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‘串枝红’与‘赛买提’杏正、反交后代果实性状遗传倾向分析

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摘　要：【目的】探究杏果实主要性状的遗传倾向以及其在正、反交后代中的遗传差异，为杏育种过程中的父母本选配以及后代性状表现的预测提供依据。**【方法】**对‘串枝红’与‘赛买提’正、反交组合的单果质量、果面盖色、果实形状、果肉硬度和可溶性固形物含量等性状进行了调查，每株杂交后代调查10个果实。**【结果】**正、反交后代果实大小（单果质量与果实纵、横、侧径）均有偏小的遗传倾向；果面盖色属于质量性状，有彩色相对于无色为显性；果实形状（果实外观形状、纵径/横径、侧径/横径）果实形状表现为趋圆的遗传倾向；正、反交后代果肉硬度与可溶性固形物含量均呈偏低遗传的倾向；果实风味表现为偏酸的遗传倾向。**【结论】**‘串枝红’与‘赛买提’正、反交后代单果质量、纵、横、侧径多为累加效应形成，且正、反交组合果实累加效应相似，均完全解体；两组合可溶性固形物虽然存在加性效应数量性状的解体，但在子代中由于新的累加效应形成，后代出现超高亲株系。

关键词：杏；正、反交后代；果实性状；遗传倾向

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Analysis of inherited tendency of fruit characteristics in F_1 group of reciprocal crossing between ‘Chuanzhihong’ and ‘Saimaiti’ in apricots

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Abstract:【Objective】The study was undertaken to explore the genetic tendency of main traits in F1 generation of apricot, so as to provide a basis for the prediction of parental selection and offspring traits in apricot breeding.【Methods】In this experiment, the cross combinations were set as ‘Saimaiti’ × ‘Chuanzhihong’ and ‘Chuanzhihong’ × ‘Saimaiti’. The ‘Saimaiti’ × ‘Chuanzhihong’ was the positive cross combination including 213 strains, while ‘Chuanzhihong’ × ‘Saimaiti’ was the negative cross combination including 110 strains. They were crossed in 2006 and planted in 2007, and fruit traits were investigated in 2018 and 2019. In order to examine the fruit shape, fruit surface color, single fruit weight, fruit hardness and soluble solid content of the reciprocal cross combination for ‘Saimaiti’ and ‘Chuanzhihong’, ten fruits were collected from each hybrid. The fruit weight was measured with an electronic balance and the vertical, horizontal and side diameters of the fruit were measured with a vernier caliper. The content of soluble solids was determined by a digital Brix spindke. Fruit hardness was

