

不同花粉授粉对瑞香红苹果果个、果形和硬度的影响

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摘要:【目的】筛选可改善瑞香红苹果单果质量、果形和硬度的优良花粉。【方法】以自然授粉为对照, 选用21种不同的花粉对瑞香红进行控制授粉, 测定果实生长发育的纵横径、成熟时单果质量、偏斜率和硬度等指标, 结合隶属函数和聚类分析对授粉效果进行综合评价。【结果】不同授粉组合的果实单果质量、果实硬度和密度呈现不同程度差异。用舞美授粉后果实单果质量最大, 为289.86 g, 比自然授粉显著增长20.79%, 其次为自由, 比自然授粉增长13.66%, 扎矮76和杂交优系3授粉果实单果质量变小, 分别为183.47 g、169.80 g, 粉红女士授粉后果实最小, 为156.52 g, 分别比自然授粉降低23.55%、29.25%和34.78%, 处理间差异显著; 用瑞香红授粉后果实偏斜率最低, 相比对照显著降低64.88%, 金世纪授粉后果实偏斜率最高, 显著增加18.73%; 不同授粉组合的果形指数无显著差异, 用杂交优系3授粉后果实密度最大, 为 $1.34 \text{ g} \cdot \text{cm}^{-3}$; 用北京1号海棠授粉后果实硬度最大, 为 $10.13 \text{ kg} \cdot \text{cm}^{-2}$, 自由授粉后果实硬度最小, 为 $8.32 \text{ kg} \cdot \text{cm}^{-2}$, 比自然授粉显著降低7.75%。【结论】在增加果实单果质量、维持果形、降低偏斜率及硬度上, 舞美是瑞香红的首选花粉。

关键词: 苹果; 瑞香红; 授粉

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Effects of different types of pollens on fruit size, shape and hardness in Ruixianghong apple

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Abstract:【Objective】In order to select excellent pollen that can improve the fruit size, fruit shape and hardness of Ruixianghong apple, the present experiment was undertaken. 【Methods】We selected 21 different types of pollens to control pollination of Ruixianghong with natural pollination serving as the control. The fruit setting rate was investigated, the vertical and horizontal diameters of fruit during development were measured after pollination, and the fruit weight, deflection rate and hardness of the harvested fruit were also measured. The pollination effect was comprehensively evaluated by combining membership function and cluster analysis. 【Results】The effects of different pollination combinations on fruit setting rate, fruit longitudinal and transverse diameter growth, fruit shape index, fruit weight, fruit hardness and density at maturity were different. The longitudinal and transverse diameters of the fruits pollinated by each variety mainly increased in the early stage and tended to stop increasing at harvest. At the early stage of fruit development, the increase of fruit longitudinal diameter was greater than that of transverse diameter, and the increase of longitudinal diameter and transverse diameter of most pollination combinations showed a downward trend at harvest. In the process of fruit growth and development, the fruit longitudinal diameter and fruit shape index of Ruixianghong were larger after it was pollinated by Maypole and Hybrid superior line 2 and the fruit transverse diameter growth and fruit shape index were larger after it was pollinated by Freedom and B118, while the longitudinal diameter

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growth and fruit shape index were smaller after it was pollinated by Hybrid superior line 3 and Zha' ai 76. The fruit weight of Ruixianghong was the largest (289.86 g) after it was pollinated by Maypole, which was significantly higher than that of the control and other pollination combinations, 20.79% higher than that of the control (239.98 g), and Hybrid superior line 2. The fruit weight of Ruixianghong decreased after it was pollinated by Zha' ai 76 (183.47 g) and Hybrid superior line 3 (169.80 g). The fruit weight was the smallest after it was pollinated by Pink Lady, which was 156.52 g, and the difference between treatments was significant. The effects of other pollination combinations on fruit weight were different, but the difference was not significant. There was no significant difference in the effect of different types of pollens on fruit shape index. The average fruit shape index was about 1.0, indicating that pollination had little effect on the fruit shape, and the variety had excellent high-L/D retention. The fruit deviation rate (4.33%) was the lowest after it was pollinated by Ruixianghong pollen, which was significantly reduced by 64.88%, compared with the control (12.33%). The fruit deflection rate with Jin Shiji pollen was the highest (18.73%), which was significantly different from the control. Except for the pollen of Ruixianghong, the fruit deflection rates with Hybrid superior line 1 (5.25%), *Malus* sp. Beijing No. 1 (8.00%), B118 (8.33%), *M. prunifolia* (Willd.) Borkh. (9.40%), Anna (9.67%) and Maypole (9.67%) were less than 10%, which were qualified as grade I fruits. Compared with natural pollination, they were significantly reduced by 57.42%, 35.12%, 32.44%, 23.76%, 21.57% and 21.57%. The fruit deflection rate of other pollination combinations was greater than 10%. The results showed that Ruixianghong maintained the fruit with high-L/D characteristic, increased the fruit weight and reduced the deviation rate after it was pollinated by Maypole. The fruit weight of Ruixianghong was smaller and the fruit deflection rate was higher after it was pollinated by Zha' ai 76, Pink Lady and Hybrid superior line 3. In terms of fruit density, compared with natural pollination ($1.01 \text{ g} \cdot \text{cm}^{-3}$), Ruixianghong significantly increased fruit density after it was pollinated by Hybrid superior line 3 and *M. sieversii* (Ledeb.) Roem.. The fruit density of Ruixianghong decreased after it was pollinated by Zha' ai 76 ($0.77 \text{ g} \cdot \text{cm}^{-3}$) and Pink Lady ($0.75 \text{ g} \cdot \text{cm}^{-3}$), but the difference was not significant. In terms of fruit hardness, the fruit hardness of Ruixianghong significantly increased ($10.13 \text{ kg} \cdot \text{cm}^{-2}$), followed by the pollens of Nagafu No.2 ($9.94 \text{ kg} \cdot \text{cm}^{-2}$). The fruit hardness of Ruixianghong was the lowest ($8.32 \text{ kg} \cdot \text{cm}^{-2}$) after Freedom served as a pollinator, and then *M. sieversii* (Ledeb.) Roem. ($8.45 \text{ kg} \cdot \text{cm}^{-2}$), which was significantly reduced by 7.75%, compared with the natural pollination ($9.16 \text{ kg} \cdot \text{cm}^{-2}$). The membership function method was used to establish a comprehensive evaluation on the efficacy of different pollens. The results showed that the top pollens were Maypole, Freedom, *M. sieversii* (Ledeb.) Roem., Liaofu, Anna, etc. The fruits pollinated by Pink Lady, Zha' ai 76, Nagafu No. 2, India and Jin Shiji ranked lower than the control. The pollination effects of 21 types of pollens can be divided into 4 categories by means of mean cluster analysis. The fruit deviation rate was large, the fruit shape index was small, the fruit weight was relatively small compared with other pollination combinations, and the Zha' ai 76, India and Pink Lady, which ranked lower, were divided into one category. The comprehensive ranking of Maypole, Freedom and natural pollination, LG2, *M. sieversii* (Ledeb.) Roem., Liaofu, Golden Delicious, Anna and Orin were divided into one category; B118, *M. prunifolia* (Willd.) Borkh., Hybrid superior line 1, Ruixianghong and *Malus* sp. Beijing No. 1, Hybrid superior line 2, Jin Shiji, Envy and Nagafu No. 2 were divided into one category. 【Conclusion】 Maypole has the best comprehensive effect after it serves as a pollinator, which is characterized by large fruit, small hardness and low deflection rate. It is the preferred pollen for Ruixianghong.

