

# 苯噻草酮疏果剂对苹果边果营养与激素含量的影响

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**摘要:** 为明确苯噻草酮疏果剂对苹果边果的疏除作用, 以 9 年生天红 2 号/SH38/八棱海棠为试材, 在最大边果直径 6 mm 左右时喷 300 mg/kg 苯噻草酮 2 次, 清水为对照, 生理落果后调查坐果率及坐果比例; 喷药后 7、9、11、17、29 d 采集处理和对照边果, 测定氮磷钾矿质营养, 淀粉、葡萄糖、果糖、蔗糖和山梨醇碳水化合物, 可溶性蛋白质含量以及玉米素 (Z)、赤霉素 ( $GA_3$ )、生长素 (IAA) 和脱落酸 (ABA) 激素含量。结果显示, 苯噻草酮处理后, 花序坐果率和花朵坐果率较对照降低 17.95% 和 27.63%, 坐单果比例显著提高, 坐三果及三果以上的比例显著降低 ( $P<0.01$ ); 处理总体上提高了边果无机营养含量, 显著降低了可溶性蛋白质含量 ( $P<0.05$ ); 淀粉含量较对照提高了 5.57%~37.20%, 但不同程度地降低了蔗糖、葡萄糖、果糖及山梨醇含量, 从而使可溶性碳水化合物含量较对照降低了 9.55%~52.60%; 处理后脱落酸含量显著升高 ( $P<0.05$ ), ( $Z+GA_3+IAA$ )/ABA 比值显著降低。说明苯噻草酮在苹果上具有较好的疏除边果作用, 其疏除作用与可溶性蛋白质含量降低, 可溶性碳水化合物供应不足, 以及 ABA 含量升高及生长型激素/抑制型激素比值降低有关。

**关键词:** 激素; 营养; 苯噻草酮; 坐果率; 苹果

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## 0 引 言

苹果疏花疏果是调整树体负荷、提高果实品质、减轻大小年结果的必要技术, 包括人工疏花疏果、化学疏花疏果和机械疏花疏果。人工疏花疏果主要在中国应用, 美国、德国的商业化果园开始试验示范机械疏花疏果, 化学疏花疏果则是欧美发达国家普遍采取的苹果生产花果调控技术<sup>[1-4]</sup>。疏果相对于疏花来说, 安全系数高, 更受果农青睐。研究表明, 萘乙酸、西维因、6-BA、ACC、乙烯利等在一定浓度范围内均有疏除幼果、平衡负载量作用<sup>[5-8]</sup>, 对其疏除机理也有相关报道, 如西维因阻碍营养物质运输养分、萘乙酸干扰激素代谢、乙烯利促进乙烯生成等造成幼果脱落<sup>[9-10]</sup>。苯噻草酮是一种光合系统 II (PS II) 抑制剂, 主要用作除草剂。2014 年安道麦公司发布苯噻草酮可作为一种低毒、安全的果树疏果剂, 主要应用在苹果和梨上, 不少学者开展了相关研究<sup>[11-12]</sup>。本课题组从光合和荧光角度研究了苯噻草酮对苹果叶片抑制作用的影响<sup>[13]</sup>, 但是, 对于苯噻草酮如何影响幼果的生理代谢国内外均未见相关报道。

本文以矮砧苹果树为试材, 研究了在最大边果直径 6 mm 左右时喷施苯噻草酮对苹果的疏果效应及对边果营养和激素含量的影响, 从碳水化合物及激素调控角度初步揭示了苯噻草酮的疏果机制, 为生产提供了参考依据。

## 1 材料与方法

### 1.1 试验材料

试验在山东省果树研究所天平湖基地 (北纬 36°12'55.36", 东经 117°01'09.87", 海拔 168 m) 进行。试材为 9 年生天红 2 号/SH38/八棱海棠 ('天红 2 号' 为红富士芽变品种), 株行距 0.75 m×4.0 m, 采用高纺锤树形、行间生草、树盘覆盖、肥水一体化技术, 管理水平中等偏上。试验地有机质质量分数 0.79%, 速效氮 86.11 mg/kg, 速效磷 73.71 mg/kg, 速效钾 116.32 mg/kg。

### 1.2 处理方法

选取长势基本一致健康的苹果树 30 株, 设喷药和对照 2 个处理, 各处理 15 株树, 5 株树为 1 个小区, 3 次重复, 处理和对照之间保留 2 株树作为保护株。每株树随机选 3 个主枝, 统计花序数和花朵数, 挂牌标记。

