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新疆红肉苹果杂交二代2个功能型株系果实风味品质的评价

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摘 要:【**目的**】探讨杂交二代(F_2)2个功能型苹果优株及对照品种'嘎拉'的果实风味品质,旨在为新疆野苹果资源的利用保存及功能型苹果育种理论与技术提供基本资料。【**方法**】以2个功能型苹果优株'红心7号'和'红心9号'为试材,以栽培品种'嘎拉'为对照,对果实的类黄酮组分、糖酸组分、挥发性成分等风味物质的组成和含量进行检测分析。【**结果**】'红心7号'与'红心9号'硬度、Ca、Fe、Zn和花青苷含量及抗氧化能力均显著或极显著高于'嘎拉';3个参试材料均以果糖和苹果酸含量最高,2个功能型苹果优株糖、酸总量均显著高于'嘎拉';'红心9号'果实各类挥发性成分种类数和特征香气成分种类数最高,含量以'嘎拉'最高,但'红心7号'各类挥发性成分和特征香气成分的种类数及含量均最低;'红心9号'与'红心7号'类黄酮含量分别是'嘎拉'的3.1倍和2.3倍,但'红心9号'味感偏酸,而'红心7号'味感甜酸适口,与'嘎拉'基本一致。【**结论**】'红心7号'硬脆多汁,甜酸适口,果实类黄酮、花青苷和Ca、Fe、Zn含量及抗氧化能力均显著或极显著高于'嘎拉'。因此,从新疆红肉苹果杂交二代分离群体中能够选育出综合品质优良的功能型苹果新品系。

关键词:功能型苹果;杂交二代优株;风味品质;新疆红肉苹果;利用保存
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Evaluation on fruit flavor quality in two second-generation hybrid apple lines

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Abstract:【Objective】Functional apple is defined as a kind of health-promoting apple with high content of flavonoids and can be fresh consumed or processed. Breeding for functional apple is to realize integration of multiple quality traits (genes), which requires multiple parental crosses and repeated backcrosses and selection. In this study, we investigated the flavor quality of two functional apple lines using the conventional cultivar 'Gala' as the control.【Methods】The 2 functional apple lines were 'Hongxin 7' and 'Hongxin 9', which were the second generation of hybrid between 'Gala' and a hybrid F_1 plant from the population of *Malus sieversii* f. *neidzwetzkyana* × conventional cultivars ('Fuji' 'Golden Delicious' 'Starkrimson' 'Hanfu', etc.). Relevant indicators of flavor substances were measured and analyzed. The contents of calcium, iron and zinc were determined with atomic spectrophotometer. Aroma substances were extracted by the solid phase microextraction (SPME) and detected with a GC/MS-QP2010 gas chromatography-mass spectrometer (Shimadzu, JPN). The characteristic aroma components were determined