Key words: Apple; Ruixianghong; Pollination

苹果(*Malus × domestica* Borkh.)属蔷薇科苹果属,是我国栽培面积最大、产量最高的落叶果树。果品供应周期长,营养丰富,美味可口,备受消费者喜爱,在我国水果产业发展中占有重要地位^[1-4]。苹果属于自交不亲和性果树,生产上需要配置适宜的授粉品种或通过人工辅助授粉来实现高产量和获得被市场喜爱的果实质量^[5-8]。

不同品种花粉授粉对苹果果实坐果率和品质的影响差异较大^[9]。薛志霞等^[10]研究发现用秦冠、嘎拉授粉红富士苹果,表现亲和性强,提高了果实坐果率;徐臣善^[11]用3个授粉品种对长富2号授粉后,显著改变了果实中的内源激素含量,进而调控了果实的生长发育;毛凯俊^[12]研究结果表明红富士和嘎拉苹果经秦冠、皮诺娃授粉后果实坐果率和果形指数大幅度提高;王延秀等^[13]用不同海棠品种及宫崎富士的花粉给阿斯苹果进行授粉,发现授粉后果个、果形指数和硬度显著增大;王海波等^[14]用5个品种对烟富3富士苹果授粉后,结果表明不同品种花粉对果实挥发性物质存在显著的影响;Zhang等^[15]用榅桲花粉对烟富3号和印度苹果授粉后,显著影响了果实的内在品质,提高了单果质量、硬度、糖酸比、维生素C、总酚和总黄酮含量。

目前生产中对授粉树以及专用花粉的选择具有一定的盲目性,随着苹果栽培规模的不断扩大,如何为特定苹果品种选择高效的花粉进行授粉变得越来越重要。

瑞香红是由西北农林科技大学以秦富1号×粉红女士杂交选出的优质晚熟红色苹果品种。该品种具有果形高桩、色泽艳丽、香气浓郁、香甜可口、极耐贮藏等特点^[16],是陕西省近年来重点发展的新品种。该品种果个中等,但在管理不当的情况下易出现果实偏小、偏斜、偏硬等问题。合理的授粉能有效改善苹果单果质量、果形以及其他果实性状。靳元凯^[17]选用栽培品种富士、嘎拉、瑞雪以及授粉品种秋实对瑞香红进行授粉研究,初步认为可在生产园中配置富士和秋实作为授粉树,但选用的授粉品种少,选择范围窄,同时未对瑞香红果个、果形、果实硬度等重要品质指标开展综合评价。

笔者在本研究中选用21种不同的苹果花粉对瑞香红开展授粉试验,比较不同花粉对瑞香红果实大小、果形、果实硬度等的影响,同时运用隶属函数法和聚类分析法综合分析授粉效果的差异,以期在

保持瑞香红果实高桩等外观特性的基础上,筛选最合适的花粉,完善瑞香红配套花果管理技术,为瑞香红优质生产提供参考。

1 材料和方法

1.1 试验地概况

试验于2022年3—10月在陕西省渭南市白水县西北农林科技大学白水苹果试验站瑞香红示范园(109.552° E, 35.206° N, 海拔829 m)中进行。试验园区地势平坦,土壤养分丰富,配备水肥一体化滴灌系统。

1.2 试验材料

试验材料为2020年春季定植的瑞香红/M26,树形为高纺锤形,株距1.2 m,行距4.0 m,行内覆盖黑色地布,栽培管理和施肥一致。采集花粉的材料有栽培品种长富2号、金世纪、爱妃、瑞香红、粉红女士、王林、金冠、安娜、辽伏、印度、自由和舞美;授粉品种北京1号海棠;野生资源富平楸子和新疆野苹果;砧木扎矮76、辽砧2号、B118;杂交优系1、杂交优系2和杂交优系3。采集铃铛期花蕾,用镊子取出花药置于硫酸纸上室内阴干,待花粉完全散出后,收集装入5 mL离心管中,密封放入4 °C冰箱备用。

1.3 试验设计

人工授粉:果园中去除边行边树,选取生长健壮、通风透光良好、树势相近的瑞香红为试验树,以单株为小区,每个处理设置3次重复,采用随机排列的方法,于2020年4月5日进行人工授粉,授粉前进行套袋处理,随机选取状态基本一致大蕾期的花朵,人工去雄后用棉签蘸取花粉对其进行授粉,花序间距20 cm左右,摘除其他多余的花朵,授粉后立即套袋并挂牌标记,授粉后7 d摘袋,坐果后30 d统计坐果率。以自然授粉为对照,对试验树进行常规管理,套袋栽培,每株树负载量基本一致。在果实发育过程中定果测量纵横径,果实成熟后,选择成熟度一致,无机械损伤、无病虫害的果实测定相关指标。

1.4 果实性状指标测定

在果实发育过程中,随机选取30个果子为每个授粉组合的样本量,花后2周挂牌定果测量果实纵横径,之后每间隔4周再定果依次测量,直至采收。

果实采收后,以30个果实为每个授粉组合的样本量,统计果实单果质量、纵径、横径、果形指数、密度、硬度等果实性状指标。

单果质量(g):用精度0.01 g的电子天平称量;
纵横径(mm):用精确度为0.01 mm的电子数显游标卡尺测定;
果形指数:果实纵径/果实横径;
果实密度($\text{g} \cdot \text{cm}^{-3}$):用排水法测量果实体积;
果实密度=单果质量/果实体积
硬度:用FTA GS-25水果质地分析仪测定(南京铭奥仪器公司);
果形偏斜率(图1):参考杜研等^[18]的方法,利用公式(1)计算。

$$\text{DD} = 2(H \times R - h \times r) / (H \times R + h \times r)。 \quad (1)$$

