

资阳香橙×枳8个杂交后代的耐碱性评价

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摘要:【目的】研究资阳香橙(*Citrus junos* Sieb. ex Tanaka)×枳(*Poncirus trifoliata* Raf.)杂交的8个F₁代株系(ZZ1、ZZ6、ZZ7、ZZ31、ZZ42、ZZ60、ZZ65、ZZ948)在pH 8.22的碱性土壤上耐碱性差异,为选育新的耐碱砧木积累数据和材料。【方法】测量了8个杂种砧木及其亲本在碱性土壤上的株高、茎粗、黄化指数、叶片光合色素以及营养元素含量,应用AHP-TOPSIS法对这些砧木的耐碱性做出综合评价。【结果】播种生长23个月的杂种砧木,株高差异显著,在68.52~228.23 cm范围均有分布,其中ZZ6最矮,约为枳株高的1/2;ZZ65最高,约为资阳香橙株高的1.6倍。总体上,砧木茎粗与株高相呼应,株高较高的砧木茎粗值也较大。统计杂种砧木黄化指数得出,ZZ6黄化指数最低,ZZ7、ZZ31和ZZ948黄化指数较低,ZZ1黄化指数中等,ZZ42和ZZ60黄化指数较高,ZZ65黄化指数最高。随砧木黄化指数的升高,叶片叶绿素a、叶绿素b和叶绿素a+b含量随之降低。砧木叶片元素测定结果显示,叶片中活性铁含量与砧木黄化指数呈显著负相关,叶片P含量与黄化指数呈显著正相关,全铁和其余元素含量与叶片黄化无显著相关性。通过AHP-TOPSIS法综合评价得到砧木耐碱性排序为资阳香橙>ZZ6>ZZ31>ZZ948>ZZ7>ZZ1>ZZ60>ZZ42>ZZ65>枳。【结论】筛选出3个耐碱性强的砧木品种(ZZ6、ZZ31和ZZ948),其中ZZ6为矮化耐碱砧木资源。

关键词:资阳香橙×枳;杂种砧木;砧木评价;耐碱;叶片黄化;缺铁

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Evaluation of alkali tolerance of 8 hybrid rootstock progenies of Ziyang Xiangcheng and Trifoliolate Orange

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Abstract:【Objective】The alkali-resistance of eight F₁ generation lines (ZZ1, ZZ6, ZZ7, ZZ31, ZZ42, ZZ60, ZZ65, ZZ948) of hybrid rootstocks of Ziyang Xiangcheng (*Citrus junos* Sieb. ex Tanaka) × Trifoliolate Orange (*Poncirus trifoliata* Raf.) in an alkaline orchard with pH 8.22 were tested in this study in order to accumulate data for the selection of new excellent rootstocks with the advantages of Ziyang Xiangcheng and Trifoliolate Orange. Alkali stress has become an important factor restricting the development of fruit industry, leading to iron deficiency and chlorosis of fruits and the decline of fruit quality and yield in citrus fruit trees. Thus, it is necessary to breed new rootstocks.【Methods】We transplanted the biennial nucellar seedlings of these 8 rootstocks to the orchard with alkaline soil in 2016. At the same time, the seedlings of Ziyang Xiangcheng and Trifoliolate Orange with same age were planted to-