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measured with an Agrosta2019 fruit texture detector. The test was made after peeling, the penetration depth was 8.5mm, the penetration speed was 15mm/s, and the selected probe area was 1cm^2. The data of this experiment were collated by Excel 2019, statically analyzed by SPSS 19, plotted by Origin 2015 and calculated by genetic transmission force and coefficient of variation. 【Results】The frequency distribution of fruit weight tended to be normal distribution. The average single fruit weight of the progeny of the reciprocal cross combinations was lower than the low parent. The average fruit weight of positive combinations was lower than that of low parent, being 92.94% and 84.72%, respectively. The negative cross was 96.08% and 82.85%, respectively. The tendency toward small heredity was manifested. The variation coefficients of fruit weight in positive combinations were 30.38% and 35.48% but those in negative cross combinations were 25.34% and 24.14%. The degree of variation was significant. In each combination, there were no superhigh parent lines in longitudinal, transverse and side diameters in the progeny of the reciprocal cross combinations, and they were generally lower than the low affinity value. The coefficients of variation of all groups were consistently lower, and the genetic transmission was higher. The results showed that the heredity of longitudinal diameter, transverse diameter and lateral diameter of fruit was less affected by environmental factors. The fruit shapes of 'Chuanzhihong' and 'Saimaiti' were oval. Meanwhile, the oval, oblate, irregular, heart-shaped and round-shaped separation occurred in the reciprocal cross combinations. The oval strains of each combination accounted for the highest proportion, reaching about 90%. The tendency was toward oval heredity. The fruit color of 'Chuanzhihong' was red, and the fruit color of 'Saimaiti' was colorless. In the progeny of reciprocal cross combinations, the pink, orange-red, red color and colorless were found. In 2018, among the offsprings of orthogonal combination, the proportion of plants colorless on fruit surface was 24.46%, and the proportion of colorful blush color strains was 75.54%. In 2019, the proportion of colorless in the offsprings of orthogonal combinations was 41.87%, colorful blush color accounted for 58.13%. In 2018, the proportion of colorless was 37.25%. The proportion of colorful blush color strains was 62.75%. In 2019, the proportion of colorless was 33.33%, and the proportion of colorful blush color was 66.67%. The colorful blush color of the reciprocal cross offsprings occupied a large proportion. After the card square test, the result was in a ratio of 1∶3, which showed that the colorful blush color of apricot fruit was dominant, compared with colorless. The result also showed that, the contents of soluble solids in the progeny of 'Chuanzhihong' and 'Saimaiti' were continuously variable, and normally distributed. The soluble solids content of apricot fruit was a quantitative trait controlled by multiple genes. The mean value of soluble solids in the progenies of the reciprocal cross combinations was lower than the mean value of affinity. The proportions higher than the high parent in orthogonal cross combinations were 10.87% and 2.96%, and the proportions lower than low parent were 10.87% and 2.96%, respectively. The proportions higher than the high parent in negative cross combinations were 15.69% and 4.76%, and the proportions lower than low parent were 31.38% and 9.52%. The heritability of each combination was 91.09%, 96.99%, 94.91% and 96.72%, respectively. The variation coefficients of each combination were 15.73%, 14.25%, 12.31% and 11.51%, respectively. The mean fruit hardness of the 18-year and 19-year progenies of 'Chuanzhihong' and 'Saimaiti' were lower than the median of parents. Most of them were lower than low parent. The proportions of fruit hardness lower than low parent of positive cross combinations were 75% and 85.22%. In the negative cross, the proportions of fruit hardness lower than low parent were 67.65% and 75.24%. It showed an obvious tendency toward low inheritance. The variation coefficients of reciprocal cross combinations were 34.12%, 26.37%, 18.65% and 28.64%, respectively. In two years of investigation, the heritability of each combination was 61.37%, 66.63%, 68.84% and 71.62%, respectively. The fruit flavor of ‘Chuanzhihong’ was mainly sweet and sour, and the fruit flavor of ‘Saimaiti’ was mainly sweet. In two years, strains tasted sweet and sour had the largest number in all the combinations, surpassing 70%. Minute quantity strains tasting sweet and/or sour were found in all the combinations, so the fruit flavor showed a genetic tendency to sour taste.【Conclusion】Fruit weight, vertical diameter, lateral width and ventral width almost formed by additive effect in the reciprocal crossed population. The additive effect of orthogonal cross combination was similar to negative cross combination, and they were disintegrated completely. The additive effect of soluble solids content in all the reciprocal cross combinations was disintegrated, but new additive effect formed in the progeny, and there were new strains that were higher than the high parent in the progeny.

Key words: Apricot; Reciprocal crossed; Fruit characters; Inherited tendency

普通杏（*Prunus armeniaca* L.）原产于我国，为蔷薇科（Rosaceae）李属（*Puruns* L.）植物[1]，栽培历史悠久，主要生长在温带地区[2]。杏果实外形美观，果皮颜色丰富多样，口感细腻且富有层次[3]，是深得消费者喜爱的时令水果。杏成熟期处于鲜果类供应淡季，调节了夏季初期鲜果市场需求，丰富了淡季鲜果供应[4]。在果树栽培结构调整及经济林建设等方面，杏树同样发挥着重要的作用[5]。

常规杂交育种是果实品质改良的主要方式之一[6]。杏作为高度杂合的多年生果树，在杂交过程中会出现多样且复杂的变异[7]，掌握杏果实性状的遗传倾向，对选配适当的亲本并选育出期望的杂交后代果实性状起到至关重要的作用。目前，有部分文献报道杏果实主要性状遗传倾向的研究。赵习平等[8]对‘串枝红’及‘水白杏’杂交 F_1 代果实性状进行调查研究得出果实形状为以圆为主的多形性变异的倾向，单果质量与可溶性固形物含量呈降低的遗传倾向；武晓红等[9]对‘金太阳’与‘串枝红’正、反交组合后代果实性状遗传倾向进行研究调查得出杏果面盖无色相对于彩色为显性，果实单果质量呈变小的遗传倾向，可溶性固形物含量呈趋中遗传的倾向；姜凤超等[10]对‘串枝红’与‘骆驼黄’杂交 F_1 代果实糖酸性状的遗传倾向进行分析，认为蔗糖、葡萄糖、果糖是由多基因控制的数量性状。Celia 等[11]发现桃果实可溶性固形物含量呈连续的正态分布；徐铭等[12]研究表明杏的仁味为受单基因控制的质量性状，且苦仁味相对于甜仁味为隐性，单果质量表现为降低的遗传倾向。以上研究多以正常杂交群体后代为试材，而使用正、反交组合进行试验的研究较少，且试材群体普遍较小。