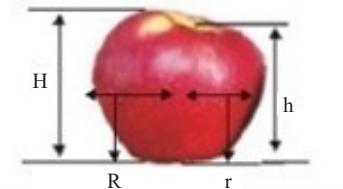


图1 果实偏斜率的表示^[19]

Fig. 1 Representation of fruit deflection rate^[19]

根据多年试验及瑞香红自然授粉果形偏斜率分布,将瑞香红大致划分为四个等级:I级,DD(%)≤10%;II级,10%<DD(%)≤15%;III级,15%<DD(%)≤20%;IV级,DD(%)>20%。

1.5 数据处理

参考孙佩光等^[20]的方法,运用隶属函数法综合评价不同花粉对瑞香红果实性状的影响。其中正相关指标(果实纵径、横径、单果质量、果形指数、密度)用公式(2)计算初始数据,负相关指标(果实偏斜率、硬度)用公式(3)计算初始数据。隶属函数计算公式如下:

$$U_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}}, \quad (2)$$

$$U_{ij} = 1 - \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}}, \quad (3)$$

$$Y_{ij} = \frac{1}{n} \sum U_{ij}。 \quad (4)$$

公式(2)、(3)、(4)中: U_{ij} 为第*i*花粉*j*指标的果实性状变化隶属函数值; X_{ij} 为第*i*花粉*j*指标的平均值, X_{\max} 和 X_{\min} 分别表示*j*指标中所有参试花粉的最大值、最小值; Y_{ij} 为第*i*花粉*j*个指标在不同条件下隶属值所累加得到的平均隶属函数值,其 Y_{ij} 值越大,表明果实综合性状越好,反之则较差。

用Excel 2022进行数据整理和计算,用SPSS 22进行差异显著性分析(LSD法, $p < 0.05$),用Ori-

gin Pro 23绘制聚类热图(最长距离法)。

2 结果与分析

2.1 不同花粉授粉对瑞香红苹果果实生长发育的影响

用不同花粉授粉后的瑞香红果实纵横径增长幅度均表现出不同差异,果实纵横径增长过程接近S型曲线。授粉果实纵径生长动态变化如图2所示。在花后2~6周、14~18周各授粉组合及自然授粉的果实纵径增长量较大,花后6~14周、18~26周纵径增长量较小,花后6周纵径净增长量峰值大于花后18周。在采收时,除杂交优系2和B118授粉果纵径有所增加外,其余授粉组合果实纵径增长量降低到最小值,表明各授粉品种果实纵径的生长以前期为主,后期增长速率较小,在采收时趋于停止生长,其中用杂交优系3和北京1号海棠授粉果实纵径增长量最小。瑞香红授自由花粉后果实在生长前期纵径增长量相对较大(花后6~18周),其次是杂交优系2;用舞美花粉授粉后果实在花后22周纵径增长量大,可能使果实在采收时纵径较大;瑞香红经杂交优系3、扎矮76授粉后纵径在果实整个生长发育期增长量较小,这可能导致在采收时果实纵径较小。

不同花粉授粉后对瑞香红果实横径生长动态的影响如图3所示。各授粉组合及自然授粉在花后6周、花后10周的果实横径增长量较大,花后6周横径增长量峰值大于花后10周。在花后14~18周,瑞香红除授B118、杂交优系2、富平楸子、金世纪、长富2号、杂交优系3、扎矮76、粉红女士外,其余授粉组合横径增长量均有所增加;在花后22~26周时,用舞美授粉果实横径增长明显大于其他授粉组合,印度、扎矮76、杂交优系3授粉果实的横径呈增长趋势,其余授粉组合果实横径增长量下降趋于零,表明各授粉品种果实横径增长速率前期较快,后期缓慢,其中经王林授粉后果实横径增长最少。在果实整个发育期,瑞香红用自由、B118和新疆野苹果授粉后横径增长量相对较大,用长富2号、杂交优系3和扎矮76授粉后果实横径增长量较小,这可能是横径差异的原因之一。

瑞香红苹果授粉后的果形指数动态变化如图4所示,在果实发育过程中,各授粉组合及自然授粉的果形指数先降低后逐渐稳定。在果实发育前期(花后2~6周),用粉红女士授粉后的果实果形指数最