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gether in the test orchard as control varieties. We measured the plant height and stem thickness, investigated the yellowing index of the seedling lines, analyzed the difference of leaf photosynthetic pigment and nutrient element contents of the seedling lines and plants of the control in 2018. The weight of core index was calculated by Analytic Hierarchy Process (AHP), and the comprehensive score was calculated by Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). Then the tolerance of the seedling lines to alkali were evaluated using AHP-TOPSIS. 【Results】The seedling lines showed different growth vigor, ranging from 68.52 cm to 228.23 cm. Among them, ZZ6 was the shortest, about 1/2 of the height of Trifoliate Orange; ZZ65 was the tallest, about 1.6 times of the height of Ziyang Xiangcheng. The seedling lines could be divided into three types according to the height, dwarfing type: ZZ6, ZZ7, ZZ948; moderate type: ZZ1, ZZ42, ZZ60; tall type: ZZ31, ZZ65. The stem thickness was related to the plant height. The stem thickness of ZZ31 and ZZ65 was significantly bigger than those of the other seedling lines. According to the statistical results of the yellowing index of the seedling lines, ZZ6 was the lowest; ZZ7, ZZ31 and ZZ948 were low; ZZ1 was medium; ZZ42 and ZZ60 were high; ZZ65 was the highest and its chlorination degree was next to that of Trifoliate Orange. There were significant differences in photosynthetic pigment contents among the seedling lines, ZZ6, ZZ31 and ZZ948 were significantly higher than those of the other seedling lines. The contents of chlorophyll a, chlorophyll b and chlorophyll a+b of ZZ6 were the highest, next to Ziyang orange. ZZ42, ZZ60 and ZZ65 with higher yellowing index had lower contents of chlorophyll a, chlorophyll b and chlorophyll a+b in leaves. The contents of chlorophyll a, chlorophyll b and chlorophyll a+b in leaves decreased with the increase of the yellowing index of the seedling lines. The element determination results showed that the ferrous Fe content of the seedling lines in leaves from high to low was Ziyang Xiangcheng, ZZ6, ZZ31, ZZ948, ZZ7, ZZ1, ZZ60, ZZ42, ZZ65, Trifoliate Orange. We could conclude that the ferrous Fe content in the leaves was negatively correlated with the yellowing index of rootstock, the P content in the leaves was positively correlated with the yellowing index of the seedling lines, while the total Fe and other elements in the leaves had no significant correlation with the yellowing index of the seedling lines. In other words, the leaf chlorosis of the seedling lines was closely correlated with the low ferrous Fe and the high P content in the leaves. We used AHP to calculate the weight of chlorophyll a+b, yellowing index, ferrous Fe and P content in leaves (0.562 2, 0.096 1, 0.288 9, 0.052 8 respectively). Afterwards, we performed a comprehensive evaluation of the alkali resistance of the seedling lines using the AHP-TOPSIS method. The order of the resistance was Ziyang Xiangcheng > ZZ6 > ZZ31 > ZZ948 > ZZ7 > ZZ1 > ZZ60 > ZZ42 > ZZ65 > Trifoliate Orange. The alkali resistance of ZZ6, ZZ31 and ZZ948 could be considered as strong ZZ7 and ZZ1 moderate ZZ60 and ZZ42 weak and ZZ65 very weak. The alkali resistance of the seedling lines was distributed in range of the Ziyang Xiangcheng and the Trifoliate Orange. Three seedling lines with strong alkali resistance were selected for further evaluation. 【Conclusion】In this study, three rootstocks (ZZ6, ZZ31 and ZZ948) with strong alkaline tolerance were screened out, among which ZZ6 was a dwarf alkali tolerant rootstock.

Key words: Ziyang Xiangcheng and Trifoliate Orange; Hybrid rootstock; Rootstock evaluation; Alkali resistance; Leaf chlorosis; Iron deficiency

砧木是决定果树优质丰产的重要因素,不仅影响接穗品种的生长发育和果实品质,对接穗品种的抗病性、抗逆性等方面也有较大的影响^[1-3]。在世界柑橘主产国中,美国多以施文格枳柚(*C.paradisi* Macf. × *Poncirus trifoliate* Raf.)、卡里佐枳橙(*C. sinensis* Osb. × *P. trifoliate* Raf.)、印度酸橘(*C. reshni* Hort. ex Tanaka)等为主要砧木^[4];日本多使用枳

(*Poncirus trifoliate* Raf.)砧木^[7];我国主要使用的砧木有枳、资阳香橙、红橘(*C. tangerine* Hort. ex Tanaka)等。

土壤碱化是制约果树产业发展的重要因素^[8-9]。在我国四川、重庆等柑橘主产区,部分柑橘园为碱性石灰质土壤,碳酸盐含量高,易导致柑橘出现缺铁黄化,进而导致柑橘果实品质及产量的下

