

## 不同矮化中间砧对烟富3号苹果幼树叶片 内源激素及糖含量的影响

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**摘要:**【目的】研究不同矮化中间砧对烟富3号苹果幼树叶片内源激素及糖含量的影响,筛选出最适合静宁地区发展的烟富3号苹果砧穗组合。【方法】以烟富3号为接穗,以西府海棠为砧木,以M26、GM256、P16、P2、M27、T337、SH40、SH6和M9为中间砧,定植3 a(年)后调查树体生长指标,然后测定其叶片中ZT、GA<sub>3</sub>、IAA、ABA、蔗糖、果糖、葡萄糖、山梨糖醇的含量。【结果】P16作为烟富3号的矮化中间砧时,株高最小,ZT含量最高;P2作为烟富3号的矮化中间砧时,节间长最短,ABA含量最高,IAA/ABA和(ZT+IAA+GA<sub>3</sub>)/ABA的比值最小;以P16为烟富3号的矮化中间砧时,叶片中果糖与葡萄糖含量最高;以T337为烟富3号的矮化中间砧时,叶片中山梨糖醇与蔗糖含量最高。相关性分析发现株高、茎粗和节间长与ABA含量均呈负相关,节间长与IAA/ABA和(ZT+IAA+GA<sub>3</sub>)/ABA的比值呈正相关。【结论】P2和P16作为烟富3号的矮化中间砧时,树体生长量最小,叶片中的ABA含量显著高于其他砧穗组合,IAA/ABA和(ZT+IAA+GA<sub>3</sub>)/ABA的比值最小,说明P2和P16矮化性在9种矮化中间砧中最好。SH40和SH6的矮化性仅次于P2和P16,树体与P2和P16相比更为中庸,仅从树势与矮化性方面来看,更适合作为烟富3号的矮化中间砧。

**关键词:**苹果;烟富3号;矮化中间砧;叶片;内源激素;糖含量

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## Effects of different dwarfing interstocks on endogenous hormone and sugar contents in leaves of young Yanfu No. 3 apple trees

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**Abstract:**【Objective】As the dwarf cultivation mode of apple becomes an inevitable trend, Yanfu No. 3 has been the main cultivar in Jingning area. In order to further screen out the most suitable stion combinations in Jingning area, the effects of different dwarfing interstocks on endogenous hormone and sugar contents in leaves of young Yanfu No.3 trees were investigated, so as to lay the foundation for further screening of the stion combinations suitable for the development in the Jingning area. 【Methods】In this experiment, Yanfu No.3 was used as scion, *Malus micromalus* as the base rootstock, and M26, GM256, P16, P2, M27, T337, SH40, SH6 and M9 as the intermediate stocks. The trees were planted in 2017 and an investigation was made on tree height, shoot thickness, annual shoot length, internode length, leaf area and SPAD after shoot growth stopped in autumn of 2020. Then the leaves were collected and brought back to the laboratory to determine the contents of ZT, GA<sub>3</sub>, IAA, ABA, sucrose, fructose, glucose and sorbitol in the leaves. Three trees were selected from each scion/rootstock combination with three repli-

