第 28 卷第 6 期
2019 年 12 月
激 光 生 物 学 报
ACTA LASER BIOLOGY SINICA
Vol. 28 No. 6
Dec. 2019

采后果蔬软化机制及调控方法研究进展

徐海山[1]，丁胜华[2]，周　辉[1]，易有金[1]，邓放明[1]，王蓉蓉[1*]

（1. 湖南农业大学食品科学技术学院，长沙 410128；2. 湖南省农业科学院农产品加工研究所，长沙 410125）

摘　要：果蔬软化是限制其采后贮藏品质和商品价值的重要因素，涉及种类和品种、呼吸作用、乙烯产生、细胞壁物质降解、微生物侵染等方面。本文综述了近年来国内外调控果蔬软化的方法，包括物理调控、化学调控、生物调控方面的研究进展，以期为改善果蔬采后品质提供一定的理论参考。

关键词：果蔬；采后；软化；机制；调控；方法

中图分类号：S37　　**文献标志码：**A　　**DOI：**10.3969/j.issn.1007-7146.2019.06.004

Advances in Mechanism and Regulation Methods of Postharvest Fruits and Vegetable Softening

XU Haishan[1], *DING Shenghua*[2], *ZHOU Hui*[1], *YI Youjin*[1], *DENG Fangming*[1], *WANG Rongrong*[1*]

(1. Agricultural College of Food Science and Technology, Hunan Agricultural University, Changsha 410128, China; 2. Agricultural Product Processing Institute, Hunan Academy of Agricultural Sciences, Changsha 410125, China)

Abstract: Softening of fruits and vegetables is a crucial factor limiting their postharvest quality and commercial value, including species and varieties, respiration rate, the production of ethylene, degradation of cell wall, microorganism etc. This paper reviews regulation methods of postharvest fruits and vegetables softening at home and abroad, including physical regulation, chemical regulation, and biological regulation, in order to provide the theoretical foundations for the improvement of postharvest fruits and vegetables quality.

Key words: fruits and vegetables; postharvest; soften; mechanism; regulation; methods

果蔬营养丰富，含有机酸、糖、维生素、矿物质等成分，深受消费者喜爱。然而，果蔬在采后贮藏过程中极易发生软化，严重限制其贮藏品质和商品价值。国内外已有大量研究集中在果蔬软化方面，主要是关于软化机制及调控方法[1-6]。果蔬软化主要与果蔬种类和品种[1,7]、呼吸作用[2,8]、乙烯产生[3,4]、细胞壁降解[5,9]、微生物侵染[6,10]等因素有关，但具体机制尚未完全清晰。基于影响果蔬软化的因素，目前的调控方法以物理和化学为主[6,11]。近来，随着保鲜技术的发展，一些新的保鲜方法也逐渐被应用于果蔬软化调控中，如生物保鲜等。本文主要综述了果蔬软化机制及调控方法，以期为提高果蔬采后贮藏品质提供理论参考。

收稿日期：2019-04-11；**修回日期：**2019-04-25。

基金项目：国家自然科学基金项目（31601525）；湖南省自然科学基金项目（2019JJ50256）；湖南省教育厅科学研究优秀青年项目（16B123）；湖南农业大学引进人才项目（20654/540490316002）；湖南农业大学第三批重大科研项目（创新团队培育工程）；湖南农业大学“双一流”建设子项目-科学研究培育项目；湖南农业大学“双一流”项目（SYL201802006）。

作者简介：徐海山，硕士研究生。

* **通讯作者：**王蓉蓉，讲师，主要从事果蔬加工及贮藏方面的研究。E-mail：sdauwrr@163.com。

1 果蔬软化机制

1.1 果蔬种类、品种与软化

果蔬种类和品种不同,其质构也不相同,这主要与细胞壁组成和结构有关。对于桃、荔枝、杏、梅等核果类果实,细胞壁中纤维素含量低于0.5%,果胶含量少,细胞壁强度低[11],在相同贮藏条件下软化速度快,而对于纤维素和果胶含量高的苹果、胡萝卜、梨等果蔬,组织结构致密,细胞壁强度大[7],因此在采后贮藏过程中软化速度慢,贮藏时间长。Szymańska-Chargot 等[1]分析了苹果和胡萝卜中所含纤维素的含量和结构,结果发现两者存在显著差异,苹果有更细长的纳米纤维,而胡萝卜纤维素的结晶度更高,因此细胞壁和纤维素结构更加复杂和牢固。即使对于相同种类的果蔬,品种不同其质构也存在显著差异。Camps 等[12]分析了 12 个品种的土豆质构,发现不同品种的土豆质构参数明显不同。因此,不同种类与品种的果蔬即使在相同贮藏条件下,其软化程度也不尽相同,对于细胞壁结构强度大的果蔬,其在整个贮藏期间质构变化较缓慢。

