

‘玉露香’梨果实发育过程中糖、酸积累特性研究

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摘要:【目的】了解‘玉露香’梨果实发育中糖、酸含量变化。【方法】采用高效液相色谱法,对其糖、酸组分含量进行测定。【结果】在‘玉露香’梨果实生长发育过程中,总糖含量呈“慢一快一慢一快”的上升趋势;总酸含量呈先上升后下降的趋势;幼果期果实中的糖以山梨醇为主,酸以苹果酸为主;成熟果实中的糖以果糖为主,酸仍以苹果酸为主,成熟时果糖含量占总糖含量的43.07%,柠檬酸和苹果酸含量占总酸含量的71.9%。蔗糖含量从坐果到花后60 d内一直保持较低水平,从花后60 d开始迅速上升,直到成熟期其含量上升了3.81倍。山梨醇含量从坐果到花后75 d,含量逐渐上升并达到最大值,之后开始下降。【结论】‘玉露香’梨为高果糖型果实;按照苹果酸型、柠檬酸型和酒石酸型三大果实类型分类,属苹果酸型。

关键词:‘玉露香’梨;糖;酸;品质

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Study on sugar and organic acid accumulation during fruit development in ‘Yuluxiang’ pear

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Abstract:【Objective】Sugar and organic acid contents in the fruit are not only the dominant factor affecting fruit quality, but also the basic raw material for synthesis of carotenoids, vitamins, pigments and aromatic substances, which determines the quality of fruit flavor. Sugar and organic acid accumulated differently in different kinds of fruits. The aim of this research is to understand the changes about the sugar and organic acid contents during fruit development of ‘Yuluxiang’ pear.【Methods】The contents of sugar and organic acid were determined by the High Performance Liquid Chromatography(HPLC). Earlier researches showed that the major components of soluble sugars were sucrose, glucose, fructose and sorbitol. The fructose content showed the highest value, and the glucose content was the second, the proportion of these two sugars to total soluble sugars was 72.17%, and sucrose content was the lowest, and glucose and fructose showed a very significant positive correlation with total soluble sugars. The major components of organic acids were malic acid, citric acid, quinic acid, shikimic acid, and oxalic acid. The contents of malic acid and citric acid were significantly higher than others, and the proportion of the two organic acids to total organic acids was 89.79%, and this showed a very significant positive correlation with total organic acids. In terms to different species, the contents of total soluble sugars and total organic acids in *Pyrus bretschneideri* Rehd. and *P. pyrifolia* (Burm. f.) Nakai were relatively lower, the contents in *P. ussuriensis* Msxim. were relatively higher, the content of total soluble sugars in *P. sin-*

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kiangensis Yu was relatively higher, and total organic acids was intermediate, the content of total soluble sugars in *P. communis* Linn. was relatively higher, and total organic acid was the highest. The ratio of total sugars to total acids varied considerably and ranged from 6.95 to 33.87, and the ratio of total sugars to total acids was higher in *P. bretschneideri* Rehd. and *P. pyrifolia* (Burm. f.) Nakai, *P. ussuriensis* Msxim. and *P. sinkiangensis* Yu were intermediate, and *P. communis* Linn. was relatively lower. 【Results】The results showed that, during ‘Yuluxiang’ pear fruit development, the total sugar content showed the “slow-fast-slow-fast” ascending trend. It can be roughly divided into four stages: the first stage was from early May to late Jun, which was from fruit setting to 60 days after anthesis, when the soluble sugar content in fruit increased slowly; the second stage was from late June to late July (from 60 days after anthesis to 90 days after anthesis), when the total sugar content increased rapidly, which was the first peak of sugar accumulation; the third stage was from late July to early August (from 90 days after anthesis to 105 days after anthesis), when the total sugar content changed insignificantly; and the fourth stage was from early August to fruit maturity, which was the second peak of sugar accumulation, when the total sugar content began to increase rapidly, and reached the highest value at harvest. The total acid content was the “up-down” trend during ‘Yuluxiang’ pear fruit development. It can be roughly divided into three stages: the first stage was from early May to late June (from fruit setting to 60 days after anthesis), when the organic acid content increased slowly; the second stage was from late June to early August (from 60 days after anthesis to 105 days after anthesis), when the organic acid content accumulated rapidly and reached its peak; and the third stage was from early August to fruit maturity (after 105 days after anthesis), when the organic acid content began to decline rapidly. In the young-fruit period, the main type of sugar and acid was sorbitol and malic acid, respectively. In the mature period, fructose was the main fruit sugar, and malic acid was the main acid. In the mature period, the fructose took up 43.07% of the total sugar and the malic acid took up 71.9% of the total acid. The sucrose content remained low from fruit setting to 60 days after anthesis. From 60 days after anthesis to pre-maturity, sucrose content began to rise rapidly, and its content increased by 3.81 times. Sorbitol content increased gradually and reached its maximum from fruit setting to 75 days after anthesis, and then began to decrease. 【Conclusion】‘Yuluxiang’ pear is a fruit with high fructose content, and it should be classified as the malic acid type according to three conventional fruit classification: malic acid type, citric acid type and tartaric acid type.

