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桃果实采后生理生化及冷害研究进展

周慧娟[1],苏明申[1],叶正文[1*],杜纪红[1],卢 昆[2],张夏南[1],李雄伟[1]

([1]上海市农业科学院林木果树研究所,上海 201403;[2]安顺学院,贵州安顺 561000)

摘 要:桃果实采后极易发生腐败变质现象,低温可延长果实的贮藏保鲜期,但长期的不适低温冷藏易使果实产生木质化、絮败、果肉褐变、果肉变红、糖酸比失调、固有芳香成分丧失或有害挥发性物质生成等品质劣变症状。不同类型桃果实甚至不同品种桃果实的采后品质劣变规律不同,低温的敏感度及冷害的发生时间点、综合表现特征亦有较大差异,其保鲜技术一直是国际上的难题。笔者对果实品质劣变发生的症状进行归纳,并从酶学、分子生物学和蛋白质组学等方面进行了相关机制阐释。建议对不同肉质类型桃采后生理特性和贮运特性进行系统性研究,制定相应的采后品质劣变调控技术,开发高效、安全的保鲜技术并应用于实践,为桃果实采后处理及保鲜贮运技术的应用提供一定的理论支撑。

关键词:桃;品质;生理生化;冷害

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Advances in the research into physiological and biochemical characteristics and chilling injury of peach fruits after harvest

ZHOU Huijuan[1], SU Mingshen[1], YE Zhengwen[1*], DU Jihong[1], LU Kun[2], ZHANG Xianan[1], LI Xiongwei[1]

([1]Forest and Fruit Tree Research Institute, Shanghai Academy of Agricultural Sciences, Shanghai 201403, China; [2] Anshun University, Anshun 561000, Guizhou, China)

Abstract: The peach belongs to the Rosaceae family, subfamily Prunoideae, genus *Prunus*, subgenus *Amygdalus* L. which has a history of more than 4 000 years and is the main fruits produced in china. It was renowned for its rich nutrition, excellent quality and fresh flavour. Because of the biological and physiological characteristics of peach fruit such as soften, thin skin and juicy, as well as the high temperature and humidity, which reduce peach to decay and go bad quickly. Peach can be divided into four types (stiff solute, soft solute, solute and stony hard) according to their flesh texture. The sensitivity to low-temperature as well as comprehensive characteristics of peach fruits subjected to chilling injury are different. At present, more than 1 000 peach varieties are cultivated in the world. Most of soft solute peaches can be stored under room-temperature only for 3-5 d, the following is hard solute peach (5-7 d), and for stony hard peach is 10-14 d. It is crucial for classification of different kinds of solute peach according to postharvest quality, physiological and biochemical characteristics. As is known to all, there are double respiratory peak and ethylene releasing peak in peach fruits after harvest. The softening of fruit suture is related to the ethylene release rate and the appearance time of respiratory peak, however, it is different among various varieties. Once the autocatalytic ethylene synthesis pathway is activated during the development of the fruit, it will accelerate to soften process and then loss commodity value soon. The enzymes that related to fruit softening are pectinase, lipoxygenase and galacturonic acid polymer enzyme. It was reported that

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作者简介:周慧娟,女,助理研究员,硕士,主要从事果品采后生理与贮藏保鲜技术研究工作。Tel:021-37195676,E-mail:zhouhuijuanzc@163.com