降^[10]。碱胁迫下,土壤有效养分溶解度下降,无机离子的运输和积累遭到破坏,造成离子失衡,特别是根际高pH环境和高渗透压,影响植物细胞、组织和器官对养分的吸收,从而抑制植物的正常生长^[11-12]。柑橘生产上常用化学改良方法(如使用生理性酸性肥)和生物改良方法(如选择耐碱性砧木)应对土壤碱化^[13],在碱性土壤上使用耐碱砧木效果最为显著且能节约经济成本,从而实现果园减施化肥的生产目标。因此,柑橘耐碱砧木的选育显得尤为重要。

枳为世界柑橘砧木品种改良的首选资源,优点甚多,以其为砧木的柑橘嫁接树,具有耐强酸性土壤、早结丰产、果实糖度高、抗柑橘衰退病(CTV)、抗根结线虫等优良特性^[14-15]。国际上报道的几个砧木均以枳为父本杂交,从而得到具有枳的某些优点的砧木^[16]。施文格枳柚和卡里佐枳橙是美国早期选育的杂种砧木,皆是以枳为父本杂交获得,抗CTV且高产^[6]。美国农业部2001年选育了砧木US-812,系以枳为父本和酸橘杂交获得,抗CTV且对柑橘黄龙病有一定抗性^[17-18]。但枳也具有易感柑橘裂皮病与碎叶病、不耐碱等缺点,枳对碱性土壤非常敏感,极易出现缺铁黄化,致使树势衰弱乃至死亡。目前国内外选育的耐碱砧木品种较少。国外使用较为广泛的卡里佐枳橙仅耐弱碱性土壤而不适宜高碱性土壤^[2]。我国近年来使用的耐碱砧木为资阳香橙,耐碱性极强,以其为砧木的柑橘嫁接树,具有根系发达、树势强健、丰产、耐寒等优良特性,在我国柑橘碱性土产区大面积推广,解决了紫色土地区多种柑橘砧木出现缺铁黄化的难题,但资阳香橙也具有不耐强酸性土、不耐黏重土壤、不抗根结线虫等缺点^[19-21]。

为了选育具有枳优点的耐碱柑橘砧木,曹立等^[22]曾以枳为父本、资阳香橙为母本杂交得到资枳杂种砧木材料F₁代群体,并初步筛选到多个耐碱的杂种单株。笔者选取了8个形态学偏枳遗传的多种子又多胚的株系,评价和分析各单株珠心苗群体的生长情况和田间耐碱性,以期进一步确定这些材料作为砧木应用的潜在可行性,并为开发优质多抗砧木品种积累数据和材料。

1 材料和方法

1.1 试验材料及地点

2008—2009年,课题组以资阳香橙为母本、枳为父本进行杂交授粉,获得杂种苗近200株^[22]。

2016年从资枳杂交F₁代已开花结果的株系筛选出几个丰产、每果种子数大于10粒、且多胚的株系,播种培育成实生苗幼苗,3个月后移栽到标准营养土的容器中育苗,第一年培育成一年生实生苗,2017年分别选取20株实生苗定植于重庆市中国农业科学院柑桔研究所果园。该果园为碱性紫色土,土壤碱化严重,2000年建园以来卡里佐枳橙砧木在该园地连年出现缺铁黄化症状,pH 8.22,有机质(w,后同)15.46 g·kg⁻¹,碱解氮106.67 mg·kg⁻¹,有效磷37.99 mg·kg⁻¹,速效钾261.52 mg·kg⁻¹,交换钙6 681.82 mg·kg⁻¹,交换镁155.54 mg·kg⁻¹,有效铁5.21 mg·kg⁻¹,有效锰8.36 mg·kg⁻¹,有效锌2.43 mg·kg⁻¹,有效铜0.55 mg·kg⁻¹,有效硼0.41 mg·kg⁻¹。笔者于2018—2019年选取8个两年生杂种(ZZ1、ZZ6、ZZ7、ZZ31、ZZ42、ZZ60、ZZ65和ZZ948)作供试材料进行耐碱综合评价,以树龄相同且栽植于同一果园的资阳香橙和枳为对照。