Key words: ‘Yuluxiang’ pear; Sugar; Organic acid; Quality

果实糖酸含量不仅是果实品质优劣的主导因素,而且是类胡萝卜素、维生素、色素和芳香物质等合成的基础原料,决定着果实风味的好坏^[1-2]。糖酸在不同种类果实中有着不同的积累模式。草莓果实发育过程中,葡萄糖、果糖和蔗糖的含量持续增加,而蔗糖在成熟期才开始快速积累^[3]。桃果实发育过程中,果糖和葡萄糖含量有下降趋势,蔗糖在成熟前则急剧增加且成熟时以蔗糖含量为主^[4]。‘鲜黄梨’在果实的整个发育期内,果实的果糖、葡萄糖、蔗糖及总糖含量逐渐增加,山梨糖醇含量先增加后降低^[5]。‘南果梨’幼果期果实的可溶性糖以山梨醇为主,花后80 d果糖的含量超过山梨醇含量,到果实采

收时果糖含量占总糖含量的50.9%,成为果实中最主要的糖分;果实幼果期不含蔗糖,仅在近成熟期出现蔗糖并迅速积累,在采收时达到最大值^[6]。‘云红梨1号’和‘美人酥’幼果期果实可溶性糖以山梨醇为主,在成熟期含量有所下降。成熟的‘美人酥’中山梨糖醇含量低于果糖和蔗糖,而成熟的‘云红梨1号’果实中山梨糖醇仍是含量最多的糖,其次为果糖,蔗糖和葡萄糖的含量较低^[7]。梨果实中的可溶性糖主要由果糖、葡萄糖、蔗糖和山梨醇组成。所有天然糖中果糖甜度最高;葡萄糖的甜度约为蔗糖的一半,山梨醇甜度与葡萄糖相当,具有清凉的甜味,能给人以浓厚感^[8-10]。

果实中有机酸组分和含量是影响其风味品质形成的重要因素之一^[11]。梨果实中有机酸主要是苹果酸和柠檬酸,根据柠檬酸和苹果酸比值可将不同品种划分为苹果酸优势型和柠檬酸优势型。白梨、砂梨和新疆梨中两种类型都有,但主要是苹果酸优势型^[12-13]。果实中的有机酸通常在果实发育早期形成,随着果实成熟逐渐减少。有机酸减少的主要原因是部分有机酸会转变为糖^[14]。

目前有关‘玉露香’梨的研究,大多集中于生物学特性和栽培管理技术等方面,未见‘玉露香’梨果实品质发育动态的相关报道,而对其糖酸组分与含量特征的系统了解,掌握果实生长发育规律是梨优质、高效生产的基础^[15]。笔者对‘玉露香’梨果实发育过程中糖、酸积累特性进行了研究,旨在为全面系统了解‘玉露香’梨品质形成机理积累数据,为‘玉露香’梨标准化、优质生产提供科学依据。

1 材料和方法

1.1 试验材料

‘玉露香’梨采自山西省农业科学院果树研究所梨示范园,地处北纬37°26',东经112°32',年均气温9.8 °C,大于10 °C的年积温3 529 °C,年日照时数2 500~2 600 h,无霜期149 d,年降雨量450 mm左右,蒸发量为降水量的4倍,约1 800 mm,海拔高度750 m。树龄为15 a(年)左右,树形为疏散分层形,分别在树冠外围四周,于落花坐果后15 d开始,每15 d在每株树冠外围不同方向随机选取10个大小一致、无病害的果实用于指标测定,直至果实成熟。将梨果实清洗、去皮、去核,采用四分法取样,可食用部分破碎混匀,再打成匀浆,液氮速冻后放-70 °C超低温冰箱保存备用。