2018 年 4 月 21 日进行了苯噻草酮试验浓度筛选试验, 设置 100、200、300、400、500 mg/kg 5 个浓度处理, 清水为对照。选用背负式电动喷雾器对全树进行喷布, 喷至幼果湿润轻微滴水为止。生理落果后调查有挂牌的主枝坐果情况, 统计花序坐果率和花朵坐果率, 花序坐

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果率(%) = 坐果花序数/总花序数 × 100%, 花朵坐果率(%) = 坐果数/总花朵数 × 100%。

2019年4月19日在最大边果直径6 mm左右时喷300 mg/kg 苯噻草酮, 4月22日喷第二次; 对照喷清水。喷施方法同2018年, 生理落果后调查坐果率和坐果比例, 单果率(%) = 坐单果花序数/总花序数 × 100%, 双果率(%) = 坐双果花序数/总花序数 × 100%, 三果及以上(%) = 100 - (单果率 + 双果率)。

### 1.3 取样与测定

分别在第一次喷药处理后7、9、11、17及29 d从处理及对照试验树上取边果, 前3次每个小区(5株树)共采果90个左右, 后2次每个小区(5株树)共采果60个左右, 均为3个重复, 去除果柄及萼片后, 用铝箔纸包好, 放入液氮罐中速冻, 带回实验室放至-80℃冰箱保存, 用于测定氮磷钾、碳水化合物、蛋白质及激素。

#### 1.3.1 矿质营养测定

全氮测定用半微量蒸馏法, 全磷测定用钼锑抗吸光度法, 全钾测定用火焰光度计法, 具体测定步骤参考崔建宇等<sup>[4]</sup>方法。所有指标均重复3次。

#### 1.3.2 碳水化合物含量测定

单糖和低聚糖提取参考Kang等<sup>[15]</sup>方法, 葡萄糖、果糖、山梨醇用水提取, 称取约0.2 g样品, 加入1 mL水, 匀浆, 过夜浸提。蔗糖用乙腈提取, 称取约0.2 g样品, 加入1 mL 80%乙腈, 匀浆, 50℃水浴30 min, 8 000 g离心10 min, 取上清液, 针头式过滤器过滤后待测。用Waters 1525高效液相色谱仪测定, 示差检测器为Shodex RI-201H。葡萄糖、果糖、山梨醇用Carbomix Ca-NP 8%色谱柱(300 mm × 7.8 mm, 10 μm), 柱温80℃, 流动相为水, 流速0.4 mL/min, 进样体积10 μL; 蔗糖用Sepax HP-Amino氨基柱(4.6 mm × 250 mm, 5 μm), 柱温40℃, 流动相乙腈:水=80:20, 流速0.4 mL/min, 进样体积10 μL。根据葡萄糖、果糖、山梨醇、蔗糖标准曲线和样品峰面积计算含量。

将提取可溶性糖的残余物用高氯酸水解成葡萄糖, 蒽酮比色法测定葡萄糖含量, 测定波长为620 nm, 由葡萄糖标准曲线计算淀粉含量。

#### 1.3.3 可溶性蛋白质含量测定

可溶性蛋白含量测定采用考马斯亮蓝染色法<sup>[16]</sup>。

#### 1.3.4 激素含量测定

激素提取方法参考Yan等<sup>[17]</sup>, 称取约0.2 g样品, 加入1 mL预冷的20%甲醇, 4℃浸提过夜; 8 000 g离心10 min, 取上清液, 残渣用0.5 mL 20%甲醇水溶液浸提2 h, 离心后取上清液, 合并2次上清, 40℃减压蒸发至不含有机相, 加入2 mL石油醚60~90℃萃取脱色3次, 移去石油醚; 向下层水相中加入2 mL乙酸乙酯萃取, 转移上层有机相至新的EP管, 重复萃取3次, 合并3次有机相, 氮吹吹干, 加入0.2 mL流动相溶解, 混匀, 针头式过滤器过滤后待测。采用RIGOL L3000高效液相色谱仪, Kromasil C18反相色谱柱(250 mm × 4.6 mm, 5 μm), 波长为254 nm, 柱温30℃, 流动相流速0.8 mL/min, 进