1.2 树体生长量测定

每种砧木选取10株树,用卷尺测量树干近地面根颈至树冠顶端的高度以及离地5 cm处的树干直径,即株高和茎粗。

1.3 砧木黄化指数统计

参照彭良志等^[23]的叶片分级方法,将叶片黄化症状分为5级:1级(无任何黄化症状),2级(叶脉绿色,脉间部分叶肉为黄绿色或淡绿色),3级(叶脉及其附近叶肉为绿色,其余叶肉为黄绿色),4级(叶脉为绿色,其余部分为白色或黄白色),5级(全叶均为黄白色或白色,或者仅叶脉为淡绿色)。将叶片划分黄化等级后,再采用李青萍等^[24]计算受害指数的方法统计不同砧木的黄化指数,每个杂种砧木各10株,黄化指数=Σ(黄化级值×同级株数)/(最高级值×处理总株数)×100。

1.4 叶片光合色素含量测定

叶片叶绿素a、b含量测定参照凌丽俐等^[25]的方法,于9月下旬采集叶样,采集当年生秋梢倒数第三片叶,每株10枚,3株混为1个样,设3次重复,用96%(φ)乙醇浸提-紫外可见分光光度计法测定光合色素含量。

1.5 叶片元素含量测定和分级标准

于秋季落叶前养分回流期(9月28日),按东南西北四个方位采集当年生春梢老熟叶片,每株30枚,10株树混为一个样。叶片经清洗、105 °C杀酶

30 min、75 ℃烘干至恒重、粉碎后装入自封袋保存备用。叶片营养元素按照中华人民共和国林业行业标准^[26]的方法测定,N含量用浓硫酸消解-凯氏定氮仪法测定;P含量用混合酸($m_{\text{硝酸}}:m_{\text{高氯酸}}=5:1$)消解-钼锑抗比色法测定;K、Ca、Mg、Fe、Mn、Zn、Cu含量用混合酸($m_{\text{硝酸}}:m_{\text{高氯酸}}=5:1$)消解-原子吸收火焰分光光度法测定;B含量用干灰化-甲亚胺比色法测定。叶片营养元素分级参照庄伊美^[27]的分级标准,共分缺乏、低量、适量、高量和过量5个级别。参照高丽等^[28]的方法测定叶片活性铁含量,采集当年生秋梢中部新鲜叶片,每株15枚,每3株混合为一个样,设3次重复。将叶片洗净后剪碎,用1 mol·L⁻¹盐酸浸提-原子吸收火焰分光光度法测定。

1.6 砧木耐碱性综合评价

参照龚剑等^[29]的方法应用AHP-TOPSIS法建立砧木耐碱综合评价模型,采用层次分析法(AHP)确定核心指标的权重,根据指标权重利用理想解法(TOPSIS)计算综合评分。