河北地方杏品种‘串枝红’以其大果、丰产、外观艳丽、风味极佳而受到种植者及消费者的喜爱，已经成为华北地区的主要栽培品种之一。但随着经济的发展，人们对生活品质的追求日益提升，对果品质量便有了更高的要求。然而，华北地区主要栽培的‘串枝红’品种口感较酸，需要通过品种选育进行改良。新疆优质品种‘赛买提’因其成熟后高甜低酸的口感深受消费者欢迎，但因其色泽较差、易裂果，而不能在华北杏主产区大面积推广。故，本试验使用上述品种及二者的正，反交组合后代株系为材料，探讨了果实大小、果型指数、果面盖色、果实形状、可溶性固形物含量、果实硬度、果实风味等性状的遗传倾向，旨在为今后杏育种工作中的亲本选配及预测后代性状表现提供依据。

1　材料和方法

1.1　材料

本试验试材来自国家果树种质熊岳李杏圃，包括 2 个亲本‘赛买提’‘串枝红’及正交组合‘赛买提’×‘串枝红’，和反交组合‘串枝红’×‘赛买提’。于 2006 年杂交，2007 年定植，正、反交组合分别有 230 株、130 株，并于 2012 年陆续结实。2018 年及 2019 年，分别对正、反交组合中随机选取了 213 株、110 株后代进行果实性状调查。亲本株行距为 3 m×5 m，所有杂交后代株系株行距为 0.8 m×3 m，资源圃土质为沙壤土；所有株系采用相同的管理措施。

1.2　方法

果实成熟时，每株随机选取树冠中部果实 10 个，采至实验室分别对单果质量、果实纵径、果实横径、果实侧径、果实形状、果面盖色、果实去皮硬度、可溶性固形物含量、果实风味等进行测定；测定标

准统一按照《杏种质资源描述规范和数据标准》[13]执行。果型指数参照《International union for the protection of new varieties of plants》[14]对纵横比、侧横比进行计算。

单果质量使用电子天平进行测定，果实纵、横、侧径使用游标卡尺进行测定。果实硬度使用Agrosta2019款果实质地检测仪进行测定，测定部位为去皮后的果实胴体部，探入深度为8.5 mm，探入速度为15 mm·s^{-1}，所选探头面积为0.5 cm^2。可溶性固形物含量使用数显糖度计测定。

1.3 数据分析

本试验数据使用Excel 2019进行整理，使用SPSS 19进行统计分析，使用Origin 2015进行绘图。并对遗传传递力及变异系数[15]进行计算。

遗传传递力：Ta/%=$\bar{x}$/F×100，式中$\bar{x}$为子代均值，F为亲中值。

变异系数：CV/%=σ/$\bar{x}$×100，式中$\bar{x}$为子代均值，σ为标准差。

2 结果与分析

2.1 ‘串枝红’与‘赛买提’正、反交后代果实大小的遗传倾向

‘串枝红’与‘赛买提’正、反交后代单果质量的频率分布趋近于正态分布，如图1所示，表现为多基因控制的数量性状遗传特点；2018年两组合后代单果质量、纵径、横径、侧径与2019年测得数据均呈显著相关（$p>0.05$）。如表1所示，正、反交组合后代株系的平均单果质量均低于低亲值；正交组合平均单果质量低于低亲的比例分别为92.94%和84.72%，反交组合分别为96.08%和82.85%，表现为偏小遗传的趋势。正交组合单果质量的变异系数为30.38%和35.48%，反交组合为25.34%和24.14%，变异程度较大。在各组合中，单果质量遗传传递力分别为43.58%、42.86%、48.58%和50.73%，遗传传递力小，易受环境条件影响。在正、反交组合后代群体中纵径、横径、侧径均未出现超高亲株系且普遍低于低亲

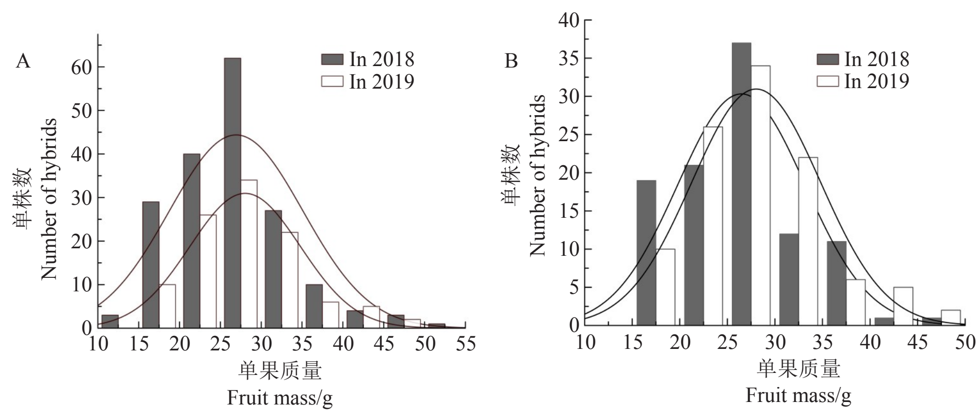

图1 ‘串枝红’×‘赛买提’（A）‘赛买提’×‘串枝红’（B）杂交后代单果质量分布

Fig. 1 The frequency distribution of the fruit mass in the number of hybrids of ‘Chuanzhihong’×‘Saimaiti’（A）and ‘Saimaiti’×‘Chuanzhihong’（B）