样体积10 μL, 走样时间35 min。

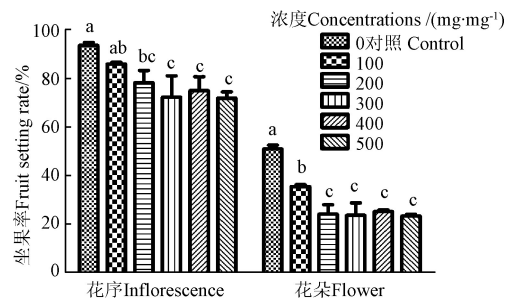
### 1.4 数据分析

所有数据均采用SPSS软件进行差异显著性比较, 应用GraphPad Prism 5软件绘图。

## 2 结果与分析

### 2.1 苯噻草酮适宜浓度筛选

不同浓度苯噻草酮处理对坐果率的调查结果如图1所示。可以看出, 与清水对照相比, 100~500 mg/kg的苯噻草酮处理降低了花序坐果率和花朵坐果率, 其中对照与200~500 mg/kg处理间的花序坐果率存在显著性差异( $P < 0.05$ ), 而对照与所有苯噻草酮处理的花果坐果率均存在显著性差异( $P < 0.05$ )。200~400 mg/kg 3个浓度之间差异性不显著, 以300 mg/kg的花序坐果率和花朵坐果率最低, 分别为72.39%和23.52%, 故选300 mg/kg作为后续试验的喷施浓度。



注: 不同小写字母表示不同浓度处理 0.05 水平差异性显著。

Note: Different small letter indicates significant difference at 0.05 level between different concentrations.

图1 不同浓度苯噻草酮处理对坐果率的影响

Fig.1 Effect of metamitron with different concentrations on fruit setting rate

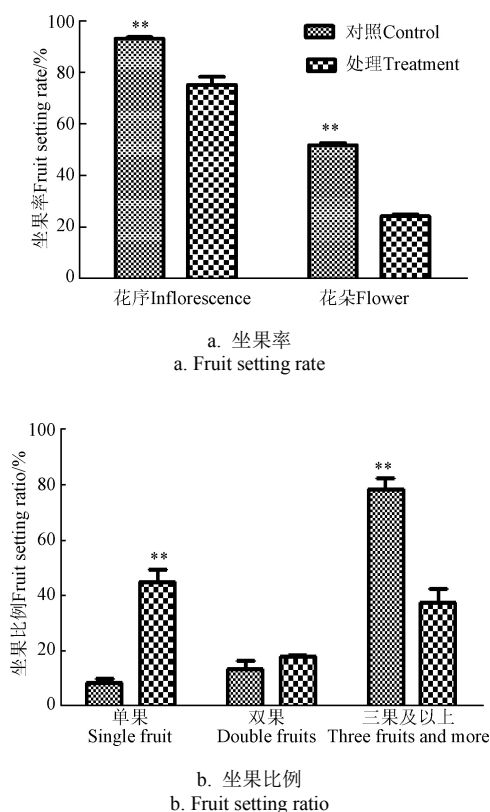
### 2.2 苯噻草酮处理对坐果率和坐果比例的影响

由图2a可见, 与对照相比, 幼果期苯噻草酮处理显著降低了坐果率( $P < 0.01$ ), 其中花序坐果率降低17.95%, 花朵坐果率降低27.63%。同时, 苯噻草酮处理显著提高了花序坐单果比例( $P < 0.01$ ), 处理单果率为44.80%, 为对照的5.28倍, 且保留的单果均为中心果, 说明苯噻草酮仅对边果起作用, 对中心果无影响; 处理显著降低了花序坐三果及以上的比例( $P < 0.01$ ), 处理为对照的47.91%; 坐双果比例也有所增加, 但未达到显著水平(图2b)。说明苯噻草酮在富士苹果上有较好的疏果作用, 疏除力强, 单果率高, 分布均匀。

### 2.3 苯噻草酮对无机营养的影响

由表1可以看出, 苯噻草酮处理后, 所有时期的全氮含量均高于对照, 在喷施后7和9 d二者差异不显著, 可能与处理时间较短有关; 喷施11 d之后, 处理的全氮含量均显著高于对照( $P < 0.05$ )。苯噻草酮处理对全磷和全钾的影响更为显著, 几乎所有处理的全磷和全钾含量均显著高于对照( $P < 0.05$ ), 喷后11、29 d处理的全磷含量为对照的2.05和1.67倍, 全钾含量为对照的1.93和1.51倍。说明苯噻草酮的疏果作用不是由于氮磷钾无