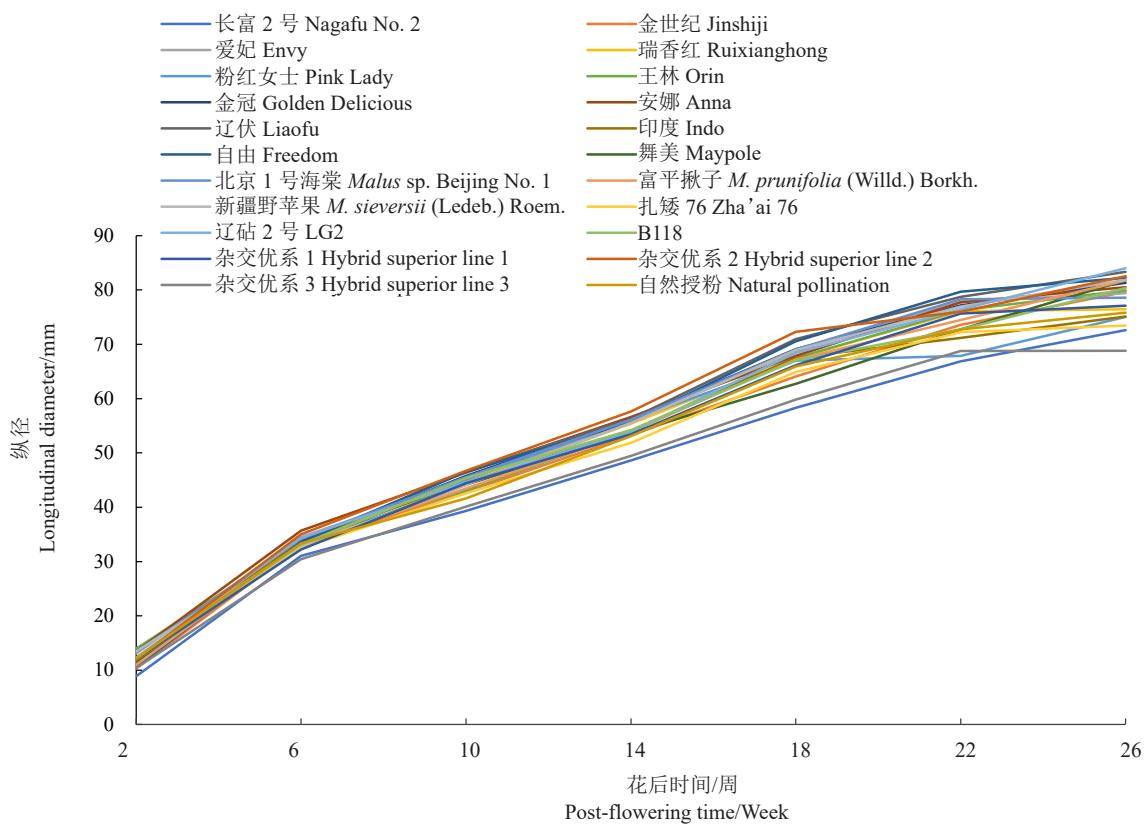


图 2 不同花粉授粉对瑞香红苹果果实纵径的影响

Fig. 2 Effects of different pollen pollination on the vertical diameter of Ruixianghong apple fruit

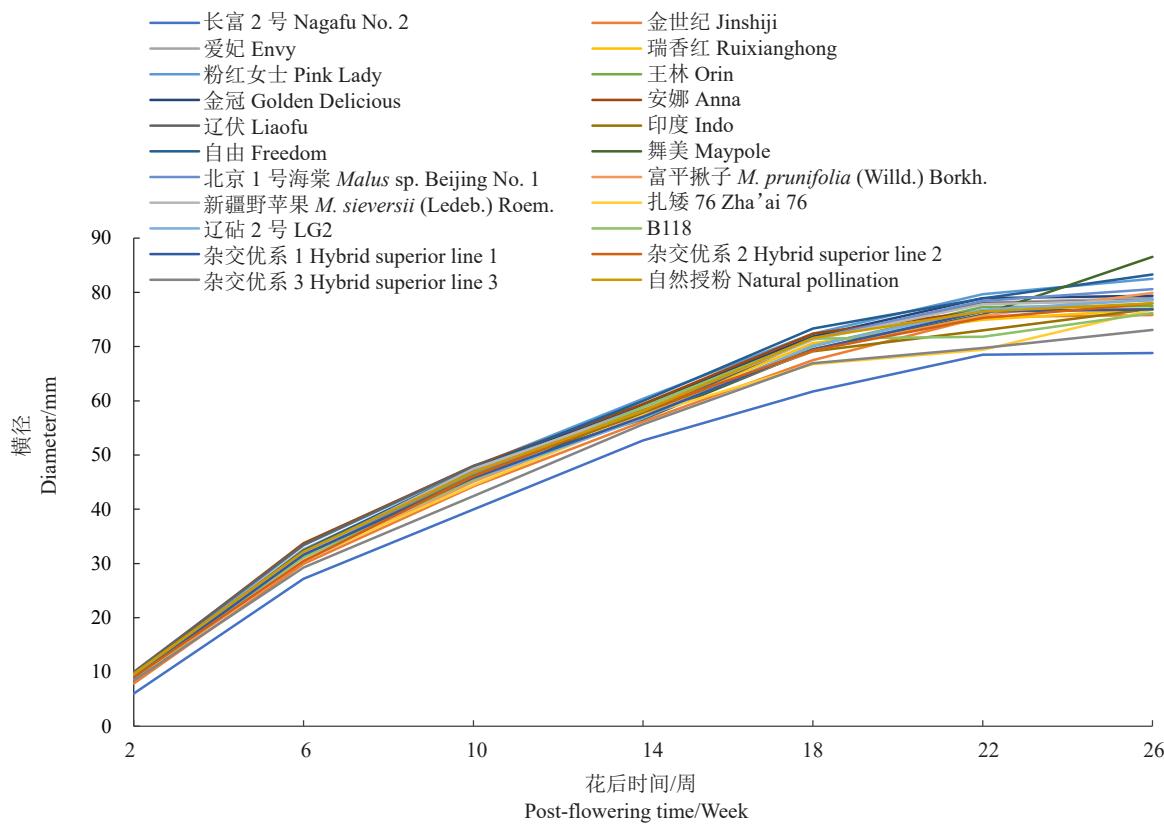


图 3 不同花粉授粉对瑞香红苹果果实横径的影响

Fig. 3 Effects of different pollen pollination on fruit diameter of Ruixianghong apple

