,桂味对照的成花枝率只有( $37.1 \pm 6.9\%$ ),处理的成花枝率达( $64.8 \pm 5.8\%$ ),糯米糍对照为( $29.2 \pm 7.9\%$ ),而处理植株的成花枝率则达( $49.0 \pm 6.7\%$ ),增加的幅度超过了50%(图4)。

## 2.3 稀土元素叶面肥处理对荔枝坐果和产量的影响

在花后10 d平均每个花穗有小果35~45个,但随着果实发育过程中落果的发生,平均每个花穗的果数急剧下降,至果实成熟时平均每穗均有2个左右(图5-A)。处理与对照的果穗在花后10 d时平均穗果数无显著差异,但随着果实发育,稀土叶面肥处理的植株平均每穗果数均显著高于对照,至果实成



Rubisco. 1,5-二磷酸核酮糖羧化/加氧酶; GAPDH. 磷酸甘油酸激酶; PRK. 磷酸核酮糖激酶。

Rubisco. Ribulose bisphosphate carboxylase/oxygenase; GAPDH. Glyceraldehyde-3-phosphate dehydrogenase; PRK. Phosphoribulose kinase.

图3 稀土元素叶面肥处理对荔枝上一年度秋梢叶片叶绿素水平(A)和光合作用关键酶活性(B~D)的影响

Fig. 3 Effects of rare earth foliate application on chlorophyll levels (A) and the activities of key photosynthetic enzymes (B-D)

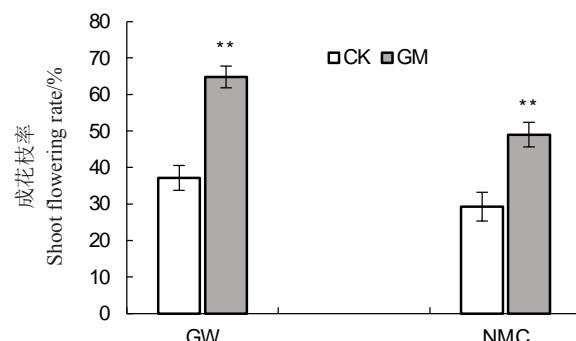


图4 冬季稀土元素叶面肥处理对桂味和糯米糍荔枝成花枝率的影响

Fig. 4 Effects of winter rare earth foliate application on flowering flush rate of Guiwei (GW) and Nuomici (NMC)

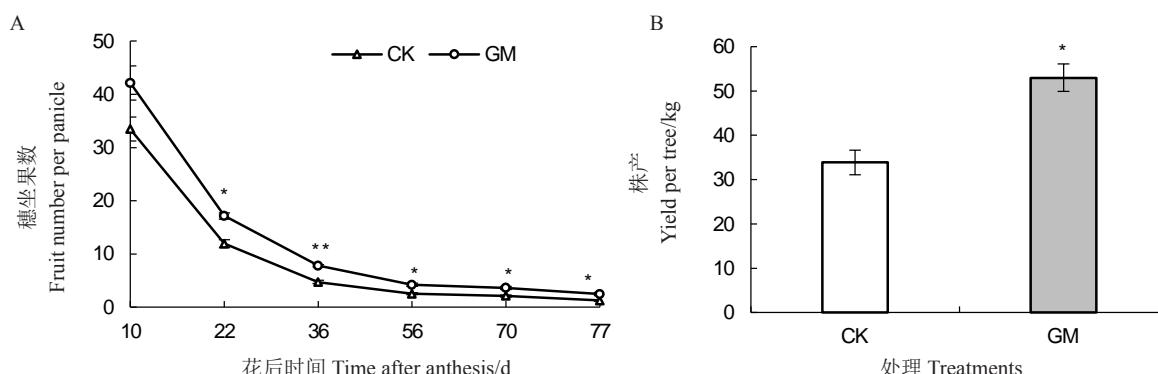


图5 稀土元素叶面肥处理对荔枝坐果和单株产量的影响

Fig. 5 Effects of rare earth element foliate application on the fruit set and yield of litchi

