

# 套袋瑞雪苹果果皮褐变发生规律 及其与温度的关系

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**摘要:**【目的】研究套袋瑞雪苹果(*Malus domestica* Borkh. ‘Ruixue’)果皮褐变发生规律及其与温度的关系。【方法】以瑞雪为试验材料, 调查了专用果袋、G果袋处理的瑞雪果实全发育期褐变率, 监测果袋内和空气中的温度, 分析果袋内外温度差异与褐变率之间的关系。【结果】随着套袋时间的延长, 果实褐变率升高, G果袋处理的果实褐变率高于专用果袋; 果袋内的日平均温( $T_{\text{mean}}$ )、日最高温( $T_{\text{max}}$ )、昼夜温差( $TD$ )、有效积温( $GDD$ )、日最高温积累量( $ST_{\text{max}}$ )、昼夜温差的积累量( $STD$ )均低于空气中的对应参数, 而果袋内的日最低温( $T_{\text{min}}$ )、日最低温积累量( $ST_{\text{min}}$ )与空气中的无显著差异; 果袋内 $GDD$ 、 $ST_{\text{max}}$ 、 $STD$ 的积累速率低于空气中的积累速率, 而 $ST_{\text{min}}$ 的积累速率高于空气中的, 果袋内温度环境较袋外稳定; 果袋内外 $|\Delta GDD|$ 、 $|\Delta ST_{\text{max}}|$ 、 $|\Delta ST_{\text{min}}|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 存在极显著相关性, 其中 $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 的相关性最大, 且存在非线性回归关系, 说明果袋内外 $GDD$ 、 $STD$ 较大的差异是瑞雪苹果果皮褐变发生的关键因素。【结论】果袋内外有效积温( $GDD$ )、昼夜温差的积累量( $STD$ )的差异与瑞雪苹果果实果皮褐变紧密相关, 是套袋诱发瑞雪果皮褐变的重要生态因素。

**关键词:** 瑞雪苹果; 褐变; 套袋; 温度

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## A study of the characteristics of browning in bagged Ruixue apple fruit and its relationship to temperature

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**Abstract:** 【Objective】In order to explore the effect of temperature factors on browning during fruit development in Ruixue apple, the article studied the relationship of pericarp browning of bagged Ruixue apple (*Malus domestica* Borkh. ‘Ruixue’) with temperature. 【Methods】Five-year-old Ruixue trees were used as the experimental material and M<sub>26</sub> as rootstock. The study investigated the fruit browning rate 90, 120, 150, 160, 170, 180, 190 and 200 days after full bloom. Temperatures in the fruit bag and in the air during fruit development were recorded. The relationship of the temperature difference between the air and the fruit bags and the browning rate was analyzed. 【Results】The results showed that with the extension of bagging time, the browning rate of the pericarp of Ruixue apple became higher. 200 days after full bloom, the browning rate of G bag reached 85.56% and the browning rate in bagging treatment with a special bag type reached 70%. Fruit in G fruit bags started to appear symptoms 150 days after full bloom, while those in the special fruit bags begun to appear the symptoms of browning 160 days after full bloom. The browning rate of fruit in G fruit bags was higher than those in special fruit bags. From 150 to 200 days after full bloom, the browning rate in G fruit bags was 4.44% to

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24.44% higher than that in special fruit bags. The daily average temperature ( $T_{\text{mean}}$ ), daily maximum temperature ( $T_{\text{max}}$ ), daily the difference of day and night temperature ( $TD$ ), effective accumulated temperature ( $GDD$ ), accumulated daily maximum temperature ( $ST_{\text{max}}$ ), and accumulated daily the difference of day and night temperature ( $STD$ ) in the fruit bags were lower than in the air. Daily minimum temperature ( $T_{\text{min}}$ ) and accumulated daily minimum temperature ( $ST_{\text{min}}$ ) had no difference between the fruit bags and the air. From 150 to 200 days after full bloom,  $GDD$  in the special fruit bag was 24.0 °C to 72.0 °C lower than in the air, and  $STD$  was 140.2 °C to 330.3 °C lower than in the air.  $GDD$  in G fruit bag was 62.0 °C to 126.7 °C lower, and  $STD$  224.2 °C to 467.6 °C lower than in the air. The accumulated rate of  $GDD$ ,  $ST_{\text{max}}$  and  $STD$  in the air were higher than in the fruit bags, while the accumulated rate of  $ST_{\text{min}}$  in the air was lower. The accumulation rate of  $GDD$  in the air, special fruit bag and G fruit bag was 3.64, 2.66 and 2.34 °C · d<sup>-1</sup>, the accumulation rate of  $ST_{\text{max}}$  23.02, 19.82 and 18.54 °C · d<sup>-1</sup>, the accumulation rate of  $STD$  16.17, 12.30 and 11.22 °C · d<sup>-1</sup>, and the accumulation rate of  $ST_{\text{min}}$  6.85, 7.52, and 7.32 °C · d<sup>-1</sup>, respectively. From 150 to 200 days after full bloom, the temperature factors inside the fruit bags were quite different from those in the air. The  $\Delta GDD$  of the G fruit bags was 38.00 °C to 54.72 °C lower than in the special fruit bags.  $\Delta ST_{\text{max}}$  in G fruit bag was 98.60 °C to 161.50 °C lower than in the special fruit bags. The  $\Delta STD$  in G fruit bag was 84.00 °C to 137.30 °C lower, and  $\Delta ST_{\text{min}}$  14.60 °C to 24.20 °C lower than in the special fruit bags.  $|\Delta GDD|$ ,  $|\Delta ST_{\text{max}}|$ ,  $|\Delta ST_{\text{min}}|$  and  $|\Delta STD|$  had a significant correlation with  $|\Delta PB|$ , of which  $|\Delta GDD|$  and  $|\Delta STD|$  had the greatest correlation. In the special fruit bag, the correlation coefficients were 0.881 and 0.88, respectively, while in the G fruit bag, the correlation coefficients were 0.947 and 0.943, respectively, and there was a non-linear regression relationship among  $|\Delta GDD|$ ,  $|\Delta STD|$  and  $|\Delta PB|$ . The big differences in  $GDD$  and  $STD$  between the inside and outside of the fruit bags were the key factor in the occurrence of peel browning in Ruixue. 【Conclusion】The temperature factors inside and outside the bags were quite different in the later stage of fruit development, therefore peel browning in the bagged Ruixue apple was caused by the temperature conditions in the later stage. According to the correlation analysis, the browning of the bagged Ruixue apple was closely related to the lower effective accumulated temperature and the lower accumulation of diurnal temperature difference in the fruit bags.