*通信作者 Author for correspondence. Tel:021-37195676, E-mail:yezhengwen1300@163.com

pectinase activities were closely related to the softening rate. What's more, the salt soluble pectin content had high correlation with firmness, water soluble pectin, chelating pectin and salt soluble pectin. It was also reported that the browning of peach was related to the total phenol and chlorogenic acid content. Treatment with 1.25, 2.5 and 5 mmol·L^{-1} SA could inhibit the activities of polyphenol oxidase and lipoxygenase, and decrease the content of O^{2-} and malondialdehyde. It could also inhibit the browning of the flesh during low-temperature storage. The change of aromatic compound also should be concerned. More than 200 compounds have been identified from peach fruits till now. However, only a few ingredients or representative compounds which were named characteristic decision compounds could determine fruit aroma feature. Changes of aromatic compounds during peach fruit development and postharvest period have been reported. The accumulation of volatile substances is associated with peach maturity, and hexanal, benzaldehyde, linalool, γ-decalactone and δ-decalactone were the major aroma compounds. Long-time storage under low-temperature could reduce the fruit aroma and then chilling injury symptom appeared, however, 1-MCP and jasmonic acid methyl ester could inhibit this phenomenon. With the extension of storage time and the aging of yellow-peach, the cell wall of pericarp deformed, the structure became loose, intercellular space increased. The number of osmiophilic globules increased first and then decreased, and the volume presented increasing tendency. The mitochondria structure became blurred, mitochondria was deformed and stretched, the number of gorgias reduced and the structure collapsed. The aging process of mitochondria is later than chromoplast. Molecular biological tools have been used to identify increasing numbers of genes involved in fruit ripening and senescence. Other studies were carried out on peach ripening, stress response and defense. Some functional proteins of peach fruit are differentially regulated during the course of maturity. The last important symptom of peach after harvest is chilling injury. Low-temperature could prolong the storage time, however, that could also lead to chilling injury such as lignifications, woolliness, flesh browning, flesh red, sugar acid ratio imbalance, aromatic compounds loss, formation of harmful volatile substance and so on. Although, enzymology, molecular biology and proteomics have been employed to study the symptoms of fruit quality deterioration, the effective control of chilling injury through the quality control technology and biological engineering technology has not been successfully done yet. We should formulate fresh-keeping technology according to the physiology and storage characteristic of peach with different flesh texture.

Key words: Peach; Quality; Phsiology and bio-chemistry; Chilling injury

桃是蔷薇科(Rosaceae)李属(*Prunus* L.)桃亚属(*Amygdalus* L.)多年生落叶果树,原产于我国,距今已有4 000多a(年)的栽培历史。根据世界粮食与农业组织的统计,2011年世界桃栽培总面积157.06万hm^2,总产量2 152.87万t,为世界第三大落叶果树树种[1]。此外,桃果肉营养丰富,含有多种糖、酸、蛋白质、粗纤维、矿物质以及胡萝卜素、维生素C、尼克酸等人体必需的物质,其中桃果实中尼克酸的含量仅次于红枣和柑橘,在水果中居第三位。

由于桃果肉质软、果皮薄,保护性差,极易受到机械损伤,再加上成熟正值高温季节,果实易产生腐败变质现象,其保鲜是果蔬保鲜上公认的一个国际难题。低温可延长果实的贮藏保鲜期,但长期的低温冷藏易使果实产生木质化、絮败、果肉褐变、果肉变红、糖酸比失调、固有芳香成分丧失或有害挥发性物质生成等冷害症状。桃可分为硬溶质、软溶质、不溶质和stony hard等类型,不同类型桃果实甚至不同品种桃果实的采后品质、生理生化变化差异很大,且对低温的敏感性及冷害的发生时间点、综合表现特征亦有较大差异。目前我国栽培和研究的桃品种约有1 000多个[1],其中软溶质水蜜桃贮藏性最差,常温下货架期仅能维持3~5 d;其次为硬溶质桃,贮藏

期为5~7 d；而stony hard 常温贮藏期为10~14 d。因此对不同溶质类型桃果实采后品质及生理生化的变化进行分类研究至关重要。笔者通过对桃果实采后呼吸强度、乙烯释放速率、细胞壁成分、芳香成分、超微结构、冷害等的变化进行详细阐述和分析，以期为采后贮运保鲜技术的研发打下一定的理论基础。

1 呼吸强度与乙烯的释放

Lambardi 等[2]首先提出植物体内乙烯生物合成的前提是蛋氨酸，随后证明标记的 ^{14}C 蛋氨酸在苹果组织内转变成为标记的 ^{14}C 乙烯，植物体内少量的蛋氨酸可以合成大量的乙烯。贾慧娟等[3]研究表明，乙烯参与了桃果实内酯类物质的生成，低温通过抑制乙烯的生成，导致花香型香气酯类物质代谢发生障碍，果实品质下降。

