

黄金百香果杂交子代果实性状遗传倾向分析

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摘要:【目的】探究黄金百香果杂交子代果实外观和主要品质性状的遗传规律,阐明杂交子代的遗传倾向,为选育百香果新品种提供理论依据。【方法】以大黄金百香果作为母本,小黄金百香果作为父本进行人工杂交。随机选取200个杂交子代和亲本的成熟果实为材料,测量分析果实外观和主要品质性状。【结果】除横径、纵径、果形指数、可食率、可溶性固形物含量这5个指标外,其他性状的变异系数均在15%以上,具有较高的遗传多样性。变异系数排序为固酸比(30.63%)>总酸含量(23.43%)>单果质量(22.63%)>果皮质量(21.45%)。相关性分析表明,可食率与果实纵径、单果质量呈极显著正相关,与果实横径呈显著正相关,与果皮质量呈显著负相关。聚类分析表明,杂交子代和母本之间有明显的遗传趋向。【结论】杂交子代和母本之间有明显的遗传趋向和杂种优势。杂交子代可溶性固形物含量和总酸含量受母本性状影响较大,可食率高的杂交子代果实呈椭圆形且果实较重。从杂交遗传群体中筛选出6-4-27和6-12-65两个性状优良的单株。

关键词:黄金百香果;杂交子代;遗传倾向

中图分类号:S667.9

文献标志码:A

文章编号:1009-9980(2022)09-1587-10

Analysis of genetic tendency of fruit characters in hybrid progenies of *Passiflora edulis* f. *flavicarpa* Deg.

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Abstract: 【Objective】 In order to provide theoretical basis for breeding new varieties of yellow passion fruit, the inheritance tendency of the fruit appearance and main quality traits of the hybrid progeny of yellow passion fruit was studied. The genetic tendency of the fruit shape index, edible rate and solidity-acid ratio of hybrid progenies was clarified based on the characteristics of universality and irregularity of separation of hybrid progenies. 【Methods】 In this study, the large yellow passion fruit tree was used as female parent (The fruit is large, oval, high acidic with, thin skin and high edible rate) and small yellow passion fruit tree was used as male parent (The fruit is small, round and high in soluble solid content). The seeds obtained by hybridization were sown, cultivated and managed in the field. The mature fruits of 200 hybrid progenies and parents were randomly selected as materials. The transverse and longitudinal diameter of fruits were measured with Vernier caliper, and the fruit shape index was calculated. The single fruit weight and rind weight of fruits were weighed with electronic balance, and the edible rate of fruit was calculated. The soluble solid content and total acid content of fruits were measured with sugar acid instrument (ATAGO PAL-BX / ACID1), and the solidity-acid ratio was calculated.

收稿日期:2022-01-29

接受日期:2022-03-31

基金项目:海南省科技项目资助(ZDYF2021XDNY119);三亚崖州湾科技城管理局2020年度科技计划项目(SKJC-2020-02-008)