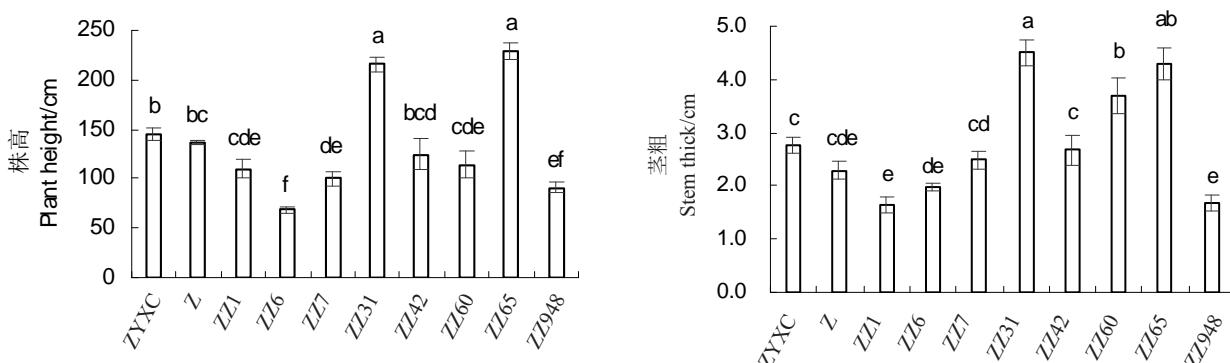
1.7 数据处理与分析

数据用SPSS 22.0软件进行处理与分析,制表用Excel 2016,作图用GraphPad Prism 8.0软件。

2 结果与分析

2.1 砧木树体生长状况

如图1所示,杂种砧木生长势各异,株高在68.52~228.23 cm范围均有分布,株高平均值在枳和资阳香橙以下的砧木分别为ZZ1、ZZ6、ZZ7、ZZ42、ZZ60、ZZ948,其中以ZZ6最矮(68.52 cm),其株高约为枳的1/2;ZZ31和ZZ65株高显著大于其余砧木,ZZ65为最高(228.23 cm),约为资阳香橙株高的1.6倍。结合砧木株高情况,可将杂种砧木分为3种株高类型的砧木——矮化型:ZZ6、ZZ7、ZZ948;中庸型:ZZ1、ZZ42、ZZ60;乔化型:ZZ31、ZZ65。图2展示了3种株高类型的代表株系在碱土上的生长状况。砧木茎粗与株高相呼应,砧木茎粗范围为1.64~4.50 cm,ZZ31和ZZ65茎粗显著高于其余砧木;株



ZYXC为资阳香橙;Z为枳;ZZ1为杂种砧木1号,其余杂种砧木同理。不同小写字母表示在 $p < 0.05$ 差异显著。下同。

ZYXC is the abbreviation of Ziyang Xiangcheng; Z is the abbreviation of trifoliate orange; ZZ1 is the hybrid rootstock No. 1, the rest of the hybrid rootstocks are the same. Different small letters mean significant difference at $p < 0.05$. The same below.

图1 不同砧木的株高和茎粗差异

Fig. 1 The growth indexes of different rootstocks

高较低的ZZ6、ZZ948、ZZ1茎粗也较小。

2.2 砧木叶片光合色素含量及黄化指数

从图2、图3中也可以看出,ZZ6黄化指数最低(0),ZZ6与资阳香橙表型一致均未出现任何程度的黄化;ZZ7、ZZ31和ZZ948黄化指数较低,均在10以下;ZZ1黄化程度中等;ZZ42和ZZ60黄化程度较高;ZZ65黄化指数显著高于其余杂种砧木,黄化程度仅次于枳。

各砧木叶片间叶绿素含量存在显著差异,ZZ6、ZZ31和ZZ948显著高于其余杂种砧木,其中ZZ6的叶绿素a、叶绿素b以及叶绿素a+b含量均为最高,仅次于资阳香橙;黄化程度较高的ZZ42、ZZ60和ZZ65的叶绿素a、叶绿素b以及叶绿素a+b含量较低。总体上,随着黄化指数的升高,砧木叶绿素a、叶绿素b以及叶绿素a+b含量均呈现逐渐降低的趋势。



图 2 代表株系(ZZ6, ZZ60, ZZ31)及亲本资阳香橙和枳的 2 年生实生苗在碱性土壤上的生长表现

Fig. 2 Growth performance of biennial seedlings of represent rootstocks (ZZ6, ZZ60, ZZ31) and their parents Ziyang Xiangcheng and trifoliate orange in alkaline soil

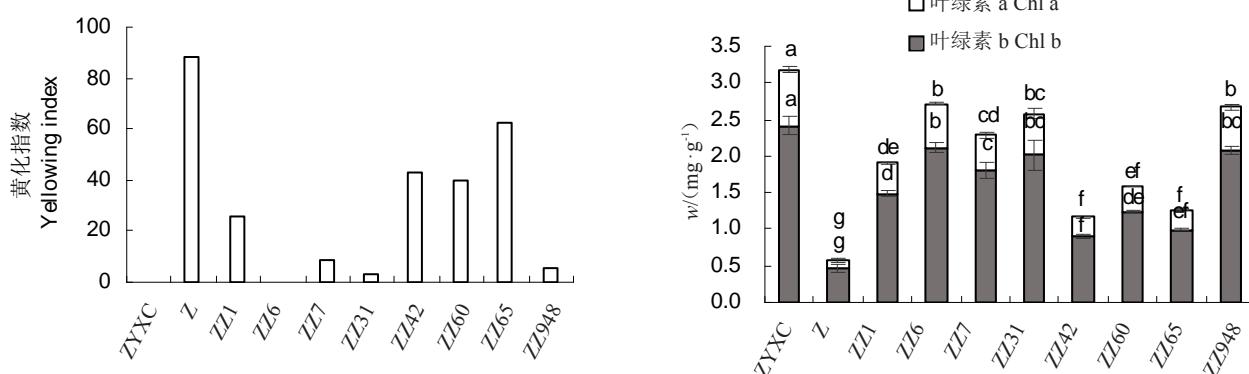


图 3 不同砧木黄化指数及光合色素含量的差异

Fig. 3 Differences in yellowing index and photosynthetic pigment content of different rootstocks