熟时,处理植株平均每穗( $2.5\pm0.6$ )个果实,对照只有( $1.3\pm0.3$ )个。成熟采收时统计平均单株产量,发现与显著增加坐果的结果相一致,稀土叶面肥处理显著增加单株产量,处理植株平均产量为( $53.0\pm6.2$ )kg,对照仅为( $33.9\pm5.6$ )kg,增产幅度近60%(图5-B)。

#### 2.4 稀土元素叶面肥处理对荔枝果实品质的影响

在花期和幼果期进行植株稀土叶面肥的喷施,在果实成熟时取样进行果实品质的测定,研究处理在增加产量的同时对果实品质的影响。如表1所示,与对照相比,处理的果实平均质量为22.5 g,略

小于对照果实23.6 g,但未达到显著水平;在果实颜色方面,处理与对照果实的色泽参数L、a、b和色度角均无显著差异;在果实的可食率两者也无显著差异,但在可溶性固形物含量方面,处理果实(16.2%)显著低于对照(16.8%),然而,利用高效液相色谱技术测定了处理和对照假种皮中蔗糖、葡萄糖、果糖和总糖的含量,发现处理假种皮中的糖分含量略高于对照,但未达到显著水平,说明处理对果肉的糖含量无显著影响(图6)。

#### 2.5 稀土叶面肥处理效益分析

如表2所示,按每kg井岗红糯20元计算,扣掉

表1 花期和果实发育早期稀土叶面肥处理对荔枝果实品质的影响

Table 1 Effects of rare earth element foliate application on the fruit quality of litchi

处理 Treatment	单果质量 Fruit weight/g	L	a	b	h	可食率 Flesh recovery/%	w(可溶性固形物) TSS/%
CK	$23.6\pm0.57$	$36.1\pm0.92$	$28.7\pm0.92$	$14.1\pm0.44$	$26.3\pm1.47$	$78.7\pm0.24$	$16.8\pm0.19^*$
GM	$22.5\pm0.46$	$35.8\pm0.76$	$28.4\pm0.86$	$14.2\pm0.28$	$26.6\pm1.12$	$78.9\pm0.46$	$16.2\pm0.12$

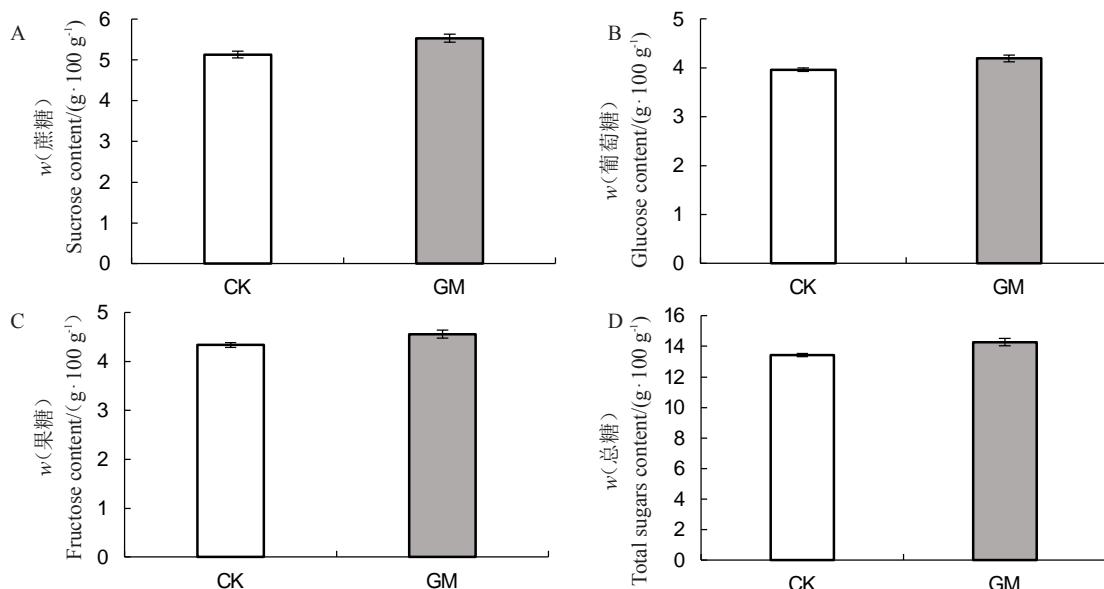


图6 稀土元素叶面肥处理对荔枝假种皮糖含量的影响

Fig. 6 Effects of rare earth element foliate application on the contents of sugars in the aril of litchi