1.2 测定方法

糖酸测定参照文献[16-18]的方法,并加以改良。称取冷冻保存的果肉2 g放入研钵中,加入80%乙醇溶液提取,置于37 °C恒温水浴锅30 min,超声波提取15 min,在4 °C下12 000 r·min⁻¹离心15 min,上清液转到25 mL容量瓶中,重复提取3次,定容。取2 mL用旋转蒸发仪蒸干,用超纯水定容1 mL,经过C₁₈SPE固相萃取小柱过滤固体并祛除叶绿素等有色物质,0.45 μm滤膜过滤,待上机分析。可溶性糖的测定:色谱条件:流速0.8 mL·min⁻¹;流动相为脱气后的超纯水。有机酸的测定:流动相为

2% 甲醇和98% 20 mmol·L⁻¹磷酸氢二钠缓冲液,流速0.7 mL·min⁻¹。

1.3 数据处理

数据采用SAS软件分析。

2 结果与分析

2.1 ‘玉露香’梨果实不同发育时期可溶性糖含量变化动态

2.1.1 总糖含量的变化动态 ‘玉露香’梨果实中可溶性糖含量呈“慢—快—慢—快”的动态变化趋势,大致可分为四个阶段:第一阶段,从坐果至花后60 d(5月上旬至6月下旬),果实中可溶性总糖含量缓慢升高;第二阶段,从花后60 d至花后90 d(6月下旬至7月下旬),为第一个糖积累高峰,此时总糖含量上升较快;第三阶段,花后90 d至花后105 d(7月下旬至8月上旬),总糖含量变化不大;第四阶段,从花后105 d以后(8月初至果实成熟),为第二个糖积累高峰,总糖含量又开始迅速增加,并于采收时达到最高值(图1)。

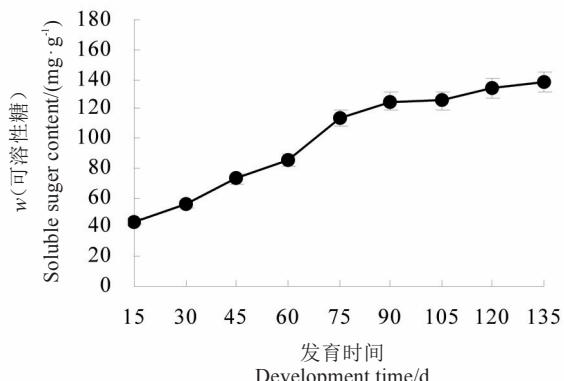


图1 ‘玉露香’梨果实发育过程中可溶性糖含量的变化动态

Fig. 1 Change of soluble sugar content during fruit development in ‘Yuluxiang’ pear

2.1.2 果糖、葡萄糖、蔗糖、山梨醇含量及百分比的变化动态 ‘玉露香’梨果实中的可溶性糖总糖主要包括:果糖、葡萄糖、蔗糖和山梨醇。第一阶段,组分糖含量均保持在相对稳定的水平,其中山梨醇含量最高,占51.52%;其次为果糖、葡萄糖,含量分别占32.68%和9.92%;蔗糖含量最低,占5.88%。第二阶段,山梨醇、果糖、葡萄糖、蔗糖含量分别上升了2.44、1.80、1.62、1.19倍,分别占总含糖量的41.83%、36.13%、12.22%、9.81%。第三阶段,总含糖量无明显变化,但组分糖中,果糖含量迅速上升,山梨醇含

量迅速下降。第四阶段,果糖含量继续上升,其在总糖含量中所占比例上升至45.82%,葡萄糖含量在此期间有所积累,上升至17.56%,蔗糖含量上升至13.85%,山梨醇含量下降至22.77%。

从‘玉露香’梨果实整个发育期来看,幼果期果实中糖分以山梨醇为主,其次为果糖;随着果实的成熟山梨醇含量快速降低,果糖快速积累,成熟时果糖含量最高,依次为山梨醇、葡萄糖、蔗糖(图2)。