1.2 呼吸作用与软化

采后果蔬仍进行呼吸作用,一方面促进果蔬品质的形成和抗性能力的提高,另一方面会加速果蔬成熟衰老[8]。采后果蔬中的糖、酸等有机物作为呼吸作用的底物,被细胞消耗利用,加速了风味物质形成和果蔬成熟。同时,呼吸作用使果蔬体内产生大量活性氧,造成活性氧代谢失衡,细胞膜中的脂质大量氧化,产生大量丙二醛(malondialdehyde,MDA),破坏其结构[2]。而过量的活性氧自由基还会攻击果蔬的 DNA 分子,引起核酸损失、酶失活[13],造成果蔬衰老和软化。目前,Wang[14]、Chen[15]和 Dong[16]等分别研究了 β-葡聚糖、涂膜、茉莉酮酸甲酯处理对不同果蔬代谢及相关品质的影响,表明不同处理相比于对照组都能很好保持果蔬贮藏期间的品质。然而,即使利用不同调控方法进行保鲜,MDA 含量在整个贮藏期间都呈上升趋势。此外,由于果蔬采后呼吸强度减弱,产生 ATP 的含量不足以维持果蔬能量代谢,而导致能量代谢失衡,细胞新陈代谢紊乱,从而引起细胞衰老[17]。

1.3 乙烯产生与软化

乙烯作为一种促进果蔬成熟衰老的激素,在果蔬生长发育过程中会影响呼吸作用、细胞壁降解酶活性等。果蔬在生长发育过程中都会释放乙烯,但大多情况下乙烯的释放量是极其微弱的,而在成熟软化过程中,乙烯的释放量大量增加[3,4]。根据果蔬成熟过程中呼吸速率的变化,果蔬分为跃变型和非跃变型两种[4]。研究发现,不同品种猕猴桃果实在后熟软化过程中,乙烯高峰均出现在果实软化后期,由此推测乙烯可能只是决定猕猴桃果实后熟软化的因子之一,而并非启动因子[18]。在甜瓜、苹果等多种呼吸跃变型果蔬中,乙烯往往有系统 I 和系统 II 两条合成途径,且部分果蔬中系统 I 和系统 II 可相互转化。其中,1-氨基环丙烷-1-羧酸(1-aminocyclopropane-1-carboxylate,ACC)是一种重要的前体物质,ACC 含量直接决定乙烯合成的多少[19]。此外,Gwanpua 等[20]研究表明乙烯表达能够促进细胞壁降解酶和膜脂氧化酶基因的表达,如果胶甲酯酶(pectinesterase,PME)、聚半乳糖醛酸酶(polygalacturonase,PG)、脂氧化酶(lipoxygenases,LOX)等,进一步加速采后果蔬的软化。同时,少量的外源乙烯可促进采后果蔬内源乙烯的大量合成,而反之利用适当浓度的乙烯抑制剂处理果蔬,如 1-甲基环丙烯(1-methylcyclopropene,1-MCP),则可抑制内源乙烯的产生,延缓软化[21]。

1.4 细胞壁物质降解与软化

细胞壁结构影响质构,不同果蔬的细胞大小和形状不同,其质构也不相同。果蔬细胞壁由初生壁、胞间层和次生壁三部分构成,主要包括纤维素、半纤维素和果胶等。其中,果胶存在于细胞壁的初生层和中胶层中,起粘合剂和增强细胞强度的作用[9],对果蔬软化调控具有关键作用。随着果蔬软化的发生,果蔬中水溶性果胶和螯合性果胶含量会增加,碱溶性果胶含量明显减少,果胶侧链被水解,且在果胶降解过程中,纤维素和半纤维素空间结构也会发生解聚[5]。研究表明,在果蔬软化过程中,*PG* 基因得以表达,其 mRNA 大量转录,促进 PG 的合成[22],生成的 PG 水解多聚半乳糖醛酸中的 1,4-α-D 半乳糖苷键,使其生成低聚半乳糖醛酸。大多数果蔬具有内切和外切两种 PG,如柿子和离核毛桃,在内外切 PG 的作用下,完成对多聚半乳糖醛酸的水解[23],但外切-PG 对底物的特异性较弱,内切-PG 则较强。PME 在果蔬软化中也起重要作用,通过水解高度甲酯化的果胶,消除酯化基团(主要是羟甲基或羟乙基),增加果胶在水中的溶解度,从而形成适于 PG 作用的条件[24]。Wen 等[25]发现 PE 反义抑制果实,果胶甲酯基的程度明显增加,但软化速率没有明显改