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ed. 【Results】 The coefficients of variation of fruit traits in hybrid progenies were 5.04%-30.63%, and the coefficient of variation of solidity-acid ratio was the highest. The coefficient of variation of other traits was over 15% except for the transverse diameter, longitudinal diameter, fruit shape index, edible rate and soluble solids content, which had high genetic diversity. Their coefficients of variation of the solidity-acid ratio, total acids content, single fruit weight and rind weight were 30.63%, 23.43%, 22.63% and 21.45%, respectively. The longitudinal diameter of hybrid progenies tended to be the mid value of the parents, with an average of 7.38 cm. The transverse diameter and single fruit weight of the hybrid progenies showed superiority over the female parent. Among them, the fruit transverse diameter of 1.50% of the hybrid progenies was longer than that of the female parent, and the single fruit weight of 3.00% of the hybrid progenies was larger than that of the female parent. The fruit shape index, edible rate and total acid exhibited the tendency to exceed the female parent, and the proportion over female parent traits were 19.00%, 91.00% and 28.50% respectively. The soluble solid content showed the tendency to surpass the male parent. The standard deviation of the fruit weight and fruit shape index was small and concentrated, and their genetic trend was consistent, but the standard deviation of the solidity-acid ratio was large and the coefficient of variation was high, which led to the high degree of dispersion of genetic trend in hybrid progenies. Correlation analysis showed that the single fruit weight were highly, significantly and positively correlated with the fruit longitudinal diameter and transverse diameter; the rind weight were highly, significantly and positively correlated with the fruit longitudinal diameter, transverse diameter and single fruit weight; The edible rate highly, significantly and positively correlated with the fruit longitudinal diameter and single fruit weight, but it was significantly and negatively correlated with the rind weight. According to the cluster analysis of soluble solids content and total acids content, 202 samples could be divided into three categories (group similar to female parent, female parent group and male parent group) when the cluster distance was 10. The female parent group is the largest, includes 97 hybrid progenies and female parent, accounting for 48.50% of the total samples. The characteristics were biased towards the female parent, with low soluble solid content and high total acid content. 【Conclusion】 There were obvious genetic tendency and heterosis among hybrid progenies. The transverse diameter, fruit shape index, single fruit weight, edible rate, soluble solids content and total acids content of hybrid progenies showed the tendency to exceed those of the parent with high value. However, the fruit shape index, rind weight, soluble solids content and solidity-acid ratio of hybrid progenies showed the tendency to be inferior to those of the parent with low value. The soluble solids content and total acids content of the hybrid progenies were greatly affected by the characteristics of the female. The fruits of the hybrid progenies with high edible rate were oval and heavier. Two excellent individual plants of No. 6-4-27 and No. 6-12-65 were selected from the hybrid population.

Key words: Yellow passion fruit; Hybrid progenies; Genetic tendency

黄金百香果又名黄果西番莲(*Passiflora edulis* f. *flavicarpa* Deg.), 属西番莲科西番莲属多年生藤本植物, 生长于海拔180~1900 m, 通常生长温度不低于0℃。据测定, 百香果果实内含有100多种芳香物质^[1], 可散发出荔枝、香蕉、芭乐等多种水果的浓郁香味, 因而得名百香果^[2], 是一种极具加工开发潜力的热带亚热带的优质水果。百香果不仅因独特的风味和香气引人注目, 还富含17种氨基酸, 尤其

是维生素C和维生素E含量较多^[3]。百香果原产于澳大利亚和南美洲的巴西, 广泛种植于热带和亚热带地区, 中国的福建、台湾、广东、海南、广西、贵州、云南等地均有种植^[4]。

近些年来, 随着百香果产业规模的迅速扩大, 主栽品种的遗传背景狭窄, 类型单一, 出现品种退化、抗性减弱的现象。因此, 期望通过杂交育种选育抗性强、香味浓郁、固酸比高等优良性状的新品系。杂

交育种是一种传统的育种方法,在新品种选育方面运用比较广泛,如:水稻杂交培育了川农26III-422、川农26II-397等优秀品种^[5],蝴蝶兰花卉培育出了红霞蝴蝶兰、红珍珠蝴蝶兰等各类新优品种^[6],苹果杂交培育出了浓果4号、浓果25号等优秀品种^[7]。目前中国百香果育种方法主要以杂交育种为主,早在1819年,Thomas Milne已开展百香果杂交工作,1972年Knight通过百香果杂交育种获得了一个发芽率高和坐果率高的杂交种^[8]。1974年Ruberte-Torres等^[9]通过对7个百香果品种的42个组合进行异花授粉,育成6个新杂交种。大多数杂交种生命力旺盛,但开花倾向不同。虽然在叶、花和果实的形态特征上介于亲本之间,但其果实香气和味道优于亲本。由此可见,百香果杂交育种是培育优良百香果新品种的主要途径,能够获得性状优于亲本的新品种。

西番莲属的基因组杂合度高,其中栽培种(台农)基因组杂合度为3.32%,属于高杂合度物种^[10],杂交子代的种子数量多容易产生分离。黄金百香果是我国市场上主要用于鲜食的品种之一,其果型、甜度、可食率等指标是最受市场欢迎的主要因素。笔者在本研究中采用大黄金百香果作为母本,以自主从本地选育的小黄金百香果作为父本进行人工杂交。其中母本具有果大、椭圆形、酸度高、果皮薄、可食率高等特点;父本具有果小、圆形、可溶性固形物含量高特点。利用杂交子代分离的广泛性和不规则性,对杂交子代遗传群体的果形指数、固酸比、可食率等果实外观和内在品质性状进行比较分析,为筛选出果实大、甜度高、可食率高的新品系奠定基础,也为进一步开展百香果杂交种的遗传改良研究积累基础资料 and 提供理论依据,从而为我国百香果产业的健康和可持续发展奠定优良品种基础。

