

石灰水质量浓度和喷布覆盖率对柑橘 日灼程度和品质的影响

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摘 要:【目的】研究石灰水喷施浓度和覆盖率对‘纽荷尔’脐橙和‘沃柑’的果面温度、叶面温度、日灼发生率、果实品质等影响,以确定日灼防控的适宜喷施浓度和覆盖率。【方法】以‘纽荷尔’脐橙和‘沃柑’杂柑为材料,设置5个石灰水质量浓度0(CK)、5、10、20、40 g·L⁻¹和2个喷施覆盖率30%和50%,于夏季高温来临前对树冠进行喷施。【结果】与对照相比,喷施石灰水能显著降低叶面和果面温度,但其降温效果具有阈值。随喷施浓度和覆盖率的升高,叶面反光率升高,日灼程度和日灼发生率降低。质量浓度40 g·L⁻¹覆盖率50%的处理叶面反光率最高,日灼发生率和日灼程度最低。喷施石灰水能显著增加果实硬度,影响维生素C含量、色度L值、可溶性固形物含量和可滴定酸含量。主成分分析表明,采用石灰水质量浓度为40 g·L⁻¹、喷施覆盖率为50%提高‘纽荷尔’脐橙和‘沃柑’果实品质的效果最好。【结论】喷施石灰水能显著降低果实和叶片日灼,且对果实品质无不良影响,在日灼易发区,推荐喷施石灰水质量浓度为40 g·L⁻¹、覆盖率为50%。

关键词: 柑橘;石灰水;温度;日灼;果实品质

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Effects of lime concentration and spray coverage on the severity of citrus sunburn and fruit quality

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Abstract: 【Objective】Sunburn is a serious physiological disease in citrus production, which leads to significant loss of fruit quality and yield. With the frequent exposure to high temperature and strong light in summer, the occurrence of sunburn is increasing and causes serious economic losses in citrus industry. To date, there are many ways to reduce the damage of sunburn, such as spraying sunscreen, spraying water, bagging, stamping shade net, carrying out sod-culture, and building shelterbelt. Among these methods, spraying lime suspension on the canopy of citrus trees is regarded as the most economical and applicable way. However, there are different opinions on suitable lime concentration for reducing sunburn, and there has been no systematic study on the control effect with lime suspension. In this study, we compared the fruit and leaf surface temperatures, the incidence of sunburn, and the quality of fruit at the different treatments with spraying of lime suspension at different concentrations and coverages, to establish suitable concentration and coverage for sunburn control. 【Methods】Two cultivars, ‘Newhall’ navel orange and ‘Orah’ mandarin, were used as the materials for the experiment. Five concentrations of lime [0 g·L⁻¹ (CK), 5 g·L⁻¹, 10 g·L⁻¹, 20 g·L⁻¹, and 40 g·L⁻¹] and two spraying coverages (30% and 50%) were used. The surface of leaves and fruit in the outer canopies were sprayed before the

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commence of summer high temperatures. The surface temperatures of the leaf and the fruit near sunburn spot were measured with an infrared thermometer. After the end of high temperature season, the degree and incidence of sunburn were statistically analyzed. The quality indexes, including peel chrominance, pericarp thickness, peel hardness, flesh recovery, and contents of vitamin C, titratable acids and soluble solids were measured at the commercially mature stage. Principal component analysis of these quality parameters was carried out to establish the optimal treatment. 【Results】Compared with the control, the treatment of spraying lime suspensions significantly improved the leaf light reflectance in both varieties. With the increase in concentrations or spraying coverage, the reflectance of leaves increased significantly. At the same time, spraying lime suspension effectively reduced the surface temperature of the leaves and the fruit, but there was a ceiling value in the cooling effect with the lime suspension. Above the ceiling value, the surface temperatures of the fruit and the leaf showed no significant change with the further increase in the concentration or spraying coverage. The ceiling value was shown to be $10 \text{ g} \cdot \text{L}^{-1}$ in ‘Orah’ mandarin. In contrast, the incidence and degree of sunburn varied with the increase in lime concentration or spray coverage. The lowest incidence of sunburn was found in the treatment at the concentration of $40 \text{ g} \cdot \text{L}^{-1}$ and the coverage of 50%. The application of lime suspension affected the quality of fruit, and the most significant effect was found in the hardness of fruit peel, which was significantly increased compared with the control. In addition, the treatment also affected the brightness of the peel, with significant reduction in L value but no significant effect on a and b values. Spraying lime suspension increased vitamin C content in the fruit. In ‘Newhall’ navel orange, vitamin C content was significantly increased in all treatments compared with the control. Titratable acid content and soluble solid content in the treatments were also higher than the control, but only a few of them were significantly different from the control. Beyond the above indicators, there was no significant difference among the treatments. Principal component analysis of the quality indexes showed that the score of control treatment was 0.109 7 (ranking the fourth) in ‘Orah’ mandarin, and 0.125 6 (ranking the fourth) in ‘Newhall’ navel orange. When the concentration of lime suspension was higher than $20 \text{ g} \cdot \text{L}^{-1}$, the comprehensive score was higher than the control. Among these treatments, the one with the concentration of $40 \text{ g} \cdot \text{L}^{-1}$ and coverage of 50% had the highest comprehensive score. The results showed that the best lime treatment to reduce fruit sunburn and improve quality was to spray the canopy with lime at the concentration of $40 \text{ g} \cdot \text{L}^{-1}$ with 50% coverage. 【Conclusion】The application of lime suspension can significantly reduce the incidence of fruit and leaf sunburn, and has no significant adverse effect on fruit quality. For sunburn control, it is recommended to spray $40 \text{ g} \cdot \text{L}^{-1}$ lime suspension with a coverage of 50%.