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using index of aroma value with lg(aroma value) > 0 assigned as the characteristic aroma component. Aroma value was the ratio of a compound content to the aroma threshold of the compound. Sugar and acid components were measured using high performance liquid chromatography (510, Water, US). The flavonoid components were also determined with high performance liquid chromatography (Dionex, US). The firmness and brittleness were measured with a TA.XT plus texture analyzer (Stable Microsystems, Godalming, U.K.). The taste evaluation of fruits was carried out by a group of seven people. 【Results】There were significant differences in some fruit traits among the three tested materials. Some traits, such as fruit size, fruit shape index, brittleness and soluble solids were of no defined pattern. The content of anthocyanins, fruit firmness and antioxidant power in 'Hongxin 7' and 'Hongxin 9' were significantly higher than those in 'Gala'. The contents of calcium, iron and zinc in 'Hongxin 7' and 'Hongxin 9' were significantly higher than those of 'Gala', and calcium in 'Hongxin 7' and 'Hongxin 9' was 1.93 and 1.96 times of that of 'Gala', respectively. Four sugars and seven organic acids were detected from the 3 materials, and the contents of fructose and malic acid were the highest among sugar and acid components, respectively. Sucrose, lactic acid and acetic acid, and other sugars and acids in 'Hongxin 7' and 'Hongxin 9' were significantly higher than those in 'Gala'. Therefore, the two functional apple lines had significantly higher contents of total sugars and acids than 'Gala'. Total sugar content was the highest in 'Hongxin 7', while total acid content highest in 'Hongxin 9'. The ester compounds were the highest aromatic compounds in the 3 tested materials, but the categories and contents of aroma components and characteristic aroma components were different. The numbers of aroma components and characteristic aroma components in 'Hongxin 9' were the highest; but their contents in 'Gala' were the highest, while their numbers and contents in 'Hongxin 7' were the lowest. Flavanoids such as flavanols, dihydrochalcones and flavonols were detected in the 3 tested materials, but their contents differed among the tested materials. Eleven components were detected in 'Hongxin 9' and the total content of flavonoids was (299.49±13.30) $mg \cdot kg^{-1}$, while nine components were detected in 'Hongxin 7' and the total content of flavonoids was (229.21±9.55) $mg \cdot kg^{-1}$. The flavonoid content in 'Hongxin 7' and 'Hongxin 9' was significantly and 3.1 and 2.3 times higher than that of 'Gala', respectively. Based on taste evaluation, 'Hongxin 9' tasted sour, while 'Hongxin 7' and 'Gala' was sweet and sour.【Conclusion】Sugar and acid compositions were consistent in the three detected materials, but the antioxidant power and the contents of flavonoids, anthocyanin, calcium, iron and zinc in 'Hongxin 7' and 'Hongxin 9' were significantly higher than those in 'Gala'. 'Hongxin 7' was hard-crispy and juicy with low categories and contents of aroma components and characteristic aroma components. Similar to 'Gala' ' Hongxin 7' tasted sweet-sour with very light astringency and had a good flesh quality that is highly acceptable among the majority of consumers. Therefore, we can select functional apple cultivars with excellent comprehensive quality from hybrid or backcross progeny segregating populations of *Malus sieversii* f. *neidzwetzkyana*.

Key words: Functional apple; F_2 superior lines; Flavor quality; *Malus sieversii* f. *neidzwetzkyana*; Utilization and preservation

"医食同源"是发展方向，"吃营养，吃健康"已经成为人们的共识[1]。苹果中含有较高比例的、人体容易吸收的游离多酚，在抗氧化、预防心脑血管疾病及抗肿瘤等方面均具有较好的作用，世界上相当多的国家大力推荐其为主要消费果品[2-3]。我国是苹果属（*Malus*）植物的起源演化中心，Velasco等[4]、Steven等[5]及陈学森等[6]对苹果基因组测序、世界范围内3 000余份红肉苹果种质资源R6基因型鉴定与分类以及新疆红肉苹果杂种后代遗传变异的研究结果表明，新疆野苹果及其红肉变型（*Malus sieversii* f.

neidzwetzkyana)是世界栽培及红肉苹果的祖先种，遗传多样性丰富，是品质育种的珍贵基因库。因此，进一步有效利用新疆野苹果资源培育类黄酮含量高的功能型苹果等特色多样化品种，符合保护自然、利用自然、回归自然的发展理念，对新疆野苹果资源的科学保护与持续高效利用、栽培苹果品种遗传基础拓展、苹果产业供给侧改革与转型升级及人类健康水平提升等均具有重要意义[7-8]。