1 材料和方法

1.1 试验材料

以大黄金百香果(B5-6)为母本,该母本引自巴西农业研究公司Brazilian Agricultural Research Corporation;父本小黄金百香果(D7-39)源自海南省琼海市东红农场本地种植品种,由中国热带农业科学院海口实验站通过对该本地品种进行实生苗选育获得的优良单株。

大黄金百香果(B5-6)与小黄金百香果(D7-39)

组合于2018年人工杂交获得种子,于2019年栽植于中国热带农业科学院海口实验站红洋队百香果品种选育基地,行株距为2.0 m×1.5 m,常规管理。于2021年3月随机选取200个杂交子代和亲本的成熟果实进行采样,每一株系采集成熟果实5个,测定果实外观和主要品质性状,以及对子代遗传趋势进行分析。

1.2 试验方法

1.2.1 果形指数的测定 采用游标卡尺对果实横径、纵径进行测量,并计算果形指数:果形指数=纵径/横径。

1.2.2 可食率的测定 将成熟果实去除果柄后,用电子天平称量单果质量;将果实的果浆取出后,用50 mL离心管置于4℃冰箱保存备用,洗净果皮用电子天平称量果皮质量,并计算果实可食率:可食率(%)=[(单果质量-果皮质量)/单果质量]×100。

1.2.3 固酸比的测定 从备用果浆中吸取1 mL的果浆,用糖酸仪(ATAGO PAL-BX/ACID1)测量可溶性固形物含量;用蒸馏水将果浆原液稀释50倍后吸取1 mL样液用糖酸仪测量总酸含量,计算固酸比:固酸比=可溶性固形物含量/总酸含量。

1.3 数据统计分析

利用Excel 2016进行数据分析,并计算杂交子代果实表型性状及品质性状的平均值(F_i)和标准差、变异系数(CV)和杂交优势指数(HI)^[11]。HI(%)= $F_i/[(P_1+P_2)/2] \times 100$ (P_1 为父本, P_2 为母本),对杂交子代果实性状进行中亲优势、超亲优势、低亲优势评价;应用SPSS软件进行相关性分析、聚类分析及图表的制作。

2 结果与分析

2.1 杂交子代果形指数性状遗传变异分析

杂交子代成熟果实大小遗传变异如表1所示,父本的果实明显比母本的果实小且更圆(图1)。子代果实纵径介于5.75~8.59 cm之间,平均值为7.38 cm,最大值和最小值均介于亲本之间。横径介于5.40~7.75 cm之间,平均值为6.53 cm,其中大于母本(7.52 cm)占比1.50%。果形指数分布于0.90~1.26之间,平均值为1.13,其中小于父本(1.02)占比3.00%,大于母本(1.17)占比19.00%。果实子代横径、纵径及果形指数的变异系数均小于15%,说明子代群体的横径、纵径及果形指数变异程度和离散程度较低^[12]。