**Key words:** Ruixue apple; Browning; Bagging; Temperature

套袋是苹果(*Malus domestica* Borkh.)生产上较为常规的栽培技术<sup>[1]</sup>。苹果套袋既有优点,也有缺点。套袋能使苹果果皮的亮度增加,果面变得光滑,果点密度下降,果点变小,促进果皮着色,显著改善果实外观<sup>[2]</sup>;套袋还能防止病虫害的发生<sup>[3]</sup>,减少农药残留,从而降低饮食风险<sup>[4]</sup>。套袋也会对苹果果实品质带来一些负面影响,使苹果果实的糖、酸、多酚含量降低以及抗氧化能力下降等<sup>[5-6]</sup>。此外,套袋苹果管理不当易出现如日灼、苦痘病等<sup>[7-9]</sup>一些生理性病害。

瑞雪苹果是西北农林科技大学选育的具有中国自主知识产权的优良新品种,具有风味独特、质地细腻、香气浓郁等特点,极具推广价值<sup>[10]</sup>。近年来,为生产

出精品瑞雪果实,栽培者广泛采用传统富士套袋技术对瑞雪进行管理,结果发现,套袋瑞雪在接近成熟期时果皮易发生褐变的现象,严重影响了果实的外观品质<sup>[11-12]</sup>。由于不套袋果实未出现褐化问题,进而推断瑞雪果皮褐化必定与套袋改变的内在环境有关。而在生产上发现提前卸袋可以缓解瑞雪苹果果皮的褐变现象,因此研究果袋内的环境条件,预测瑞雪苹果果皮发生褐变的温度条件,确定具体的卸袋时间,对缓解瑞雪苹果果皮褐变具有一定的指导意义。赵才瑞<sup>[11]</sup>和李静<sup>[12]</sup>的研究认为,瑞雪果皮褐变可能是由于果袋内的高温胁迫所致。套袋所改变的温度因子必然是多样的,这些改变的温度因子与果实褐变率之间的关系仍然未知。

为明确套袋后诱发瑞雪果面褐变的温度因子,探索瑞雪苹果果面外观品质形成与温度因子之间的关系,笔者统计了瑞雪果实发育过程中褐变率的变化规律,比较了套袋后果袋内和自然环境中的温度差异,分析了温度各因子差异与果实褐变率之间的关系,以为解决瑞雪苹果套袋诱发的褐变问题提供科学依据,也为研究瑞雪果实外观品质形成奠定基础。

## 1 材料和方法

### 1.1 材料与处理

试验于2019年6—11月在西北农林科技大学白水苹果试验站(35°2' N, 109°6' E)进行。以矮化自根砧 M<sub>26</sub>栽培的5年生瑞雪苹果为试验材料,选取9株生长健壮、树势一致的植株,在盛花后45 d进行套袋,以不套袋为对照。所用果袋为专用果袋和G果袋,果袋的规格如表1所示。每个处理选3株树,即3次生物学重复。每株树选取60个果实,用于花后90、120、150、160、170、180、190、200 d调查果实的褐变率。在树体的中部正南方向相近区域选择大小一致的果实,套专用果袋和G果袋,将温度探头放入果袋内,并以果袋临近的

表1 果袋信息

Table 1 The information of fruit bags

果袋类型 Fruit bag type	厂家 Manufacturer	规格 Specification/mm	材质 Material
专用果袋 Special fruit bag	鸿泰果袋厂 Hongtai Fruit Bag Factory	155×180	外纸:42 g黄条纹,内纸:22 g白双光。 Outer paper: 42 g yellow stripe paper, Inner paper: 22 g white double light.
G果袋 G fruit bag	鸿泰果袋厂 Hongtai Fruit Bag Factory	155×180	外纸:57 g木浆本色复合纸,内纸:32 g双光双蜡黑纸。 Outer paper: 57 g wood pulp composite paper, Inner paper: 32 g double gloss double wax black paper.

空气温度为对照。

### 1.2 温度监测

在树体中部(大概距离地面1.5 m)用ZDR-20温湿度记录仪(杭州泽大仪器有限公司)连续监测果袋内和自然环境(空气)的温度( $\pm 0.5$  °C),每20 min记录1次数据。温度探头放入果袋时,要避免探头与果面接触,并用细绳扎紧果袋口,另将一个温度探头放在果袋的附近,监测空气的温度。

### 1.3 温度参数计算

日平均温度( $T_{\text{mean}}$ , °C)为24 h记录点的平均值;日最高温度( $T_{\text{max}}$ , °C)为24 h记录点的最大值;日最低温( $T_{\text{min}}$ , °C)为24 h记录点的最小值;昼夜温差( $TD$ , °C)为日最高温与日最低温之差。

有效积温( $GDD$ , °C)的计算参照Gu<sup>[13]</sup>的方法,以10 °C作为苹果的生物零度,日平均温度高于10 °C为有效温度,一段时间中有效温度的积累量为有效积温;日最高温积累量( $ST_{\text{max}}$ , °C)为日最高温之和;日最低温积累量( $ST_{\text{min}}$ , °C)为日最低温之和;昼夜温差积累量( $STD$ , °C)为日昼夜温差之和。

$\Delta GDD$ (°C)为果袋内的有效积温与空气中的有效积温之差; $\Delta ST_{\text{max}}$ (°C)为果袋内日最高温的积累量与空气中日最高温的积累量之差; $\Delta ST_{\text{min}}$ (°C)为果袋内日最低温的积累量与空气中日最低温的积