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cates, totaling for 81 trees. Correlation and significance analyses were used to screen out the most suitable combination of Yanfu No.3 and interstock. **【Results】**There were significant differences in tree growth among the 9 scion/rootstock combinations. As a dwarfing interstock, P16 had the lowest tree height, while M9 had the highest tree height. The change pattern of shoot diameter and internode length was basically consistent with tree height. The shoot diameter and internode length with P2 and P16 interstocks were the smallest among 9 rootstocks. The leaf areas with P2 and P16 were larger, and their SPAD values were also higher. The ZT content in leaves with P16 was  $23.97 \text{ ng} \cdot \text{g}^{-1}$ , which was significantly higher than that with other interstocks. The ZT content with P2 was significantly higher than that with other interstocks except P16, and the ZT content with P2 was 21.52% lower than that with P16. The GA<sub>3</sub> content in leaves with M26 was significantly higher than that with other interstocks ( $13.63 \text{ ng} \cdot \text{g}^{-1}$ ). The GA<sub>3</sub> content in leaves with SH40 was the lowest ( $5.99 \text{ ng} \cdot \text{g}^{-1}$ ), and the content with M26 was 2.27 times that with SH40. The IAA content in leaves with GM256 was significantly higher than that with other interstocks ( $149.25 \text{ ng} \cdot \text{g}^{-1}$ ). The IAA contents with P2 and P16 were at a low level. The ABA content with P16 was  $164.86 \text{ ng} \cdot \text{g}^{-1}$ , which was 38.43% lower than that with P2. The ratio of IAA/ABA was consistent with the pattern of the ratio of  $(\text{ZT}+\text{GA}_3+\text{IAA})/\text{ABA}$ , with GM256 having the highest ratio and P2 having the lowest ratio. Combined with the analysis of tree growth indicators, the hormone ratio was relatively consistent with the tree growth pattern, i.e. the smaller the ratio of IAA/ABA to  $(\text{ZT}+\text{GA}_3+\text{IAA})/\text{ABA}$ , the more dwarfed the tree was, so P2 and P16 had the best dwarf ability, while SH40 and SH6 could result in more moderate trees. When P16 was used as the dwarfing interstock, the contents of fructose and glucose in leaves were the highest, while when SH40 or SH6 was used as the interstock, the contents of fructose and glucose in leaves were next only to P16. When T337 was used as the dwarf interstock, the contents of sorbitol and sucrose in leaves were the highest, and the sorbitol content in leaves with P2, P16, SH40 and SH6 was next only to that with T337, while the sucrose content was at a lower level. Correlation analysis showed that tree height was negatively correlated with glucose, ZT and ABA contents. The shoot diameter was negatively correlated with fructose, glucose, sorbitol and ABA contents. Internode length was significantly and negatively correlated with fructose, glucose and ABA contents, IAA/ABA and  $(\text{ZT}+\text{IAA}+\text{GA}_3)/\text{ABA}$  ratios, and sucrose content. Correlation analysis showed that tree height, shoot diameter and internode length were negatively correlated with ABA content, indicating that tree growth was related to ABA content in leaves. Internode length was positively correlated with IAA/ABA and  $(\text{ZT}+\text{IAA}+\text{GA}_3)/\text{ABA}$  ratios, indicating that tree growth was related to hormone content in scion leaves. Most of the sugar components in scion leaves were negatively correlated with tree growth index, indicating that sugar accumulation in scion leaves also affected tree dwarfing degree. **【Conclusion】**When P2 and P16 were used as dwarfing interstocks of Yanfu No. 3, the tree growth was the lowest, and the ABA content in leaves was significantly higher than that in leaves with other interstocks. The ratio of IAA/ABA and  $(\text{ZT}+\text{IAA}+\text{GA}_3)/\text{ABA}$  was the lowest, indicating that the dwarfing efficacy of P2 and P16 was the best among the 9 dwarfing interstocks. SH40 and SH6 were next only to P2 and P16 in terms of dwarfing, and the tree vigors were more moderate compared to P2 and P16, making them more suitable as dwarfing intermediate rootstocks for Yanfu No. 3 only in terms of tree vigor and dwarfing.

**Key words:** Apple; Yanfu No.3; Dwarfing interstocks; Leaves; Endogenous hormones; Sugar content

苹果矮砧密植栽培具有早果、丰产、质优和便于管理等优点,已成为苹果产业发展的重要栽培模式<sup>[1-3]</sup>。不同的砧木品种对树体的影响存在差异,适宜的矮化砧木能够更好地调节果树的生殖生长和营养生长之间的平衡,改善树体的枝类组成,并对果实品质有直接影响<sup>[3]</sup>。由于矮化砧木可以提高果树的光合速率<sup>[4]</sup>,合理分配生成的有机物<sup>[5]</sup>,与乔化果树相比矮砧果树更加矮小、早果,便于集约经营管理,所以诸多学者对矮化机制进行研究。张鹤<sup>[6]</sup>研究发现:M9作为中间砧时,砧木段*MdPIN8*的表达量显著低于接穗和基砧,IAA向下转运受阻,从而导致树体矮化;王丽琴等<sup>[7]</sup>指出矮砧M26是通过影响IAA向基部运输而达到树体矮化效果。郝捷等<sup>[8]</sup>研究发现:国红×长富6的实生后代以SH38为中间砧时,叶片中IAA、GA、CTK含量低于实生苗,但ABA含量显著提高,即IAA/ABA、(IAA+GA+ZR)/ABA比值小于实生苗。隗晓雯等<sup>[9]</sup>和曹敏格等<sup>[10]</sup>进一步对矮化砧木植物激素的系统进行研究,证实苹果树叶片IAA/ABA、(IAA+GA+ZR)/ABA可作为砧木矮化性预测的重要参考指标,比值越小,苹果树体的矮化程度越高。

不同的矮化中间砧不仅对植株叶片中激素含量有影响,而且对植株叶片中糖含量也有影响。苹果叶片中主要的光合产物运输形式和可溶性储存物质是山梨醇<sup>[11]</sup>,它与葡萄<sup>[12]</sup>、柑橘<sup>[13]</sup>和玉米<sup>[14]</sup>等植物中蔗糖的作用相同。吴丹<sup>[15]</sup>研究不同的矮化中间砧对瑞阳苹果叶片光合速率的影响时,发现以M26和T337为中间砧的树体叶片光合速率显著大于以SH38和B9为中间砧的树体。周晏起<sup>[16]</sup>在研究矮化中间砧与乔砧对寒富苹果幼树碳素营养特征的影响时,发现矮化中间砧树(寒富/GM256/山荆子)叶片中的总糖含量高于乔砧树(寒富/山荆子)叶片,在秋季之前,矮化中间砧树叶片中的山梨醇、蔗糖和果糖含量整体高于乔砧树叶片;在养分回流期,矮化中间砧树叶片中的山梨醇和葡萄糖含量高于乔砧树叶片。陈汝等<sup>[17]</sup>研究不同矮化中间砧对红将军苹果树体生长、光合和果实品质的影响时发现,红将军/M26的组合叶片中SPAD和净光合速率以及该组合的果实品质都显著高于红将军/Mark和红将军/CG8的组合。李民吉等<sup>[18]</sup>研究SH系矮化中间砧对宫藤富士树体生长和果实品质的影响时,发现不同的矮化中间砧对果实中糖的含量、类型及存在比例皆有