表 1 杂交子代及亲本的性状指标比较

Table 1 Comparison of fruit character index in hybrid progenies and parents

杂交参数 Crossbreeding parameters	性状指标 Character index			单果质量 Single fruit weight/g	果皮质量 Rind weight/g	可食率 Edible rate/%	w(可溶性固形物) Soluble solids content/%	w(总酸) Total acids content/%	固酸比 Solidity- acid ratio
	纵径 Longitudinal diameter/cm	横径 Transverse diameter/cm	果形指数 Fruit shape index						
父本 P1(D7-39) Male parent P1(D7-39)	5.43	5.34	1.02	51.45	35.44	31.12	17.90	1.03	17.38
母本 P2(B5-6) Female parent P2(B5-6)	8.82	7.52	1.17	153.24	80.45	47.50	12.43	2.58	4.83
子代 6-4-27 Progeny 6-4-27	6.68	5.66	1.18	172.21	67.09	61.04	19.33	2.31	8.37
子代 6-12-65 Progeny 6-12-65	7.84	6.65	1.18	100.44	32.42	67.72	15.90	1.40	11.38
杂交子代均值 Mean value of hybrid progenies, Fi	7.38	6.53	1.13	109.15	46.95	56.44	16.59	2.27	7.82
最大值 Max	8.59	7.75	1.26	176.56	74.97	68.75	19.67	3.66	14.87
最小值 Min	5.75	5.40	0.90	61.22	28.13	40.69	10.60	1.17	3.31
标准差 SD	0.48	0.39	0.06	24.64	10.04	0.06	1.52	0.53	2.39
变异系数 CV/%	6.52	5.99	5.04	22.63	21.45	10.49	9.21	23.43	30.63
杂交优势指数 HI	1.04	1.02	1.03	1.07	0.81	1.44	1.09	1.26	0.70
子代大于高亲值比例 Over-parent heterosis/%	0.00	1.50	19.00	3.00	0.00	91.00	15.50	28.50	0.00
子代介于双亲值比例 Mid-parent heterosis/%	100.00	98.50	78.00	97.00	89.00	9.00	83.00	71.50	95.50
子代小于低亲值比例 Low-parent heterosis/%	0.00	0.00	3.00	0.00	11.00	0.00	1.50	0.00	4.50



母本 B5-6 Female parent B5-6

父本 D7-39 Male parent D7-39

杂交子代 Hybrid progenies

图 1 母本、父本及子代果实照片

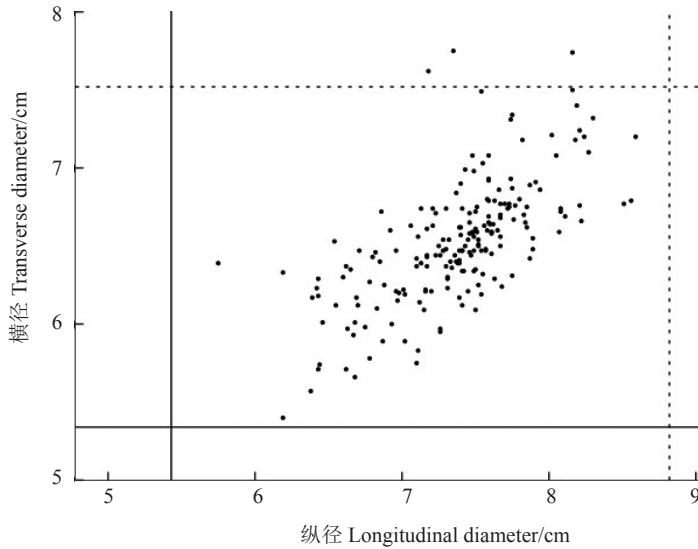
Fig. 1 Photos of female parent, male parent and hybrid progenies

从子代果实大小遗传趋势(图2)可以看出,子代横径、纵径及果形指数的标准差较小,分布集中,其子代果实纵径介于双亲值之间。杂交群体中6-4-27和6-12-65的果形指数均为1.18,果实为椭圆形。

2.2 杂交子代果实质量性状遗传变异分析

杂交子代成熟果实可食率遗传变异如表1所示,父本单果质量平均为51.45 g,母本单果质量平均为153.24 g,由此可见母本果实明显比父本大。

子代果实单果质量介于61.22~176.56 g之间,平均值为109.15 g,其中超过母本(153.24 g)占比3.00%。果皮质量介于28.13~74.97 g之间,平均值为46.95 g,其中低于父本(35.44 g)占比11.00%。可食率介于40.69%~68.75%之间,平均可食率为56.44%,其中高于母本(47.50)占比91.00%。子代果实单果质量、果皮质量的变异系数较高,分别为22.63%和21.45%,说明子代群体在单果质量和果皮质量方面存在一定



实线表示父本值,虚线蓝色表示母本值。下同。

Full line. Green represents the parent value; Dotted line. Blue represents the parent value. The same below.