Key words: Citrus; Lime water; Temperature; Sunburn; Fruit quality

日灼是柑橘生产上的常见问题,也是导致中期落果的主要原因之一,是一种由高温和强光引起的生理病害^[1-3]。果实灼伤部位果皮坚硬粗糙,果色黄色或棕褐色,果实畸形、囊瓣枯缩、果味差、品质劣,叶片灼伤部位则会变厚变脆、停止生长,失去功能^[4]。我国大部分柑橘产区7—8月高温伏旱严重,常遭遇长时间 38°C 以上高温, $41\sim 42^\circ\text{C}$ 的高温天气也不鲜见,极易造成柑橘果实和叶片的日灼损伤,特别是以树冠外围结果为主的品种,日灼更为严重,如‘茂谷柑’和近年大面积种植的‘沃柑’,日灼果比例

可高达1/3以上,给生产带来严重损失。长期以来,国内外对柑橘^[2,5-6]、苹果^[7-9]、梨^[10-11]等水果的日灼开展了众多研究,也发明了众多的有效防控方法,诸如喷或涂防晒剂^[12-14]、喷水^[15-17]、贴防晒纸^[18-19]、套袋^[16,20]、盖遮阳网^[21-23]、生草栽培^[24]和建设防护林等。然而,现有的防日灼方法都没有同时解决高防效、经济性和可操作性三者兼顾的难题,特别是目前农村劳动力越来越短缺的情况下,柑橘日灼仍然困扰柑橘生产^[25-27]。在众多的柑橘防日灼方法中,喷布石灰水是最经济、简单的方法,也有较好效果,但一直以来对

石灰水的研究主要停留在简单的浓度试验上^[26-29],对不同喷布浓度和覆盖率的反光和降温程度、防灼效果和果实品质等缺乏系统研究。为此,笔者以‘纽荷尔’脐橙和‘沃柑’为材料,研究不同石灰水浓度和喷布覆盖率对减轻日灼的效果,以期为生产上石灰水的合理使用提供依据。

1 材料和方法

1.1 试验材料 with 处理

试验于2018年和2019年的7—9月在中国农业科学院柑桔研究所试验果园进行。2018年7月16—26日,重庆北碚区连续11 d气温 $\geq 38\text{ }^{\circ}\text{C}$,整个7月气温超过 $37\text{ }^{\circ}\text{C}$ 的时间高达15 d,最高气温可达 $40\text{ }^{\circ}\text{C}$ 。2019年8月17日至26日期间,出现了连续10 d的高温(气温 $\geq 38\text{ }^{\circ}\text{C}$)。供试品种为成年‘纽荷尔’脐橙(*Citrus sinensis* Osbeck. ‘Newhall’ navel orange)及高接换种3 a的‘沃柑’(‘Orah’ mandarin)。

根据生产上石灰水施用的实际情况,采用生石灰粉末配制5个质量浓度梯度:0、5、10、20、40 $\text{g}\cdot\text{L}^{-1}$,各浓度缩写为CK、T1、T2、T3、T4,以清水($0\text{ g}\cdot\text{L}^{-1}$)喷施为对照,每个浓度设置30%和50% 2个喷施覆盖率(石灰水占叶面或果面的面积)。喷施覆盖率通过喷头挥动次数控制,30%覆盖率挥动喷头3次,50%挥动喷头5次。于高温来临前对树冠外围进行喷施,若试验过程中遇大雨,在天气晴朗时补喷至原设定的覆盖率,直至高温结束。选择长势一致的植株进行处理,每个处理各6株,单株重复。

1.2 叶面果面温度测定

石灰水喷施后,选定气温为 $38\sim 42\text{ }^{\circ}\text{C}$ 的高温晴朗天气,在13:00—15:00时段,使用红外测温仪(福禄克 FLUCK 62MAX)对向阳面日灼斑附近正常的叶面或果皮进行温度测定。

1.3 叶面反光度的测定

石灰水处理40 d后,从田间采集各处理的叶片于实验室中进行反光度的测定。提供一定光源,并用照度计(台湾泰仕 TES-1332A)测定光源值,然后将照度计安置在固定位置,在不放置样品的情况下,用照度计测定背景值。然后在不挪动照度计的情况下,将叶片放置在固定位置,使用照度计进行测定,得到样品测定值。每株树选取6枚叶片,每个处理36枚叶片,单叶重复。反光率计算公式为:

$$\text{反光率}/\%=(\text{样品测定值}-\text{背景值})/\text{光源值}\times 100。$$

1.4 叶片相对叶绿素的测定

石灰水处理40 d后,从田间采集叶片进行清洗擦干,使用 SPAD-502 型叶绿素仪(日本 KONICA MINOLTA)对叶片叶绿素相对含量(SPAD)进行测定。每株树选取8枚叶片,每个处理6株树,每处理共计48枚叶片。

1.5 叶片果实日灼程度的统计

高温天气结束后,约石灰水喷施一月后,采用随机抽样法对每棵树的叶片及果实的日灼情况进行统计。从植株向阳面随机挑选枝条进行统计并分级,分级标准参照张彦坤^[30]、孙爱梁等^[31]的方法并做了一定修改。叶片/果实分级标准如下:0级日灼:无肉眼可见日灼症状;1级日灼:有轻微日灼症状,日灼部位颜色开始出现淡绿黄色,果实后期可恢复;2级日灼:日灼斑明显,日灼斑占叶面积1/5,或占果实向阳面1/5;3级日灼:日灼斑占叶面积1/5~1/3,或占果实向阳面1/5~1/2;4级日灼:日灼斑明显,日灼斑占叶面积 $> 1/3$,或占果实向阳面 $> 1/2$ 。根据统计情况,计算日灼发生率和日灼程度。

$$\text{果实日灼发生率}/\%=\text{日灼果数}/\text{统计数}\times 100。$$

$$\text{果实日灼程度}=\text{0级果数}\times 0+\text{1级果数}\times 1+\text{2级果数}\times 2+\text{3级果数}\times 3+\text{4级果数}\times 4。$$