表1 ‘串枝红’与‘赛买提’正、反交后代单果质量的遗传参数

Table 1 The hereditary variation of fruit mass in hybrid progenies of ‘Chuanzhihong’ and ‘Saimaiti’

年份 Year	组合 Group	亲本单果质量 Fruit mass of parents/g			杂种单果质量 Fruit mass of hybrids/g		超亲植株 Percentage of hybrid/%		CV/%	Ta/%
		母本 Famale	父本 Male	亲中值 MP	$\bar{x}$±s	分布范围 Range	超高亲 Higher than parents	低于低亲 Lower than parents		
2018	串枝红×赛买提 Chuanzhihong×Saimaiti	84.76	38.90	61.83	26.93±8.10	12.79~66.67	0.00	92.94	30.38	43.58
	赛买提×串枝红 Saimaiti×Chuanzhihong	38.90	84.76		26.48±6.71	15.21~49.63	0.00	96.08	25.34	42.86
2019	串枝红×赛买提 Chuanzhihong×Saimaiti	76.60	33.90	55.25	26.84±9.52	11.00~70.81	0.00	84.72	35.48	48.58
	赛买提×串枝红 Saimaiti×Chuanzhihong	33.90	76.60		28.03±6.77	15.36~46.72	0.00	82.85	24.14	50.73

值，变异系数较小，均为10%左右，遗传传递力较强，均为75%左右，表明果实纵径、横径、侧径的遗传受环境因素的影响较小，也表现为相似的趋势。

2.2 ‘串枝红’与‘赛买提’正、反交后代果实形状的遗传倾向

‘串枝红’与‘赛买提’果实形状均为卵圆形，在正、反交组合中出现了卵圆形、扁圆形、不规则圆形、心脏形和圆形的分离（图2），2年间正、反交组合果实形状分布规律相似，正交组合的果实形状年间差异较小。2019年反交组合与2018年相比增加了少量的果实形状为圆形及不规则圆形的株系。各组合果实形状均为卵圆形的株系占比最高，为90%左右。2018年正、反交后代果实纵径/横径介于双亲值之间的株系最多，占比为40%左右；而在2019年的调查中超高亲值的株系占比最多，正、反交组合超高亲值株系分别为54.68%、40.95%，个组合变异系数分别为5.74%、6.23%、7.34%和6.39%，变异系数较低。各组合遗传传递力分别为100.56%、100.37%、103.90%和101.62%，遗传传递力较强。

2018年正、反交组合后代果实侧径/横径低于低亲值的占比较高，分别为63.19%与50.98%；2019年正、反交组合均出现了较多介于双亲值的株系，占比分别为44.34%与47.63%。各组合变异系数分别为6.90%、6.90%、5.73%和6.39%，变异系数较小。各组合遗传传递力分别为94.4%、95.63%、100.53%和100.9%，遗传传递力较高。