功能型苹果是指“在果实中富含类黄酮、可鲜食或加工的保健型苹果”，因此功能型苹果育种是多个品质性状（基因）的有效集成与平衡[9]。为全面提升育种效率，笔者课题组一方面提出并实施了“三选两早一促”的苹果育种法（专利号ZL201310205419.6）、易着色苹果品种培育法及果树多种源品质育种法，创建了高效育种技术体系[10]；另一方面，及时地以性状基本稳定的后代株系为果实试材，对绵/脆肉[11-12]、糖/类黄酮[3, 9, 13-15]及硬度/香气[1]等品质性状的发育机制进行了研究，结果表明，在功能型苹果新品系选育过程中，必须注意风味品质与贮藏品质、外观品质（花青苷含量）与保健品质（黄烷醇和黄酮醇含量）以及保健品质与鲜食品质的平衡问题。王立霞等[16]以新疆红肉苹果×‘红富士’F_1群体中选出的4个功能型苹果优株为试材研究表明，4个参试优系的香气成分种类数及其含量、糖酸含量及糖酸比等风味品质构成因素存在明显差异，进一步与‘富士’等苹果品种进行回交改良很有必要；而刘静轩等[1]研究发现，从新疆红肉苹果杂交一代(F_1)与‘嘎拉’苹果品种的杂交二代(F_2)中选育出的‘红心7号’和‘红心9号’2个功能型苹果新品系，在贮藏期间的果实硬度、乙烯释放速率、酯类含量以及相关基因的表达量均存在明显差异，‘红心7号’耐贮性明显优于‘红心9号’，但有关这2个优系的果实风味品质评价，目前尚未见研究报道。因此，笔者对‘红心7号’与‘红心9号’及对照品种‘嘎拉’果实风味品质进行了评价，旨在为新疆野苹果资源的利用保存及功能型苹果育种理论与技术的构建提供基本资料。

1 材料和方法

1.1 材料

试验于2014—2016年在山东农业大学作物生物学国家重点实验室和聊城市冠县果树育种基地进行，材料为新疆红肉苹果(*Malus sieversii* f. *neidzwetzkyana*)与‘富士’‘金冠’‘新红星’和‘寒富’等苹果品种杂种一代(F_1)群体中的30~40株红肉株系混合花粉与‘嘎拉’苹果品种杂种后代选出的‘红心7号’和‘红心9号’2个功能型苹果株系。各试材均为中早熟品种，树龄均为5 a生，生长结果正常。试验地为沙壤土，地势平坦，管理条件一致。于2014年7月28日即果实成熟期采收。

对照为苹果栽培品种‘嘎拉’，采自泰安市道朗镇更新的25 a生老龄苹果园。每株系和品种采集完全成熟的果实样品20个，用冰盒带回实验室，用于类黄酮组分、香气成分、糖酸组分等各项指标的测定。

1.2 方法

1.2.1 果实部分常规指标的测定 单果质量、果形指数、可溶性固形物含量、抗氧化能力的测定参照陈学森等[6]的方法进行；硬度与脆度的测定使用英国Stable MicroSystems公司生产的TA.XT plus型质构仪，参照Zhang等[17]的方法进行；花青苷的测定参考孙莎莎等[18]的方法进行；利用原子分光光度计测定果肉钙、铁、锌含量[19]；参照苹果种质资源描述标准[20]，组成7人品评小组，评价各品种果实味感特征。

果质量、果形指数、可溶性固形物含量的测定均10次重复，取平均值；果实硬度与脆度、矿质元素、花青苷含量、抗氧化能力等指标测定均3次重复，取平均值。

1.2.2 香气物质的提取与检测 参照王传增等[21]的方法，使用美国Supelco公司生产的固相微萃取器手柄及SPME纤维萃取头50/30 μm DVB/CAR/ PDMS进行萃取。果实洗净切碎后准确称取25 g放入50 mL锥形瓶中，加入内标物3-壬酮($0.1\ g\cdot L^{-1}$)5 μL，加盖封口后平衡10 min，再插入事先老化好的纤维萃取头萃取40 min，进行GC-MS检测。香气物质的检测利用Shimadzu GC/MS-QP2010气相色谱-质谱联用仪。定性方法：用计算机检索并与NIST05质谱库相匹配，结合人工图谱解析及资料分析确定相关香气物质成分。定量方法：选择质量浓度$0.1\ g\cdot L^{-1}$的3-壬酮为内标，其体积为5 μL，并用SIM（选择离子检测）方式定量。计算公式为：香味各组分的质量分数/($\mu g\cdot g^{-1}$)=[各组分的峰面积/内标的峰面积×内标浓度($g\cdot L^{-1}$)×1 000]/样品质量(g)。