累量之差; $\Delta STD$ (°C)为果袋内昼夜温差的积累量与空气中昼夜温差的积累量之差。

### 1.4 褐变率调查

果皮褐变率的计算参照Jun等<sup>[14]</sup>的方法。

褐变率( $PB$ )% = (褐变个数/果实总数)×100;

褐变率差异量( $\Delta PB$ )% = 套袋处理的褐变率 - 对照的褐变率。

### 1.5 数据处理

用Excel 2016软件进行数据处理和作图分析,用Origin 2018软件进行线性回归和Logistic拟合分析,采用SPSS 22.0进行皮尔逊相关性分析和Duncan法多重比较,显著性水平为 $p < 0.05$ 。

## 2 结果与分析

### 2.1 瑞雪果实发育期果皮褐变率的变化

如图1和图2所示,在瑞雪果实发育过程中,不套袋的果实未发生褐变,套袋的果实均出现了褐变,且随着套袋时间的延长,果面褐变加重。G果袋和专用果袋处理的果实开始出现果皮褐变的时间分别为花后150和160 d。花后150、160、170、180、190和200 d,G果袋处理的果皮褐变率比专用果袋分别显著提高4.44%、12.22%、15.56%、24.44%、15.55%、15.56%。

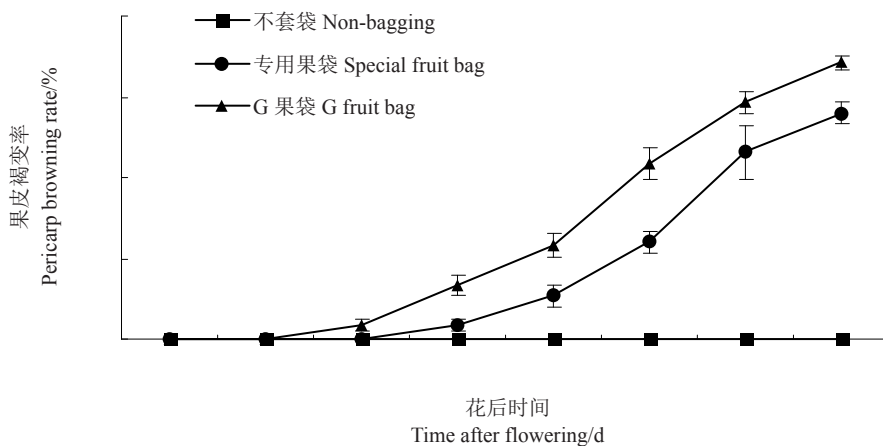


1~8 分别代表盛花后 90、120、150、160、170、180、190 和 200 d; A、C、E 分别代表不套袋、套专用果袋、套 G 果袋瑞雪苹果的梗洼; B、D、F 分别代表不套袋、套专用果袋、套 G 果袋瑞雪苹果的果面。

1-8 respectively represent 90, 120, 150, 160, 170, 180, 190 and 200 d after flower blooming; A, C, E respectively represent the fruit stems of Ruixue apples with non-bagging, special fruit bags and G fruit bags; B, D, F represent the fruit surface of Ruixue apples with non-bagging, special fruit bags, and G fruit bags.

图 1 套袋瑞雪果实发育过程中果皮褐变动态变化

Fig. 1 Dynamic changes in peel browning in bagged Ruixue apple during fruit development



花后 45 d 进行套袋,以不套袋为对照。不同的小写字母或大写字母表示相同采样日不同处理差异显著或相同处理不同采样日差异显著 ( $p < 0.05$ )。

Bagging treatment was carried out 45 days after flowering, with unbagged fruit as a control. Values marked by different lowercase letters or capital letters were significantly different among different treatments on the same sampling day and among sampling days in the same treatment respectively ( $p < 0.05$ ).

图 2 套袋对发育期瑞雪果皮褐变率的影响

Fig. 2 Effect of bagging on peel browning rate in Ruixue apple during fruit development

## 2.2 瑞雪发育期温度参数的变化

2.2.1 瑞雪发育期果袋内外日平均温、日最高温、日最低温、昼夜温差的变化 在果实整个发育期中,果袋内外的日平均温、日最高温和日最低温均呈现下降的趋势,而昼夜温差则存在波动,两种果袋内的日平均温、日最高温、日最低温、昼夜温差差别较小。空气中的日平均温、日最高温、昼夜温差均高于果袋内,最低温没有明显差异。果袋内外在4个温度参数上差异最大的是昼夜温差,花后90、120、150、160、170、180、190、200 d,专用果袋的昼夜温差比空气中分别低了0.66%、0.96%、7.33%、6.13%、9.24%、8.07%、8.16%、9.73%,G果袋比空气中分别低了2.45%、2.46%、9.88%、8.81%、11.74%、10.85%、14.49%、13.14%(图3-A~D)。

2.2.2 瑞雪发育期有效积温、日最高温积累量、日最低温积累量、昼夜温差积累量的变化 如图4所示,随着果实发育,有效积温积累量增加。花后90~120 d,有效积温积累速度较快。花后150~200 d,有效积温积累速度较慢,但果袋内外有效积温差异较大,果袋内的有效积温低于空气中的有效积温,专用果袋内的有效积温比空气中分别低24.0、37.2、39.5、57.4、65.0、72.0 °C, G果袋的有效积温比空气中分别低62.0、80.8、87.6、108.1、117.5、126.7 °C(图4-A)。

花后90~120 d,果袋内和空气中在日最高温积累量和昼夜温差积累量差异不明显。花后150~200 d,果袋内和空气中日最高温积累量和昼夜温差的积累量相差较大,果袋内的日最高温积累量和昼夜温差积累量均低于对照的积累量。专用果袋中,日最高温积累量比对照分别低104.4、133.2、169.1、205.3、233.1、261.0 °C,昼夜温差积累量比对照分别低140.2、174.9、217.7、261.0、295.7、330.3 °C;G果袋中,日最高温积累量分别比空气低203.0、246.0、289.8、340.8、385.6、422.50 °C,昼夜温差积累量分别比空气中低224.2、271.0、319.7、375.4、424.6、467.6 °C(图4-B, D)。在花后90~200 d,果袋内外日低温积累量没有明显差异(图4-C)。