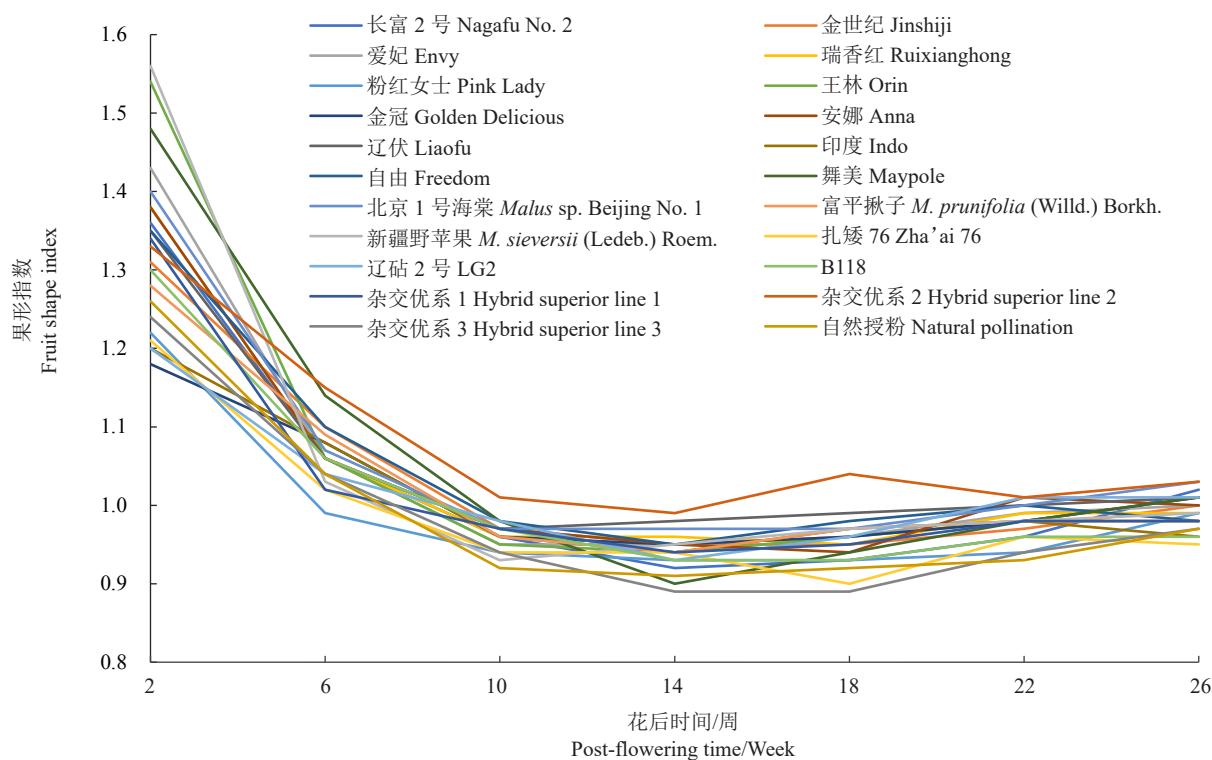


图4 不同花粉授粉对瑞香红苹果果形指数的影响

Fig. 4 Effects of different pollen pollination on fruit shape index of Ruixianghong apple

小;在花后6~10周,除杂交优系2,经舞美授粉后的果形指数大于其他授粉组合,杂交优系2授粉后在花后6~18周,果形指数明显大于自然授粉和其他授粉组合;在果实发育中期(花后14~18周),杂交优系3授粉瑞香红的果形指数最小。在果实整个生长发育时期,用自由、B118授粉的瑞香红果实果形指数相对其他授粉组合较大,用粉红女士、扎矮76、杂交优系1和杂交优系3授粉的瑞香红果实果形指数相对其他授粉组合较小。

综上可知,不同花粉对瑞香红果实生长发育及果形指数会产生不同程度的影响。在果实发育初期,表现为果实纵径增长量大于横径增长量,并在采收时大多数授粉组合纵横径增长量呈下降趋势。在果实生长发育过程中,瑞香红用舞美和杂交优系2花粉授粉后果实纵径和果形指数较大,用自由和B118花粉授粉后横径和果形指数较大,而经杂交优系3和扎矮76授粉后纵径横径和果形指数均较小。

2.2 不同花粉授粉对瑞香红苹果坐果率、单果质量与果形的影响

苹果自花授粉坐果率低,属于异花授粉果树,不同花粉授粉对果实性状会产生不同的影响,常用单

果质量、果形指数、果形偏斜率来评价果个大小、果形优劣和果实偏正度^[21-22]。

不同花粉授粉对瑞香红苹果坐果率和果实时单果质量有不同影响(表1)。与自然授粉相比,人工授粉在一定程度上提高了瑞香红苹果的坐果率,其中用王林授粉花朵坐果率最高,为91%,其次为用舞美和辽砧2号授粉,坐果率相比自然授粉分别显著提高了18%、14%和13%;而用瑞香红和杂交优系1授粉花朵坐果率较低,相比对照差异显著。自花结实坐果率最低,低于25%,未达到授粉要求,后期不考虑果实品质相关指标的测定。

在单果质量方面,瑞香红用舞美授粉,单果质量最大(289.86 g),显著高于对照和其他授粉组合,较对照(239.98 g)增大了20.79%,其次是用杂交优系2授粉;用扎矮76(183.47 g)、杂交优系3(169.80 g)授粉果实时单果质量变小;用粉红女士授粉果单果质量最小,为156.52 g,处理间差异显著;其余授粉组合对果实时单果质量有不同程度影响,但与对照差异不显著。不同花粉对果形指数的影响差异不显著,果形指数均值为1.0左右,表明授粉对其果形的影响程度小,体现了该品种具有优良的高桩保持性。

在果实偏斜率方面,瑞香红(4.33%)授粉果实

表1 不同花粉授粉对瑞香红苹果坐果率、单果质量与果形的影响

Table 1 Effects of different pollen pollination on fruit setting rate, single fruit weight and fruit shape of Ruixianghong apple

花粉 Pollen	坐果率 Percentage of fertile fruit/%	单果质量 Fruit mass/g	果形指数 Fruit shape index	偏斜率 Deflection rate/%
长富2号 Nagafu No. 2	77±6 bc	215.90±22.04 cde	1.02±0.03 a	14.22±0.42 bc
金世纪 Jinshiji	79±7 ab	240.49±10.40 bcd	1.00±0.02 a	18.73±2.74 a
爱妃 Envy	80±3 ab	242.19±8.02 bcd	1.00±0.03 a	12.75±1.14 bc
瑞香红 Ruixianghong	59±6 e	219.22±12.01 cde	0.99±0.02 a	4.33±1.86 f
粉红女士 Pink Lady	79±4 ab	156.52±4.91 h	0.99±0.03 a	16.67±2.91 ab
王林 Orin	91±4 a	250.84±4.10 bcd	0.98±0.02 a	11.25±1.35 cd
金冠 Golden Delicious	80±5 ab	250.75±3.31 bcd	1.00±0.02 a	15.25±1.75 ab
安娜 Anna	71±3 cd	245.99±8.61 bcd	1.00±0.02 a	9.67±0.45 de
辽伏 Liaofu	70±5 cd	248.11±5.39 bcd	1.01±0.03 a	12.00±0.21 bc
印度 Indo	71±3 cd	236.13±14.25 bcd	0.96±0.04 a	15.50±1.69 ab
自由 Freedom	82±3 ab	272.77±7.86 b	0.98±0.05 a	11.33±1.18 cd
舞美 Maypole	88±4 a	289.86±2.05 a	1.01±0.03 a	9.67±0.33 de
北京1号海棠 <i>Malus</i> sp. Beijing No. 1	75±3 bc	248.19±5.61 bcd	1.03±0.02 a	8.00±1.15 de
富平楸子 <i>M. prunifolia</i> (Willd.) Borkh.	80±8 ab	243.45±9.50 bcd	0.98±0.05 a	9.40±0.56 de
新疆野苹果 <i>M. sieversii</i> (Ledeb.) Roem.	77±4 bc	260.45±6.30 bc	0.99±0.01 a	13.33±0.28 bc
扎矮76 Zha'ai 76	68±2 d	183.47±12.72 f	0.95±0.02 a	14.80±2.27 ab
辽砧2号 LG2	87±7 a	256.64±8.85 bc	1.01±0.02 a	14.89±2.87 ab
B118	80±5 ab	261.13±4.40 bc	0.96±0.01 a	8.33±1.03 de
杂交优系1 Hybrid superior line 1	44±1 f	225.50±24.89 cd	0.98±0.05 a	5.25±1.38 ef
杂交优系2 Hybrid superior line 2	81±3 ab	268.73±10.88 b	1.03±0.02 a	16.67±2.33 ab
杂交优系3 Hybrid superior line 3	83±3 ab	169.80±7.42 g	0.97±0.03 a	16.00±2.73 ab
自然授粉 Natural pollination	77±7 bc	239.98±11.93 bcd	0.97±0.01 a	12.33±1.33 bc
自花结实 Self-flowering fruiting	21±5 g	无 None	无 None	无 None