变,这从基因水平证明了 PE 的作用;β-半乳糖苷酶(β-galactosidase,β-Gal)作用于具有半乳糖残基直链的木葡聚糖和鼠李糖半乳糖醛酸聚糖 I,改变细胞壁一些组分的稳定性,有利于细胞壁降解酶的进入,从而使果胶降解。在果蔬软化过程中,往往是 PG、PE、β-Gal 三种酶协同作用,完成对果胶的降解,从而破坏细胞壁结构,促进果蔬软化,具体降解途径如图 1 所示。此外,也有研究发现果蔬细胞壁的降解与一些非酶促因素有关。Fry 等[26]研究发现,H_2O_2 和抗坏血酸在 pH5.5 下混合后所产生的·OH 可显著降解细胞壁多糖,并用指纹印迹法证明梨成熟软化过程中,·OH 的存在能降解细胞壁多糖物质,如果胶、木葡聚糖等;Dumville 等[27]表明·OH 可导致土豆中果胶的非酶促降解,且具有剂量效应;Zhang 等[28]也发现 Fe^{2+}、抗坏血酸、H_2O_2 等可有效降解银耳中细胞壁多糖,提高银耳的抗性能力。因此,细胞壁多糖的降解是由酶促因素和非酶促因素共同引起的,但细胞壁水解酶是调控细胞壁降解的主要因素。