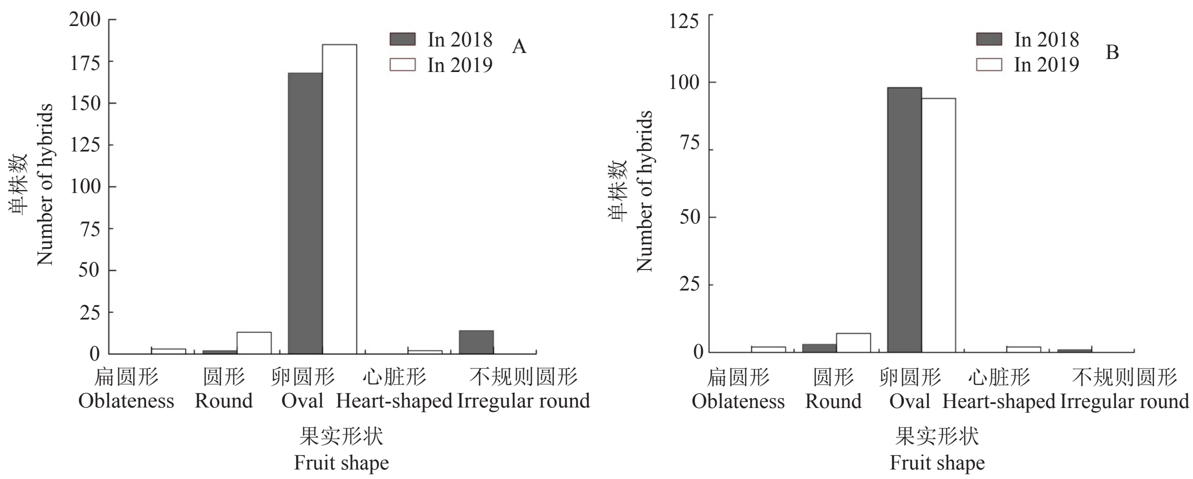

图2 ‘串枝红’×‘赛买提’（A）‘赛买提’×‘串枝红’（B）杂交后代的果实形状分布

Fig. 2 The frequency distribution of the fruit shape in the number of hybrids of ‘Chuanzhihong’×‘Saimaiti’（A）and ‘Saimaiti’×‘Chuanzhihong’（B）

从以上分析可以看出，‘串枝红’与‘赛买提’正、反交组合后代纵径/横径表现为增加的趋势，侧径/横径表现为降低的趋势，结合对果实外形的调查结果得出，果实形状表现为趋圆的遗传倾向，且环境因素带来的影响较小。

2.3 ‘串枝红’与‘赛买提’正、反交后代果面盖色的遗传倾向

由表2可以看出，‘串枝红’果面盖色为红色，‘赛买提’无色。在正、反交组合后代中出现了无盖色、粉红色、橙红色及红色的分离。2019年正交组合的果面盖色无彩色株系比2018年增加了17%，果面盖色为粉色的株系减少了15%。与2018年比较，2019年反交组合出现了更多的粉色株系且红色果实的株系占比有所降低。2018年正交组合后代中果面无盖色植株占比为24.46%，有彩色株系占比为75.54%；反交组合后代中果面无盖色株系占比为37.25%，有彩色株系占比为62.75%。2019年正交组合后代中果面无盖色株系占比为41.87%，有彩色株系占比为58.13%；反交组合后代中果面无盖色株系占比为33.33%，有彩色株系占比为66.67%。正、反交组合后代中果面盖色有彩色的株系占有较大比重。经卡平方检验，2018年正交组合 $\chi^2=1.00<3.84$ (p = 0.05)及2019年反交组合 $\chi^2=0.075<3.84$ (p = 0.05)均符合1∶3的比例，说明杏果面盖色有彩色相对于无彩色为显性。

2.4 ‘串枝红’与‘赛买提’正、反交后代果实可溶性固形物含量的遗传倾向

由图3可知，‘串枝红’与‘赛买提’正、反交后

表2 ‘串枝红’与‘赛买提’正、反交后代果面盖色的遗传参数

Table 2 The hereditary variation of fruit color in hybrid progenies of ‘Chuanzhihong’ and ‘Saimaiti’

年份 Year	组合 Group	亲本表型 Phenotype of parents		子代分离比例 Proportion of separation for hybrids/%			卡方检测 χ^2
		母本 Female	父本 Male	无彩色 Without color	粉色 Pink	红色 Red	
2018	串枝红×赛买提 Chuanzhihong×Saimaiti	红色 Red	无彩色 Without color	24.46	41.30	34.24	1.000
	赛买提×串枝红 Saimaiti×Chuanzhihong	无彩色 Without color	红色 Red	37.25	27.45	35.29	0.013
2019	串枝红×赛买提 Chuanzhihong×Saimaiti	红色 Red	无彩色 Without color	41.87	26.60	31.53	-
	赛买提×串枝红 Saimaiti×Chuanzhihong	无彩色 Without color	红色 Red	33.33	43.81	22.86	0.075