桃属于典型的呼吸跃变型果实，跃变开始前，组织内部乙烯浓度极低，呼吸强度较低，在即将发生跃变前，乙烯浓度明显上升，呼吸强度急速增加，引起呼吸跃变。桃果实采后有双呼吸高峰和乙烯释放高峰，呼吸强度是苹果的3~4倍，乙烯释放量较高，这是桃不耐贮藏的重要生理原因，且不同品种达到呼吸高峰的时间有很大区别[4]。在果实的成熟过程中，一旦自动催化乙烯合成途径被激活，果实将加速软化，导致果实短期内失去商业价值[5]。阚娟等[6]发现在果实成熟过程中，硬度较高的‘加纳岩’比易软化的‘雨花3号’乙烯释放量高，并发现a-Af基因表达与2个品种果实的软化及果实内源激素的积累有密切关系。同一品种、不同成熟度桃果实与桃果核同一时间出现呼吸高峰，九成熟果实采后硬度下降速率显著高于七八成熟果实[7]。外源乙烯可通过抑制细胞色素氧化酶（COX）的活性，以及亚基因COX-Ⅰ、COX-Ⅱ和COX-Ⅲ的表达，从而加速果实的软化衰老[8]。

2 细胞壁组分及相关酶变化

果实软化时，在细胞壁中发生的最显著的变化是果胶的溶化，伴随出现细胞壁中胶层、胞间层的溶解和初生壁的破坏。果实软化与细胞壁降解酶的活性，尤其与果胶酶（脂肪氧合酶、多聚半乳糖醛酸酶）的活性紧密相关。彭丽桃等[9]研究发现，软质油桃‘秦光’和非软质油桃‘阿姆肯’果实淀粉酶、蔗糖酶、纤维素酶和PG活性与果肉的软化速率密切相关，且水溶性果胶、螯合性果胶和盐溶性果胶3种果胶中，盐溶性果胶与硬度的相关性最高[10]，与Zhang等[11]和皮钰珍等[12]研究的桃果实的硬度与盐溶性果胶的含量和纳米结构关系最紧密的结论一致。用原子力显微镜（AFM）技术分析‘仓方早生’和‘松森早生’2个桃品种的果实在2 ℃、8 ℃和15 ℃贮藏过程中水溶性果胶（WSP）和螯合水溶性果胶（CSP）的结构表明[13]，在贮藏过程中，长线性链的果胶逐渐减少，短链的果胶逐渐增加，贮藏温度越高，这种趋势越明显。

3 果实缝合线软化

桃果实缝合线处易先于其他部位软化，导致果实局部变软，耐贮运性大大降低，严重影响了桃果实的食用价值和经济价值。缝合线异常软化开始表现为缝合线处凸起，随着果实的发育凸起越发明显，先于其他部位先红、变软，可能与种仁乙烯的释放有密切关系[14]。

4 果实芳香成分的变化

4.1 桃果实内可能的香气合成途径

根据前人[3]的研究发现，桃果实内的特征香气成分为醛类、醇类、酯类和内酯类化合物。根据它们各自的合成途径，将桃果实内可能的香气合成途径总结为3条，LOX途径合成果实内的醛类、醇类和酯类物质；β-途径则主要负责合成果实内的内酯类物质；氨基酸以芳香族氨基酸为前提，主要合成桃果实内含有苯环的香气物质。此外，桃果实内的萜类物质则主要通过甲基赤藓糖醇磷酸合成途径（MEP）得到，其中的产物β-胡萝卜素还可以在LOX酶的作用下向酯类物质转化。

4.2 采后果实芳香成分的变化

贾慧娟等[3]研究发现，可溶性固形物、γ-癸内酯、辛内酯、γ-十二内酯影响桃果实的总体风味和甜度；可滴定酸、反-2-十六内酯、异-3-己烯醇影响桃果实的青草味和酸味；γ-十六内酯对桃果实的青草味、水果味、整体风味及酸味起作用。其中，挥发性物质十内酯、八内酯、己内酯与可溶性固形物含量呈较高的负相关；3种内酯物质与具有桃芳香风味的特性呈正相关，而与具青气风味特征呈负相关。吕昌文等[15]用高氧和茉莉酮酸酯处理水蜜桃果实，可延缓冷害的发生，较好地保持果实固有风味。1-MCP 处理可抑制桃果实醇类、脂肪族酯类、内酯和