表2 井岗红糯花果期稀土叶面肥处理的效益

Table 2 Cost-benefit analysis of Jinganghongnuo after treated with rare earth

处理 Treatment	单株产量 Yield per plant/kg	单株销售收入 Sale income per plant/Yuan	单株肥料投入成本 Cost per plant/Yuan	单株增加收入 Addition income per plant/Yuan	单株每元肥料投入净增值 Income increment per cost per plant/Yuan
对照 Control	33.9	678	0.0	678	-
处理 Treatment	53.0	1060	5.0	1055	75.4

注:稀土元素叶面肥每瓶1 L,售价150元,800倍液,每树用水量10 L,两次处理,共用水20 L,每瓶肥料可喷40株树,每株肥料款3.75元,按人工和水费1.25元计,投入合计5.0元。

Notes: The content of rare earth element foliar fertilizer is 1 liter per bottle, the price is 150 yuan per bottle, each liter of foliar fertilizer is added with 800 times of water, the water consumption of each tree is 10 liter, and 20 liter of water is shared for two treatments. So each bottle of fertilizer can treat 40 trees. The fertilizer cost per plant is 3.75 yuan, the labor cost and water cost are calculated as 1.25 yuan, and the total investment is 5.0 yuan.

肥料和人工支出后,处理和对照平均株收入分别为1060和678元,每元肥料和人工投入净增值为75.4元,说明在花果期进行稀土元素叶面施肥处理是荔枝增加收益的有效技术措施。

### 3 讨 论

#### 3.1 稀土叶面肥通过提高气孔导度提高荔枝净光合速率

树体的碳素储备和合理分配是作物高产优质的保障。荔枝的幼叶在展开一半的时候才开始有净光合产物积累,完全展开并变成深绿色时达到最大光合速率<sup>[21]</sup>。荔枝的光合速率一般低于落叶果树<sup>[6]</sup>,因而其碳素供应能力相对较弱。笔者测定不同叶龄的老熟叶片的光合指标,结果表明新成熟叶的净光合速率为7~9  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ,明显高于前一趟梢的老熟叶片(3~5  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ),同样气孔导度也是新成熟叶片明显大于前一趟梢的老熟叶。这结果说明老叶气孔导度的下降可能是其净光合速率下降的主要原因。影响光合作用的内在因素主要包括每单位叶的Rubisco活性、RuBP合成速率和CO<sub>2</sub>供应,而CO<sub>2</sub>供应由气孔导度和环境CO<sub>2</sub>决定<sup>[22]</sup>。气孔介导了光合作用所有CO<sub>2</sub>的94%~99%,气孔导度限制占总光合限制的60%<sup>[23]</sup>。气孔导度上调会增加气体交换,较高的气孔导度可促进CO<sub>2</sub>扩散到叶片中并提高光合速率,这是决定生长和产量的重要因素<sup>[24]</sup>。稀土元素喷施荔枝树冠显著提高了叶片的净光合速率,特别是前一趟梢的老熟叶,同时气孔导度也有显著的提升,而对叶片的叶绿素和光合作用关键酶的活性影响不大。这结果说明稀土元素可通过增加叶片气孔导度的方式提升荔枝叶片的净光合速率。

#### 3.2 提高净光合速率在荔枝成花坐果中的作用

荔枝属于比较难成花的树种,在诱导性低温来临前,必须有足够的碳水化合物储备,一般枝梢碳水化合物含量高,成花率也高<sup>[3, 5]</sup>。在荔枝生产中,螺旋环剥、生长抑制剂处理等调控措施均能显著提高树体的碳素水平,同时提高成花枝率,减轻大小年的发生<sup>[1]</sup>。本研究中利用稀土叶面肥喷施荔枝树冠,在显著提升净光合速率的同时也显著提高了荔枝的成花枝率。这个结果再一次印证了碳素营养在荔枝成花中的重要作用,也说明生产上在荔枝花芽诱导前利用光合作用提升剂叶面喷施处理是提高成花枝率的有效手段。