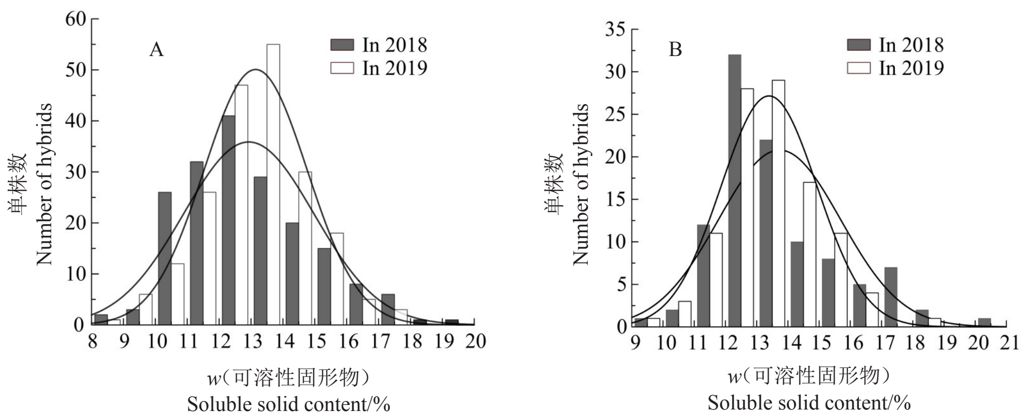

图3 ‘串枝红’×‘赛买提’(A)‘赛买提’×‘串枝红’(B)杂交后代可溶性固形物含量分布

Fig. 3 The frequency distribution of the SSC in the number of hybrids of ‘Chuanzhihong’×‘Saimaiti’(A),‘Saimaiti’×‘Chuanzhihong’(B)

代可溶性固形物含量均为连续变异，且为正态分布。经相关性分析表明，两组合2018年与2019年可溶性固形物含量呈显著正相关($p > 0.05$)。说明杏的可溶性固形物含量为多基因控制的数量性状；正、反交组合后代可溶性固形物含量均值均低于亲中值。在连续两年的调查中，正交后代中超高亲株系占比分别为10.87%和2.96%，低于低亲株系占比为51.09%和15.76%；反交后代中超高亲株系占比为15.69%和4.76%，低于低亲株系占比为31.38%和9.52%。各组合遗传传递力分别为91.09%、96.99%、94.91%和96.72%，遗传传递力较高。各组合变异系数分别为15.73%、14.25%、12.31%和11.51%，变异程度较小(表3)。正、反交组合可溶性固形物含量均表现为趋中遗传的倾向。

表3 ‘串枝红’与‘赛买提’正、反交后代可溶性固形物含量的遗传参数

Table 3 The hereditary variation of SSC in hybrid progenies of ‘Chuanzhihong’ and ‘Saimaiti’

年份 Year	组合 Group	w(亲本可溶性固形物) SSC of parents/%			w(杂种可溶性固形物) SSC of hybrids/%		超亲植株 Percentage of hybrid/%		CV/%	Ta/%
		母本 Female	父本 Male	亲中值 MP	x±s	分布范围 Range	超高亲 Higher than parents	低于低亲 Lower than parents		
2018	串枝红×赛买提 Chuanzhihong×Saimaiti	12.72	15.60	14.16	12.90±2.03	8.26~19.58	10.87	51.09	15.73	91.09
	赛买提×串枝红 Saimaiti×Chuanzhihong	15.60	12.72		13.73±1.96	9.78~20.74	15.69	31.38	14.25	96.99
2019	串枝红×赛买提 Chuanzhihong×Saimaiti	11.50	16.20	13.85	13.14±1.62	8.46~17.66	2.96	15.76	12.31	94.91
	赛买提×串枝红 Saimaiti×Chuanzhihong	16.20	11.50		13.40±1.54	9.82~18.58	4.76	9.52	11.51	96.72

2.5 ‘串枝红’与‘赛买提’正、反交后代的果实硬度遗传倾向

对于所有后代的杏果肉硬度而言，2019年的检测数值普遍低于2018年。2018年及2019年正、反交后代的果实硬度均值低于亲中值，多数低于低亲值，正交后代果实硬度低于低亲值占比为75%和85.22%，反交后代果实硬度低于低亲值占比为67.65%和75.24%，表现为明显的偏低遗传的趋势（表4）。正、反交组合变异系数分别为34.12%、26.37%和18.65%、28.64%，变异系数较高。在连续两年的调查中，各组合遗传传递力分别为61.37%、66.63%、68.84%和71.62%，遗传传递力较低，说明果实硬度易受环境因素影响。

表4　‘串枝红’与‘赛买提’正、反交后代果实硬度的遗传参数

Table 4　The hereditary variation of hardness in hybrid progenies of ‘Chuanzhihong’ and ‘Saimaiti’

年份 Year	组合 Group	亲本果实硬度 Fruit hardness of parents/(kg·cm^{-2}) 母本 Female	父本 Male	亲中值 MP	杂种果实硬度 Fruit hardness of hybrids/(kg·cm^{-2}) x±s	分布范围 Range	超亲植株 Percentage of hybrid/% 超高亲 Higher than parents	低于低亲 Lower than parents	*CV*/%	Ta/%
2018	串枝红×赛买提 Chuanzhihong×Saimaiti	1.07	2.00	1.54	0.94±0.32	0.59~3.13	1.08	75.00	34.12	61.37
	赛买提×串枝红 Saimaiti×Chuanzhihong	2.00	1.07		1.02±0.19	0.71~1.57	0.00	67.65	18.65	66.63
2019	串枝红×赛买提 Chuanzhihong×Saimaiti	2.20	3.20	2.70	1.86±0.49	0.89~3.84	2.46	85.22	26.37	68.84
	赛买提×串枝红 Saimaiti×Chuanzhihong	3.20	2.20		1.93±0.55	0.95~3.40	3.81	75.24	28.64	71.62