对花后150~200 d果袋内和空气中的日平均温、日最高温、日最低温、昼夜温差积累量与时间进行回归分析发现,空气中有效积温积累速率为 $3.64\text{ }^{\circ}\text{C}\cdot\text{d}^{-1}$ ,高于专用果袋( $2.66\text{ }^{\circ}\text{C}\cdot\text{d}^{-1}$ )和G果袋( $2.34\text{ }^{\circ}\text{C}\cdot\text{d}^{-1}$ );空气中日最高温积累速率为 $23.02\text{ }^{\circ}\text{C}\cdot\text{d}^{-1}$ ,高于专用

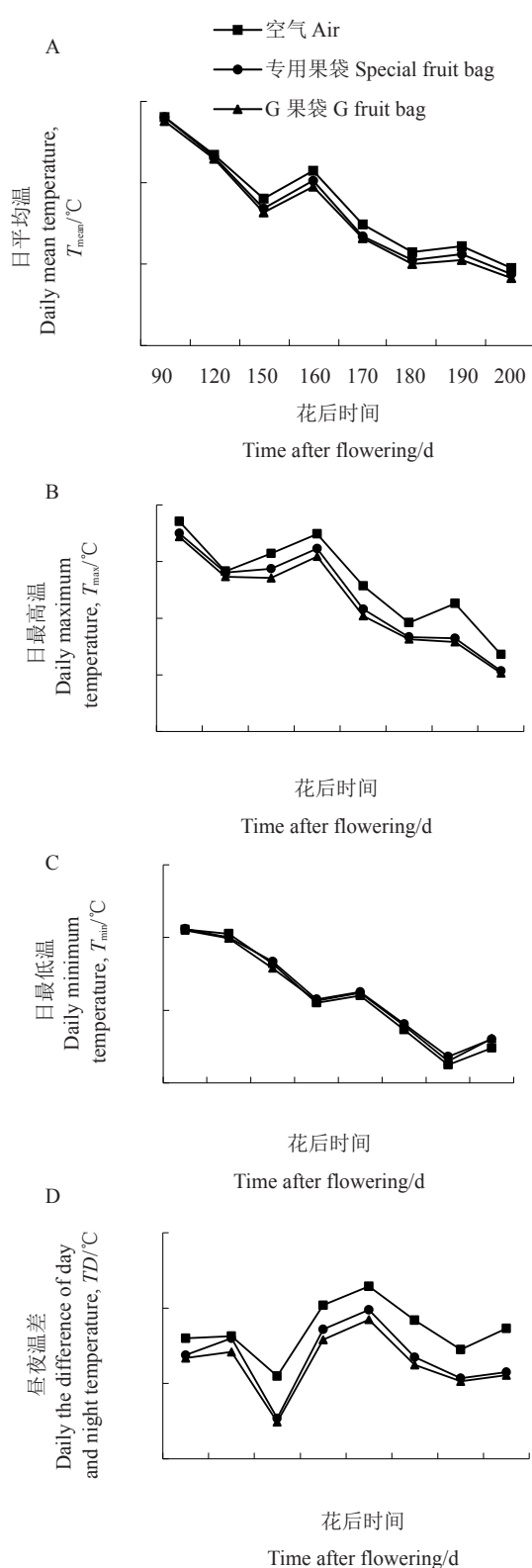


图3 瑞雪苹果发育期日平均温、日最高温、日最低温、昼夜温差的变化

Fig. 3 Changes in daily mean temperature, daily maximum temperature, daily minimum temperature, and daily difference of day and night temperature in the fruit bags and in the air during the development of Ruixue apple