影响,SH6嫁接树果实糖酸比显著高于SH1、SH3和SH9,由此可见,矮化砧木不仅会对树体生长有影响,对果实品质也会有不同的影响<sup>[19]</sup>。

静宁县位于甘肃东部,地处黄土高原丘陵沟壑区,属暖温带半湿润半干旱气候,气候温和,光照充足,非常有利于苹果生产,因此被农业部评为“黄土高原优生苹果最佳栽植区域”,苹果的矮化栽培模式已成必然趋势,烟富3号是静宁地区的主栽品种,因此笔者采用9种矮化中间砧木嫁接烟富3号,定植3 a(年)后调查树体生长指标,然后测定其叶片的内源激素和糖含量,探索9种矮化中间砧对烟富3号幼树叶片的内源激素、糖含量和树体生长影响,以期为烟富3号的矮化栽培提供理论依据,为进一步筛选出适合静宁地区发展的砧穗组合打下基础。

## 1 材料和方法

### 1.1 试验材料

试验选用矮化中间砧M26、GM256、P16、P2、M27、T337、SH40、SH6和M9(表1),长度为25 cm,基砧为西府海棠,嫁接品种为烟富3号,各组合名称依次用所选砧木表示。试验材料嫁接后于2017年定植,嫁接口距离地面高度为5 cm,株行距为2 m×

表1 矮化中间砧介绍

Table 1 Introduction to dwarfing interstocks

砧木 Rootstock	亲本 Parent	育种机构 Breeding institution
M9	自然授粉实生苗选育 Selection and breeding of naturally pollinated live seedlings	英国东茂林试验站 East Mailing Research Station
M26	M16×M9	英国东茂林试验站 East Mailing Research Station
M27	M9×M13	英国东茂林试验站 East Mailing Research Station
T337	M9优系 M9 superior system	荷兰木本苗木植物苗圃检测服 务中心 Naktuinbouw
SH6	国光×武乡海棠 Guoguang×Wuxiang Begonia	山西农科院果树研究所(中国) Shanxi Academy of Agricultural Sciences Polomogy Istitute (China)
SH40	国光×武乡海棠 Guoguang×Wuxiang Begonia	山西农科院果树研究所(中国) Shanxi Academy of Agricultural Sciences Polomogy Istitute(Chi- na)
P2	M9×普通安托诺夫卡 M9×Ordinary Antonovka	波兰园艺研究所 Polish Horticultural Institute
P16	M9×普通安托诺夫卡 M9×Ordinary Antonovka	波兰园艺研究所 Polish Horticultural Institute
GM256	海棠果×M系 Carambola×M system	吉林农科院果树研究所(中国) Jilin Academy of Agricultural Sciences Polomogy Istitute (China)

4 m, 树形修剪采用纺锤型, 园区管理一致。每种砧穗组合选择3株苗木, 3次重复, 共计81株, 所选砧穗组合苗木生长状况良好且均未结果。2020年秋梢停长后先测定树体生长指标, 然后在每株树上随机摘取30枚叶片完整无病虫害的功能叶, 用超纯水洗干净, 用滤纸吸干叶面水分后除去叶脉, 用锡箔纸包好放入液氮中速冻带回实验室, 于-80 °C冰箱保存以备后用。

## 1.2 测定方法

1.2.1 树体生长指标的测定 每种砧穗组合各选择长势一致的3株树, 3次重复, 分别记录各砧穗组合的植株生长情况, 主要内容包括株高、茎粗、1年生枝长、节间长、叶面积及SPAD值, 数据采集后进行统计分析。株高和1年生枝长采用卷尺进行测量; 茎粗和节间长采用游标卡尺测量; 叶面积采用YPYX-A叶面积仪测量; SPAD采用SPAD-502叶绿素仪测定; 枝类组成调查参照王贵平等<sup>[20]</sup>的方法: 短枝<5 cm, 中枝5~15 cm, 长枝>15 cm。

1.2.2 内源激素的测定 参考马宗桓等<sup>[21]</sup>的方法, 将2 g冷冻的叶片在液氮中快速研磨成粉末, 用10 mL 80%的色谱甲醇(超纯水配制)分3次洗入10 mL离心管中, 放4 °C冰箱中浸提24 h, 期间每隔1 h震荡混匀1次, 8000 r·min<sup>-1</sup>离心10 min。吸取上清液用旋转蒸发仪在38 °C下浓缩除去甲醇, 得到约2 mL的浓缩液, 用50%的甲醇冲洗蒸发瓶瓶壁, 最后定容至1.5 mL, 用一次性针管吸取2 mL过0.22 μm有机膜, 装入1.5 mL的离心管放入冰盒中避光保存, 3次重复, 测定ZT、IAA、GA<sub>3</sub>和ABA含量。