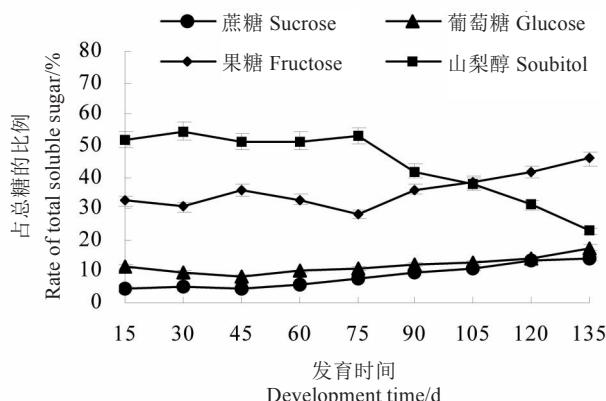


图2 ‘玉露香’梨果实发育过程中不同糖所在比例的动态变化

Fig. 2 Change of different soluble sugar rate during fruit development in ‘Yuluxiang’ pear

2.2 ‘玉露香’梨果实不同发育时期有机酸含量变化动态

2.2.1 总酸含量的变化动态 ‘玉露香’梨果实中有机酸含量总体呈先上升后下降的动态变化趋势,此过程大致可分为三个阶段:第一阶段,从坐果至花后60 d(5月上旬至6月下旬),果实中有机酸含量缓慢上升;第二阶段,从花后60 d至花后105 d(6月下旬至8月上旬),有机酸含量快速积累并达到高峰;第三阶段,花后105 d之后(8月上旬至果实成熟期),有机酸含量开始迅速下降(图3)。

2.2.2 苹果酸、柠檬酸、奎尼酸、莽草酸、草酸含量及百分比的变化动态 ‘玉露香’梨果实中的有机酸主要由苹果酸、柠檬酸、奎尼酸、莽草酸、草酸组成。果实生长发育进程中,各种有机酸含量变化的差别较大。苹果酸、柠檬酸含量的变化趋势与有机酸基本相同,成熟时苹果酸、柠檬酸含量分别比峰值下降了38.20%和55.94%。奎尼酸、莽草酸、草酸在整个果实生长期都呈现缓慢上升的趋势。果实成熟时苹果酸含量最高,占总有机酸的71.91%,其次为柠檬酸占20.61%,两种酸占总酸的比例是92.52%,并且与

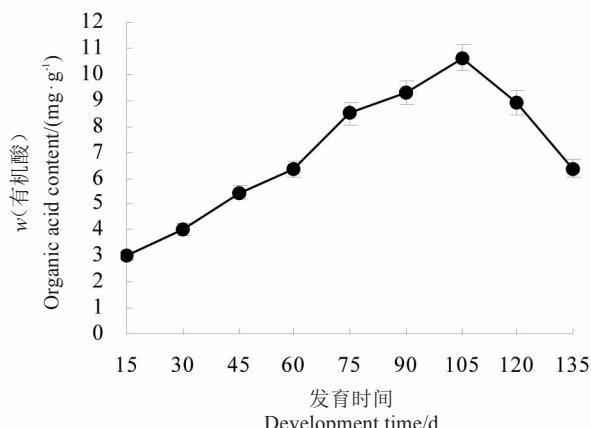


图3 ‘玉露香’梨果实发育过程中不同酸含量的变化动态

Fig. 3 Change of different organic acid during fruit development in ‘Yuluxiang’ pear

总酸呈极显著正相关;奎尼酸、莽草酸分别占总酸含量的4.44%和2.38%,草酸所占比例最低,仅占0.66%(图4)。

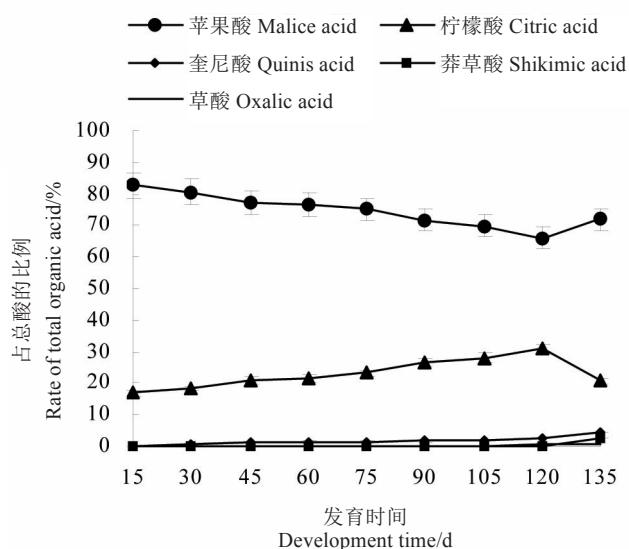


图4 ‘玉露香’梨果实发育过程中不同酸所在比例的动态变化

Fig. 4 Change of different organic acid rate during fruit development in ‘Yuluxiang’ pear