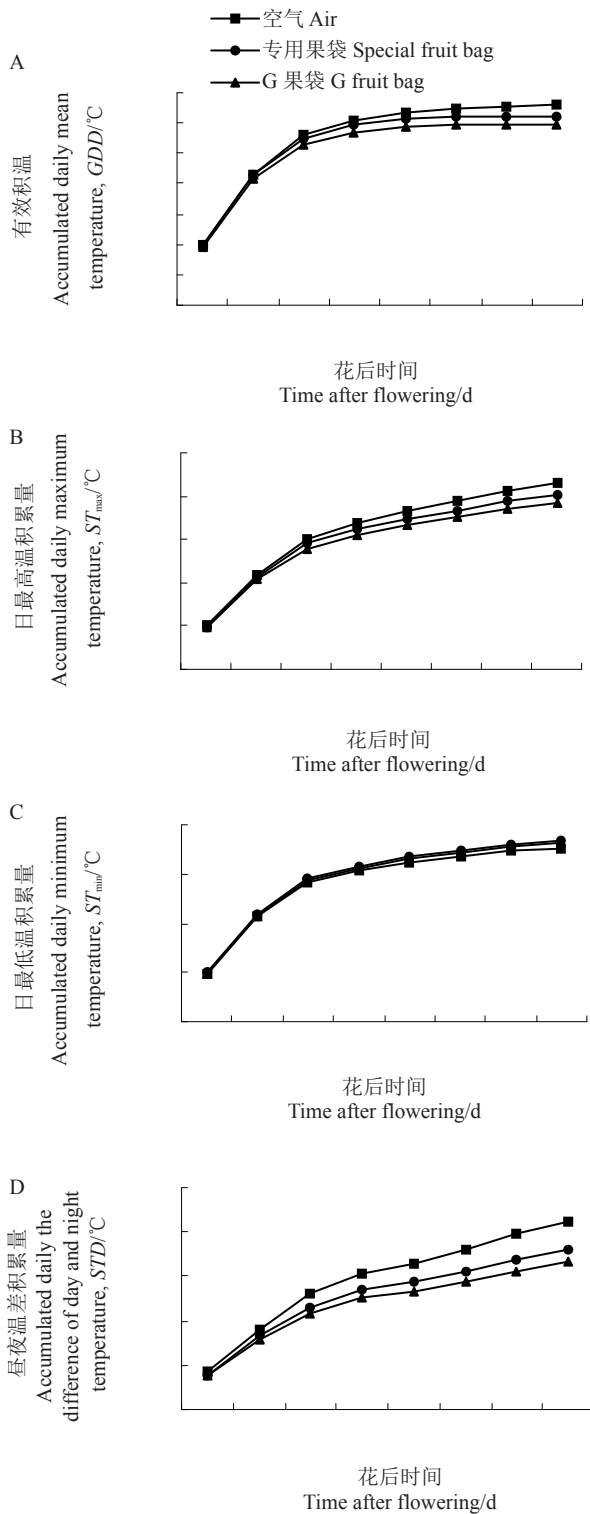


图4 瑞雪苹果发育过程中果袋内和空气中有效积温及日最高温、日最低温、昼夜温差积累量的变化

Fig. 4 Changes in accumulation of daily mean temperature, daily maximum temperature, daily minimum temperature, and daily the difference of day and night temperature in the fruit bags and in the air during the development of Ruixue apple

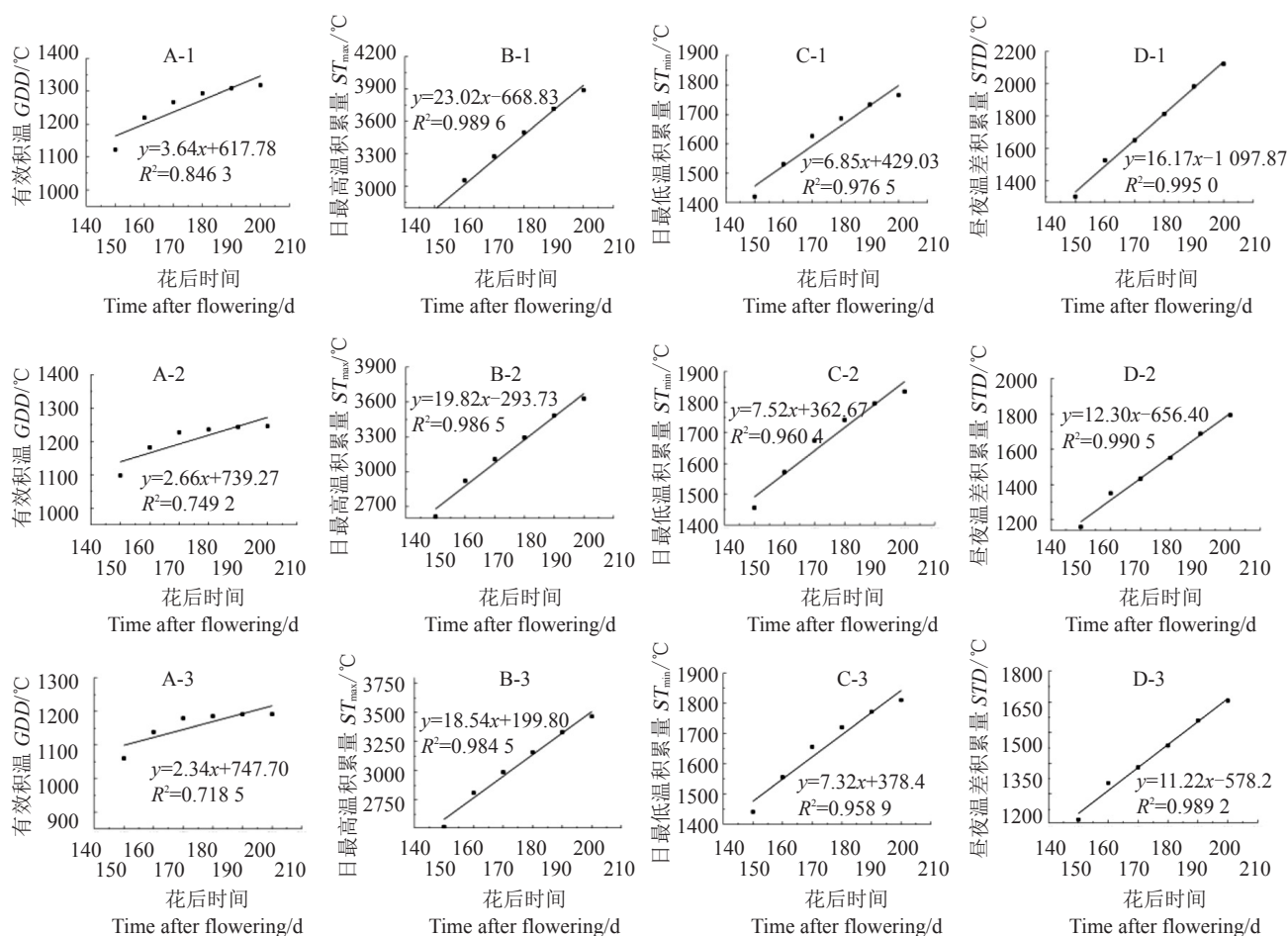
果袋(19.82 °C ·d<sup>-1</sup>)和G果袋(18.54 °C ·d<sup>-1</sup>);空气中昼夜温差的积累速率为16.17 °C ·d<sup>-1</sup>,高于专用果袋(12.30 °C ·d<sup>-1</sup>)和G果袋(11.22 °C ·d<sup>-1</sup>)(图5-A~B, D)。而空气中日最低温的积累速率为6.85 °C ·d<sup>-1</sup>,低于专用果袋(7.52 °C ·d<sup>-1</sup>)和G果袋(7.32 °C ·d<sup>-1</sup>)(图5-C)。空气中的温度因子处于一个剧烈变化的状态,而果袋的温度因子处于一个相对稳定的状态。