通过计算lg（香气值）来确定特征香气成分，lg（香气值）> 0的成分为特征香气成分。香气值=某

种化合物含量/该化合物香气阈值。

1.2.3 果实糖酸组分的提取与测定 测定方法参照王立霞等[16]的方法,采用美国510型Waters高效液相色谱仪进行糖酸组分测定,利用N2000色谱工作站(Ver.3.30)计算糖酸组分含量。

1.2.4 果实类黄酮组分的提取与测定 参照陈学森等[6]的方法,采用美国Dionex公司的高效液相色谱系统进行测定,采用安捷伦公司的反相C18色谱柱(4 μm粒径,250 mm × 4.6 mm),美国Waters公司的C18 Nova Pack保护柱。柱温45 ℃,进样体积1 μL。采用Dionex PDA-100检测器,PAD扫描波长为200~700 nm。流动相:已过滤的乙腈(A),体积分数为0.2%的甲酸溶液(B);梯度:A:0~0.1 min,5%;A:20 min,20%;A:22 min,80%;A:22.1 min,5%;A:25 min,5%,流速为0.3 mL·min^{-1}。350 nm分析黄酮醇类物质,280 nm分析黄烷醇和二氢查尔酮类物质。

1.3 数据分析

采用Excel进行数据处理和作图,用DPS7.05进行显著性检验。

2 结果与分析

2.1 果实形态及品质性状

参试材料的果实大小等性状的测定结果见表1。由表1可以看出,'红心7号'与'红心9号'的花青苷含量、抗氧化能力、硬度、Ca、Fe、Zn含量均显著或极显著高于'嘎拉';'红心9号'味感偏酸,'红心7号'味感甜酸适口,与'嘎拉'基本一致。

表1 2个功能型苹果株系及其对照'嘎拉'部分果实性状的比较

Table 1 Fruit characters comparison among 2 functional apple lines and 'Gala'

试材 The test material	花青苷含量 Anthocyanin content/(U·g^{-1})	ω(Ca)/(μg·g^{-1})	ω(Fe)/(μg·g^{-1})	ω(Zn)/(μg·g^{-1})	果实质量 Fruit weight/g	果形指数 Shape index	硬度 Firmness/(kg·cm^{-2})	脆度 Fracturability/(kg·s^{-1})	抗氧化能力 Ferric reducing antioxidant power/(μmol·g^{-1})	ω(可溶性固形物) Soluble solids content/%	味感评价 Taste evaluation
嘎拉 Gala	0	12.692 b	12.350 b	1.042 c	113.80 a	0.93 a	0.425 c	1.208 b	17.427 C	12.64 B	甜酸 Sweet and sour
红心7号 Hongxin 7	15.514 B	24.49 7a	27.838 a	2.070 a	84.98 b	0.93 a	0.650 a	1.185 b	22.586 B	13.93 A	甜酸 Sweet and sour
红心9号 Hongxin 9	32.586 A	24.873 a	12.692 c	1.242 b	71.40 c	0.89 b	0.460 b	1.739 a	31.074 A	13.94 A	偏酸 More acidic

注:不同小写字母代表 $P < 0.05$ 差异显著,不同大写字母代表 $P < 0.01$ 差异极显著。下同。

Note: Different small letters mean significant difference at $P < 0.05$, different capital letters mean significant difference at $P < 0.01$. The same below.