叶片日灼发生率与日灼程度的计算方式与果实相同。

1.6 果实品质的测定

果实成熟后,从树冠外围,主要是向阳面采集果实样品做品质测定。‘纽荷尔’脐橙每株树6个果,‘沃柑’每株树5个果,每个处理6株树,每2株树为1个重复,共3次重复。采用日本美能达公司研制的 CR-10 手持式色差仪测定 L (亮度)、 a (红色)、 b (黄色),以标准白板为参考。采用游标卡尺测定果皮厚度。采用硬度计(艾德堡 GY-4,探头直径3.5 mm)对果皮硬度进行测定。对果实和果皮进行称重,并用公式:可食率/ $\%=(\text{果质量}-\text{果皮质量})/\text{果质量}\times 100$,对可食率进行计算。采用 PAL-1 数显糖度仪(日本 ATAGO 公司)对可溶性固形物含量(TSS)进行测定;采用 NaOH 中和滴定法对果实可滴定酸含量进行测定;采用 2,6-二氯吡啶酚钠滴定法进行维生素 C(Vc)含量的测定。

1.7 数据处理

试验数据以2018年数据为主,其中叶面果面温度、叶面反光度和果实品质数据均为2018年测定。

果实及叶片日灼情况统计和叶片相对叶绿素含量测定数据均来源于2019年。采用 Microsoft Office Excel 2013 对数据进行处理及作图,并用 SPSS18.0 进行方差分析和主成分分析。统计分析采用单因素 ANOVA 的 LSD 比较差异的显著水平($\alpha=0.05$)。表中数据均以平均值 \pm 标准误表示。

2 结果与分析

2.1 喷施石灰水对叶片叶绿素相对含量和叶面反光率的影响

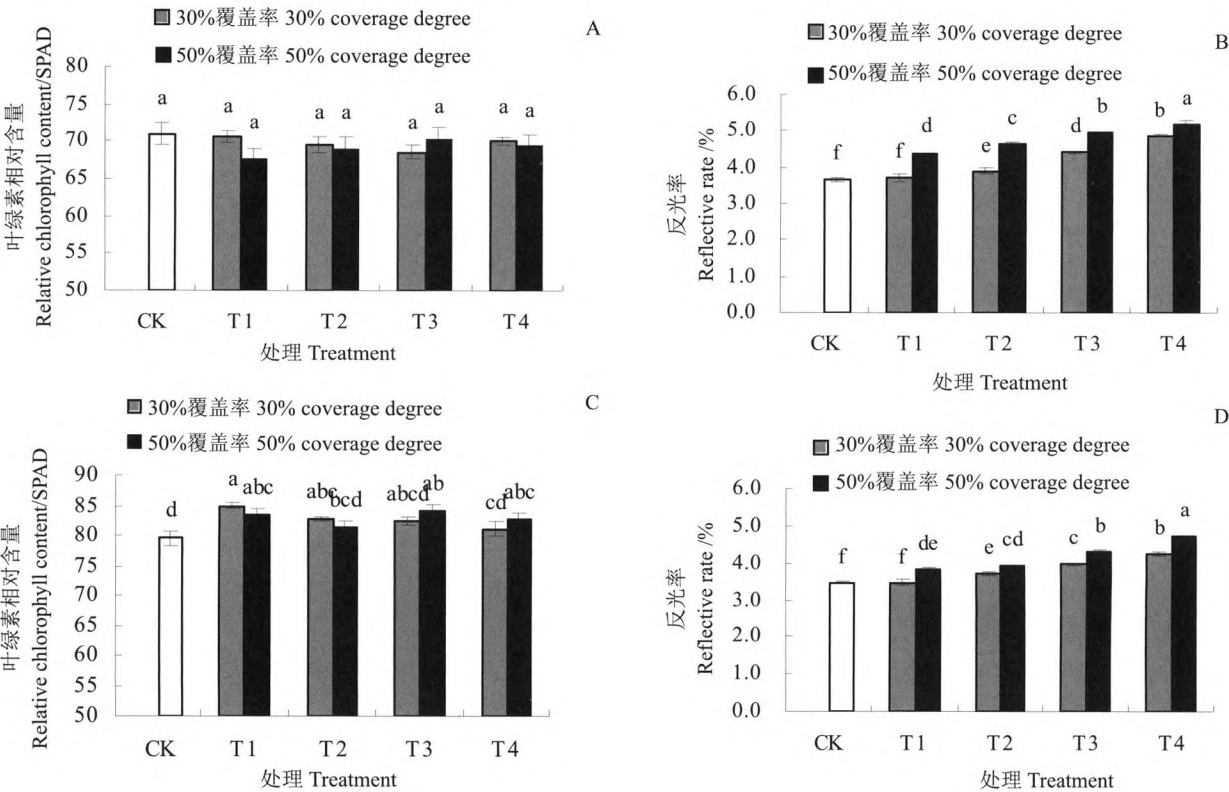
喷施石灰水对‘沃柑’叶片叶绿素相对含量无显著影响,但随着喷施浓度和覆盖率的升高,叶面反光率升高;相同浓度下,覆盖率为50%的叶面,反光率更高,比30%覆盖率的叶片高0.3%到0.8%左右。‘纽荷尔’脐橙的叶片相对叶绿素 SPAD 值在 79.60~84.97,各处理的 SPAD 值均显著高于对照(79.60)。随着石灰水喷施浓度的升高和覆盖率的增加,‘纽荷尔’叶片的反光率呈上升趋势,且相同浓度下,