色谱条件:Symmetry C18色谱柱(4.6 mm×250 mm、

5 μm);流动相为甲醇与0.1%磷酸的体积比为1:9, 流速为1.0 mL·min<sup>-1</sup>, 检测波长为254 nm, 柱温为30 °C, 进样量为10 μL。

1.2.3 糖含量的测定 使用美国Waters Acuity Arc高效液相色谱仪进行糖类组分及含量的测定, 参照Bernardez等<sup>[22]</sup>和刘玉莲等<sup>[23]</sup>的方法并略作修改。

样品提取方法:叶片加液氮研磨后准确称取0.5 g, 移至10 mL离心管中, 加入5 mL 80%乙醇, 35 °C下超声提取20 min、12000 r·min<sup>-1</sup>下离心15 min, 取上清液。重复提取2次, 每次加80%乙醇2 mL, 合并上清液, 定容至10 mL。取2 mL于离心管中, 真空离心浓缩仪旋转蒸发(60 °C), 旋转蒸发至全干, 用1 mL超纯水1 mL乙腈复溶, 过0.22 μm有机相微孔滤膜过滤, 将滤液加入样品瓶中, 3次重复, 测定果糖、葡萄糖、山梨糖醇和蔗糖的含量。

色谱条件:XBridge BEH Amide色谱柱(4.6 mm×150 mm, 2.5 μm), 流动相为75%乙腈+0.2%三乙胺+24.8%超纯水, 流速为0.8 mL·min<sup>-1</sup>, 检测波长为254 nm, 柱温为40 °C, 进样量为10 μL, 流动相使用前用0.22 μm有机滤膜过滤, 超声脱气。

## 1.3 数据分析

使用Microsoft Excel和SPSS 22.0进行数据整理分析, 并用OriginPro 9.0作图。

## 2 结果与分析

### 2.1 不同矮化中间砧对树体生长发育的影响

从表2可以看出9种矮化中间砧对树体的生长发育影响不同, 调查数据显示P16的株高最小, P2的株高与P16无显著差异, M9的树体最高, T337树体

表2 不同矮化中间砧对树体的影响

Table 2 Effect of different dwarfing intermediate rootstocks on the tree

砧木 Rootstock	株高 Plant height/cm	冠径 Canopy diameter/cm	茎粗 Stems thick/mm	一年生枝长 Annual branches Length/cm	节间长 Intervals length/mm	叶面积 Leaf area/mm <sup>2</sup>	SPAD值 SPAD value
M26	261.33±2.49 bcd	164.50±0.57 e	20.15±0.15 cd	19.95±0.84 a	21.25±0.78 cde	3 042.52±155.71 bc	51.77±1.09 c
GM256	255.33±2.49 de	184.30±0.41 c	19.97±0.72 cd	18.01±0.37 ab	23.33±0.39 abc	2 627.49±332.24 c	50.57±0.58 c
P16	221.33±3.09 g	148.50±0.33 h	18.54±0.86 d	15.06±1.10 b	20.29±0.57 de	3 743.86±238.61 ab	57.63±0.61 a
P2	228.33±2.05 fg	137.13±0.25 i	18.50±0.39 d	15.34±0.62 b	19.73±0.28 e	3 629.36±518.05 ab	56.33±0.61 ab
M27	258.67±2.87 cde	189.73±0.45 b	25.14±1.24 ab	19.93±0.94 a	24.89±0.30 a	2 859.40±230.63 bc	55.97±0.54 b
T337	276.67±2.49 ab	170.40±0.73 d	23.58±0.72 abc	15.67±0.80 b	23.90±0.94 ab	3 983.02±789.47 a	51.37±0.57 c
SH40	274.67±2.87 abc	151.40±0.57 g	21.68±0.31 bcd	20.58±1.16 a	21.78±0.90 bcde	2 338.67±339.63 c	47.80±1.07 d
SH6	243.33±3.30 ef	160.70±0.65 f	18.97±0.37 d	15.73±0.84 b	21.98±0.44 bcde	3 595.29±120.07 ab	55.33±0.76 b
M9	284.33±3.40 a	195.40±0.24 a	26.84±1.67 a	20.03±1.01 a	22.49±0.78 bcd	2 690.33±268.75 c	51.90±0.16 c

注:同一列不同字母表示在p<0.05水平下各处理之间差异显著。下同。

Note: The different letters in the same column indicate significant differences in different treatment at p<0.05. The same below.