2.3 砧木叶片元素含量分布状况

由不同砧木叶片元素含量(表1)可知,ZZ7、ZZ42、ZZ60叶片N含量处于适量水平,对照资阳香橙叶片N含量处于高量水平,其余砧木均处于过量水平;P含量除ZZ948处于适量水平外均居于高量水平;K、Ca含量多处在适量或低量水平;ZZ948和对照枳叶片Mg含量处于缺乏水平,ZZ31和ZZ65处于低量水平,其余砧木均处于适量水平;全铁含量多处于高量或适量水平;Mn含量除ZZ6处于低量水平外均处于适量水平;Zn含量大多处于低量或缺乏水平,仅ZZ6处于适量水平;Cu、B含量基本上都处于适量水平;砧木叶片活性铁含量由高到低依次为资阳香橙、ZZ6、ZZ31、ZZ948、ZZ7、ZZ1、ZZ60、ZZ42、ZZ65、枳。通过分析砧木叶片元素与黄化指数间的相关性可知,P含

量与黄化指数呈极显著正相关($r = 0.825, p < 0.01$),活性铁与黄化指数呈显著负相关($r = -0.861, p < 0.05$),其余叶片元素与黄化指数均未达到显著相关水平。

2.4 砧木耐碱性综合评价

通过层次分析法计算得到4个耐碱指标叶绿素a+b、黄化指数、活性铁、P的权重分别是0.562 2、0.096 1、0.288 9、0.052 8(表2)。根据各指标的权重计算各砧木品种的综合得分(表3),得到砧木的耐碱性排名为资阳香橙>ZZ6>ZZ31>ZZ948>ZZ7>ZZ1>ZZ60>ZZ42>ZZ65>枳,所有杂交砧木的耐碱性评分介于高值亲本资阳香橙和低值亲本枳之间,ZZ6、ZZ31和ZZ948的耐碱性强,ZZ7和ZZ1耐碱性中等,ZZ60和ZZ42的耐碱性较弱,ZZ65的耐碱性极弱。