图2 杂交子代及亲本的横纵径遗传趋势

Fig. 2 Genetic trend of fruit transverse and longitudinal diameter in hybrid progenies and parents

的变异程度和离散程度。

从子代果实质量性状遗传趋势(图3)可以看出,质量性状和果形指数性状具有一致性。子代6-4-27和6-12-65均表现出超亲优势,其中6-4-27单果质量为172.21 g,超过母本单果质量,可食率达61.04%;6-12-65的单果质量介于亲本之间,但果皮质量(32.42 g)低于父本,可食率达67.72%。

2.3 杂交子代果实固酸比性状遗传变异分析

杂交子代成熟果实固酸比性状遗传变异如表1所示,父本口感较甜,可溶性固形物含量为17.90%;母本口感偏酸,总酸含量为2.58%。子代果实可溶性固形物含量介于10.60%~19.67%之间,平均值为16.59%,其中有15.50%的子代可溶性固形物含量超过父本,仅有1.50%的子代低于母本。子代果实总

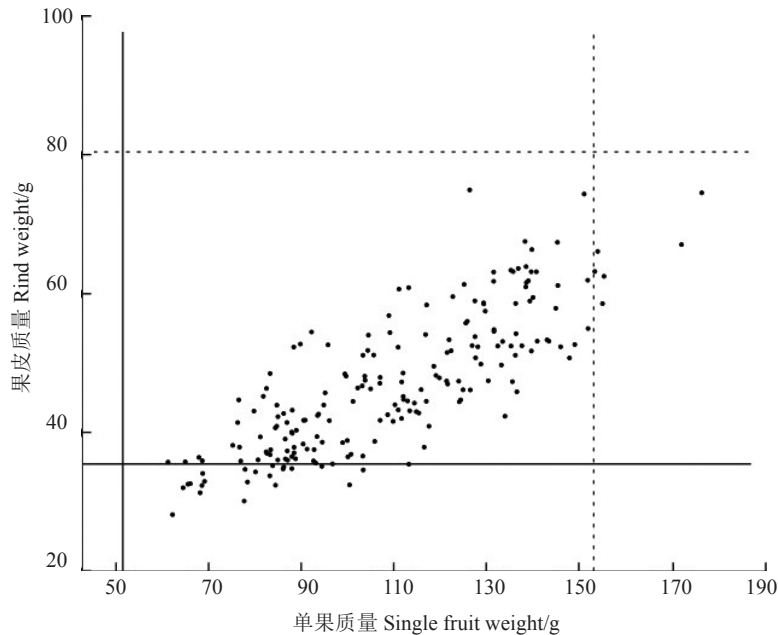


图3 杂交子代及亲本的果实质量性状遗传趋势

Fig. 3 Genetic trend of single fruit weight in hybrid progenies and parents

酸含量介于1.17%~3.66%之间,平均值为2.27%,其中有28.50%的子代总酸含量高于母本。综合杂交子代固酸比性状,介于3.31~14.87之间,平均值为7.82,其中有4.50%的比例低于母本(4.83)。

子代果实固酸比性状遗传趋势(图4)表明,标准差较大、变异系数较高,导致子代离散程度高。其子代6-4-27的可溶性固形物含量偏高(19.33%),超过亲本值;6-12-65表现出低酸高固酸比,口感酸甜

可口。

2.4 杂交子代果实果形指数、可食率、固酸比间相关性分析

由表2可知,总酸含量与可溶性固形物含量呈极显著负相关(-0.22);固酸比与可溶性固形物含量呈极显著正相关(0.47),与总酸含量呈极显著负相关(-0.92)。果实横径与纵径呈极显著正相关(0.67);果形指数与果实纵径呈极显著正相关