萜烯的产生,SA处理则可促进醇类、脂肪族酯类、羰基化合物、内酯和萜烯的释放[16]。施加外源乙烯能促进特征香气芳樟醇和γ-癸内酯的合成,抑制己醛、反-2-己烯醛和苯甲醛的释放,青草型与花香型香气比值降低,从而有利于果实品质的改善[17]。

5 果实超微结构的变化

果实采后正常后熟期间胞间层分解和胞间隙扩大,初生壁变化不明显,无次生加厚现象发生。随着果实软化衰老,果实细胞壁中胶层溶解、电子密度降低、细胞间隙增大、质壁分离、部分初生壁开始降解、纤维丝松懈、细胞器变形或解体;长期冷藏期间,果实细胞壁有不均匀的加厚,厚度部分皱缩;之后细胞壁中胶层溶解,电子密度降低,细胞壁膨大松散;严重者细胞壁松散,部分细胞壁结构崩溃[18]。常温贮藏期间,'沪454'和'锦绣'黄桃果实均出现果皮细胞壁降解、细胞间隙增大、有色体中嗜锇颗粒数目增多、片层类囊体膜结构瓦解、果皮线粒体内基数目减少及结构解体的现象。且较耐贮的'沪454'黄桃果皮有色体和线粒体较'锦绣'黄桃稳定[19]。陈安均等[20]研究发现,桃果实乙烯和PG是影响超微结构衰老变化的重要因素,Lox可能是引起超微结构前期变化的因素,果实超微结构的成熟衰老变化先于乙烯高峰的出现和PG酶活性的快速上升。段玉权等[21]报道,1-MCP处理能够维持冷藏'中华寿桃'贮藏后期果肉组织细胞结构(线粒体、质体和液泡等细胞器)的完整性,保护了PPO与酚类物质区域化分布,延缓了果实冷害的发生。

6 采后果实内含物的变化

贮藏期间,果实维生素C含量和有机酸含量呈现下降的趋势;可溶性固形物含量呈先升后降的趋势[22],与唐燕等[23]利用介电常数研究的'秦光2号'油桃果实硬度、可溶性固形物含量、可滴定酸含量和含水率随着贮藏时间的延长不断降低的结论一致。不同成熟度、不同品种的桃果实的糖酸组分及其代谢存在一定差异,'湖景蜜露'水蜜桃风味劣变快于'沪油018'油桃和'玉露'蟠桃,且低温(1±1 ℃)和室温(25±2 ℃)贮藏期间,糖组分及含量变化均较缓和,酸组分及含量变化较剧烈[24]。0 ℃贮藏的'玉露'果实较5 ℃贮藏的果实具有较高的蔗糖含量和较低的葡萄糖与果糖含量[25]。1 mmol·L^{-1}乙酰水杨酸处理可显著抑制'华光'油桃果实5 ℃冷藏后货架期间果实硬度和可滴定酸含量的下降,抑制果实过氧化氢和呼吸速率的升高[26]。'迪克西兰'('Dixiland')桃果实在39 ℃热处理、0 ℃冷藏、20 ℃贮藏的不同处理组合下半乳糖苷和棉子糖含量差异较大,多胺和腐胺含量差异也较大[27]。

7 冷　害

冷害是许多原产于热带、亚热带植物由于冰点以上低温(≤12 ℃)所引起的生理失调而造成细胞伤害的生理性病害。冷害大致可以分为膜相改变与膜损害而引起代谢紊乱,桃果实采后冷害症状主要表现为絮败、革质化、果肉褐变、果肉变红、失去固有芳香和风味、不能正常成熟等[28]。