表1 不同砧木叶片元素含量

Table 1 Leaf element content of different rootstocks

砧木品种 Rootstock (g·kg ⁻¹)	w(N)/ (g·kg ⁻¹)	w(P)/ (g·kg ⁻¹)	w(K)/ (g·kg ⁻¹)	w(Ca)/ (g·kg ⁻¹)	w(Mg)/ (g·kg ⁻¹)	w(Fe)/ (mg·kg ⁻¹)	w(Mn)/ (mg·kg ⁻¹)	w(Zn)/ (mg·kg ⁻¹)	w(Cu)/ (mg·kg ⁻¹)	w(B)/ (mg·kg ⁻¹)	w(Ferrous Fe)/ (mg·kg ⁻¹)
ZYXC	30.05±0.16 d(H)	1.67±0.14 d(H)	9.42±0.16 d(L)	36.17±0.92 a(A)	2.72±0.06 e(A)	123.32±4.31 cd(H)	40.56±0.48 c(H)	18.42±0.75 cd(L)	6.87±0.31 bc(A)	82.48±0.03a(A)	41.21±3.38a
Z	36.56±2.40 a(E)	2.52±0.17 a(H)	11.72±0.24 c(L)	32.55±0.14 d(A)	1.08±0.01 i(D)	105.85±12.24 e(A)	26.84±0.62 f(H)	17.78±0.14 de(D)	7.04±0.25 b(A)	44.88±0.91 f(A)	12.89±1.82e
ZZ1	35.73±0.06 ab(E)	1.72±0.06 cd(H)	11.69±0.09 c(L)	33.89±1.16 bcd(A)	4.65±0.03 c(A)	183.48±4.55 a(H)	38.76±0.55 d(H)	17.16±1.04 de(D)	5.28±0.29 de(A)	75.45±3.24b(A)	23.91±1.60cd
ZZ6	33.35±0.57 c(E)	1.83±0.11 bc(H)	14.53±0.34 ab(A)	27.42±0.32 f(L)	3.72±0.04 b(A)	110.81±0.71 de(A)	20.54±0.52 h(L)	28.12±0.44 a(A)	4.61±0.22 fg(L)	43.74±2.09f(A)	31.87±0.89b
ZZ7	29.82±0.24 d(A)	1.61±0.03 d(H)	9.98±0.45 d(L)	34.93±0.18 ab(A)	2.54±0.02 e(A)	118.48±2.06 cde(A)	35.83±0.75 e(H)	18.55±0.11 cd(L)	5.03±0.59 ef(A)	66.68±0.57d(A)	25.50±2.73c
ZZ31	35.53±0.10 ab(E)	1.64±0.03 d(H)	14.24±0.86 b(A)	33.38±1.19 cd(A)	2.08±0.07 g(L)	187.84±4.51 a(H)	53.46±0.92 a(H)	16.60±0.70 e(D)	15.45±0.10 a(A)	69.67±2.83cd(A)	31.07±2.75b
ZZ42	29.77±0.03 d(A)	1.72±0.06 cd(H)	14.54±0.01 ab(A)	26.97±0.85 f(L)	3.81±0.03 a(A)	155.10±7.57 b(H)	24.80±0.70 e(H)	18.60±1.40 cd(L)	5.67±0.36 d(A)	71.05±3.67c(A)	20.53±2.36d
ZZ60	29.35±0.24 d(A)	1.90±0.08 b(H)	14.91±0.02 ab(A)	26.21±0.91 f(L)	3.35±0.04 d(A)	78.99±2.60 f(A)	41.81±1.22 b(H)	21.25±0.28 b(L)	6.49±0.20 c(A)	58.67±1.60e(A)	20.75±2.65d
ZZ65	33.75±0.92 c(E)	1.98±0.03 b(H)	11.56±0.42 c(L)	34.03±0.96 bc(A)	2.33±0.04 f(L)	126.23±0.32 c(H)	34.81±0.47 e(H)	20.11±0.96 bc(L)	6.64±0.16 bc(A)	66.95±1.98d(A)	13.05±0.50e
ZZ948	34.28±0.17 bc(E)	1.45±0.05 e(A)	15.20±0.62 a(A)	29.77±0.12 e(L)	1.46±0.01 h(D)	122.90±3.15 cd(H)	25.11±0.50 g(H)	18.80±1.84 cd(L)	4.24±0.19 g(L)	33.19±2.35g(A)	25.93±1.66c

注:D. 缺乏;L. 低量;A. 适量;H. 高量;E. 过量。表中数据均为平均值±标准差,不同小写字母表示 $p < 0.05$ 差异显著水平。

Note: D. Deficient; L. Low; A. Appropriate; H. High; E. Excess. The data in the table are Mean ± SD, different small letters mean significant difference at $p < 0.05$.

表2 耐碱指标的权重

Table 2 Weight of alkali resistance index

指标 Index	权重 Weight
叶绿素 a+b Chl a+b	0.562 2
黄化指数 Yellowing index	0.096 1
活性铁 Ferrous Fe	0.288 9
P	0.052 8

表3 砧木各品种耐碱综合得分

Table 3 Composite score of alkali resistance of the rootstock

砧木品种 Rootstock	综合得分 Composite scores	排名 Ranking
资阳香橙 Ziyang Xiangcheng	0.982 2	1
枳 Trifoliate orange	0.000 0	10
ZZ1	0.524 8	6
ZZ6	0.785 1	2
ZZ7	0.639 8	5
ZZ31	0.757 7	3
ZZ42	0.329 7	8
ZZ60	0.402 0	7
ZZ65	0.255 1	9
ZZ948	0.715 6	4