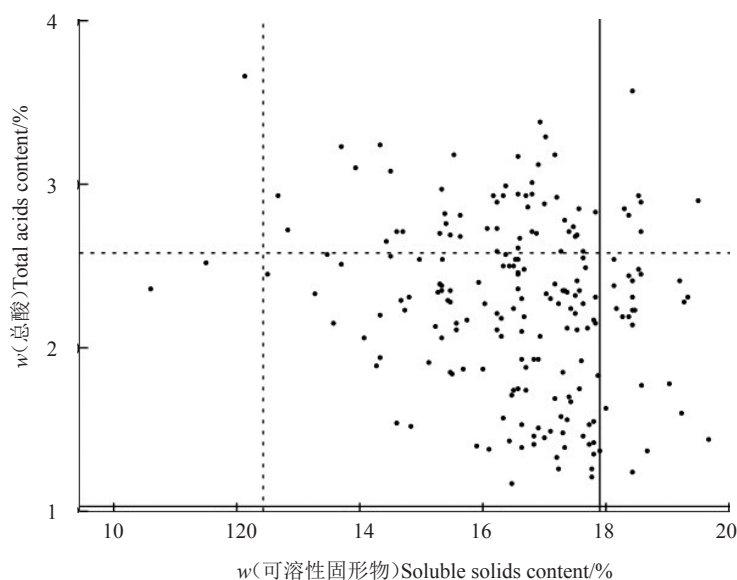


图4 杂交子代及亲本的果实固酸比性状遗传趋势

Fig. 4 Genetic trend of solidity-acid ratio in hybrid progenies and parents

(0.51),与果实横径呈极显著负相关(-0.30)。单果质量与果实纵径、横径呈极显著正相关;果皮质量与果实纵径、横径、单果质量呈极显著正相关;可食率与果实纵径、单果质量呈极显著正相关,与果实横径呈显著正相关,与果皮质量呈显著负相关,说明可食率越高的品种,果实纵径和单果质量越大。

2.5 杂交子代果实果形指数、可食率、固酸比的聚类分析

采用聚类分析法中Ward法和平方Euclidean距离基于杂交亲本及子代果实外观与品质指标分别进行聚类分析,分类结果如图5所示。根据分类的相似度及合理性^[13],在果形指数、可食率等外观性状方面,当聚类距离为13时,202个样本可分为3类。第I类聚集96个杂交子代,果实纵径、横径、单果质量、果形指数等性状介于父母本之间,但偏向于母本,为类母本类群;第II类聚集47个杂交子

代和母本,果实纵径、横径、单果质量、果皮质量等性状趋向于母本性状,为母本类群,具有果大的特征;第III类聚集57个杂交子代和父本,为父本类群,其特点更偏向于父本,具有果小且果实偏向圆形等特征。

在可溶性固形物、总酸含量等品质性状方面,当聚类距离为10时,202个样本可分为3类。第I类聚集97个杂交子代和母本,是3个类群中最大的,占总数的48.50%,为母本类群,可溶性固形物含量偏低,总酸含量偏高,其特点偏向于母本,具有果味酸的特征;第II类聚集34个杂交子代和父本,占总数的17.00%,为父本类群,可溶性固形物含量高,总酸含量低,其特点偏向于父本,具有果味甜的特征;第III类聚集69个杂交子代,虽然可溶性固形物含量较高,但没有超过父本,总酸含量高且更趋向于母本,为类母本类群,固酸比更偏向于母本。

表 2 果实主要品质性状相关性分析

Table 2 Correlation analysis of main quality characters of fruit

品质性状 Quality character	可溶性固形物含量 Soluble solids content	总酸含量 Total acids content	固酸比 Solidity-acid ratio	纵径 Longitudinal diameter	横径 Transverse diameter	果形指数 Fruit shape index	单果质量 Single fruit weight	果皮质量 Rind weight	可食率 Edible rate
可溶性固形物含量 Soluble solids content	1.00								
总酸含量 Total acids content	-0.22**	1.00							
固酸比 Solidity-acid ratio	0.47**	-0.92**	1.00						
纵径 Longitudinal diameter	-0.12	-0.08	0.03	1.00					
横径 Transverse diameter	-0.04	-1.13	0.12	0.67**	1.00				
果形指数 Fruit shape index	-0.10	1.05	-0.10	0.51**	-0.30**	1.00			
单果质量 Single fruit weight	-0.04	-0.02	0.03	0.63**	0.61**	0.10	1.00		
果皮质量 Rind weight	-0.08	0.03	-0.02	0.54**	0.57**	0.04	0.82**	1.00	
可食率 Edible rate	0.04	-0.08	0.08	0.23**	0.16*	0.10	0.42**	-0.16*	1.00

注: * $p < 0.05$ 显著相关, ** $p < 0.01$ 极显著相关。

Note: * $p < 0.05$ significant correlation, ** $p < 0.01$ extremely significant correlation.