2.2 果实香气成分种类及含量

由表2和表3可以看出,2个功能型苹果株系及其对照'嘎拉'果实各类挥发性成分种类数和特征香气成分及其含量存在明显差异,'红心9号'果实各类挥发性成分总种类数和特征香气成分数最高,但含量以'嘎拉'最高,'红心7号'果实各类挥发性成分总种类数和特征香气成分数及其含量均最低。

2.3 果实糖酸组分及含量

由表4可以看出,所有参试材料均检测到4种糖和7种有机酸组分,在各种组分中,均以果糖和苹果酸含量最高。2个功能型苹果优株糖与酸总量均显

表2 2个功能型苹果株系及其对照'嘎拉'果实各类挥发性成分种类数及含量

Table 2 Categories and contents of aroma components in the 2 functional apple lines and 'Gala'

化合物 Compound	嘎拉 Gala		红心7号 Hongxin 7		红心9号 Hongxin 9	
	种类 Type	ω/(μg·g^{-1})	种类 Type	ω/(μg·g^{-1})	种类 Type	ω/(μg·g^{-1})
酯类 Esters	27	3.714	6	0.267	35	2.761
醇类 Alcohols	2	0.527	3	0.153	5	0.108
烷烃类 Alkanes	4	0.016	5	0.098	9	0.102
醛类 Aldehydes	3	0.134	5	0.059	3	0.050
萜烯类 Terpenes	4	0.151	1	0.125	3	0.108
酮类 Ketones	1	0.004	1	0.021	1	0.010
杂环类 Heterocycles	2	0.010	1	0.089	1	0.007
总种类数及含量 Total numbers and contents	43	4.557	22	0.812	57	3.109

表3 2个功能型苹果株系及其对照'嘎拉'果实的特征香气成分及含量

Table 3 Contents of character impact volatile constituents in the 2 functional apple lines and 'Gala'

挥发性成分 Volatile compounds	香气阈值 Odor threshold/(ng·g⁻¹)	ω/(μg·g⁻¹) 嘎拉 Gala	红心7号 Hongxin 7	红心9号 Hongxin 9
1-己醇 1-hexanol	500	0.526 1(0.02)	–	–
己醛 Hexanal	10.5	0.051 5(0.69)	0.010 9(0.02)	–
(E)-2-己烯醛 (E)-2-hexenal	17	0.077 5(0.65)	–	0.033 7(0.30)
壬醛 Nonanal	1	–	0.015 2(1.18)	–
乙酸丁酯 Butyl acetate	66	0.151 0(0.36)	–	0.146 0(0.34)
乙酸戊酯 Pentyl acetate	43	0.076 3(0.25)	–	0.061 5(0.16)
乙酸己酯 Hexyl acetate	2	1.285 4(2.81)	0.158 1(1.90)	0.933 7(2.67)
乙酸-2-甲基丁酯 2-methylbutyl acetate	11	0.774 6(1.85)	–	0.509 8(1.67)
乙酸-(E)-3-己烯酯 (E)-3-hexenyl acetate	2	0.308 2(2.19)	0.096 9(1.69)	0.098 2(1.69)
丙酸丁酯 Propanoic acid, buty	25	–	–	0.126 0(0.70)
丙酸己酯 Propanoic acid, hexyl	8	0.034 7(0.64)	–	0.091 8(1.06)
丁酸乙酯 Ethyl butyrate	1	0.079 3(1.90)	–	0.023 9(1.38)
丁酸丙酯 Propyl butyrate	18	–	–	0.101 2(0.75)
丁酸丁酯 Butyl butyrate	100	–	–	0.107 8(0.03)
丁酸己酯 Hexyl butyrate	250	–	–	0.285 1(0.06)
2-甲基丁酸丁酯 Butyl 2-methylbutyrate	17	0.053 1(0.49)	–	0.048 7(0.46)
2-甲基丁酸己酯 Hexyl 2-methylbutyrate	6	0.040 2(0.83)	–	0.050 7(0.93)
己酸乙酯 Ethyl pentanoate	1	0.226 1(2.35)	–	0.019 1(1.28)
种类数 Numbers		13	4	15
ω/(μg·g⁻¹)		3.684 0	0.281 1	2.637 2

注:括号中数值为香气值的常用对数值。

Note: The numerical value in parenthesis was the common logarithm of odour unit value.