机养分的缺失造成的。

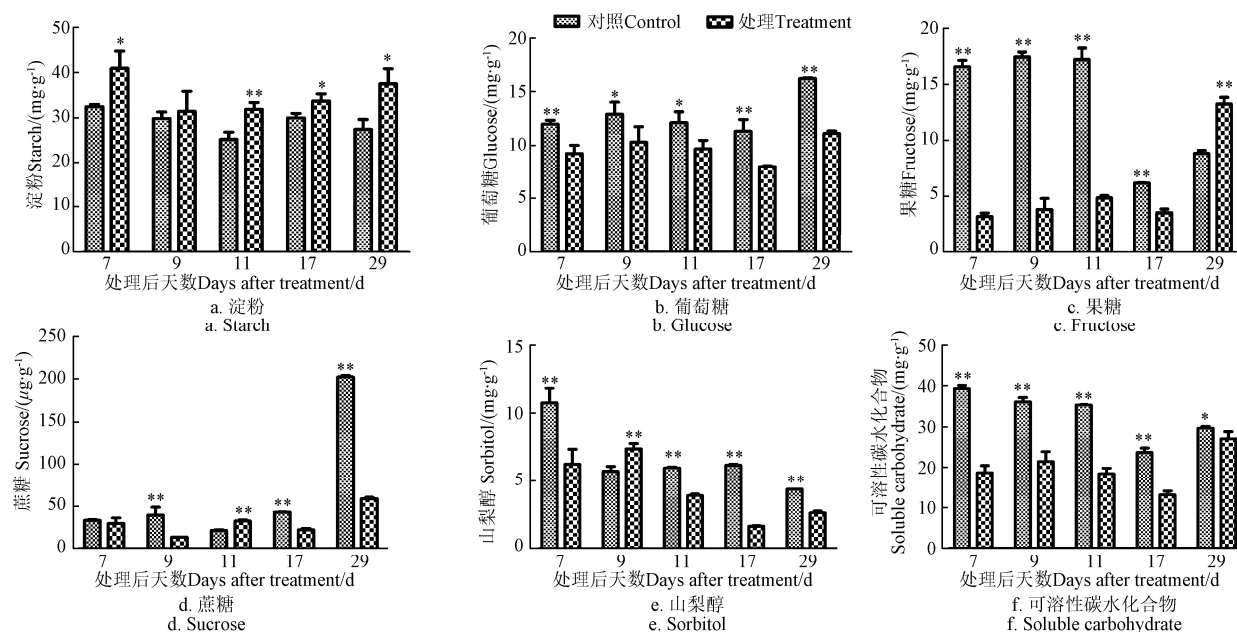


注: \*\*表示处理与对照间 0.01 水平差异性显著, 下同。

Note: \*\* indicates significant difference at 0.01 level between treatment and control, the same below.

图 2 苯噻草酮处理对坐果率及坐果比例的影响

Fig.2 Effect of metamitron treatment on fruit setting rate and ratio



注: \*表示处理与对照间 0.05 水平差异性显著, 下同。

Note: \* indicates significant difference at 0.05 level between treatment and control, the same below.

图 3 苯噻草酮处理对果实碳水化合物含量的影响

Fig.3 Effect of metamitron treatment on fruit carbohydrate content

表 1 苯噻草酮处理对氮磷钾营养元素的影响

Table 1 Effect of metamitron treatment on nitrogen, phosphorus and potassium nutrient elements %

处理后天数 Days after treatment/d	处理 Treatment	全氮 Total N	全磷 Total P	全钾 Total K
7	对照	0.434±0.005 a	0.035±0.003 b	0.308±0.003 b
	处理	0.428±0.038 a	0.060±0.001 a	0.397±0.047 a
9	对照	0.387±0.039 a	0.040±0.005 b	0.293±0.021 b
	处理	0.413±0.044 a	0.072±0.005 a	0.369±0.027 a
11	对照	0.197±0.004 b	0.041±0.002 b	0.248±0.006 b
	处理	0.471±0.024 a	0.084±0.034 a	0.478±0.047 a
17	对照	0.154±0.001 b	0.054±0.002 a	0.231±0.003 b
	处理	0.340±0.032 a	0.045±0.001 a	0.352±0.010 a
29	对照	0.177±0.004 b	0.030±0.001 b	0.243±0.006 b
	处理	0.388±0.013 a	0.050±0.002 a	0.367±0.021 a

注: 不同小写字母表示处理与对照间 0.05 水平差异性显著。

Note: Different small letter indicates significant difference at 0.05 level between treatment and control.