2.2.3 瑞雪发育期果袋内外有效积温、日最高温、日最低温、昼夜温差积累量差异的变化  $\Delta GDD$ 、 $\Delta ST_{max}$ 、 $\Delta STD$ 呈现下降的趋势,花后90~120 d下降速度较慢,花后150~200 d下降速度较快。 $\Delta ST_{min}$ 呈现上升的趋势,花后90~120 d上升幅度较小,花后150~200 d上升幅度较大。花后150~200 d,在专用果袋和G果袋中, $\Delta GDD$ 、 $\Delta ST_{max}$ 、 $\Delta STD$ 、 $\Delta ST_{min}$ 的差异均较大。花后150~200 d,G果袋的 $\Delta GDD$ 比专用果袋分别低了38.00、43.60、48.14、50.64、52.46、54.72 °C,G果袋的 $\Delta ST_{max}$ 比专用果袋分别低了98.60、112.80、120.70、135.50、152.50、161.50 °C,G果袋的 $\Delta STD$ 比专用果袋分别低了84.00、96.10、102.00、114.40、128.90、137.30 °C,G果袋的 $\Delta ST_{min}$ 比专用果袋分别低了14.60、16.70、18.70、21.10、23.60、24.20 °C(图6-A~D)。

2.3 果袋内外温度差异与果皮褐变率的关系

$|\Delta GDD|$ 、 $|\Delta ST_{max}|$ 、 $|\Delta ST_{min}|$ 、 $|\Delta STD|$ 与 $\Delta PB$ 均有极显著的相关性,专用果袋中, $|\Delta GDD|$ 、 $|\Delta ST_{max}|$ 、 $|\Delta ST_{min}|$ 、 $|\Delta STD|$ 与 $\Delta PB1$ 的相关系数分别为0.881、0.864、0.860、0.880;在G果袋中, $|\Delta GDD|$ 、 $|\Delta ST_{max}|$ 、 $|\Delta ST_{min}|$ 、 $|\Delta STD|$ 与 $\Delta PB2$ 的相关系数分别为0.947、0.923、0.918、0.943(表2)。在2种果袋中, $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $\Delta PB$ 的相关系数都显著高于 $|\Delta ST_{max}|$ 、 $|\Delta ST_{min}|$ 与 $\Delta PB$ 的相关系数,说明 $|\Delta GDD|$ 和 $|\Delta STD|$ 与瑞雪苹果果皮褐变相关性更强。

为了定量 $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 的关系,对温度参数中的 $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 进行了曲线回归分析,选用Logistic模型拟合,得到了较好的拟合效果。G果袋中 $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 的拟合优度分别为0.993 6、0.997 9,专用果袋 $|\Delta GDD|$ 、 $|\Delta STD|$ 与 $|\Delta PB|$ 的拟合优度分别为0.973 5、0.992 4。G果袋的拟合优度均好于专用果袋。 $|\Delta STD|$ 与 $|\Delta PB|$ 的拟



A. 有效积温 ( $GDD$ ); B. 日最高温积累量 ( $ST_{max}$ ); C. 日最低温积累量 ( $ST_{min}$ ); D. 昼夜温差积累量 ( $STD$ ); 1、2、3 分别代表空气、专用果袋、G 果袋。

A. Accumulated effective temperature ( $GDD$ ); B. Accumulated daily maximum temperature ( $ST_{max}$ ); C. Accumulated daily minimum temperature ( $ST_{min}$ ); D. Accumulated daily the difference of day and night temperature respectively ( $STD$ ); 1, 2, and 3 show air, special fruit bags, and G fruit bags, respectively.

图5 日平均温、日最高温、日最低温、日较差积累量与时间的回归分析

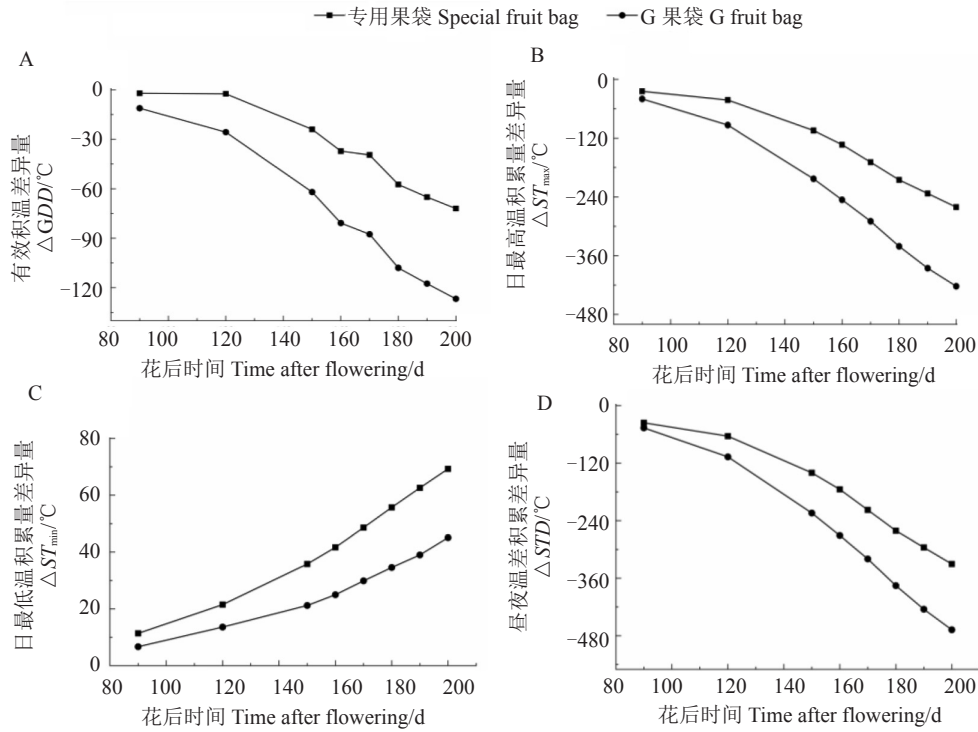
Fig. 5 Analysis of regression among accumulated daily mean temperature, accumulated daily maximum temperature, accumulated daily minimum temperature, accumulated daily the difference of day and night temperatures