表4 2个功能型苹果株系及其对照'嘎拉'果实的糖酸组分

Table 4 Contents of sugar and acid constituents in the 2 functional apple lines and 'Gala'

ω/(mg·g⁻¹)

组分 Content	嘎拉 Gala	红心7号 Hongxin 7	红心9号 Hongxin 9
果糖 Fructose	52.603 c	58.245 a	55.648 b
葡萄糖 Glucose	8.106 b	10.796 a	8.366 b
蔗糖 Sucrose	26.510 a	17.251 c	20.648 b
山梨醇 Sorbic alcohol	2.756 c	6.882 b	8.077 a
草酸 Oxalic	0.272 b	0.291 b	0.372 a
苹果酸 Malic	1.884 c	2.927 b	3.315 a
乳酸 Lactic acid	0.295 a	0.016 b	0.031 c
枸橼酸 Citric acid	0.032 c	0.058 b	0.110 a
琥珀酸 Succinic acid	0.060 b	0.072 b	0.103 a
酒石酸 Aartaric acid	0.067 c	0.081 b	0.139 a
乙酸 Acetic acid	0.003 a	0.003 a	0.002 a
总糖 Total sugar	89.975 c	93.174 b	92.739 a
总酸 Total acid	2.615 c	3.448 b	4.072 a

著高于'嘎拉'。

2.4 果实类黄酮组分及含量

由表5可以看出,3个参试材料果实类黄酮组分及其含量存在明显差异。所有参试材料均检测到黄烷醇、二氢查尔酮和黄酮醇3类类黄酮,其中从'红心9号'果实中检测到黄烷醇、二氢查尔酮和黄酮醇3类11种组分,总质量分数高达(299.49±13.30) mg·kg⁻¹,而'红心7号'果实中检测到黄烷醇、二氢查尔酮和黄酮醇3类9种组分,总质量分数为(229.21±9.55) mg·kg⁻¹,2个功能型苹果株系果实类黄酮含量显著高于'嘎拉'。

3 讨 论

糖既是类黄酮合成的前体物质,也是调节类黄酮生物合成的信号物质[22]。研究发现,'金冠'味感甜酸,'红脆1号'味感偏酸,'红脆1号'糖总量显著低于'金冠'[16],而类黄酮含量则高于'金冠'[6,23],这与'皇家嘎拉'的研究结果一致[24-25]。以上研究表明,果实类黄酮含量的提高会伴随果实涩味的增加,降低果实的鲜食品质。因此,糖和类黄酮的平衡与调控是功能型苹果果实品质调控的核心[9]。Vogt等[26]研究表明,花青苷等类黄酮糖苷的合成场所是细胞质,且合成的底物是糖。许海峰等[15]以新疆红肉苹果杂种一代优系'红脆1号'为试材研究发现,MdVGT1可能与MdTMT1在液泡膜形成复合体共同转运细胞质中的葡萄糖进入液泡,从而增加果实含糖量,提高鲜食品质;进一步研究发现,MdSUT4定

表5　2个功能型苹果株系及其对照'嘎拉'果实果肉类黄酮组分及其含量

Table 5 Comparison of the composition and contents of flavonoids in flesh among the 2 functional apple lines and 'Gala'

ω/(mg·kg^{-1})