2.6 ‘串枝红’与‘赛买提’正、反交后代果实风味的遗传倾向

‘串枝红’果实风味以酸甜为主，‘赛买提’果实风味以甜为主。在连续两年的调查中，正、反交组合后代的果实风味为酸甜比例最高，均占70%以上，仅出现了极少量的酸及甜酸株系，正、反交组合中二者合计占比均在15%以下（表5）。反交组合后代中无果实风味为酸的株系出现。果实风味表现为口感偏酸的遗传倾向。

经相关性分析表明，果实单果质量与果实侧径呈极显著相关，果实硬度与横径、纵径/横径及果实形状呈极显著相关，与侧径及侧径/横径呈显著相关（表6）。

表5　‘串枝红’与‘赛买提’正、反交后代果实风味的遗传倾向

Table 5　The hereditary variation of fruit flavor in hybrid progenies of ‘Chuanzhihong’ and ‘Saimaiti’

年份 Year	组合 Group	亲本表型 Phenotype of parents 母本 Female	父本 Male	子代分离比例 Proportion of separation for hybrids/% 酸 Sour	甜酸 Sweet and sour	酸甜 Sour and sweet	甜 Sweet
2018	串枝红×赛买提 Chuanzhihong×Saimaiti	甜酸 Sweet and sour	甜 Sweet	1.09	2.17	85.87	10.97
	赛买提×串枝红 Saimaiti×Chuanzhihong	甜 Sweet	甜酸 Sweet and sour	0.00	0.00	92.16	7.84
2019	串枝红×赛买提 Chuanzhihong×Saimaiti	甜酸 Sweet and sour	甜 Sweet	3.94	4.93	71.92	19.21
	赛买提×串枝红 Saimaiti×Chuanzhihong	甜 Sweet	甜酸 Sweet and sour	0.00	15.23	70.48	14.29

3 讨　论

3.1 果实大小

果实大小通常是由果实单果质量与果实纵、横、侧径共同决定的。一般认为，单果质量是由多基因控制的数量性状。本研究发现，杏正、反交组合后代果实普遍呈偏小的遗传趋势，与前人研究基本一致[6,9]。各组合中均未出现单果质量高于高亲值的株系，这可能是由于该性状多为累加效应形成，且两组合累加效应完全解体，所以并无超亲后代株系出现。低于低亲值的平均比例为89.15%，表现为严重的劣变。各组合果实质量变异较大，而果实

表6 相关性分析

Table 6 correlation analysis

	单果质量 Fruit mass	纵径 Longitudinal diameter	横径 Transverse diameter	侧径 Lateral diameter	纵横比 Longitudinal/ transverse	侧横比 Lateral/ transverse	果形 Fruit shape	可溶性固形物含量 SSC	硬度 Hardness
单果质量 Fruit mass	1								
纵径 Longitudinal diameter	0.621**	1							
横径 Transverse diameter	0.696**	0.568**	1						
侧径 Lateral diameter	0.724**	0.506**	0.593**	1					
纵横比 Longitudinal/transverse	-0.139**	0.127**	-0.306**	0.160**	1				
侧横比 Lateral/ transverse	-0.169**	0.139**	-0.114**	0.355**	0.398**	1			
果形 Fruit shape	-0.054	0.028	0.015	0.143**	0.028	0.237**	1		
可溶性固形物含量 SSC	-0.006	-0.031	-0.023	-0.027	-0.010	-0.003	-0.015	1	
硬度 Hardness	-0.005	0.015	-0.132**	0.066*	0.225**	-0.068*	-0.242**	0.046	1

注：*和**分别表示差异显著（$p < 0.05$）和差异极显著（$p < 0.01$）。

Note: * and ** mean significant difference at $p < 0.05$ and $p < 0.01$.