覆盖率越高(50%覆盖率)叶片反光率越高,最高值为50%覆盖率下的T4处理,其值是对照的1.36倍(图1)。

2.2 喷施石灰水对叶面和果面温度的影响

石灰水处理后,‘沃柑’果面温度较对照而言,下降0.6~2.1℃。覆盖率为30%的T3、T4处理;覆盖率为50%的T2、T3、T4处理,均能显著降低果面温度,但这些处理间对果面的降温效果无显著差异。相较果实而言,石灰水的喷施对叶面温度的影响更为显著。与对照相比,石灰水处理后的叶面温度下降了1.6~3.8℃。在同一覆盖率下,喷施浓度越高,叶面温度越低,且与对照相比,各处理均能达到显著差异;同一浓度下,覆盖率越高,叶面温度越低。整体而言,覆盖率50%,质量浓度20、40 g·L⁻¹的处理,对‘沃柑’叶面的降温效果最好,其叶面温度比对照(45.47℃)低3.78℃(图2-A~B)。

2种覆盖率下,喷施质量浓度为10、20、40 g·L⁻¹的石灰水均能有效降低‘纽荷尔’脐橙果实表面温



不同小写字母表示差异显著($p < 0.05$)。CK、T1、T2、T3、T4 分别表示石灰水浓度为 0、5、10、20、40 g·L⁻¹。下同。
Different small letters mean significant difference at 0.05 level. CK, T1, T2, T3 and T4 indicate that the concentration of lime water is 0, 5, 10, 20 and 40 g·L⁻¹, respectively. The same below.

图1 不同石灰水处理对‘沃柑’(A和B)和‘纽荷尔’脐橙(C和D)叶面反光率和叶绿素相对含量的影响
Fig. 1 Effects of different lime treatments on the reflectance and relative chlorophyll content in the leaves of ‘Orah’ mandarin (A and B) and ‘Newhall’ navel orange (C and D)

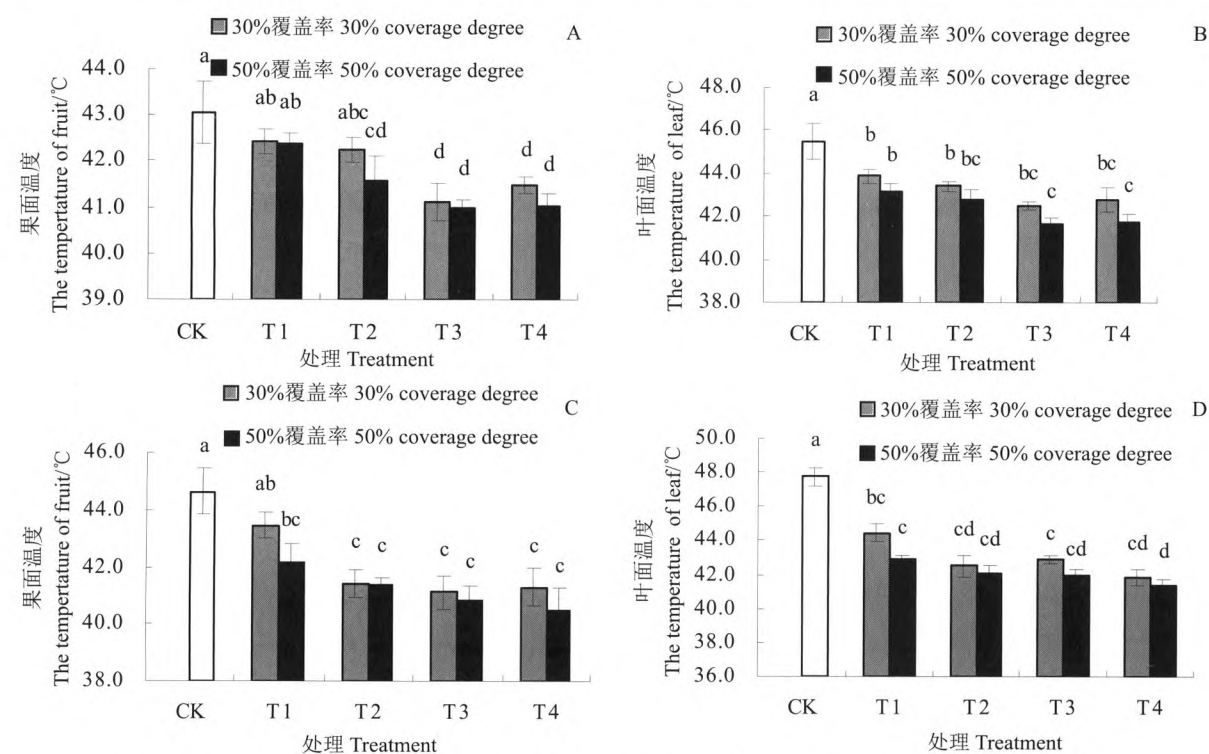


图 2 不同石灰水处理对‘沃柑’(A 和 B)和‘纽荷尔’脐橙(C 和 D)果面叶面温度的影响

Fig. 2 Effect of different lime treatments on fruit surface and leaf surface temperatures in ‘Orah’ mandarin (A and B) and ‘Newhall’ navel orange (C and D)