类黄酮 Flavonoid		嘎拉 Gala	红心7号 Hongxin 7	红心9号 Hongxin 9
黄烷醇 Flavanols	原花青素B2 Procyanidin B2	1.13±0.05 c	3.29±0.54 b	4.83±1.05 a
	表儿茶素 Epicatechin	39.88±5.58 c	101.76±1.21 b	113.42±1.08 a
	儿茶素 Catechin	28.83±1.58 b	37.28±7.07 ab	44.49±4.85 a
二氢查耳酮 Dihydrochalcones	根皮素-葡萄糖苷 Phloretin glucoside	1.22±0.16 c	2.56±0.59 b	3.49±0.39 a
	根皮苷 Phloridzin	6.96±1.36 b	23.38±6.25 a	10.36±0.54 b
黄酮醇 Flavonols	槲皮素 Quercetin	19.10±1.57 c	58.98±6.59 b	121.24±10.06 a
	槲皮素-半乳糖苷 Quercetin galactoside	0.72±0.05 b	1.39±0.15 a	0.94±0.16 b
	槲皮素-葡萄糖苷 Quercetin glucoside	0.56±0.12 a	0.40±0.25 a	0.50±0.21 a
	槲皮素-木糖苷 Quercetin xyloside	0	0.17±0.14 a	0.13±0.06 a
	槲皮素-阿拉伯糖苷 Quercetin arabinoside	0.02 b	0	0.04±0.02 a
	槲皮素-鼠李糖苷 Quercetin rhamnoside	0	0	0.03±0.01
合计 Total		98.04±5.72 c	229.21±9.55 b	299.49±13.30 a

位于苹果液泡膜，可能将蔗糖从液泡中转运到细胞质，降低液泡中糖含量，增加了胞质中类黄酮合成的前体物质，从而促进类黄酮的合成[9]。本研究结果表明，'红心7号'果实类黄酮含量虽然是'嘎拉'的2.3倍，但糖总量显著高于'嘎拉'与'红心9号'。因此，'红心7号'果实的涩味很轻，整体味感甜酸适口，与'嘎拉'基本一致，在多数消费者的可接受范围之内。

钙是我国居民较易缺乏的膳食营养素之一[27]。人体钙摄入不仅和骨骼健康有关系，而且与预防慢性疾病发生密切相关，充足的钙摄入有利减少癌症、糖尿病、高血压、骨质疏松症等慢性疾病的风险[28-30]。在"医食同源"的背景下，食补补钙是比较科学的补钙方式，而苹果是人类膳食中Ca、Fe、K等矿质元素重要来源之一，与人类的健康有密切关系[31-32]。冯涛等[33]以新疆野苹果78个实生株系果实为试材，初步筛选出了大果型、高钙型、高锌型和大马酮型等4个特异性状单株。张小燕等[34]进一步研究发现，新疆野苹果单株钙含量普遍较高，钙平均含量是'富士''金帅'等栽培苹果品种的3.1倍。陈学森等[6]研究表明，新疆红肉苹果与'红富士'杂交F_1代群体果实Ca含量的平均值高于亲中值，具有明显的超亲遗传现象，并且出现广泛分离，变异系数在20%以上，遗传能力强，进一步选择的潜力很大。本文研究表明，杂交二代(F_2)群体中的'红心7号'与'红心9号'Ca、Fe、Zn含量均显著高于'嘎拉'，Ca含量分别是'嘎拉'的1.93倍和1.96倍。因此，进一步探讨功能型苹果株系高钙的分子机制，挖掘、鉴定钙高效基因型，是今后研究的重要切入点。

已有的研究表明，新疆红肉苹果杂交一代(F_1)群体选育出的'红脆1号'等4个优系风味品质存在明显差异，鲜食品质较差[16]。本研究发现，从杂交二代(F_2)群体选育出的'红心7号'，果实类黄酮、花青苷和Ca、Fe、Zn含量及抗氧化能力均显著或极显著高于'嘎拉'，果肉硬脆多汁，甜酸适口。上述研究结果表明，从新疆红肉苹果杂交二代(F_2)分离群体中能够选育出综合品质性状优良的功能型苹果新品系。

4　结　论

'红心7号'硬脆多汁，甜酸适口，果实类黄酮、花青苷和Ca、Fe、Zn含量及抗氧化能力均显著或极显著高于'嘎拉'。因此，从新疆红肉苹果杂交二代(F_2)分离群体中能够选育出综合品质优良的功能型苹果新品系。

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