## 2.4 苯噻草酮处理对有机营养的影响

苹果有机营养成分主要是碳水化合物, 包括淀粉、葡萄糖、果糖、蔗糖、山梨醇<sup>[18]</sup>。由图 3a 可以看出, 尽管苹果幼果中淀粉含量较低, 但苯噻草酮处理的淀粉含量多明显高于对照, 增幅为 5.57%~37.20%; 图 3b~图 3e 为可溶性碳水化合物葡萄糖、果糖、蔗糖及山梨醇含量, 可以看出, 整体趋势为对照的可溶性碳水化合物含量高于苯噻草酮处理。为了整体比较处理与对照可溶性碳水化合物含量, 对葡萄糖、果糖、蔗糖及山梨醇的总含量进行了分析, 如图 3f 所示, 可见苯噻草酮处理的可溶性碳水化合物均显著低于对照 ( $P<0.05$ ), 降幅为 9.55%~52.57%。而可溶性碳水化合物是幼果发育的直接营养物质, 说明苯噻草酮疏果可能是由于可溶性碳水化合物的供应不足造成的。

## 2.5 苯噻草酮处理对可溶性蛋白质含量的影响

如图 4 所示, 苯噻草酮处理后苹果幼果可溶性蛋白质含量明显降低, 差异达显著水平 ( $P < 0.05$ )。各个时期处理的可溶性蛋白质含量分别为对照的 71.42%、72.37%、69.68%、64.20% 和 86.02%, 说明苯噻草酮处理使苹果幼果的总体代谢能力减弱, 进而造成幼果脱落。