3 讨 论

果形指数、可食率、固酸比等性状是百香果主要的经济指标,笔者在本研究中主要针对杂交子代和亲本的主要品质性状进行比较,子代果实性状表现出广泛的性状分离,整体上趋于两亲本之间,但子代群体中个别表现出高于高亲和低于低亲的变异趋势,存在一定数量的优异单株,具有选育优良百香果新品种(系)的潜力,这与对苹果^[14]、梨^[15]、柠檬^[16]等的研究结果相一致。

果实形状是影响果实外观品质的重要因素之一,可通过果形指数进行判断,受纵径和横径的影响,父本的果形指数 1.02,果实呈圆形,母本果形指数 1.17,果实呈椭圆形。杂交子代果形指数分布于 0.90~1.26,总体介于双亲之间,但出现 3.00% 的低亲比例,杂交子代出现性状衰退现象,超过母本性高亲比例为 19.00%,说明子代果实形状出现较大的超亲优势,表现为椭圆形,该结果与红阳猕猴桃杂交试验中子代在果形指数上表现出的遗传趋势相似^[17]。果实可食率是商品价值的重要因素之一,受单果质量与果皮质量的影响,杂交子代可食率介于 40.69%~68.75% 之间,杂交优势指数较大,有 91%

的子代出现超亲优势,因此选用大黄金百香果作为母本较易获得可食率高的杂交子代。

有机酸含量是果实品质的重要组成因素,其与糖的比例决定了果实的风味差异^[18]。百香果的口感主要受固酸比的影响,比值越大,果实越甜,比值越小,果实越酸。影响果实固酸比的主要因素是可溶性固形物含量和总酸含量(以柠檬酸计),父本果实偏甜,固酸比较高(17.38),母本果实偏酸,固酸比较低(4.83)。杂交子代固酸比介于 3.31~14.87 之间,平均值为 7.82,固酸比低于亲本均值(11.105)的杂交子代比例为 86.00%,其中有 4.50% 的比例低于母本,表现出口感偏酸,比较适合用于加工。该结果与猕猴桃、梨等果树的杂交子代所呈现出的结果相似,在固酸比方面,子代和母本之间有明显的遗传趋向和杂种优势^[17,19]。

果实发育是复杂的生理生化过程^[20],对杂交子代的不同果实指标进行相关性分析发现,固酸比与可溶性固形物含量呈极显著正相关,与总酸含量呈极显著负相关,说明在杂交子代中口感酸甜度即固酸比应由可溶性固形物含量和总酸含量共同决定。可食率与果实纵径、单果质量呈极显著正相关,与果实横径呈显著正相关,与果皮质量呈显著负相关,说