注:同列数据中不同字母表示差异极显著($p<0.05, n=30$)。下同。

Note: In the same column data the difference of different capital letters is extremely significant ($p<0.05, n=30$). The same below.

偏斜率最低,相比对照(12.33%)显著降低了64.88%,瑞香红用金世纪授粉,果实偏斜率最高(18.73%),与对照相比差异显著。除授瑞香红花粉外,用杂交优系1(5.25%)、北京1号海棠(8.00%)、B118(8.33%)、富平楸子(9.40%)、安娜(9.67%)和舞美(9.67%)授粉果实偏斜率均小于10%,为I级果,与自然授粉相比分别显著降低了57.42%、35.12%、32.44%、23.76%、21.57%、21.57%,而其余花粉授粉后偏斜率大于10%。

综上所述,瑞香红用舞美授粉维持了果实高桩的性状,增大了单果质量,降低了偏斜率;用扎矮76、粉红女士、杂交优系3等授粉导致单果质量变小,偏斜率增大。

2.3 不同花粉授粉对瑞香红苹果果实密度、硬度的影响

不同花粉对瑞香红果实密度以及硬度的影响如表2所示,相对于自然授粉($1.01 \text{ g} \cdot \text{cm}^{-3}$),瑞香红用杂交优系3和新疆野苹果授粉果实密度大,分别为 $1.34 \text{ g} \cdot \text{cm}^{-3}$ 、 $1.08 \text{ g} \cdot \text{cm}^{-3}$,处理间差异显著;用扎矮

76($0.77 \text{ g} \cdot \text{cm}^{-3}$)和粉红女士($0.75 \text{ g} \cdot \text{cm}^{-3}$)授粉,果实密度小,分别减少了23.76%、25.74%,处理间差异不显著。

在果实硬度方面,瑞香红用北京1号海棠授粉,果实硬度最大,为 $10.13 \text{ kg} \cdot \text{cm}^{-2}$,其次为用长富2号授粉果($9.94 \text{ kg} \cdot \text{cm}^{-2}$),处理间差异显著;用自由授粉后瑞香红果实硬度最小,为 $8.32 \text{ kg} \cdot \text{cm}^{-2}$,用新疆野苹果授粉果实硬度为 $8.45 \text{ kg} \cdot \text{cm}^{-2}$,相对自然授粉($9.16 \text{ kg} \cdot \text{cm}^{-2}$)降低了7.75%。

2.4 不同花粉授粉对瑞香红苹果果实性状影响的隶属函数分析

为了更好地评价不同指标对瑞香红苹果果实性状的贡献作用,同时明确不同花粉的效果差异,运用隶属函数法对不同花粉的影响进行综合评价,果实性状各指标的隶属函数值如表3所示,排名靠前的花粉有舞美、自由、新疆野苹果、辽伏、安娜等;粉红女士、扎矮76、长富2号、印度、金世纪授粉果实排名靠后,低于对照。其中舞美授粉综合效果优良,分值较高,粉红女士的得分最低,表现较差。

表2 不同花粉授粉对瑞香红苹果果实密度、硬度的影响

Table 2 Effects of different pollen pollination on fruit density and hardness of Ruixianghongg apple

花粉 Pollen	密度 Density/(g·cm ⁻³)	硬度 Firmness/(kg·cm ⁻²)
长富2号 Nagafu No. 2	0.84±0.01 bc	9.94±0.18 a
金世纪 Jinshiji	0.84±0.01 bc	9.22±0.10 bc
爱妃 Envy	0.82±0.01 bc	9.71±0.23 ab
瑞香红 Ruixianghong	0.88±0.01 bc	9.98±0.32 a
粉红女士 Pink Lady	0.75±0.01 c	9.49±0.30 ab
王林 Orin	0.97±0.04 bc	8.86±0.26 cd
金冠 Golden Delicious	0.97±0.04 bc	8.84±0.25 cd
安娜 Anna	0.94±0.02 bc	9.12±0.17 bc
辽伏 Liaofu	0.86±0.02 bc	8.82±0.21 cd
印度 Indo	0.80±0.01 bc	9.23±0.11 bc
自由 Freedom	0.81±0.03 bc	8.32±0.13 de
舞美 Maypole	0.96±0.12 bc	8.79±0.28 cd
海棠北京1号 <i>Malus</i> sp. Beijing No. 1	0.82±0.01 bc	10.13±0.21 a
富平楸子 <i>M. prunifolia</i> (Willd.) Borkh.	0.79±0.06 bc	9.40±0.21 ab
新疆野苹果 <i>M. sieversii</i> (Ledeb.) Roem.	1.08±0.03 b	8.45±0.25 de
扎矮76 Zha'ai 76	0.77±0.01 c	9.05±0.28 bc
辽砧2号 LG2	0.95±0.02 bc	9.00±0.23 bc
B118	0.95±0.04 bc	9.55±0.30 ab
杂交优系1 Hybrid superior line 1	0.85±0.01 bc	9.54±0.28 ab
杂交优系2 Hybrid superior line 2	0.90±0.06 bc	9.67±0.42 ab
杂交优系3 Hybrid superior line 3	1.34±0.42 a	8.80±0.26 cd
自然授粉 Natural pollination	1.01±0.01 bc	9.16±0.04 bc

表3 不同花粉授粉对瑞香红苹果果实性状指标的综合评价

Table 3 Comprehensive evaluation of different pollen pollination on fruit traits of Ruixianghong apple