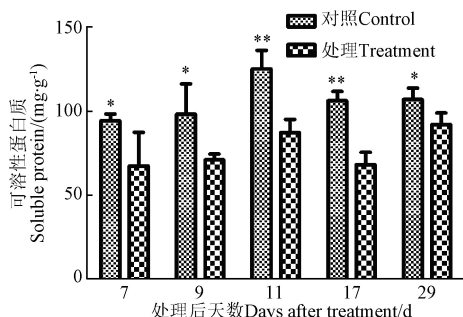


图 4 苯噻草酮处理对可溶性蛋白质含量的影响

Fig.4 Effect of metamitron treatment on fruit soluble protein content

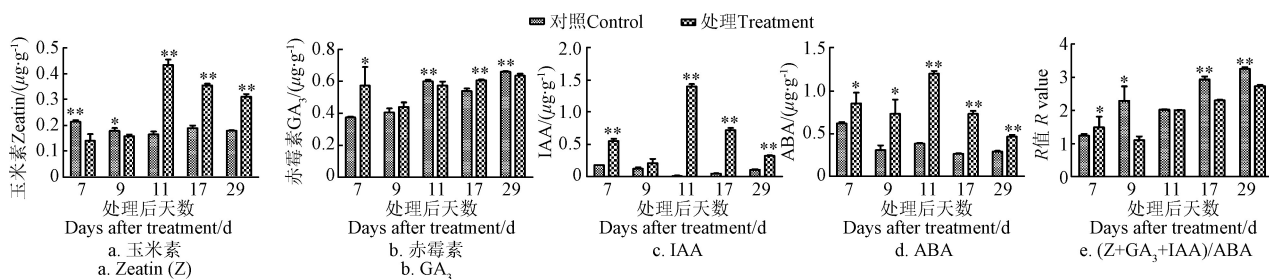


图 5 苯噻草酮处理对激素含量的影响

Fig.5 Effect of metamitron treatment on fruit hormone content

## 3 讨论

苯噻草酮作为一种苹果疏果剂有近十年的时间, 不少学者对不同生态条件下的不同品种进行了喷施时期、喷施浓度、对产量品种调控效应等研究<sup>[22-24]</sup>。Steven 等<sup>[25]</sup>研究认为, 苯噻草酮适宜喷施浓度为 300 mg/kg, 适宜喷施时期为盛花后 23 和 38 d, 与对照相比, 花朵坐果率降低了 50.63%, 单株产量降低了 37.10%, 单果质量提高了 8.54%, 分析为苯噻草酮影响叶绿素荧光所致, 使开放的 PS II 反应中心的能量捕捉效率值、PS II 光合量子产量及相对电子传导率均下降。嘎啦果适宜喷施时期为中心果直径 6.0~13.5 mm, 浓度为 1.65 kg/hm<sup>2</sup>, 喷施 2 次疏果效应更好, 分析认为嘎啦幼果脱落与叶绿素荧光及夜间温度有关<sup>[11,26]</sup>。富士适宜喷施时期为幼果直径 5~10 mm, 浓度为 350 mg/kg, 落果率 35.6%~50.9%, 且显著提高了成熟期单果质量和商品果比例<sup>[8]</sup>。本试验中, 幼果直径 6 mm 左右喷施 300 mg/kg 苯噻草酮 2 次, 花朵坐果率 24.20%, 比对照降低 27.63%, 与多数学者的疏除效应一致。然而, 也有学者认为苯噻草酮适用的幼果直径较大, 可作为一种补救型疏果剂<sup>[27-28]</sup>。

不少学者认为, 矿质养分及碳水化合物不足是导致幼果脱落的主要因素之一<sup>[29-31]</sup>。杨波等<sup>[32]</sup>研究发现, 扁桃在生理脱落期, 正常幼果的 N、P、K、B、Zn 5 种矿

## 2.6 苯噻草酮处理对激素的影响

苹果幼果脱落受内源激素调控<sup>[19-21]</sup>。在处理早期 (7 和 9 d), 对照的玉米素含量显著高于处理 ( $P < 0.05$ ); 而在处理后期, 对照的玉米素含量则明显低于处理 (图 5a)。苯噻草酮处理对赤霉素也有影响 (图 5b)。苯噻草酮处理显著提升了幼果生长素水平 ( $P < 0.05$ ), 图 5c 可见, 所有处理的 IAA 含量均明显高于对照, 差异性多为显著水平 ( $P < 0.05$ )。脱落酸是幼果脱落的主导激素种类, 苯噻草酮处理后脱落酸含量普遍升高, 各时期 ABA 含量均显著高于对照 ( $P < 0.05$ ), 处理为对照的 1.37~3.11 倍, 说明苯噻草酮提高了幼果的脱落酸含量, 从而促进了幼果脱落 (图 5d)。同时, 对 (Z+GA<sub>3</sub>+IAA)/ABA 的比值 (R 值) 进行了分析, 如图 5e 所示, 除喷施早期 (7d) 外, 对照的 R 值均高于处理, 其中 9、17 和 29 d 3 个时期二者间差异达显著水平 ( $P < 0.05$ ), 降幅最大为 51.55%, 说明低 R 值与幼果脱落相关。

质元素的浓度均高于落果, 认为扁桃幼果脱落与矿质元素浓度降低有关; 而本试验结果则表明, 处理的氮磷钾含量多高于对照, 分析认为, 疏果剂处理后果实变小直至萎蔫脱落, 氮磷钾含量在其中相对“浓缩”, 从而高于正常发育的果实, 这与关军锋等<sup>[33]</sup>的研究结果一致。徐昌杰等<sup>[31]</sup>研究认为, 柑橘幼果脱落与淀粉含量降低有关, 本试验结果则显示, 苯噻草酮处理后幼果的淀粉含量没有降低, 降低的是可溶性碳水化合物含量, 而可溶性碳水化合物含量对幼果发育的作用更为直接。

众多研究表明, 不少果树幼果脱落与激素含量及激素比例有关。易落果的柑橘品种具有较高的 ABA 含量与较低的 GA<sub>3</sub> 含量<sup>[34]</sup>; 同样扁桃幼果脱落与 ABA 含量升高及 GA<sub>3</sub> 和 IAA 含量降低有关<sup>[35]</sup>; 苹果幼果脱落与 ZT、IAA、GA 的减少及 ABA 的增加有关<sup>[36]</sup>。本试验中, 苯噻草酮处理后 ABA 含量显著升高, 与前人的研究相一致; 另外果实脱落往往不是由某一激素单独控制的, 而是由多种激素协同作用的结果, 因此本研究对 (Z+GA<sub>3</sub>+IAA)/ABA 进行了分析, 显示苯噻草酮处理后 (Z+GA<sub>3</sub>+IAA)/ABA 比值降低, 说明苯噻草酮疏果作用与低的 (Z+GA<sub>3</sub>+IAA) 生长素类激素/ABA 比值有关。