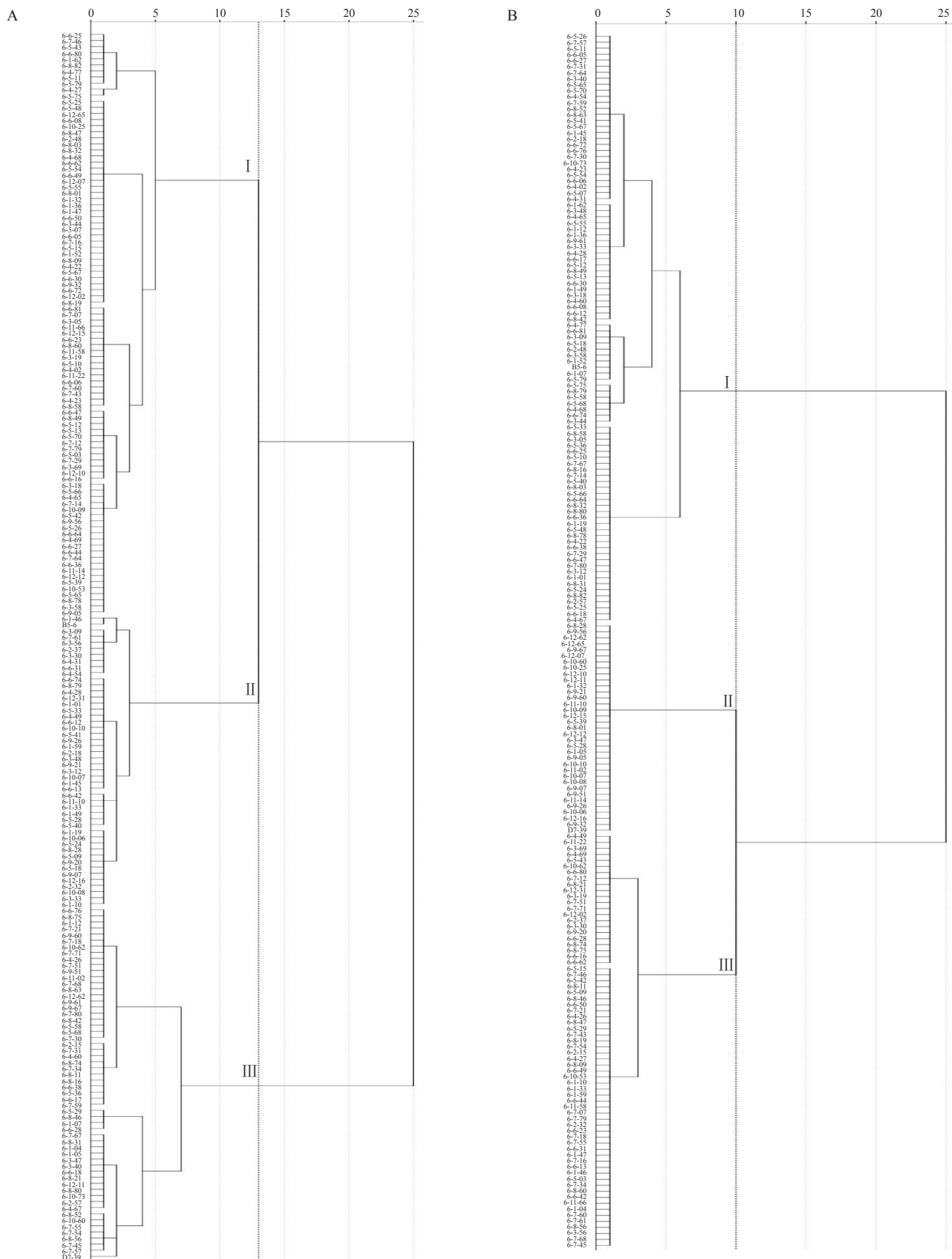


图 5 杂交子代及亲本的果实主要品质性状聚类分析

Fig. 5 Cluster analysis of main fruit quality characters of hybrid progenies and parents

明可食率越高的品种,果实纵径和单果质量越大,因此在杂交子代优良单株的筛选上,应将果形为椭圆形、果实大为选种目标,这一研究结果与前人研究相一致^[21]。

通过对杂交子代和亲本果形指数、可食率等外观性状进行聚类分析,杂交子代被划分为类母本类群、母本类群和父本类群。其中类母本类群的占比最高,占总数的48.00%,该类群果实纵径、横径、单果质量、果形指数等性状介于父母本之间,但偏向于母本,受母本性状影响较大,与遗传趋势相一致。对可溶性固形物、总酸含量等品质性状进行聚类分析时发现,杂交子代同样被划分为类母本类群、母本类群和父本类群。其中母本类群的占比最高,占总数的48.50%,该类群与母本所表现的相似,具有可溶性固形物含量低、总酸含量高、果味酸的特征。已有研究指出,果实内含物遗传具有母本优势,在苹果^[22-23]、梨^[24]、李^[25]等杂交试验中均有验证。黄金百香果杂交子代与前人研究相一致,果实内含物性状表现母本优势。当以提高百香果果实内含物含量为目标性状时,应选用内含物含量高的母本开展杂交育种。

4 结 论

可食率越高的杂交子代果实纵径和单果质量越高,且黄金百香果杂交子代的内含物指标出现母本优势,因此当以提高果实内含物含量为目标性状时应选用内含物含量高的母本开展杂交育种,在杂交子代优良单株的筛选时,应将果形为椭圆形、果实大作为选种目标。

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