的高度与M9无显著差异;茎粗的规律与株高相同,M9的茎粗最大,其次是M27和T337,三者的茎粗并无显著差异,M26、GM256、P16和P2的茎粗相对较小,且四者茎粗无显著差异;9种砧穗组合中,SH40、M9、M26和M27一年生枝长度较长,P16、PT337和SH6的一年生枝长度较短;9种砧穗组合的节间长度的规律与株高基本一致,P2的节间长度最短,P16的节间长度与P2无显著差异,M27的节间长度最长,其次是T337,但是T337的株高比M27的高;叶面积与SPAD值的规律相似,P2和P16的叶面积较大,其SPAD值也相对较大,M9和GM256的叶面积较小,SPAD值也相对较小,T337的叶面积在9个砧穗组合中最大,但是其SPAD值相对较小。9种砧穗组合的树体生长差异明显,主要体现于株高、茎粗和节间长度上,从表2的数据中看P2和P16的矮化性最好,SH40和SH6树势相对中庸。

从表3中数据可以看出不同矮化中间砧对果树枝类组成的影响明显,各砧穗组合长枝比例处于5.6%~18.80%之间,中枝比例处于15.37%~19.57%之间,短枝比例处于65.47%~77.07%之间。其中树势较为矮小的P2与P16中短枝的比例显著高于其他砧穗组合,并且其中短枝的比例达到了90%以上,而长枝比例分别只有5.6%和7.3%,显著低于其他砧穗组合,其他砧穗组合中短枝比例达到了80%,长枝比例接近10%。

表3 不同矮化中间砧对枝类组成的影响

Table 3 Effect of different dwarfing intermediate rootstocks on the composition of branch classes

砧木 Rootstock	枝类组成 The proportion of different shoot types/%		
	长枝 Long shoot	中枝 Medium shoot	短枝 Spur shoot
M26	8.70 f	18.87 ab	72.43 c
GM256	10.70 e	19.57 a	69.73 e
P16	7.30 g	18.40 bc	74.30 b
P2	5.60 h	17.33 d	77.07 a
M27	15.10 b	19.43 a	65.47 g
T337	14.10 c	17.37 d	68.53 f
SH40	13.50 c	15.37 e	71.13 d
SH6	11.80 d	15.90 e	72.30 cd
M9	18.80 a	17.53 cd	63.67 h

## 2.2 不同矮化中间砧对叶片内源激素含量的影响

不同矮化中间砧对烟富3号幼树叶片ZT含量的影响如图1-A所示:9种砧穗组合苗木中,P16叶

片内ZT的含量显著高于其他砧穗组合,含量(w,后同)为23.97 ng·g<sup>-1</sup>。P2的ZT含量显著高于除P16之外的其他砧穗组合,比P16的含量低21.52%。M27的含量仅次于P16和P2,P16含量比M27高36.50%,M9的ZT含量低于M27且有显著差异,T337的ZT含量显著低于其他砧穗组合。各砧穗组合叶片中ZT的含量由高到低依次为P16>P2>M27>M9>SH40>SH6>M26>GM256>T337。

不同矮化中间砧对烟富3号幼树叶片中GA<sub>3</sub>含量的影响如图1-B所示:M26叶片内GA<sub>3</sub>的含量显著高于其他砧穗组合,其含量为13.63 ng·g<sup>-1</sup>,SH40的GA<sub>3</sub>含量最低,其含量为5.99 ng·g<sup>-1</sup>,M26的含量是SH40的2.27倍。GM256、P2和SH63个砧穗组合的GA<sub>3</sub>含量仅次于M26,且他们三者之间并无显著性差异。T337和P162个砧穗组合叶片中GA<sub>3</sub>含量无显著差异。各砧穗组合叶片中GA<sub>3</sub>含量由高到低依次为M26>P2>GM256>SH6>M9>P16>T337>M27>SH40。

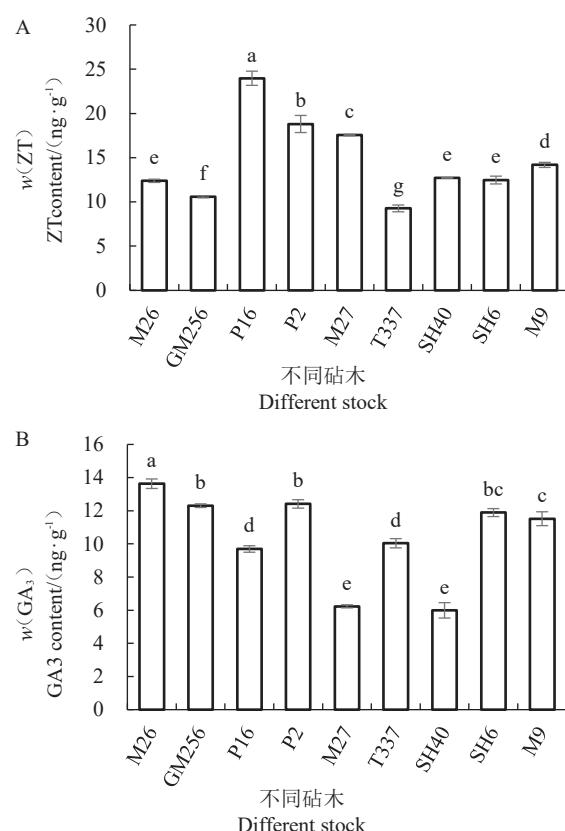


图1 不同矮化中间砧对叶片内ZT(A)和GA<sub>3</sub>(B)含量的影响

Fig. 1 Effects of different dwarfing intermediate stocks on the contents of ZT (A) and GA<sub>3</sub> (B) in leaves