合优度均好于  $|\Delta GDD|$  与  $|\Delta PB|$  的拟合优度 (图7)。

### 3 讨论

赵才瑞<sup>[1]</sup>和李静<sup>[2]</sup>认为瑞雪果实果皮的褐变是果袋内生长季的高温胁迫所致。本研究中果袋内的日平均温度和日最高温均低于袋外,因此可以排除生长期高温胁迫,这与赵才瑞<sup>[1]</sup>和李静<sup>[2]</sup>的研究结果不同。值得注意的是,果袋内日最高温和日平均温积累量的减少,可导致果袋内的有效积温减少,可能会影响果实的生长发育,从而引起果皮褐变。笔者在本试验发现果袋内的  $GDD$ 、 $ST_{max}$ 、 $STD$  均低于

果袋外,从盛花后 150~160 d,果袋内外  $GDD$ 、 $ST_{max}$ 、 $STD$  的差异明显,而果皮的褐变从盛花后 150 d 开始出现,由此可以推断瑞雪果实的褐变与后期的温度因子相关性更强,因此可以在盛花后 150 d 前进行瑞雪果实的除袋,进而改变套袋瑞雪果实的温度条件,这为科学指导瑞雪苹果除袋提供了依据。与褐变率较低的专用果袋相比,褐变率较高的 G 果袋的  $\Delta GDD$ 、 $\Delta ST_{max}$ 、 $\Delta STD$  变化幅度较大,说明 G 果袋内的环境与空气的环境差异更大,G 果袋相对于空气来说,有更低的有效积温,所以套 G 果袋的果皮对袋内的这种逆境环境更敏感,更容易发生果皮褐变,所以 G 果袋果皮褐变率高于专用果袋。



A. 有效积温差异 ( $\Delta GDD$ ); B. 日最高温积累量的差异 ( $\Delta ST_{max}$ ); C. 日最低温积累量差异 ( $\Delta ST_{min}$ ); D. 昼夜温差积累量差异 ( $\Delta STD$ )。  $\Delta GDD$ =果袋内的有效积温-空气中的有效积温;  $\Delta ST_{max}$ =果袋内日最高温的积累量-空气中日最高温的积累量;  $\Delta ST_{min}$ =果袋内日最低温的积累量-空气中日最低温的积累量;  $\Delta STD$ =果袋内昼夜温差的积累量-空气中昼夜温差的积累量。

A. Difference in accumulated effective temperature ( $\Delta GDD$ ); B. Difference in accumulated daily maximum temperature ( $\Delta ST_{max}$ ); C. Difference in accumulated daily minimum temperature ( $\Delta ST_{min}$ ); D. Difference in accumulated daily the difference of day and night temperature ( $\Delta STD$ ).  $\Delta GDD$ = effective accumulated temperature in the fruit bag - effective accumulated temperature in the air;  $\Delta ST_{max}$ =accumulated daily maximum temperature in the fruit bag - accumulated daily maximum temperature in the air;  $\Delta ST_{min}$ = accumulated daily minimum temperature in the fruit bag - accumulated daily minimum temperature in the air;  $\Delta STD$ = accumulated daily the difference of day and night temperature in the fruit bag - accumulated daily the difference of day and night temperature in the air.

图6 瑞雪苹果发育期果袋内和空气中日平均温、日最高温、日最低温、昼夜温差积累量的差异变化

Fig. 6 Difference in accumulation of daily mean temperature, daily maximum temperature, daily minimum temperature, and daily the difference of day and night temperature in the fruit bags and in the air during the development of Ruixue apple

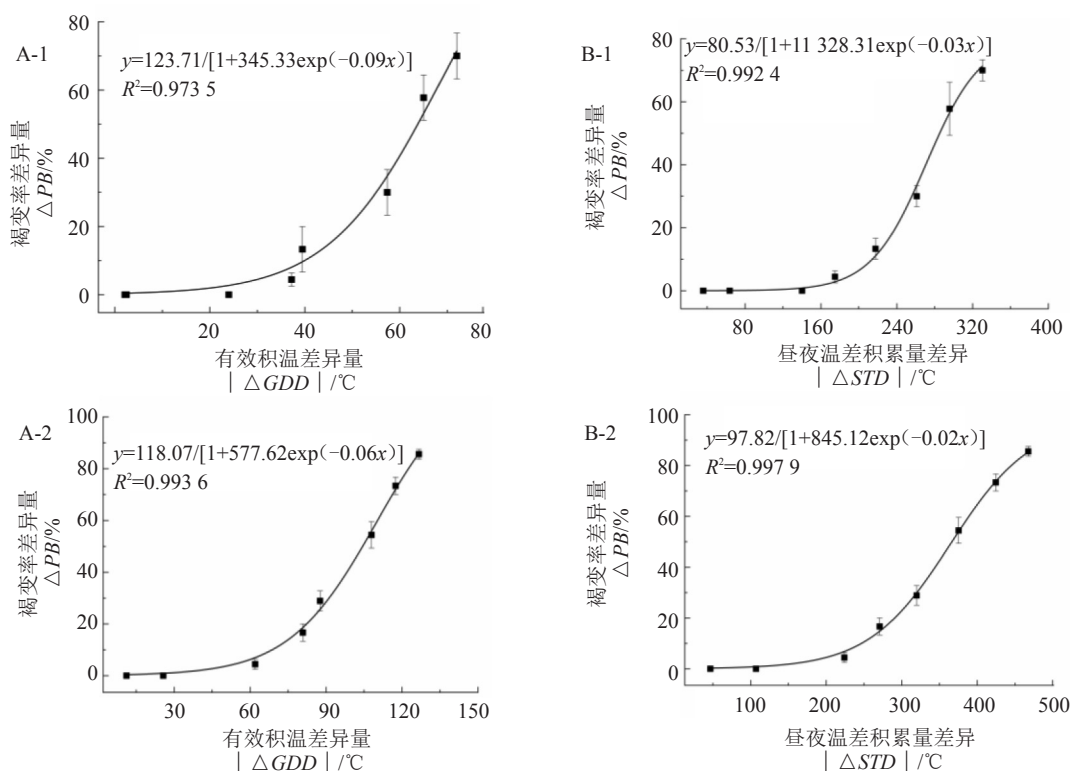
表2 |  $\Delta GDD$  |、|  $\Delta ST_{max}$  |、|  $\Delta ST_{min}$  |、|  $\Delta STD$  | 与  $\Delta PB$  的相关性分析