度,且这些处理间无显著差异。石灰水处理后,叶面温度显著降低,比对照低 3.3~6.4 ℃,均达到显著水平,其中 30%的 T1 处理温度(44.45 ℃)最高,50%的 T4 处理的温度(41.34 ℃)最低,其余处理间无显著差异(图 2-C,D)。

比较‘沃柑’和‘纽荷尔’脐橙果面和叶面温度发现,在不喷施石灰水的情况下,‘纽荷尔’脐橙果面温度比‘沃柑’高 1.59 ℃,叶面温度也比‘沃柑’高 2.26 ℃,主要原因是‘纽荷尔’脐橙果型更大、叶色更深。

2.3 喷施石灰水对日灼程度和日灼发生率的影响

喷施石灰水能显著降低‘沃柑’果实的日灼发生率和日灼程度,图 3 显示,除 30%覆盖率的 T1 处理外,其余各处理的果实日灼发生率和日灼程度均显著低于对照,其中质量浓度为 40 g·L⁻¹的石灰水处理效果最佳。对‘沃柑’叶片而言,喷施质量浓度 5 g·L⁻¹的石灰水效果差,其日灼发生率与对照无显著差异,但其日灼程度显著低于对照;喷施质量浓度为 40 g·L⁻¹的石灰水效果最好,其日灼发生率和日灼程度均显著低于对照,在覆盖率为 50%的情况下,日灼发生率较对照减少近 40%。

喷施石灰水能显著降低‘纽荷尔’脐橙果实的日

灼发生率和日灼程度,除喷施覆盖率为 30%,质量浓度为 5 g·L⁻¹的处理与对照无显著差异外,其余各处理均效果显著,且当喷施质量浓度高于 5 g·L⁻¹后,各处理间无显著差异。当石灰水喷施覆盖率为 50%时,‘纽荷尔’脐橙叶片的日灼发生率显著降低,其中覆盖率 50%,质量浓度为 40 g·L⁻¹的处理,日灼发生率最低,仅为 23.27%。与对照相比,石灰水处理后的‘纽荷尔’脐橙叶片日灼程度显著降低,其中覆盖率 50%,质量浓度为 40 g·L⁻¹的处理效果最佳。

2.4 喷施石灰水对果实品质的影响

如表 1 所示,与对照相比,石灰水处理后,‘沃柑’果皮 a、b 值无显著变化,但 L 值降低,果皮亮度降低。喷施石灰水会影响果实的厚度和硬度,对可食率无显著影响;与对照相比,各处理均导致果皮硬度的显著升高,其中 50%覆盖率的 T4 处理硬度值最大,比对照高 0.70 kg·cm⁻¹。喷施石灰水使果实维生素 C 含量升高,但只有 30%覆盖率的 T3 处理及 50%覆盖率的 T1 处理与对照达到显著差异。在石灰水处理下,大部分处理组的可滴定酸呈上升趋势。当覆盖率为 50%时,喷施石灰水均能显著提高果实的可溶性固形物含量,其中 T4 处理的可溶性固形物含量最高。