7.1 絮败

絮败是桃果实采后冷害的典型特征之一,主要症状是组织干化、汁液减少、果肉发绵。据报道,包装材质与果实的预冷特性、蓄冷特性、货架期和品质紧密相关,纸箱包装和PEP泡沫箱包装处理的果实汁液显著降低,果肉发绵、絮败,风味丧失,具有气调功能的珍珠棉包装箱能够保持果肉组织硬度,汁液丰富,肉质细腻,味甜[29]。很多研究表明[30],桃果实絮败与细胞壁代谢有关,主要涉及果胶物质的变化、果胶甲酯酶(PE)和多聚半乳糖醛酸酶(PG)等果胶酶的变化、细胞壁阳离子的变化等,归因于果实中PE、PG酶活性失去平衡和果胶失去可溶性。通过上调FAD基因的表达水平,增加亚麻酸含量,有利于支持膜脂的流动性和增强桃果实的低温抗性,减轻桃果实絮败的发生[31]。

7.2 革质化

革质化是桃果实采后冷害的另一典型特征,革质化与絮败的相同之处是组织干化、汁液减少;与絮败果实相比,革质化果实果肉出汁率更少,褐变程度更深,果肉组织不软化、非发绵的,果肉细胞壁异常增厚。七八成熟的水蜜桃在冷藏过程中果实硬度增加,出汁率在7 d后开始下降,不能正常后熟,出现明显的革质化冷害症状[32],与周慧娟等[33]研究的4 ℃以下长期低温冷藏使'大团蜜露'硬度增加,出现不可逆冷害的结论相似。

7.3 果肉褐变

桃果实贮藏期间的组织褐变是酚类物质酶促氧化的结果,组织中酚类物质含量、PPO活性和氧气的

供应是组织是否产生褐变的决定性因素。在有氧的条件下，酚类物质由PPO催化，被氧化为醌，醌通过聚合反应产生有色物质，导致组织褐变。Liu等[34]认为，桃果实褐变分成2种：一种是FB(flesh browning)，果实冷藏后即使转到室温下也不能成熟，褐变从接近果皮的果肉开始向果核发展，通常在冷害症状最剧烈时发生，伴随絮败的出现；另一种是IB(internal browning)，也可称作核褐变，其特征是褐变区域不连续，组织没有干化，并不与絮败同时出现，其影响区域极广，只余果皮下1 cm的范围未被影响。桃果实冷害后发生果肉褐变，与组织劣变和衰老有关，不同品种导致褐变的主导因子不同[35]。桃果实2~5 ℃冷藏较0 ℃冷藏易发生果肉褐变[28]。'Sudanell'桃果实在0 ℃下冷藏2周，货架期间出现了明显的果肉褐变，且不同品种的桃褐变潜伏期不同。'SudanellR'为2周，'Sudanell B'和'Sudanell-1'为3周[28]。

0 ℃冷藏抗褐变的'保佳俊'和4种优质桃品种('中华寿桃''深州蜜桃''大久保''冬雪蜜桃')果实相比，冷藏'保佳俊'果肉中的苯丙氨酸解氨酶(PAL)活性较弱，多酚类物质积累少；同时具有较低的多酚氧化酶(PPO)活性，过氧化氢酶(CAT)、过氧化物酶(POD)和超氧化物歧化酶(SOD)的活性较高[36]。5 ℃低温贮藏的'雨花三号'桃果实脂肪氧化酶(LOX)活性较20 ℃室温低，而琥珀酸脱氢酶(SDH)、细胞色素C氧化酶(CCO)和Ca2-ATP酶活性较20 ℃室温高[37]。邹丽红等[38]发现，冷藏期间，果肉酶促褐变与总酚和绿原酸含量的相关度高于与酶类的相关度。1.25、2.5和5 $mmol \cdot L^{-1}$ SA可降低1 ℃冷藏'中华寿桃'果实的PPO和LOX活性、超氧自由基含量，减轻MDA对细胞膜的伤害，维持细胞膜稳定性，显著抑制果肉褐变[39]。

7.4 果肉变红

果肉变红作为桃的一种冷害症状，只在某些桃品种上出现，且没有絮败和果肉褐变影响大。在新的油桃品种中，果实采收后，红色从点往外呈散射状发展，这种症状被认为与冷害或者失去风味等无关。'Summer Bright'和'Summer Fire'油桃中，果肉变红并不影响果实风味，它与果实成熟度有关，与贮藏温度无显著相关性。长期冷藏期间，随着果实的衰老和风味的丧失，果肉变红。果肉变红是否与贮藏性能的降低和品质劣变相关，需要进一步研究验证，是以后研究的一个热点。