2.3 ‘玉露香’梨果实中可溶性糖和有机酸之间的相关性分析

对‘玉露香’梨果实的可溶性糖和有机酸组分进行相关性分析(表1),结果表明,总糖含量与蔗糖、葡萄糖和果糖含量呈极显著正相关,与果糖的相关性最强($r = 0.948^{**}$)。总酸含量与苹果酸和柠檬酸含量呈极显著正相关,且相关性都很强,相关系数分别是0.992和0.976。总糖含量与总酸含量呈极显著正

表1 可溶性糖和有机酸组分的相关性分析

Table 1 The correlation analysis of the soluble sugar and organic acid components

	蔗糖 Sucrose	葡萄糖 Glucose	果糖 Fructose	山梨醇 Soubitol	总糖 Total sugar	苹果酸 Malice acid	柠檬酸 Citric acid	奎尼酸 Quinis acid	莽草酸 Shikimic acid	草酸 Oxalic acid	总酸 Total acid
蔗糖 Sucrose	1										
葡萄糖 Glucose	0.989**	1									
果糖 Fructose	0.984**	0.983**	1								
山梨醇 Soubitol	0.289	0.263	0.288	1							
总糖 Total sugar	0.944**	0.935**	0.948**	0.573	1						
苹果酸 Malice acid	0.623	0.579	0.627	0.863**	0.813**	1					
柠檬酸 Citric acid	0.699*	0.620	0.686*	0.710*	0.813**	0.945**	1				
奎尼酸 Quinis acid	0.969**	0.982**	0.986**	0.340	0.955**	0.644	0.662	1			
莽草酸 Shikimic acid	0.636	0.729*	0.661	-0.256	0.491	-0.036	-0.063	0.695*	1		
草酸 Oxalic acid	0.944**	0.958**	0.948**	0.053	0.832**	0.382	0.463	0.945**	0.809**	1	
总酸 Total acid	0.692*	0.639	0.691*	0.806**	0.850**	0.992**	0.976**	0.695*	0.003	0.459	1

注:**表示极显著相关关系($p < 0.01$), *表示显著相关关系($p < 0.05$)。

Note: **shows correlation is extremely significant($p < 0.01$), *shows correlation is significant($p < 0.05$).

相关。在各糖酸组分中,蔗糖与葡萄糖、果糖、奎尼酸、草酸之间呈极显著正相关,葡萄糖与果糖、奎尼酸、草酸之间呈极显著正相关,果糖与奎尼酸、草酸之间呈极显著正相关,苹果酸与山梨醇、柠檬酸之间呈极显著正相关,草酸与奎尼酸、莽草酸之间呈极显著正相关。以上分析说明‘玉露香梨’果实中可溶性糖的成分主要是果糖、蔗糖和葡萄糖,有机酸的成分主要是苹果酸和柠檬酸,这些组分的含量及其比例将最终影响果实糖酸风味的形成。

2.4 ‘玉露香’梨果实发育中糖、酸组分的主成分分析

由表2主成分分析结果表明,第一、第二主成分

表2 2个主成分的各特征向量、特征值、贡献率和累积贡献率

Table 2 Eigenvector, eigenvalue, account and total account of 2 PCA

	第一主成分 PCA1	第二主成分 PCA2
蔗糖 Sucrose	0.391	-0.068
葡萄糖 Glucose	0.390	-0.119
果糖 Fructose	0.392	-0.075
山梨醇 Soubitol	0.165	0.548
苹果酸 Malice acid	0.285	0.453
柠檬酸 Citric acid	0.297	0.405
奎尼酸 Quinis acid	0.390	-0.070
莽草酸 Shikimic acid	0.242	-0.486
草酸 Oxalic acid	0.363	-0.253
特征值 Eigenvalue	6.328	2.264
方差贡献率 Variance contribution	70.31	25.15
累计贡献率 Accumulative contribution rate	70.31	95.46