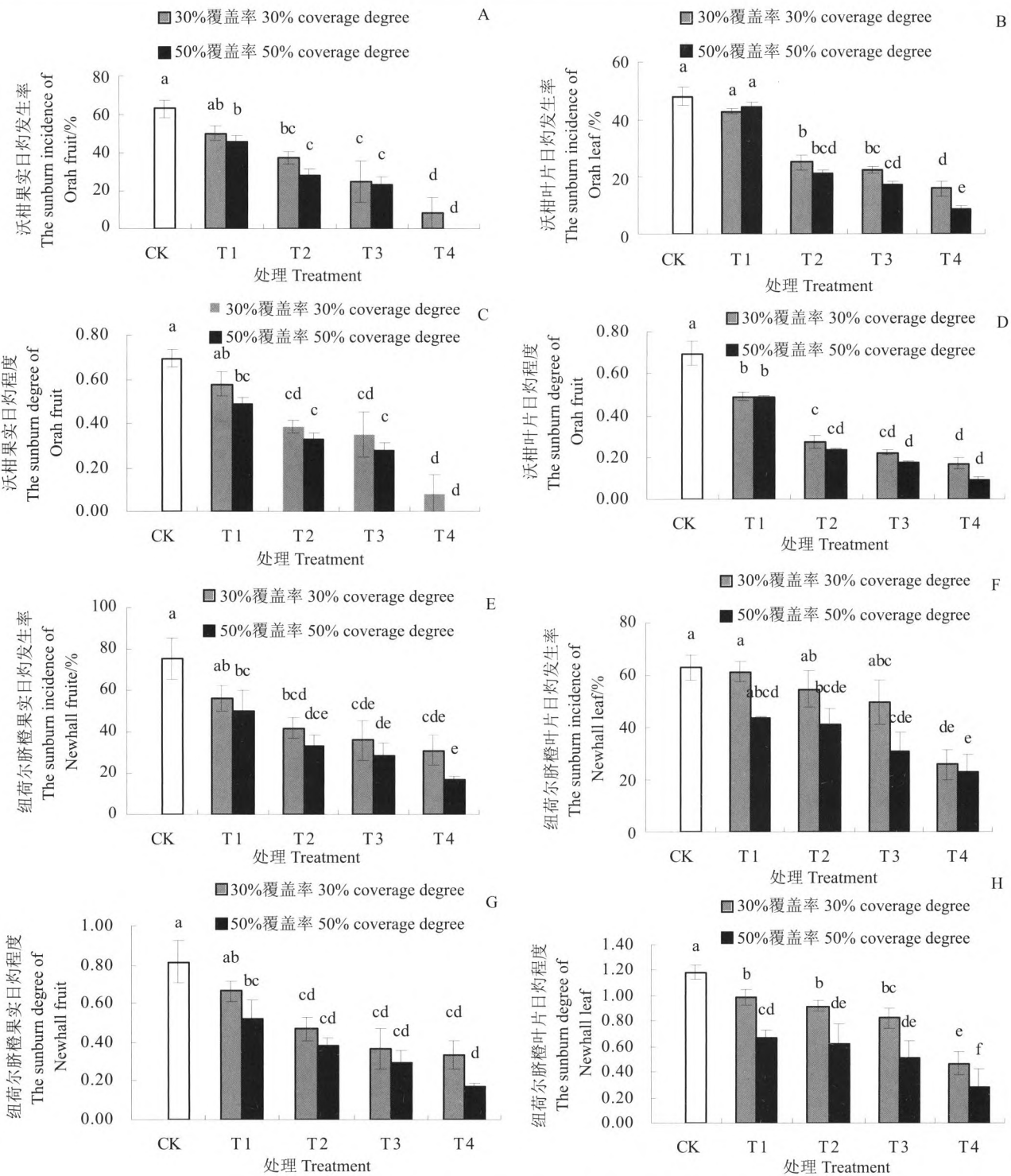


图3 不同石灰水处理对叶片和果实日灼发生率及日灼程度的影响

Fig. 3 Effects of different lime treatments on the incidence and degree of sunburn in the leaves and the fruits

表2所示为‘纽荷尔’脐橙果实品质数据,与对照相比,石灰水处理后,果皮L值显著降低,a、b值无显著变化,当喷施质量浓度为40 g·L⁻¹时,果皮厚度显著降低。同时,石灰水处理后,果皮硬度增加,覆盖率为50%、质量浓度为40 g·L⁻¹时,硬度值最大,是对照处理的1.45倍。喷施石灰水对可食率无显著影

响。各处理的维生素C含量均显著高于对照组,其中喷施质量浓度为20 g·L⁻¹时,维生素C含量最高。在石灰水处理下,大部分处理组的可滴定酸含量呈上升趋势,但与对照相比,只有覆盖率为30%的T2处理和覆盖率为50%的T3处理组达到了显著水平。覆盖率为50%的T3处理组和覆盖率为30%的T4处理组

表 1 不同石灰水处理对‘沃柑’果实品质的影响

Table 1 Effects of different lime treatments on fruit quality of ‘Orah’ mandarin

覆盖率 Coverage degree	处理 Treatment	亮度 L*	红绿色度 a*	黄青色度 b*	果皮厚度 Pericarp thickness/ mm	硬度 Fruit peel hardness/ (kg·cm ⁻²)	可食率 Flesh recovery/ %	ρ(维生素C) Vitamin C content/ (mg·100 mL ⁻¹)	w(可滴定酸) Titratable acid content/%	w(可溶性固形物) Soluble solid content/%
30%覆盖率 30% coverage degree	对照 CK	72.62±0.36 a	27.92±0.46 a	70.4±0.56 a	2.56±0.01 d	2.97±0.07 c	75.34±1.48 b	19.71±0.24 c	0.36±0.00 d	12.70±0.00 c
	T1	72.38±0.92 ab	28.56±1.33 a	70.27±1.53 a	2.97±0.19 bc	3.19±0.04 b	74.47±0.92 b	20.07±0.27 c	0.29±0.00 e	12.47±0.24 c
	T2	70.20±0.79 bc	31.37±0.17 a	68.11±0.95 a	3.40±0.07 a	3.32±0.03 b	73.35±0.69 b	20.90±0.00 bc	0.32±0.01 e	12.70±0.06 c
	T3	72.09±0.82 abc	29.66±0.89 a	69.43±0.81 a	2.64±0.04 cd	3.35±0.01 b	75.80±1.14 ab	22.41±0.14 ab	0.41±0.01 abc	13.93±0.22 a
50%覆盖率 50% coverage degree	T4	71.49±0.69 abc	30.24±1.58 a	69.5±0.92 a	2.97±0.16 bc	3.36±0.02 b	76.16±1.25 ab	20.07±1.11 c	0.40±0.02 abcd	12.60±0.00 c
	T1	69.98±0.27 c	31.35±0.49 a	67.29±0.84 a	2.85±0.09 cd	3.30±0.01 b	74.06±0.69 b	23.37±0.55 a	0.42±0.01 ab	13.70±0.06 a
	T2	71.08±0.71 abc	29.84±1.30 a	68.79±1.41 a	2.53±0.03 d	3.33±0.08 b	75.23±0.74 b	21.36±0.51 bc	0.38±0.02 cd	13.20±0.06 b
	T3	71.17±0.34 abc	30.53±0.70 a	69.38±0.69 a	3.25±0.10 ab	3.37±0.01 b	75.96±0.42 ab	20.07±0.27 c	0.39±0.00 bcd	13.55±0.09 ab
	T4	72.25±0.88 abc	29.31±2.29 a	70.24±1.21 a	2.79±0.08 cd	3.67±0.12 a	78.73±1.17 a	20.49±0.41 bc	0.42±0.01 a	13.85±0.13 a

注:同列数值后不同小写字母表示差异显著($p < 0.05$)。CK、T1、T2、T3、T4 分别表示石灰水浓度为 0.5、10、20、40 g·L⁻¹。下同。

Note: Values followed by different small letters mean significant differences ($p < 0.05$). CK, T1, T2, T3 and T4 indicate that the concentration of lime water is 0.5, 10, 20 and 40 g·L⁻¹, respectively. The same below.