IAA是植物主要的内源激素,不同矮化中间砧对烟富3号幼树叶片的IAA含量的影响如图2-A所示。GM256叶片内的IAA含量显著高于其他砧穗组合,含量为 $149.25 \text{ ng} \cdot \text{g}^{-1}$ ,SH40叶片内的IAA的含量最低,GM256的含量是SH40的2.63倍。SH6叶片内IAA的含量低于GM256,但是高于其他矮化中间砧。M27和M92个砧穗组合叶片中IAA的含量无显著差异,P16显著高于P2和SH40。各砧穗组合叶片中IAA的含量由高到低依次为GM256>T337>SH6>M26>M27>M9>P16>P2>SH40。

不同矮化中间砧对烟富3号幼树叶片ABA含量的影响如图2-B所示,P2和SH6的叶片中ABA含量显著高于其他砧穗组合,两者之间并无明显差异。其次是P16,其含量为 $164.86 \text{ ng} \cdot \text{g}^{-1}$ ,比P2的含量低38.43%。砧穗组合M26与M27叶片内ABA的含量分别是 $94.06 \text{ ng} \cdot \text{g}^{-1}$ 和 $87.56 \text{ ng} \cdot \text{g}^{-1}$ ,含量最高的P2比M26和M27高2.10倍和2.26倍。T337叶片中ABA的含量显著低于其他砧穗组合,各砧穗组合叶

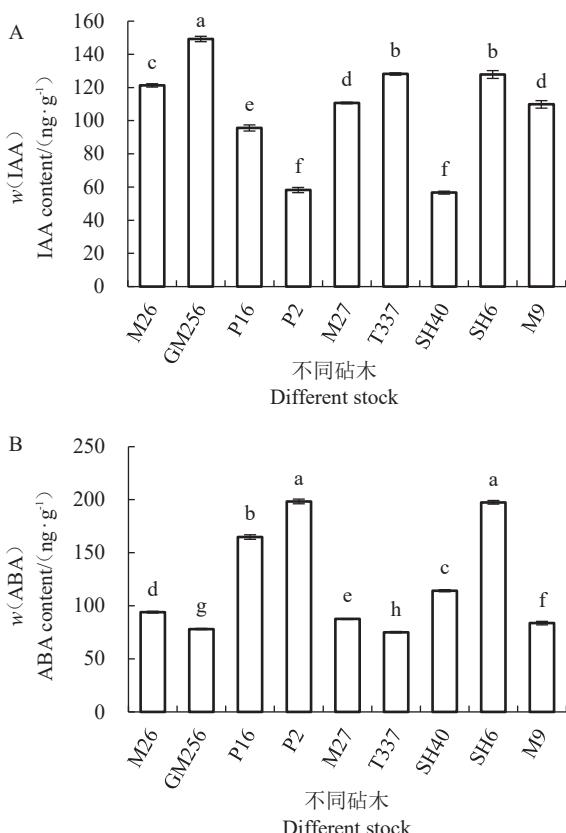


图2 不同矮化中间砧对叶片内IAA(A)和ABA(B)含量的影响

Fig. 2 Effects of different dwarfing interstocks on the contents of IAA (A) and ABA (B) in leaves

片中ABA的含量由高到低依次为P2>SH6>P16>SH40>M26>M27>M9>GM256>T337。

### 2.3 不同矮化中间砧对叶片激素比值的影响

从图3中可以看出IAA/ABA的比值与( $ZT+GA_3+IAA$ )/ABA的比值变化规律一致,GM256的比值最高,P2的比值最低,激素比值由高到低依次为GM256、T337、M9、M26、M27、SH6、P16、SH40、P2;结合树体生长指标分析,激素比值与树体生长规律相对一致,P2和P16的树体矮化性相对较好,而SH40和SH6的树势则相对较为中庸。

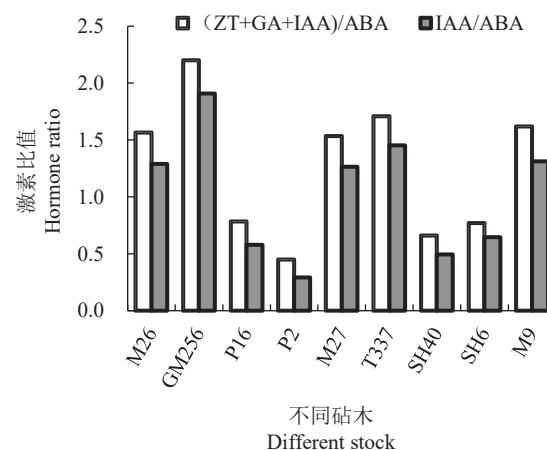


图3 不同矮化中间砧对叶片内激素比值的影响

Fig. 3 Effect of different dwarfing intermediate rootstocks on the hormone ratio in leaves