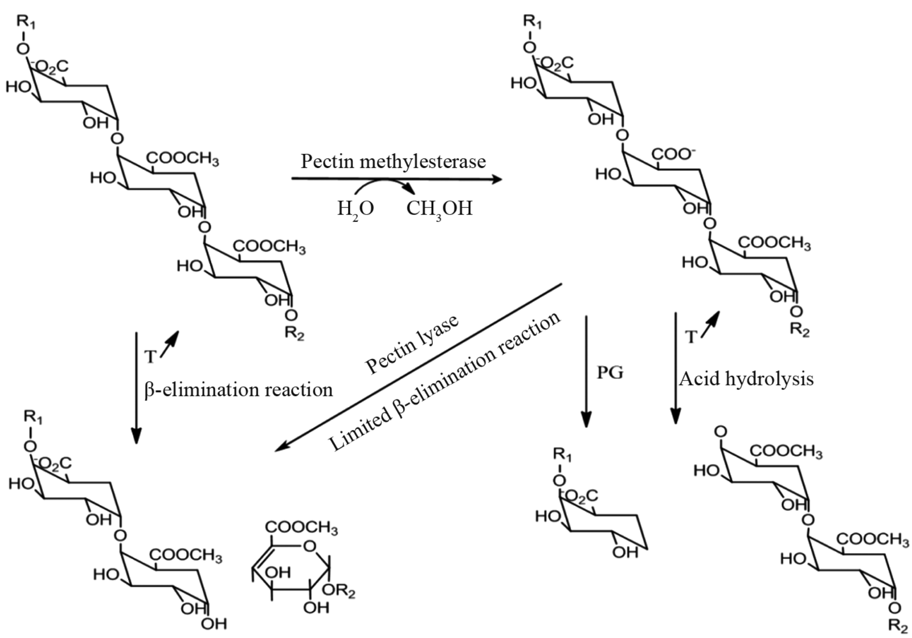

图 1 果胶降解途径

Fig. 1 The degradation pathway of pectin

1.5 微生物侵染与软化

采后果蔬因其水分含量高,营养物质丰富,若处理不当在采后贮藏过程中极易被微生物侵染,造成侵染性病害的发生并加速软化,其中以细菌和真菌为主。细菌主要通过果蔬自然孔口或伤口侵入细胞组织中,而真菌主要以菌丝或孢子萌发后形成的芽管通过自然孔口或伤口侵入组织中[10]。侵入的病原微生物会快速消耗果蔬中的营养物质,在果蔬组织细胞中大量繁殖,分泌代谢产物和胞外酶(如细胞壁降解酶等),破坏果蔬组织结构,加速果蔬软化[10]。Wang 等[29]发现腐烂草莓中发病部位的软化最为严重,主要致病菌为根酶菌。这表明外来病原菌感染会对果实组织结构产生较大破坏。随后其利用五种抑菌物质处理草莓,证实可明显抑制根酶菌的生长速度和原始菌的积累,有效延缓草莓腐烂软化。Du 等[6]利用 1-MCP 和杀菌剂结合处理感染灰霉病的西红柿,发现对照组西红柿灰葡萄孢菌生长旺盛,果蔬质构和品质均较差,而结合处理能有效抑制表面病菌生长,延缓品质劣变。Naets 等[30]通过研究次氯酸钠和乙醇对苹果表面微生物和相关品质的影响,发现采后苹果易被真菌性病菌感染,且经过处理的苹果由于蜡质层被破坏病菌侵染更为严重。

2 果蔬软化调控方法

2.1 物理调控方法

2.1.1 短波紫外线

短波紫外线(ultraviolet C,UV-C)是利用波长为 200~280 nm 的紫外线对果蔬进行辐射,起到减缓软化的目的,其效果主要取决于辐射剂量和辐射时间[31]。UV-C 辐射处理能破坏生物大分子,包括对

DNA 分子的破坏。研究发现,果蔬经 0 ~ 1 kGy 低剂量的 UV-C 处理后,能破坏附着在果蔬表面微生物的 DNA 分子,降低附着在果蔬表面的微生物数量,从而减少微生物对果蔬内部侵染,降低采后果蔬贮藏期间的腐烂率,延缓软化[31]。但 UV-C 辐射剂量达到 10 kGy 后,不仅不能起到保鲜效果,反而会破坏果蔬 DNA 分子和果胶等细胞壁大分子物质,显著缩短货架期。Zhu 等[32]用不同剂量的 UV-C 在黑暗、白光、红光、蓝光条件下处理土豆,发现在红光或黑暗条件下辐射过的土豆软化率明显低于其他组,而白光和蓝光条件下辐射的土豆软化率高于对照组。这主要是由于白光和蓝光使得葡萄孢菌(*Botrytis cinerea*)在 UV 辐射的情况下,其修复系统相关酶得以表达,提高了 *B. cinerea* 对 UV-C 的抗性,从而加速了软化的发生。Gutiérrez[33] 和 Janisiewicz[34] 等用 UV-C 分别处理芝麻菜和草莓,发现 UV-C 均能抑制其附着的细菌、霉菌等微生物的生长,延缓软化,提高贮藏品质。此外,大量研究发现被 UV-C 辐射过的果蔬,其质构被很好地保持,这与降低 PG、PME 等果胶降解酶的活性以及增强抗性酶的活性有极大关系[35,36]。

2.1.2　热处理

热处理作为一种安全的处理方式被广泛应用于果蔬贮藏,可有效延长货架期。目前,国内外常用的热处理方法有热水浸泡、热空气、微波辐射、干热空气、远红外线等[37],其中以热水浸泡和热空气处理为主。热处理往往是利用 37 ~ 55 ℃的热水或热空气处理采后果蔬 0.5 ~ 3 min,起到延缓软化的作用,这主要是由于较高温度可钝化 PG、PME、果胶裂解酶(pectin lyases,PL)等细胞降解酶和过氧化氢酶(catalase,CAT)、过氧化物酶(peroxidase,POD)等抗性酶的活性,同时还可杀灭部分附着在果蔬上的微生物。Glowacz 等[38]用 40、45、50 ℃的热水分别处理菠菜叶 30、60、120 s,结果发现利用 45 ℃热水处理 60 s 的菠菜叶理化品质维持地更好,可有效延缓衰老。Maxin 等[37]也发现用 65 ℃的热水处理苹果 20 s,可有效减少附着在苹果表面的微生物数量,抑制苹果腐烂软化。但在热处理过程中,时间和温度必须严格控制,时间过长、温度过高都不利于果蔬的保鲜,反而会破坏细胞结构,造成营养成分损失。Hong 等[39]用热水结合重碳酸盐等化学试剂处理柑橘,防软化效果也很显著。