表 2 不同石灰水处理对‘纽荷尔’脐橙果实品质的影响

Table 2 Effects of different lime treatments on fruit quality of ‘Newhall’ navel orange

覆盖率 Coverage degree	处理 Treatment	亮度 L*	红绿色度 a*	黄青色度 b*	果皮厚度 Pericarp thickness/ mm	硬度 Fruit peel hardness/ (kg·cm ⁻²)	可食率 Flesh recovery/ %	ρ(维生素C) Vitamin C con- nt/(mg·100 mL ⁻¹)	w(可滴定酸) Titratable acid/%	w(可溶性固形物) Soluble solid content/%
30%覆盖率 30% coverage degree	CK	69.37±0.16 a	33.39±0.35 abc	68.38±0.28 abc	5.58±0.53 a	2.66±0.27 c	73.98±0.53 a	51.87±0.39 e	0.62±0.02 cd	12.57±0.02 b
	T1	68.61±0.37 ab	32.44±0.82 c	68.17±0.84 abc	5.50±0.1 ab	2.98±0.01 c	71.48±0.19 a	55.86±0.79 d	0.60±0.01 d	12.62±0.02 b
	T2	67.73±0.59 b	35.18±0.31 a	66.38±0.20 c	5.21±0.12 abc	2.90±0.02 c	72.47±2.71 a	55.95±0.27 d	0.67±0.00 ab	12.50±0.13 b
	T3	67.56±0.38 b	33.67±0.39 abc	67.86±0.93 abc	4.88±0.25 abc	2.70±0.04 c	71.50±0.56 a	61.48±0.98 ab	0.62±0.00 cd	12.72±0.12 b
50%覆盖率 50% coverage degree	T4	68.35±0.28 ab	34.60±0.35 ab	67.23±0.33 abc	4.55±0.23 c	3.55±0.05 ab	72.78±0.95 a	60.04±1.5 bc	0.64±0.01 bc	13.66±0.26 a
	T1	67.83±0.60 b	33.37±0.52 abc	67.12±0.68 bc	5.39±0.19 ab	3.13±0.09 bc	71.08±1.57 a	57.82±0.46 cd	0.63±0.01 cd	12.38±0.25 b
	T2	68.38±0.20 ab	34.04±0.55 abc	67.06±0.23 bc	5.16±0.12 abc	2.71±0.09 c	71.85±1.05 a	54.53±1.24 de	0.63±0.00 cd	12.67±0.20 b
	T3	67.75±0.54 b	32.92±0.86 bc	68.92±1.06 ab	4.72±0.40 bc	3.07±0.37 bc	71.96±0.92 a	63.99±0.14 a	0.69±0.01 a	13.63±0.04 a
	T4	68.28±0.32 ab	32.46±0.06 c	69.48±0.72 a	4.47±0.07 c	3.87±0.08 a	73.96±0.89 a	57.9±1.37 cd	0.66±0.02 abc	12.86±0.14 b

可溶性固形物含量显著高于对照组,其余各组间均无显著差异。

为更好地评价石灰水喷施对成熟果实品质的影响,对 L 值、 a 值、 b 值、果皮厚度、硬度、可食率及维生素 C、可滴定酸、可溶性固形物含量 9 个品质指标进行主成分分析,表 3 各项指标的累计贡献率达 92.47%,F1、F2、F3 贡献率分别为 43.48%,33.24%和 15.75%。表 3 结果表明,当喷施质量浓度为 $40\text{ g}\cdot\text{L}^{-1}$

时,无论喷施覆盖率为多少,对‘沃柑’果实的品质均有一定的促进作用,其中石灰水浓度为 $40\text{ g}\cdot\text{L}^{-1}$,覆盖率为 50% 的处理得分最高,效果最佳。表 4 各指标的累计贡献率为 82.75%,F1、F2、F3 贡献率分别为 39.65%,26.99%和 16.11%。从综合得分排名可以看出,石灰水质量浓度为 $20\text{ g}\cdot\text{L}^{-1}$,喷施覆盖度为 50%,或石灰水质量浓度为 $40\text{ g}\cdot\text{L}^{-1}$,覆盖率为 30%或 50% 的处理,综合得分均高于对照处理,其中石灰水质量

表 3 不同处理下 ‘沃柑’ 果实的综合得分及排名
Table 3 Score and ranking of ‘Orah’ mandarin fruit under different treatments

覆盖率 Coverage degree	处理 Treatment	主成分得分 Principal Component Score			综合得分(F) Composite score	综合得分排名 Comprehensivescore ranking
		PC1(F1)	PC2(F2)	PC3(F3)		
	CK	2.217 1	-1.958 1	-1.344 9	0.109 7	4
30% 覆盖率 30% coverage degree	T1	1.728 3	-2.259 1	0.336 9	0.058 1	5
	T2	-2.030 8	-1.486 8	1.804 1	-1.182 0	8
	T3	-0.245 4	1.070 3	-1.375 2	0.035 1	6
	T4	0.644 9	0.226 8	0.798 4	0.520 8	3
50% 覆盖率 50% coverage degree	T1	-3.773 8	0.381 7	-0.977 4	-1.803 9	9
	T2	-0.655 8	-0.093 4	-0.927 9	-0.500 0	7
	T3	0.084 1	0.844 9	1.289 5	0.562 9	2
	T4	2.031 5	3.273 7	0.396 4	2.199 4	1

表 4 不同处理下 ‘纽荷尔’ 脐橙果实的综合得分及排名
Table 4 Score and ranking of ‘Newhall’ navel orange fruit under different treatments