方差贡献率分别为70.31%和25.15%,累计方差贡献率为95.46%,符合分析要求,可以用这两个主成分来评价梨果实发育过程中糖、酸的重要性。由各特征向量值可以看出,决定第一主成分大小的主要是果糖、蔗糖、葡萄糖、奎尼酸和草酸;决定第二主成分大小的主要是山梨醇、苹果酸和柠檬酸。综上所述,果糖、山梨醇、苹果酸和柠檬酸在梨果实发育过程中起主要作用。

3 讨 论

在不同树种上采用HPLC法测定果实中的可溶性糖和有机酸的组分及含量已有相关报道。桃果实中可溶性糖以蔗糖、葡萄糖、果糖和山梨醇为主,其中蔗糖占73%;有机酸主要是苹果酸和柠檬酸,其中苹果酸占总酸的60%^[19]。杏果实中蔗糖含量最高,其次为葡萄糖和果糖,山梨糖醇含量最低;有机酸中主要含有苹果酸和柠檬酸,奎尼酸含量较低。葡萄中主要糖为果糖和葡萄糖,含微量蔗糖,主要有机酸为酒石酸和苹果酸^[20]。本研究得出‘玉露香’梨果实中的主要糖是果糖、葡萄糖、蔗糖和山梨醇,其中果糖含量最高占总糖的45.82%,山梨醇含量占22.27%,葡萄糖含量占17.56%,蔗糖含量为13.85%;果实有机酸的组分包括苹果酸、柠檬酸、奎尼酸、莽草酸和草酸,其中苹果酸的含量为最高,占总有机酸的71.91%,其次为柠檬酸占20.61%,两种酸占总酸的比例是92.52%。从以上研究来看,不同树种之间可溶性糖的种类基本相似,而有机酸的种类则差别

较大。由于不同糖、酸组分及其含量的变化,最终形成了不同果品在糖酸风味方面的差别^[21]。

山梨醇是蔷薇科植物同化运输的主要形式。果实中的糖最终来源于叶片中所产生的光合产物,很大部分以山梨醇的形式存在,经韧皮部运输后卸载到果实内,进入果实之后在相关酶的作用下,进行一系列的代谢及跨膜运输,最终以果糖、葡萄糖等形式积累在果实中,产生不同的风味^[22]。*‘南果梨’*幼果期果实的可溶性糖以山梨醇为主,不含蔗糖,仅在近成熟期出现蔗糖并迅速积累,在采收时达到最大值^[6]。*‘云红梨1号’*和*‘美人酥’*幼果期果实可溶性糖以山梨醇为主,在成熟期含量有所下降^[7]。本研究表明,*‘玉露香’*梨在果实的整个发育期内,果实中的果糖、葡萄糖和蔗糖及总糖含量逐渐增加,山梨糖醇含量先增加后降低,与熊碧玲等^[5]研究相一致。

姚改芳等^[23]对分属不同栽培种的98个梨品种果实中可溶性糖组分及含量进行分析,得出不同种之间糖分的分布特点是:白梨分布在高葡萄糖和高山梨醇区域,新疆梨分布在高果糖和高葡萄糖区域。*‘玉露香’*梨的母本为库尔勒香梨属新疆梨,父本为雪花梨属白梨,*‘玉露香’*梨属于种间杂交选育,其为高果糖型。

成熟的*‘玉露香’*梨果实积累的有机酸主要为苹果酸,其次为柠檬酸,奎尼酸、莽草酸、草酸含量很低,因此按照传统有机酸的定义和果实分类,*‘玉露香’*梨应该属于苹果酸型果实。有机酸对果实风味品质的影响不仅与其组成含量有关,也取决于糖酸比。在苹果的研究上表明,一定范围内,苹果酸含量越高,糖总量越低,糖酸比越小,果实味感越强烈^[24]。*‘库尔勒香梨’*中苹果酸含量占总酸含量的60%以上,是影响果实味感的主要因子。本研究表明,*‘玉露香’*梨中苹果酸含量为总有机酸的71.91%,是果实风味好的重要贡献因子之一。

综合*‘玉露香’*梨果实中糖、酸组分的相关性分析和主成分分析可知,果糖、山梨醇、苹果酸和柠檬酸在*‘玉露香’*梨果实发育过程中起主要作用。

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