## 4 结论

1) 在边果直径 6 mm 时喷施 2 次 300 mg/kg 苯

噻草酮, 具有疏除边果的作用, 花序坐果率和花朵坐果率较对照降低 17.95% 和 27.63%, 差异达极显著水平 ( $P < 0.01$ ); 处理的单果率 44.80%, 为对照的 5.28 倍, 差异达极显著水平 ( $P < 0.01$ )。

2) 苯噻草酮处理后, 淀粉含量不降反升, 涨幅为 5.57%~37.20%; 可溶性碳水化合物总量(葡萄糖、果糖、蔗糖、山梨醇)显著降低 ( $P < 0.05$ ), 降幅最大的为 52.57%; 可溶性蛋白质含量显著降低 ( $P < 0.01$ ), 降幅最大的为 35.80%。

3) 激素测定结果显示, 苯噻草酮处理后脱落酸含量显著升高 ( $P < 0.05$ ), 处理为对照的 1.37~3.11 倍; 生长型与抑制型激素比值  $[(Z+GA_3+IAA)/ABA]$  降低, 降幅最大的为 51.55%。

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## Effects of fruit thinning agent “metamitron” on nutrition and hormone content of apple lateral fruits

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**Abstract:** The work aimed to clarify the effects of metamitron as the fruit thinning agent on the apple fruit setting rate as well as the mineral nutrition, carbohydrates, and hormones of lateral fruitlets, thus providing a reference for applying chemical thinning technology of apples. Thirty 9-year-old apple trees (Tianhong 2/SH38/*Malus micromalus*) were used as test materials, and 300 mg/kg metamitron solution was sprayed 2 times when the diameter of the biggest lateral fruits were around 6 mm. Spraying water was used as the control. The setting rate of inflorescence and flower were investigated after physiological fruit drop. The mineral nutrition, carbohydrate, soluble protein, and hormone content of lateral fruits were measured after spraying 7, 9, 11, 17, and 29 d. The total nitrogen, phosphorus, and potassium were determined by semi-micro distillation, Mo-Sb-Vc colorimetry, and flame photometer, respectively. Glucose, fructose, sorbitol, sucrose, and hormone contents were determined by HPLC, while the soluble protein content was determined by Coomassie brilliant blue staining. The results showed that the fruit setting rate of inflorescence and flowers decreased by 17.95 and 27.63% compared with the control, respectively. The proportion of inflorescence with single fruit increased by 5.28 times in the treatment, while that of sitting three fruits and more decreased significantly, which was 47.91% of the control. The results of fruit setting rate and fruit setting ratio showed that metamitron could significantly reduce the fruit setting rate, and the single fruit rate was high, with the setting fruits distributed evenly. The total nitrogen content was higher than that of the control at all stages, and the difference between the control and the treatment was significant except 7 and 9 d. The total phosphorus and potassium contents of almost all treatments were significantly higher than those of the control. The total phosphorus contents of 11 and 29 d after spraying was 2.05 and 1.67 times of the control, and the total potassium content was 1.93 and 1.51 times of the control, respectively. The results of mineral nutrition showed that the fruit thinning effect of metamitron was not caused by the deficiency of inorganic nutrients. The content of the soluble protein decreased significantly compared with the control, and the content of each treatment period was 71.42%, 72.37%, 69.68%, 64.20%, and 86.02% of the control, respectively. The starch content of metamitron treatment was significantly higher than that of the control, with an increase of 5.57%-37.20%, yet the content of sucrose, glucose, fructose, and sorbitol decreased with different degrees. Therefore, the soluble carbohydrate content decreased significantly to 9.55%-52.57%. Soluble carbohydrates are the direct nutrients for the development of young fruits, so fruit thinning of metamitron may be caused by insufficient supply of soluble carbohydrates. The abscisic acid content generally increased after the treatment, and the ABA content in each period was 1.37-3.11 times that of the control. The ratio of (Z+GA<sub>3</sub>+IAA)/ABA decreased significantly, which could cause falling off of young fruits. As a result, metamitron has a good fruit thinning effect on apples, related to the decreased soluble protein content, an insufficient supply of soluble carbohydrate, increased ABA content, and decreased (Z+GA<sub>3</sub>+IAA)/ABA ratio.

**Keywords:** hormone; nutrition; metamitron; fruit setting; apple