纵、横、侧径变异较小，变异系数均约为10%。由相关性分析可知，侧径与单果质量有较强的相关性。

3.2 果实形状

杏的果实形状是较为复杂的性状，相关研究表明，果实形状由数个位点上的若干个主效基因控制，随着贡献基因的增减，果形会发生趋向于椭圆果型和扁圆形果型的变化[16]。本研究发现，‘串枝红’与‘赛买提’果实形状均为卵圆形，其正、反交组合后代果实形状也以卵圆形为主，占比均为90%左右。正、反交组合后代纵径/横径、侧径/横径的遗传传递力明显高于纵、横、侧径的遗传传递力，且变异系数较小，说明在使用果实形状相近的品种进行杂交育种的过程中，果实形状较难改变。

3.3 果面盖色

果面盖色为少数基因控制的显性或不完全显性性状[6]。果面盖色主要由花青苷、类胡萝卜素、花色苷和叶绿素等决定[17-18]，类胡萝卜素是重要的萜类色素物质，Xi等[19]通过对‘轮台小白杏’的调查研究发现，成熟过程中其果皮颜色由绿到黄再到浅黄，果实中类胡萝卜素含量也随之降低；张圣仓等[20]通过对‘串枝红’与‘银香白’叶绿素及花色苷含量的变化研究发现‘串枝红’果实叶绿素含量在果实发育初期升高，并于盛花期达到最高，随后降低，在完熟期降为最低值。‘银香白’在成熟过程中则持续降低；二者于发育初期均未检测到花色苷，在发育后期花色苷含量大量增加并于完熟期升至最高，但二者完熟期花色苷含量差异极为明显（串枝红为9.77 mg·100 g^{-1}，银香白为0.56 mg·100 g^{-1}）。说明花色苷对杏果皮形成红色的盖色起较大的影响。

研究结果表明，2018年和2019年‘串枝红’与‘赛买提’正交组合中果面盖色无彩色的株系占比分别为24.46%和41.87%，反交组合中果面盖色无彩色的株系占比分别为37.25%和33.33%，果面盖色无彩色与有色株系经卡方检测符合1∶3的分离比例，故认为果面盖色有色相对于无彩色为显性。与方玉凤等[21]和刘文东等[22]得出的李果实有色对无色为完全显性基本一致。但是，武晓红等[8]得出杏果实果面盖色无彩色相对于有彩色为显性，笔者结论与之相反。这是否与亲本的选配有关仍需进一步研究。

3.4 果肉硬度

果肉硬度是决定果品是否耐贮运的主要性状之一。杏是公认的不耐贮运的时令水果之一，局限于较短的货架期及对运输条件的较高要求，相较于苹果、橙子等耐贮运的水果，杏的市场占有率极低，

故选育出口感好，外观好，耐贮运的杏品种是杏育种工作中的重要内容之一。

杏果肉硬度被认为是数量性状遗传且亲本果肉硬度均值要高于后代[23]，本研究表明，‘串枝红’与‘赛买提’正、反交组合后代果实硬度呈偏低的遗传倾向。遗传传递力小，说明该性状易受环境因素的影响，这与前人的研究有所不同[8]。正、反交组合中均出现了超高亲株系且该性状变异系数高，说明该组合有筛选出高硬度后代的可能。

3.5 可溶性固形物含量及果实风味

可溶性固形物含量是杏果实重要的经济性状之一，其含量高低对杏果实的营养价值、口感风味等方面有着重要的影响，且在树体耐寒、果实贮运等方面也起着重要作用。本研究表明，‘串枝红’与‘赛买提’正、反交组合后代果实可溶性固形物含量除 2018 年正交后代(38.04%)以外介于双亲之间的双亲的比例分别为 81.28%、52.93%和 85.72%，主要表现为趋中遗传的倾向，这与方玉凤等[21]的报道一致，且正反交后代均呈正态分布，遗传传递力较高，说明外界环境对其的影响较小。变异系数较大，虽然存在加性效应数量性状的解体，但在子代中产生了新的补累加效应，因此出现了部分超亲株系，说明‘串枝红’与‘赛买提’正、反交组合后代中可选育出高可溶性固形物含量的株系。本次调查研究还显示，‘串枝红’与‘赛买提’正、反交组合后代果实风味为偏酸遗传的倾向。该结果与前人的研究一致[24]。

本试验通过‘串枝红’与‘赛买提’及二者的正、反交组合后代对杏果实大小、果面盖色、可溶性固形物含量、果肉硬度等性状的遗传倾向进行了分析，但是部分形状的遗传倾向与前人的研究结果不一致，这可能还需要进一步将通过构建更多类似的遗传群体验证。同时，有关杏的树体性状、生物学特征性状和抗性等重要育种性状的遗传倾向也需要进一步探究。

4 结 论

通过对‘串枝红’与‘赛买提’的正、反交组合后代果实主要性状调查后，认为杏单果质量、果实大小由累加效应形成，且正、反交组合果实累加效应相似，并无超亲后代；可溶性固形物含量呈正态分布，虽然存在加性效应数量性状的解体现象，但在子代中产生了新的高效应组合，出现超高亲后代；果面盖色有彩色相对与无彩色为显性。

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