7.5 失去固有芳香

芳香物质的丧失与以下3方面的因素有关：(1)原有的香气物质挥发消失；(2)合成香气物质的前体物质损失或转化；(3)合成香气物质的有关酶钝化或失活。乙烯释放量与醛类物质和青草型香气含量呈显著负相关，ACC氧化酶与LOX酶通过调控乙烯合成，进而调节香气释放，影响果实的风味。'大久保'桃果实常温贮藏过程中，青草型与花香型香气成分的比值最低时风味最佳[40]。Zhang等[41]研究发现，与0 ℃相比，5 ℃条件下冷藏，桃果实已发生冷害，且显著降低了桃果实酯类和内酯类特征香气的含量，与Balbontín等[42]研究的'湖景蜜露'桃在5 ℃冷藏2周后，内酯和酯类物质的合成受阻，香味丧失的结论一致。'霞晖5号'桃果实0 ℃与5 ℃冷藏冷害果实青香型物质的相对含量增大，果香型物质的相对含量降低[43]。'湖景蜜露'桃冷害果实果香型香气物质含量较正常果实低，香气物质含量与*PpLOX1*、*PpLOX3*和*PpAAT1*基因表达水平有关。

8 分子和蛋白质表达变化

在逆境胁迫下，植物体内产生一系列生理生化变化以调节自身适应性，这些变化的本质是相关基因时空表达与调控的结果，且存在一个由不同信号转导途径组成的复杂网络，不同信号转导途径之间的协同互作[44]。代谢过程中，絮败的果实缺乏促进其成熟的必要条件，并且线粒体和叶绿体在这些过程中发挥重要作用[45]。Song等[46]报道，谷胱甘肽代谢与DEGs基因的表达显著相关，0 ℃、10~20 kPa减压处理30 d，使抗坏血酸盐基因和相关基因编码GR、MDHAR、APX表达量上调。热+1-MCP(HM)处理通过推迟高峰呼吸，增强硬度，提高谷胱甘肽过氧化物酶(GPX)活性和PpaGPXs基因的上调表达，延缓了桃果实的采后衰老[47]。

桃果实冷害的相对抗性可能涉及到胁迫保护、胁迫恢复和衰老诱导的转录因子调节，桃果实冷害可能与乙烯和生长素调节的衰老程序失调有关[48]。单核苷酸多态性(SNPs)是一个基本的基因组变异来源，研究[49]发现，1 109个SNPs组成的基因图谱中，67个SNPs与冷害症状的显现有关，最后可预测出相关的基因组序列。EXP基因在桃果实絮败过程中mRNA丰度逐渐下降，表达减弱。用μPEACH1.0和ChillPeach 2个微列阵芯片研究了1个普通桃和1

个油桃品种的果实基因表达,耐贮性较强的油桃果实中有47个基因表达量是桃果实的2倍以上,在普通桃果实中有60个基因的表达量是油桃果实的2倍,有41个冷敏感性基因的表达水平与冷害适应反应相关[50]。基于CBF基因同源性,从桃基因组数据库中获得了果实特异性的六碳重复(CRT)脱水响应元件(DRE)结合因子(CBF)基因成员(PpCBF1-6)。'湖景蜜露'桃果实的*PpCBF1/5/6*基因表达水平受低温诱导,在0 ℃下的表达水平较5 ℃高,而其他CBF基因的表达水平相对稳定[51]。乙酰辅酶A氧化酶活性及*PpACX1*基因表达与内酯类化合物的含量呈正相关,'湖景蜜露'和'锦绣'桃果实在5 ℃下贮藏较0 ℃下更易发生冷害,同时内酯类化合物的含量也相对较低[52]。香气物质含量与*PpLOX1*、*PpLOX3*和*PpAAT1*基因表达水平有关[53]。冷害抗性品种('Springlady')和冷害非抗性品种('Flordaking')的果实*PpXyl*基因表达呈现出很大差异。非抗性品种('Flordaking')和中间抗性品种('Rojo 2')果实的冷害程度均与*PpXyl*基因表达水平呈负相关,3个品种*PpXyl*基因(1 637 bp)的启动子区域无显著性差异,*PpXyl*基因的差异表达可能由其他区域的顺式元件和/或反式元件调控[54]。