落叶果树在落叶前,叶片光合作用要同时供应果实发育、枝梢生长和树体碳素营养储备的形成,而来年的花和新梢发育几乎完全依赖树体储备。常绿果树对植株碳素储备的依赖性不像落叶果树那么强,但袁炜群等<sup>[4]</sup>研究发现,随着糯米糍荔枝花穗发育及随后的开花坐果,树体的碳素储备被快速消耗,这说明荔枝花果发育期间,叶片光合作用产生的碳素营养的供应能力不能完全满足花果发育的需要。碳素的供应情况是影响荔枝落果的关键因素,碳饥饿会诱发荔枝的大量落果<sup>[25]</sup>。植物对碳素营养的利用有明显偏好。在松树中新生枝生长所需要的碳水化合物有近一半来自碳储藏库,而松针发育的碳素需求则几乎完全由当年的光合产物提供<sup>[26]</sup>。荔枝花穗和果实发育主要利用的是当季叶片的光合产物<sup>[21]</sup>。糯米糍荔枝开花和果实发育初期,天气状况不佳,光合供应碳素营养的能力弱,开花和早期坐果对树体的碳素储备依赖较大,到了果实发育中后期,果实发育基本依赖的是树体当季的光合作用提供的碳素营养<sup>[4]</sup>。这些研究均说明了当季光合作用的能力在荔枝坐果中的重要作用。本研究中在初花期和谢花期2次喷施稀土叶面肥,显著提高了平均穗坐果率和单株产量。

#### 3.3 稀土元素在促进荔枝光合作用的优势

在作物生长产中促进光合作用往往是增加产量和提高品质的重要栽培措施。磷酸二氢钾、氨基酸、赤霉素、芸薹素内酯、胺鲜酯等均有在生产上用于促进植物光合作用的报道<sup>[27-33]</sup>。然而,赤霉素、芸薹素内酯、胺鲜酯属于植物生长调节剂,只能在植物的特定发育期使用,如赤霉素对木本果树来说具有抑制成花和促进果实脱落的作用<sup>[30]</sup>,芸薹素内酯具有协调多种内源激素激发一系列酶活性的作用<sup>[28]</sup>,这些生长调节物质主要是通过促进光合机构的发育或保护光合机构来促进光合作用,提高叶绿素含量和酶活性<sup>[27-28, 30]</sup>。喷施氨基酸或尿素也往往可以促进植物的光合作用,但容易引发徒长和果实品质下降的问题<sup>[29, 31]</sup>,而磷酸二氢钾叶面喷施则对肥料质量的要求较高,且存在营养元素拮抗的问题,一般只在果实发育期使用<sup>[32-33]</sup>。荔枝叶片浓绿,成熟叶片SPAD值一般在50以上,随着叶龄的增加SPAD还会增加,最高可达60,限制荔枝叶片光合作用的关键因素可能是气孔导度。苹果正常叶面的气孔导度0.3  $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ <sup>[34]</sup>,而荔枝即使净光合速率高的新

成熟叶,气孔导度也不到 $0.2 \text{ mmol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ,老叶的气孔导度则只有 $0.1 \text{ mmol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ 左右。这些结果说明稀土元素提高荔枝净光合速率是通过解决荔枝叶片光合作用低下的核心成因即气孔导度低的问题而实现的,针对性强,且对植物的生长发育无明显的影响,迄今未有药害的报道,可作为有效的光合作用促进剂在荔枝生产中推广应用。

## 4 结 论

稀土元素可通过提高气孔导度促进荔枝叶片的光合作用,提高荔枝的成花、坐果以及果实产量,显著提高经济效益。除可能因产量提高在一定程度上降低果实大小外,对其他果实品质指标无显著影响,说明稀土元素叶面肥喷施是荔枝产业提质增效的有效栽培技术措施,值得进一步的推广应用。

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