Table 2 Correlation analysis of |  $\Delta GDD$  |, |  $\Delta ST_{max}$  |, |  $\Delta ST_{min}$  |, |  $\Delta STD$  | and  $\Delta PB$

	$\Delta PB1$	$\Delta PB2$		$\Delta PB1$	$\Delta PB2$
$\Delta GDD$	0.881**±0.006 a	0.947**±0.008 a	$\Delta ST_{min}$	0.860**±0.011 b	0.918**±0.010 b
$\Delta ST_{max}$	0.864**±0.010 b	0.923**±0.009 b	$\Delta STD$	0.880**±0.010 a	0.943**±0.008 a

注:数据以平均值±SD表示,重复3次,\*表示相关性在0.05水平上显著,\*\*表示相关性在0.01水平上显著,同列不同小写字母代表相关系数在0.05水平上差异显著。 $\Delta GDD$ =果袋内的有效积温-空气中的有效积温;  $\Delta ST_{max}$ =果袋内日最高温的积累量-空气中日最高温的积累量;  $\Delta ST_{min}$ =果袋内日最低温的积累量-空气中日最低温的积累量;  $\Delta STD$ =果袋内昼夜温差的积累量-空气中昼夜温差的积累量;  $\Delta PB$ =处理的褐变率-对照的褐变率,1,2分别代表专用果袋、G果袋。

Note: Means ± SD of three replicate experiments are listed, \* indicates that the correlation is significant at the 0.05 level, \*\* indicates that the correlation is significant at the 0.01 level, and the different small letters in the same column indicate that the correlation coefficient is significantly different at the 0.05 level.  $\Delta GDD$ = effective accumulated temperature in the fruit bag - effective accumulated temperature in the air;  $\Delta ST_{max}$ =accumulated daily maximum temperature in the fruit bag - accumulated daily maximum temperature in the air;  $\Delta ST_{min}$ = accumulated daily minimum temperature in the fruit bag - accumulated daily minimum temperature in the air;  $\Delta STD$ = accumulated daily the difference of day and night temperature in the fruit bag - accumulated daily the difference of day and night temperature in the air.  $\Delta PB$ =browning rate (treat)-browning rate (control). 1, 2 represent special fruit bag and G fruit bag, respectively.



A、B 分别代表  $|\Delta GDD|$  和  $|\Delta STD|$ ；1、2 分别代表专用果袋、G 果袋。 $\Delta GDD$ =果袋内的有效积温-空气中的有效积温； $\Delta STD$ =果袋内昼夜温差的积累量-空气中昼夜温差的积累量； $\Delta PB$ =处理的褐变率-对照的褐变率。

A, B respectively represent  $|\Delta GDD|$  and  $|\Delta STD|$ , respectively; 1, 2 represent special fruit bag and G fruit bag, respectively.  $\Delta GDD$ = effective accumulated temperature in the fruit bag - effective accumulated temperature in the air;  $\Delta STD$ = accumulated daily the difference of day and night temperature in the fruit bag - accumulated daily the difference of day and night temperature in the air.  $\Delta PB$ =browning rate (treat)- browning rate (control).

图7  $|\Delta GDD|$ 、 $|\Delta STD|$  与  $|\Delta PB|$  的 logistic 拟合曲线

Fig. 7 Logistic fitting curves of between  $|\Delta GDD|$ ,  $|\Delta STD|$  and  $|\Delta PB|$

Jam es等<sup>[15]</sup>和 Lau<sup>[16]</sup>认为生长季遭遇低温或有效积温积累量少与果实的褐变密切相关。Jam es等<sup>[17]</sup>研究的 Cripps Pink 苹果在采收前出现轻微的褐变,贮藏时扩展,生长期有效积温的积累量(GDD)低于1100 °C的地区和季节会发生果实末端果肉的褐变,当GDD处于1100~1700 °C时,易发生果实茎端的果肉褐变,当有效积温积累量大于1700 °C时,褐变现象几乎不发生。Tong等<sup>[18]</sup>发现Honey Crisp苹果在生长期遭受了低温胁迫后,容易出现果实末端果肉褐变,但是这种褐变与降雨量的关系不大。本试验表明果袋内的有效积温低于空气中的,通过对环境差异量和褐变率进行相关性分析,发现 $\Delta GDD$ 、 $\Delta ST_{max}$ 、 $\Delta STD$ 、 $\Delta ST_{min}$ 与 $\Delta PB$ 有极显著相关性,说明套袋所改变的4个温度因子与褐变率均有关系,但 $\Delta GDD$ 和 $\Delta STD$ 与 $\Delta PB$ 相关性最强,说明果袋内外有效积温以及昼夜温差的差异与果皮褐变率密切相关,与不套袋果实相比,套袋果实有较低的

有效积温,较低的昼夜温差积累量对瑞雪苹果果皮造成了伤害,进而产生褐变,这与前人的研究结果略有不同。此外,本试验对环境差异量和褐变率差异量进行了Logistic拟合,从拟合结果来看,果袋内环境和空气环境差别越大,病果率越高,这为预测瑞雪苹果果皮褐变产生建立了科学的数学模型。

综上所述,套袋瑞雪苹果果皮的褐变与果实发育后期的温度因子有关。果袋内较低的日平均温和日最高温,造成果袋内较低的有效积温和昼夜温差,使果袋内瑞雪苹果果皮形成了一种逆境胁迫,从而导致褐变的产生。在生产中,可以从选择透气性好的果袋以及在盛花后150 d前除袋等方面改善果实袋内的温度环境,进而降低瑞雪果皮褐变率。

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