覆盖率 Coverage degree	处理 Treatment	主成分得分 Principal Component Score			综合得分(F) Composite score	综合得分排名 Comprehensive score ranking
		PC1(F1)	PC2(F2)	PC3(F3)		
	CK	-1.794 2	2.878 0	0.239 8	0.125 6	4
30%覆盖率 30% coverage degree	T1	-2.345 8	-0.386 8	1.381 9	-0.981 3	8
	T2	0.184 9	0.120 0	-2.346 1	-0.328 9	5
	T3	-0.376 8	-1.981 0	0.126 5	-0.802 1	7
	T4	2.320 3	0.611 9	-0.864 8	1.143 1	2
50%覆盖率 50% coverage degree	T1	-1.465 3	-1.434 7	-0.006 1	-1.171 3	9
	T2	-1.162 8	0.121 5	-0.791 2	-0.671 6	6
	T3	2.339 0	-1.482 5	0.829 3	0.798 7	3
	T4	2.300 8	1.553 6	1.430 6	1.887 7	1

浓度为 $40\text{ g}\cdot\text{L}^{-1}$,覆盖率为 50%效果最佳。

3 讨 论

日灼的发生具有品种差异,不同品种的果实日灼临界温度有所不同^[32-34],日灼的发生率也有所差异^[3,26]。本试验中,无论是叶片还是果实的日灼发生率,‘纽荷尔’脐橙均比‘沃柑’高 10%左右。温度和太阳辐射是植物日灼发生的 2 个重要因素,Schrader 等^[33]认为高太阳辐射和高 FST 值(Fruit Surface Temperature)是果实发生日灼晒伤褐变的关键,太阳辐射是诱发日灼晒伤的必要条件。因此是否能有效降低果叶面温度和太阳辐射就是日灼防治的 2 个关键

步骤。从温度的变化来看,在本实验中,喷施过石灰水的果面和叶面的温度显著低于对照的果、叶面温度,并且随石灰水喷施浓度或覆盖率的升高,柑橘叶面和果面温度呈下降趋势。但石灰水的降温作用存在阈值,当石灰水浓度达到一定值后,即使再增加石灰水浓度或喷施覆盖率,果面和叶面温度也不会显著变化,‘沃柑’果实喷施质量浓度高于 $10\text{ g}\cdot\text{L}^{-1}$ 后,即使增加浓度或覆盖率,果面温度也不再发生显著变化。另一方面,随着喷施石灰水浓度和覆盖率的增大,柑橘叶面反光率随之增大。总的来说,石灰水防日灼的原理主要有 2 个,一个是白色反光,二是物质隔热^[19]。本研究也显示石灰水的反光和降温效果

与其喷施浓度和覆盖率成正比,但过高的浓度和覆盖率会降低光合效率,特别是高温伏旱过后,这种影响会更大。实验中发现,‘沃柑’各处理间的相对叶绿素无显著差异,而‘纽荷尔’脐橙处理的叶片叶绿素相对含量明显高于对照,这可能是因为‘纽荷尔脐橙’叶片大而深绿色,导致其日灼程度明显高于‘沃柑’,且对照叶片日灼大多处于1级及以上,叶片变黄,致使其SPAD值低于处理。

综合日灼发生率和日灼程度发现,质量浓度40 g·L⁻¹、覆盖率为50%的处理日灼程度和日灼发生率最低。果实和叶片的日灼发生率和日灼程度是随着石灰水喷施浓度和喷施覆盖率的增加而降低,这说明喷施石灰水确实可以有效防治柑橘的日灼。而柑橘的日灼程度和发生率变化趋势并非像温度一般具有阈值,则说明即使在降温效果相同的情况下,通过提高石灰水的浓度也可降低果实和叶片的日灼发生率和日灼程度,似乎日灼的发生并不完全受温度的影响,或许阳光中的紫外线等对日灼的发生也起了较大作用,因为高浓度石灰水和喷布覆盖率使果面和叶面反光度增加,减少了光线的直接伤害。

前人研究表明,喷钙会影响果实的品质,其中最显著的变化就是会增加果实的硬度,周咏梅等向葡萄进行钙处理后,日灼发病率显著降低,葡萄果实的硬度升高^[35]。王海华等^[36]发现轻质碳酸钙涂抹的‘茂谷柑’果实,能一定程度促进果皮发育,使果皮增厚,果皮手感变硬。本试验中,石灰水处理后,‘纽荷尔’脐橙和‘沃柑’果皮硬度显著升高,相较对照而言,50%覆盖率下的T4处理硬度分别升高了0.7 kg·cm⁻²和1.21 kg·cm⁻²。Bakeer等^[37]向石榴喷施氯化钙后,石榴的果皮率明显升高,但氯化钙的施用对SSC含量和总糖含量无显著影响。而简水仙^[38]则指出,通过外源钙处理‘纽荷尔’脐橙果实,可以提高其可溶性固形物含量和维生素C含量^[38]。本实验对‘纽荷尔’脐橙和‘沃柑’果实的处理结果与简水仙^[38]的结果相一致,石灰水对维生素C含量、可溶性固形物含量和可滴定酸含量有一定的正向作用,但对果皮亮度有一定负向影响。主成分分析结果表明,石灰水质量浓度40 g·L⁻¹、覆盖率为50%时综合评分最高,一定程度上提升了果实品质。

4 结 论

增加石灰水喷施浓度和覆盖率能提高反光率,

显著降低果面和叶面温度,显著降低日灼发生率和日灼程度,并对果实品质有一定的促进作用。在日灼易发区,推荐石灰水喷施质量浓度为40 g·L⁻¹、喷施覆盖率为50%。

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