花粉 Pollen	单果质量 Fruit mass	果形指数 Fruit shape index	偏斜率 Deflection rate	果实密度 Fruit density	果实硬度 Fruit hardness	Y_g	排名 Ranking
长富2号 Nagafu No. 2	0.45	0.56	0.31	0.15	0.10	0.32	21
金世纪 Jinshiji	0.63	0.64	0.00	0.15	0.50	0.38	19
爱妃 Envy	0.64	0.58	0.42	0.12	0.23	0.40	17
瑞香红 Ruixianghong	0.47	0.54	1.00	0.22	0.08	0.46	11
粉红女士 Pink Lady	0.00	0.51	0.14	0.00	0.35	0.20	23
王林 Orin	0.71	0.41	0.52	0.37	0.70	0.54	7
金冠 Golden Delicious	0.71	0.68	0.24	0.37	0.71	0.54	6
安娜 Anna	0.67	0.57	0.63	0.32	0.56	0.55	5
辽伏 Liao fu	0.69	0.71	0.47	0.19	0.72	0.55	4
印度 Indo	0.60	0.18	0.22	0.08	0.50	0.32	20
自由 Freedom	0.87	0.87	0.51	0.10	1.00	0.67	2
舞美 Maypole	1.00	0.72	0.63	0.36	0.74	0.69	1
海棠北京1号 <i>Malus</i> sp. Beijing No. 1	0.69	1.00	0.75	0.12	0.00	0.51	8
富平楸子 <i>M. prunifolia</i> (Willd.) Borkh.	0.65	0.40	0.65	0.07	0.40	0.43	16
新疆野苹果 <i>M. sieversii</i> (Ledeb.) Roem.	0.78	0.54	0.38	0.56	0.93	0.64	3
扎矮76 Zha'ai 76	0.20	0.00	0.27	0.03	0.60	0.22	22
辽砧2号 LG2	0.75	0.32	0.27	0.34	0.62	0.46	14
B118	0.78	0.07	0.72	0.34	0.32	0.45	15
杂交优系1 Hybrid superior line 1	0.52	0.37	0.94	0.17	0.33	0.46	12
杂交优系2 Hybrid superior line 2	0.84	0.99	0.14	0.25	0.25	0.50	9
杂交优系3 Hybrid superior line 3	0.10	0.30	0.19	1.00	0.73	0.47	10
自然授粉 Natural pollination	0.63	0.26	0.44	0.44	0.54	0.46	13

注: Y_g 平均隶属值。Note: Y_g . Average membership value.

2.5 不同花粉授粉对瑞香红苹果果实性状的聚类分析

不同花粉授粉后果实性状指标均值聚类分析的结果如图5所示,可将21种花粉授粉效果分为4类,使其特征性指标可视化。通过聚类分析发现,扎矮76、印度和粉红女士授粉果实可分为一类,果实偏斜率大,果形指数小,单果质量比其他授粉组合相对较小,综合排名靠后,其中粉红女士排名最低;舞美、自由与自然授粉、辽砧2号、新疆野苹果、辽伏、金冠、

安娜、王林授粉可分为一类,其中瑞香红用舞美和自由授粉后果实单果质量大,果形指数大,硬度小,用新疆野苹果授粉后果实硬度小、密度大,综合排名靠前;B118、富平楸子、杂交优系1、瑞香红与北京1号海棠及杂交优系2、金世纪、爱妃、长富2号可分为一类。

结合隶属函数和聚类分析的综合结果可知,用舞美授粉后果个大,硬度适中。而扎矮76、粉红女士花粉不适合给瑞香红授粉,其果实单果质量小、偏

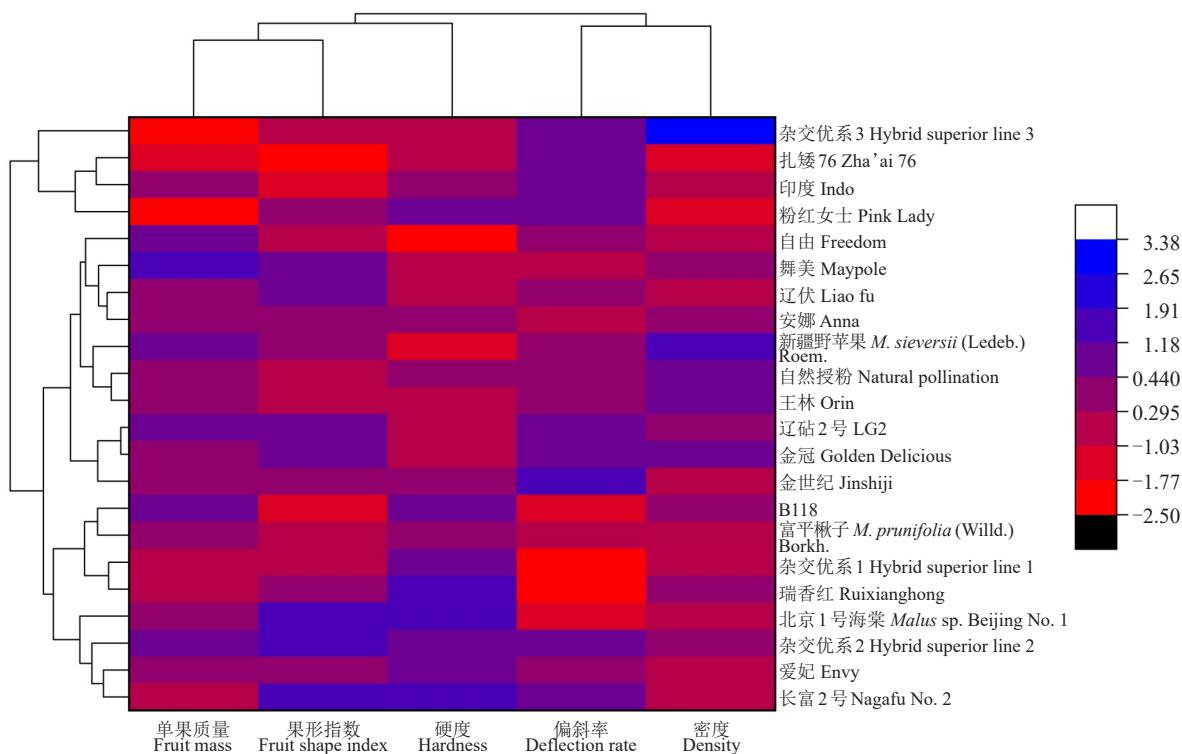


图5 不同花粉授粉后瑞香红苹果果实性状聚类分析

Fig. 5 Cluster analysis heat map of Ruixianghong apple fruit traits after different pollen pollination