### 2.4 不同矮化中间砧对叶片糖含量的影响

不同矮化中间砧对烟富3号幼树叶片糖含量的影响如表4所示,P16叶片内的果糖含量显著高于其

表4 不同矮化中间砧对叶片糖含量的影响

Table 4 Effects of different dwarfing interstocks on leaf sugar content

矮化中间砧 Dwarfing interstocks	w(果糖) Fructose/ (mg·g⁻¹)	w(葡萄糖) Glucose/ (mg·g⁻¹)	w(山梨糖醇) Sorbitol/ (mg·g⁻¹)	w(蔗糖) Sucrose/ (mg·g⁻¹)
M26	5.38±0.31 d	5.73±0.30 c	27.89±0.40 cd	1.97±0.03 e
GM256	2.08±0.06 ef	2.54±0.15 d	29.63±0.91 b	8.75±0.42 a
P16	8.28±0.11 a	9.71±0.14 a	29.36±0.43 bc	2.20±0.09 de
P2	7.06±0.27 b	9.23±0.40 ab	27.26±0.58 d	1.95±0.07 e
M27	1.72±0.02 f	2.72±0.06 d	22.51±0.37 f	6.99±0.17 b
T337	1.81±0.02 ef	1.74±0.07 e	33.50±0.68 a	9.24±0.34 a
SH40	7.44±0.23 b	8.79±0.26 b	27.59±0.85 d	2.59±0.08 d
SH6	6.36±0.26 c	5.95±0.58 c	29.22±0.91 bc	1.91±0.03 e
M9	2.24±0.23 e	1.85±0.05 e	25.33±0.66 e	5.55±0.41 c

他砧穗组合,是含量最低的M27的4.81倍。其次是SH40和P2,且两者之间无显著差异,比P16的含量分别低10.14%和14.73%。SH6的含量为 $6.36 \text{ mg} \cdot \text{g}^{-1}$ ,比P16的含量低23.19%,GM256、T337和M27的果糖含量较低且它们无显著差异。

不同矮化中间砧的烟富3号幼树叶片葡萄糖含量最高的是P16,其次是P2,且它们之间无明显差异。SH40叶片内葡萄糖的含量为 $8.79 \text{ mg} \cdot \text{g}^{-1}$ ,比含量最高的P16低9.47%。M9和T337 2个砧穗组合叶片内葡萄糖含量最低且两者之间无明显差异,P16的含量分别是M9和T337的5.25倍和5.58倍。

9种砧穗组合的幼树叶片中以T337为中间砧的山梨糖醇含量最高,其次是GM256,它的含量与T337相差 $3.87 \text{ mg} \cdot \text{g}^{-1}$ ,GM256、P16和SH6三者之间无显著差异。M27含量最少,与含量最高的T337分别相差 $10.99 \text{ mg} \cdot \text{g}^{-1}$ 。M9的含量显著高于M27,其含量比M27高12.52%。

9种矮化中间砧对烟富3号幼树叶片蔗糖含量的影响中,T337叶片内的蔗糖含量显著高于其他砧

穗组合。其次是GM256和M27,T337比它们分别高5.60%和32.18%。P2、M26和SH6的含量偏低,且它们之间没有显著差异。蔗糖含量最高的T337比含量最低的SH6高 $7.33 \text{ mg} \cdot \text{g}^{-1}$ ,M9叶片内的蔗糖含量比SH6高 $3.64 \text{ mg} \cdot \text{g}^{-1}$ 。

## 2.5 相关性分析

不同砧穗组合的叶片激素与糖含量及树型指标的相关性分析如表5所示,株高与葡萄糖含量、ZT含量和ABA含量呈显著负相关;茎粗与果糖含量、葡萄糖含量、山梨糖醇含量及ABA含量呈显著负相关;节间长与果糖含量和葡萄糖含量呈极显著负相关,与ABA含量呈显著负相关,与IAA/ABA和 $(ZT+IAA+GA_3)/ABA$ 呈显著正相关,与蔗糖含量呈极显著正相关。从相关性来看株高、茎粗和节间长与ABA含量皆呈负相关,说明树体生长与叶片中ABA的含量有关,节间长与IAA/ABA和 $(ZT+IAA+GA_3)/ABA$ 呈正相关,这说明树体生长量与接穗叶片中激素含量有关;而接穗叶片中各糖组分含量大都数与树体生长指标呈负相关,说明接穗叶片中糖的积累也会影响到树体的矮化。

表5 叶片激素与糖含量及树型指标的相关性分析

Table 5 Correlation analysis of leaf hormones with sugar content and tree shape index

指标 Index	果糖 Fructose	葡萄糖 Glucose	山梨糖醇 Sorbitol	蔗糖 Sucrose	ZT	GA <sub>3</sub>	IAA	ABA	IAA/ABA	$(ZT+IAA+GA_3)/ABA$
株高 Plant height	-0.619	-0.668*	-0.402	0.473	-0.714*	-0.219	0.137	-0.786*	0.525	0.531
茎粗 Stems thick	-0.727*	-0.715*	-0.785*	0.563	-0.254	-0.388	0.09	-0.697*	0.452	0.477
一年生枝长 Annual branches length	-0.312	-0.291	-0.507	0.18	-0.295	-0.325	0.031	-0.634	0.327	0.348
节间长 Intervals length	-0.864**	-0.848**	-0.525	0.837**	-0.495	-0.399	0.508	-0.716*	0.715*	0.705*
叶面积 Leaf area	0.204	0.164	0.268	-0.22	0.25	0.303	-0.027	0.489	-0.275	-0.286
SPAD值 SPAD value	0.257	0.293	-0.104	-0.286	0.767*	0.115	-0.02	0.62	-0.384	-0.377

注:\*\*代表极显著性相关( $p < 0.01$ );\*代表显著性相关( $p < 0.05$ )。

Note: \*\*means highly significant correlation ( $p < 0.01$ ); \* means significant correlation ( $p < 0.05$ ).