3 讨论

在高pH胁迫下,土壤中铁的溶解性降低,易形成不被植物吸收的三价铁,有效铁含量不足,进而造成植物叶片出现缺铁黄化^[30]。果树叶片缺铁黄化表现为新叶脉间失绿,严重时,除靠近叶柄处的部分呈绿色外,其他部分均呈淡黄色或白色,甚至枯死^[31]。为了评价果树缺铁黄化症状,在实验室可控条件下常用叶片的全铁含量作为诊断的指标之一。但是在田间生产上常遇到黄化叶片中全铁含量很高,有的甚至高于正常绿叶,从而出现叶片中铁含量与叶片黄化相关性极低的现象,称之为“iron chlorosis paradox(铁黄化悖论)”^[32-35]。Fu等^[36]和Incesu等^[37]研究表明,未表现黄化症状的柑橘砧木的全铁含量与表现黄化症状的无明显差异,但黄化叶片中活性铁含量低于正常绿叶中含量。本研究针对资阳香橙×枳的杂种砧木进行了田间耐碱评价试验,表现黄化的砧木叶片出现了类似缺铁的表型症状,砧木叶片活性铁与黄化指数呈显著负相关,而全铁与黄化指数没有相关性,说明叶片活性铁含量更适用于田间果树叶黄化症状诊断。此外,本试验砧木叶片P含量与黄化指数呈显著正相关,而其他元素对黄化无明显影响。武建林等^[38]在研究植物黄化与氮磷钾营

养关系时指出, P与Fe存在一种拮抗作用, 过量的P会降低Fe的有效性。磷酸铁盐的形成, 阻碍了铁在植物体内的转运, 从而加剧了生理性缺铁黄化。由此看来, 在碱性土壤上, 耐性较差的砧木出现黄化症状主要与活性铁不足和P含量偏高有关, 进而造成叶片光合色素降低, 导致叶片出现黄化。

从目前的柑橘市场来看, 与品类繁多的接穗品种相比, 商业化应用的砧木品种屈指可数^[39], 耐碱砧木更加稀缺^[40]。砧木实生苗的耐碱性是其作为砧木嫁接接穗后的耐碱性的重要依据, 与嫁接同一接穗品种后的鉴定评价相比, 可减少潜在的砧穗组合亲和性干扰。本试验旨在通过砧木实生苗鉴定, 为今后进一步嫁接主栽品种后的鉴定提供重要依据。通过田间耐碱性的综合评价, 得到ZZ6、ZZ31和ZZ948三个耐碱性强的砧木, 其耐碱性综合评分远超过父本枳, 并且从表型来看, 这三个杂种砧木在pH高达8.22的土壤上叶片黄化症状轻微, 特别是ZZ6与资阳香橙具有一样的黄化指数(0), 未表现出任何程度的黄化, 是极具耐碱潜力的砧木品种。

矮化密植栽培是世界果树生产发展的方向^[41], 但柑橘矮化砧木品种匮乏, 耐碱矮化砧木也少有报道。生产上主要应用的矮化砧木为飞龙枳(*Poncirus trifoliata* Raf.)^[42], 具有矮化树型、抗柑橘衰退病、抗根结线虫、提高接穗果实产量及品质等优点, 但其在碱性土壤上易出现与枳相似的缺铁黄化^[43]。在本试验中, 杂交后代群体除在耐碱性出现较大的性状分离外, 其株高也出现了明显的性状分离, 有树势乔化的ZZ31和ZZ65, 也有树势矮化的ZZ6、ZZ7、ZZ948, 值得注意的是, ZZ6株高约为枳株高的1/2, 矮化性状突出, 同时也兼具较强的耐碱性, 是不可忽视的优良矮化耐碱砧木资源。为选育出生产实际需要的砧木品种, 笔者将继续对上述有应用潜力的株系的具体pH值适应范围、嫁接亲和性、嫁接后品种的果实品质、抗病性以及抗逆性等方面进行深入探究。

4 结 论

在pH 8.22的碱性土壤上, 资枳杂种F₁代8个株系的生长势和耐碱性均存在差异。株高分布为65.52~228.23 cm, 有树势矮化的ZZ6、ZZ7、ZZ948, 树势中庸的ZZ1、ZZ42、ZZ60, 树势乔化的ZZ31、ZZ65。根据其耐碱性综合评分, 筛选出耐碱性强的

3个砧木材料, 分别是ZZ6、ZZ31和ZZ948。其中值得注意的是ZZ6为矮化耐碱砧木资源。

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