斜率高,综合性状差。

3 讨 论

果实大小,果形指数和整齐度是组成果实外观品质的重要指标,也是影响果农经济效益的重要因子。有研究结果表明,较自然授粉,人工授粉对苹果、梨、荔枝等果实单果质量会产生不同程度影响^[23-26]。张曼曼等^[27]用不同花粉授粉富士和红将军苹果后,显著提高了果实单果质量和果形指数;王海儒等^[28]用不同花粉对红富士进行人工授粉后,显著增加了果实单果质量、提高了果形指数,降低了果实偏斜率。本研究中,瑞香红用舞美授粉后单果质量大、偏斜率低,可能与不同花粉浓度和内源激素差异

有关,这与于立洋等^[29]用绚丽海棠花粉授粉后增大新疆野苹果优系果实单果质量,改善果形指数研究结果一致。用粉红女士、扎矮76以及杂交优系3授粉后导致瑞香红单果质量显著低于自然授粉,用金世纪授粉果实偏斜率显著高于对照,表明授粉效应并不一定是正向的影响。猜测原因可能与父本花粉和母本柱头两者的S基因型一致性比例以及不同的花粉来源导致的遗传基础差异有关^[23, 30],也可能与花朵内不同柱头之间的授粉水平相关,从而影响了果实质量和形状^[31]。表明了并不是所有的花粉均适合给瑞香红授粉,对于特定的品种需要选择不同的花粉进行授粉。苹果经不同花粉授粉后,会打破原有内源激素之间的协调,从而对果实生长发育产生

不同的影响^[11,32],其原因需进行深入研究。

果实硬度直接反映果实软化程度,是评价果品运输、储存、加工和抗性的重要指标,同时也是影响消费者鲜食接受度和偏好的主要食用因素^[33-35]。前人研究表明,苹果经不同花粉授粉后显著提高了果实硬度^[36-38];王燕等^[39]发现绿宝苹果授嘎拉花粉后显著降低了果实硬度;张玉刚等^[40]用3种不同花粉为长富2号授粉,结果表明采收后的果实硬度无明显差异。本研究中,瑞香红授粉后果实具有较高的硬度($9.19 \text{ kg} \cdot \text{cm}^{-2}$),不同授粉组合间差异显著,相对于同一地区主栽品种富士苹果的硬度($7.29 \text{ kg} \cdot \text{cm}^{-2}$),果实质地属于硬脆型,这与靳元凯^[17]研究结果不一致,猜测可能是花粉来源不同所致。有研究表明,果实硬度还与细胞间结合力、细胞构成物质机械强度和细胞膨压^[41],以及元素含量^[42-43]、乙烯^[44]及温度^[45]有关,其原因有待研究。此外,硬度是描述果实质地的指标之一,仅硬度难以进行量化比较这一衡量果实组织状态以及食用者口感的综合性状,后期应借助物性分析仪以量化更多的质地参数^[46],以更全面地评价不同花粉对这一性状的影响。

隶属函数是一种常用的多属性决策综合评价方法,可消除果品综合评价中果实时性状不同单位、量纲产生的影响,同时防止单一指标评价授粉效果的片面性。但因衡量果实时品质的各性状指标所占权重不同会影响评价结果,本研究运用隶属函数结合聚类分析可以更客观地评价果实时品质^[47-51]。隶属函数分析和聚类分析已普遍应用于猕猴桃^[52]、板栗^[53]、火龙果^[20]、葡萄^[54]、柑橘^[55]等不同树种中。

笔者利用隶属函数对21份花粉授粉效果进行综合评价,果实时单果质量大,偏斜率和硬度低,被认为综合性状优良。不同花粉的平均隶属函数值在0.36~0.66之间,相差0.30,说明不同花粉之间差异较大,具有较大的选择潜力。运用聚类分析将不同花粉的授粉效果分为4类,其中综合性状最佳的是由舞美、自由等组成的第3类,最差的是由扎矮76、印度和粉红女士组成的第2类。隶属函数分析与聚类分析综合结果基本一致,表明该分析方法可以用于不同花粉对瑞香红授粉效果的综合评价。

笔者在本研究中通过单果质量、果形和果实硬度指标初步评价了不同花粉的授粉效应,而不同的评价因子选择会影响评价结果^[56],糖酸组分、抗氧化物质、香气等也是果实时品质的重要指标,因此后续会

结合更多的果实在品质指标进行分析,同时采用不同的评价方法以更加全面评价筛选到适合瑞香红的花粉,如侯东颖等^[57]和肖艳等^[58]利用主成分分析和聚类分析筛选出了优质的无籽西瓜及大白菜,减少了指标变量的重叠,进一步简化了相关农艺性状评价指标。苹果开花主要与积温有关,而不同地区的环境因素差异可能会影响瑞香红与所选品种花期相遇,从而影响授粉效果,所以试验结果主要是为白水地区的苹果授粉提供参考,而不同花粉对不同地区瑞香红的影响还有待研究。由于苹果授粉受精易受气候和传粉媒介的影响,笔者研究团队更倾向于将筛选出的适宜花粉用于人工授粉。瑞香红经不同花粉授粉能显著提高单果质量,保持高桩特性,同时相较于自然授粉,能在一定程度上降低果实偏斜率和果实硬度。运用隶属函数和聚类分析进行综合评价得出,瑞香红经舞美授粉显著增加果实时单果质量,同时偏斜率低,硬度更加适宜,改善效果突出,同时保持了果形指数,可作为瑞香红的首选花粉。

4 结 论

通过不同花粉对瑞香红的影响分析,得出用舞美和自由授粉效果优良,可作为提升瑞香红单果质量的优秀花粉,用新疆野苹果和自由授粉可作为改善果实时硬度的优选花粉,用杂交优系1和瑞香红授粉可作为降低果实时偏斜率的良好花粉。而用粉红女士、扎矮76、杂交优系3授粉降低了单果质量,用金世纪授粉增大了果实时偏斜率,用北京1号海棠、瑞香红和长富2号授粉增大了果实时硬度。运用隶属函数结合聚类分析对授粉效果进行综合得分排名,舞美花粉在增加果实时单果质量、维持果形、降低偏斜率及硬度方面是瑞香红的首选花粉,而粉红女士花粉不适合给瑞香红授粉。

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