## 3 讨 论

砧木在果树产业发展过程中起着重要作用,不同的砧木对接穗的影响不同。不同的矮化砧木所能达到的效果也不相同,同种矮化砧木的不同嫁接方式所能展现出来的效果也是不同的<sup>[24]</sup>,矮化砧木通过影响树体的激素水平达到树体矮化的效果<sup>[9]</sup>。本试验结果表明矮化中间砧不同,矮化效果也不同,P2和P16作为烟富3号的矮化中间砧时,矮化性最好。邵开基等<sup>[25]</sup>研究苹果矮化程度与ABA含量的

关系中发现3种砧木(S20、S60、S63)母树叶片中ABA的含量越高树体越矮化,反之,树体越乔化;以这3种砧木为中间砧(砧木为山定子,品种为红星)的砧穗组合树叶片中的ABA含量同样出现差异。李海燕<sup>[26]</sup>在研究不同矮化中间砧对华红苹果幼树生理特性的影响时,发现ABA可抑制细胞分裂和细胞伸长,有利于节间缩短。张晨光等<sup>[27]</sup>提出接穗叶片中ABA含量、IAA/ABA和 $(IAA+GA+ZR)/ABA$ 的比值可以作为判断树体矮化程度的指标。本试验发现不同的砧穗组合叶片中ABA的含量差异显著,

SH6、P2、P16 和 SH40 砧穗组合叶片中ABA的含量均显著高于其他砧穗组合,说明矮化中间砧对于接穗叶片中的ABA含量有明显影响,IAA/ABA和 $(ZT+IAA+GA_3)/ABA$ 的值也显著低于其他砧穗组合,矮化性也优于其他组合,这与前人所得出的结论一致。以SH6、M26和P16为中间砧的植株叶片中IAA含量较高,可能是中间砧阻滞了IAA向基部运输从而使IAA积累在叶片中,而以P2和SH40为中间砧的植株叶片中IAA含量较低,则可能是向基部运输中被代谢。

陈长兰等<sup>[28]</sup>在研究果树矮化中间砧的致矮机理中发现碳水化合物和激素由中间砧上部向根系的运输过程中受到矮化中间砧的阻碍,影响了根系的生长发育,使得地上部分不能得到充分的水分及营养物质从而导致矮化。王中英等<sup>[29]</sup>在研究矮化中间砧苹果<sup>14</sup>C同化物分配和转运中发现矮化中间砧树对同化物有明显的滞阻作用,在养分积累期矮化中间砧树根系同化物含量明显低于乔砧树根系。刘少春<sup>[30]</sup>研究了甘蔗中4种内源激素与蔗糖积累的关系,结果表明:细胞分裂素、脱落酸与蔗糖积累呈正相关,其中脱落酸与蔗糖积累呈显著相关。赵智中等<sup>[31]</sup>研究柑橘果实品种间糖积累潜力时发现,果实中的ABA含量与糖积累之间存在显著的相关关系,内源ABA含量较高的品种,糖积累量也较多;反之,糖积累量较低。郑国琦等<sup>[32]</sup>研究认为,ABA之所以能够促使蔗糖或山梨醇进入苹果、草莓等果实的细胞,主要是通过刺激液泡膜上H<sup>+</sup>-ATPase和糖转运载体的活性,提高质膜的通透性,促进糖分跨过液泡膜主动运输到液泡中去。本试验研究发现,不同的矮化中间砧会影响接穗叶片中糖的含量,以T337为中间砧的植株叶片中山梨糖醇和蔗糖的含量最高,以P16为中间砧的植株叶片中果糖含量与葡萄糖含量最高,短枝比例较高的P16、P2、SH40和SH6 4种砧穗组合的蔗糖含量均处于较低水平,而其果糖含量则是高于其他砧穗组合,相关性分析中也表明了节间长与果糖呈极显著负相关,而节间长与蔗糖则呈极显著正相关;结合前人研究结果,各组合的叶片中糖组分的比例发生不同程度改变的现象,有可能是矮化中间砧影响了接穗叶片中激素含量,进而改变了接穗叶片中糖组分之间相互转化及各组分的转运,促使果树形成较多的中短枝。

## 4 结 论

研究表明,P2和P16作为烟富3号的矮化中间砧时,树体生长量小,叶片中的ABA含量显著高于其他砧穗组合,IAA/ABA和 $(ZT+IAA+GA_3)/ABA$ 的比值最小,说明其矮化性在9种矮化中间砧中最好。SH40和SH6的矮化性仅次于P2和P16,树体与P2和P16相比更为中庸,仅从树势与矮化性方面来看,更适合作为烟富3号的矮化中间砧。

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