凝胶电泳检测到桃果实有600多个蛋白点,经过48 ℃热水处理10 min可产生35个差异蛋白点。其中由热处理诱导产生的30个蛋白点中,43%与胁迫反应相关,17%是细胞结构蛋白,13%是蛋白代谢产物,7%与糖酵解相关,3%与成熟衰老有关,17%功能不详[30]。40 ℃热水处理'六月皇后'('June Prince')桃果实5 min和10 min,可抑制褐腐病菌生长并提高桃果实的防卫反应,果实几丁质酶(CHI)、1,3-葡聚糖酶(GNS)和苯丙氨酸解氨酶(PAL)的活性和基因表达量显著高于对照果实[34]。金薇薇等[55]利用桃果实EST库(expressed sequence tags),从成熟桃果实中克隆获取了2个含3'末端序列的ROP基因家族成员,即P_PROP1(555 bp)和P_PROP2(861 bp)。除EjROP3属于ROP蛋白家族的type II,另外的桃果实的ROP均属于typeI。Wu等[56]用蛋白质组学方法分析桃果实成熟衰老期间功能蛋白的变化,结果表明24个差异性表达功能蛋白被鉴定出与果实的成熟衰老密切相关,并被分为以下6类:氧化应激(34%)、碳代谢(29%)、呼吸链(17%)、氨基酸代谢和蛋白质生物合成(8%)、热休克蛋白(4%)、离子通道(4%)。Kang等[57]发现,NO处理可诱导'霞晖5号'产生104个差异蛋白点,主要分为以下7类:能量和代谢(30.77%)、应激反应和防御系统(25.00%)、细胞结构(8.65%)、蛋白质表达(8.65%)、运输和转导(6.73%)、成熟和衰老(5.77%)、非保密(13.46%)。其中,ACO - NO - ACC氧化酶(1-aminocyclopropane-1-carboxylic acid)为果实成熟衰老的重要功能蛋白。Jiang等[58]通过差异性蛋白研究发现,1-MCP和热激处理在抑制桃果实的成熟衰老方面具有协同作用。抗氧化剂和PR蛋白以及与糖代谢相关的酶与酵母菌和水杨酸诱导产生的抗性密切相关[59]。

9 展 望

随着人们生活水平的提高和对食品安全的关注,长期低温冷藏导致的木质化、絮败、果肉褐变、果肉变红、糖酸比失调、固有芳香成分丧失或有害挥发性物质生成等品质劣变问题日益受到关注。目前,研究者对果实品质劣变发生的症状进行研究,并从酶学、分子生物学和蛋白质组学等方面进行了相关机制阐释,但如何通过采后品质调控技术和生物工程技术等手段解决桃采后冷害问题尚未有明确定论。不同类型桃果实甚至同一类型不同品种桃果实的采后品质劣变症状、生理生化变化差异较大,且对低温的敏感性及冷害的发生时间点、品质劣变综合特征表现各异。建议对不同肉质类型桃采后冷害综合症状[(1)汁液减少、果肉褐变、果肉组织硬度增加、木质化、货架期不能正常软化;(2)果肉褐变、汁液减少、果肉糠化;(3)组织干化、汁液减少、果肉发绵、絮败]进行系统性研究,制定相应的采后品质劣变调控技术。长期冷藏期间,芳香物质的丧失或有害挥发性物质积累,不仅受某个蛋白或基因的单一调控,而是与功能蛋白互作或基因互作有关,可作为后续研究的方向之一。本文旨在对桃果实采后品质劣变研究的重点和热点及存在的问题进行综述,期望在以上研究的基础上,开发出高效、安全的保鲜技术并应用于实践,使桃果实采后品质劣变调控研究进入更高的层面,进而推动该产业的快速和持续发展。

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