2.1.3　冷激处理

冷激处理是指在采后果蔬不产生冷害或冻害的情况下,对其进行短时间低温处理,通过冷胁迫诱发果蔬自身生理抗性,抑制呼吸作用和酶活,从而提高贮藏品质[40]。冷激处理根据处理介质可分低温空气冷激处理和冰水混合物冷激处理,其中以冰水混合物处理果蔬较多。Chen 等[40]研究表明,冰水混合物浸泡‘Hass’鳄梨果实 30 min,可抑制果皮变色和硬度下降。这是由于低温抑制 PG 和纤维素酶活性,降低果实乙烯产率和呼吸速率,有效延长保质期,但对于 PME 活性没有影响。Zhang 等[41]将 0 ℃冰水混合物处理的香蕉果实在 20 ℃下贮藏,通过抑制促进果胶溶解的 PG 和 PME 活性,延迟果实软化。Yang 等[42]研究经 0 ℃/40 min、2 ℃/20 min、2 ℃/40 min、2 ℃/60 min 和 4 ℃ /40 min 处理的黄瓜的品质,结果发现用 2 ℃/40 min 冷水处理的黄瓜失重率最小,硬度最大,总酚含量和 POD 活性维持在较高水平。然而,若冷激处理温度和时间不当,反而会造成果蔬冷害,破坏结构,所以在处理过程中需严格控制。

2.1.4　气调保鲜

气调保鲜技术是在合适的温度和湿度条件下,通过提高贮藏环境中 CO_2 浓度降低 O_2 浓度,来达到保鲜效果,具有保鲜期长、安全卫生等特点[43]。目前,国内外关于果蔬气调保鲜的研究主要集中在苹果、柠檬、辣椒等呼吸跃变型果蔬。黄宇斐等[43]研究表明,O_2 浓度为 10%,CO_2 浓度为 5% 时对采后西兰花的保鲜效果最佳,可延缓西兰花衰老软化,保持贮藏期间品质。Zhu[44]、Ranjitha[45] 和李素清[46]等研究了不同气调参数对卷心菜、灯笼椒、青椒保鲜效果的影响,都表明气调保鲜可一定程度上抑制果蔬软化,维持果蔬品质。但采用此方法时需注意,低 O_2 浓度的目的是抑制果蔬有氧呼吸,减少生理作用造成的软化,但也要防止无氧呼吸的发生;同时 CO_2 浓度不能过高,否则会对果蔬产生气体伤害。

2.2　化学调控方法

2.2.1　1-MCP 处理

1-MCP 作为一种保鲜剂,因其安全无毒、成本低、操作简单等特点被广泛运用到果蔬保鲜中,可有效抑制自身产生乙烯或乙烯敏感型果蔬的成熟软化[47]。Brummell 等[24]研究表明,桃在成熟过程中,随着乙烯释放量的增加,其 PG、PME、β-Gal 等活性也呈现上升的趋势;刘超超等[48]也证实“泰山早霞”早熟苹果中 PG、Cx 活性的快速上升与乙烯调控有很大关系。然而,Hadfield 等[49]发现香瓜中 PG mRNA 转录不受乙烯影响,而 PG mRNA 翻译则受到乙烯调

控,但关于乙烯调控 *PG* 基因的具体作用机制尚不明确。经1-MCP处理的果蔬,其渗入的1-MCP与乙烯受体的结合能力强于乙烯与乙烯受体结合能力的数十倍,能长时间结合乙烯受体,致使乙烯的传导和表达受阻[47];而一旦乙烯表达受阻,PG、PE等果胶降解酶基因的表达或转录会受到较大影响,从而抑制果蔬软化。Zhang[50]和 Watkins[51]等均用低浓度的1-MCP处理采后果蔬,相同贮藏时间下处理的果蔬软化腐烂情况要低于对照组,且可有效维持果蔬的抗性能力。

2.2.2 钙处理

钙是果蔬生长发育不可或缺的元素,在维持果蔬细胞壁和细胞膜结构上发挥重要作用。研究表明,由于钙离子的粒径小于细胞壁的孔径,钙离子能有效结合在细胞壁上,且钙处理可有效抑制果蔬中乙烯的产生,从而维持果蔬质构[52]。同时,钙离子能够增强果胶分子间的结合力,浸钙处理的果蔬细胞壁果胶分子存在类似"花环"的多聚体,使果胶分子更紧密地连接细胞壁其他多糖物质。也有研究表明钙可结合果蔬中的果胶酸,形成共价键桥维持组织质构。这与其所含钙浓度的高低具有紧密联系,利用这一特点,生产中常对采后的果蔬进行浸钙处理或钙涂膜处理,以提高果蔬内源钙的含量,保持果蔬硬度[53]。Ngamchuachit 等[52]用不同浓度的氯化钙和乳酸钙处理芒果后在5 ℃下贮藏,结果发现随贮藏时间的延长,经浸钙处理的芒果硬度均大于对照组,且氯化钙与乳酸钙处理过的芒果硬度上差别不大。Silveira[54]和 Wang[55]等研究表明,由于不同果蔬结构存在差异,果蔬的最适钙浓度是不同的,只有经适宜钙浓度处理才可有效抑制果蔬软化。高浓度的钙处理不仅不能延缓果蔬软化,反而会对果蔬结构造成破坏,加快衰老腐败。

2.2.3 NO 处理

NO是存在于果蔬中用以调节成熟与衰老的信号分子,参与果蔬组织细胞新陈代谢,延缓果蔬软化[56]。研究表明,外源NO熏蒸处理可延缓桃、芒果、猕猴桃等果实的成熟衰老,抑制软化的发生[56,57]。利用外源NO熏蒸果蔬,可有效抑制ACC合成酶、ACO和ACS等酶的活性,进而有效抑制内源乙烯生物合成或降低果蔬对内源乙烯的敏感度[58]。NO还可有效调控果蔬内多种抗性酶活性,如过氧化氢酶,超氧化物歧化酶等[58];且经过NO熏蒸处理的果蔬,可降低 *PG* 基因组的表达。吴斌等[59]研究发现NO处理可对香蕉多聚半乳糖醛酸酶及 *MaPGs* 基因表达产生影响,主要是 *MaPG2*、*MaPG3* 和 *MaPG4* 基因的表达,从而有效延缓香蕉软化。但高浓度的NO熏蒸处理也会对果蔬组织结构造成破坏,加快腐烂软化,因此在应用时需特别注意。

2.2.4 化学保鲜剂复合处理

研究表明,保鲜剂复合处理可更有效抑制呼吸酶或抗氧化酶活性,降低软化速率,延缓果蔬衰老[60]。Rodriguez-Arzuaga 等[60]研究采用不同浓度的巴拉圭叶猴草、柠檬酸、抗坏血酸保鲜剂对苹果进行复合处理,结果发现1.2%巴拉圭叶猴草+0.9%柠檬酸+1.0%抗坏血酸处理可使抗氧化能力提高近36%。这与王石华等[61]对丽江雪桃的研究一致,其发现适当浓度的氯化钙、柠檬酸、抗坏血酸组成的复合保鲜剂可有效减缓果实软化。此外,将化学保鲜剂与其他保鲜方法复合处理也能得到较好的效果。研究表明,用过氧化氢浸泡处理后进行气调包装的瓜尔豆,在贮藏一段时间后重量、色泽、硬度变化较对照组小[62]。也有研究发现利用抗氧化剂、抗菌剂、乙烯抑制剂等化学保鲜剂与大分子成膜物质形成复合涂膜剂,在果蔬表面形成薄膜的同时,也可有效抑制果蔬内部呼吸作用等生理活动,保持VC、可滴定酸和可溶性固形物含量,延缓软化[63]。目前常见的作为涂膜基质的大分子物质有壳聚糖,藻酸盐等[63]。

2.2.5 植物激素

植物激素是植物自身代谢产生的微量有机化合物,是广泛存在的一类信号分子。在外界环境发生变化时,激素信号协调细胞之间的联系,调控植物生长发育[64]。乙烯作为一种调节生长,发育和衰老的内源性植物激素,在植物体内含量会随贮藏过程不断变化,在果蔬生长初期含量较低,后熟阶段开始剧增,乙烯的生成将促进呼吸作用和细胞壁水解酶等与成熟衰老相关酶的合成,提高细胞膜通透性,导致果实硬度下降[64]。因此,常使用外源激素或激素类似物调控果实成熟期的品质。Wu 等[65]采用生长素类似物2,4-二氯苯氧乙酸处理成熟期番茄果实,表明外源生长素通过抑制乙烯产生、类胡萝卜素积累及叶绿素降解,延缓番茄果实成熟。随后 Li 等[66]对外源生长素处理的果实进行转录组分析,发现外源生长素可通过调节乙烯生物合成和信号通路相关基因表达,抑制类胡萝卜素代谢和能量代谢相关基因表达,从而影响番茄成熟。Sun 等[67]研究也发现,果实中 *SlPti4* 基因在发育早期表达较低,在成熟过程中

表达迅速增加,这主要由于外源脱落酸诱导使脱落酸积累增加,乙烯释放量减少。此外,不同浓度的外源植物激素对果实影响不同,低浓度生长素抑制呼吸,高浓度则促进乙烯合成。赤霉素和细胞分裂素都能抑制呼吸跃变和乙烯生成,延缓果实成熟衰老,而脱落酸对赤霉素和细胞分裂素均有拮抗作用。

2.3　生物调控方法

生物保鲜技术主要有三种,一种是利用微生物次级代谢产物,如抗菌素、溶菌酶、动植物多糖、动植物蛋白质等,通过配置成适当浓度的溶液,采取喷淋、浸泡、涂膜的方式对果蔬进行保鲜处理;另一种是利用人工控制的拮抗菌和其产生的抗菌物质调控果蔬;此外还可通过生物工程进行调控,抑制果蔬软化。其中,将从动植物中提取的多糖类物质涂膜至果蔬表面,形成一层致密的膜,能有效减少果蔬失水,防止软化[68]。已发现魔芋葡甘聚糖、可溶性淀粉膜、羰甲基纤维素、灵芝提取液、微生物代谢产物溶菌酶、中草药提取液等涂膜处理草莓、芒果、杨梅等果蔬可显著抑制可溶性固形物下降,延缓软化[68,69]。国内外研究发现利用某些拮抗菌的生物防治能力也可有效延缓果蔬腐烂软化。目前,主要是酵母菌、细菌、霉菌中的部分菌种作为拮抗菌应用于果蔬保鲜中,且可与其他保鲜方法联用,这主要是利用拮抗菌可与附着于果蔬表面的病菌竞争生存空间和营养物质,或直接寄生于病菌上,有效抑制病菌生长[70]。Habiba 等[71]从番茄、芒果、柠檬、葡萄和青椒的未腐烂表面分离出附着生长的酵母菌,并喷施于金诺橘,发现利用酵母菌处理的金诺橘腐烂程度最小,品质保持得更好。Xu 等[72]用拮抗菌(*Candida guilliermondii*)和 UV-C 复合处理梨果实时,可显著抑制梨表面青霉菌和灰霉菌的生长,减少腐烂软化。Iglesias 等[73]利用小麦假单胞菌 CPA-7 处理梨,可有效防止腐烂,阻止香气物质挥发。近年来,生物工程保鲜技术也逐渐应用于果蔬保鲜中。张竞秋等[74]将与果蔬细胞壁水解相关酶与乙烯合成相关酶的转基因或反义 RNA 应用到果蔬保鲜中,从源头上延长果蔬货架期,保持果蔬硬度。Hamilton 等[75]首次通过表达反义 RNA 抑制了番茄的乙烯合成,延缓软化。吴静等[76]通过对香蕉 ACC 合成酶反义基因转化香蕉的研究,可有效抑制软化。不同方法调控果蔬软化效果如表 1 所示。

表 1　不同方法调控果蔬软化效果

Tab. 1　Effects of different methods on regulating fruits and vegetables softening

Methods	Materials	Treatments	Regulation effects
UV-C	Fresh-cut rocket [33]	20 kJ/m^2	Reducing the microbial load, maintaining better sensory quality and chemical characteristics
	Strawberry[34]	12.36 kJ/m^2 for 60 s	Effective in controlling gray mold, reducing fruit decay and petal infection
	Fresh-cut melon[35]	0.04 kJ/m^2 for 120 s	Lower enzymatic activities, including PG, PME, PPO, and POD, maintaining high firmness
	Tomato[36]	4.50 kJ/m^2	Higher phenol and firmness, and less PME activity, PG activity, ethylene production than control
Heat shock	Spinach leaves[38]	45 ℃ for 60 s	Positive effect on the biochemical constituents of the leaves, maintaining higher total carotenoid concentration
	Apples[37]	65 ℃ for 20 s	Killing surface microorganisms and delaying aging
	Mandarin[39]	45 ℃ for 120 s	Inhibiting the spore germination of pathogens in potato dextrose broth
Cold	Avocado[40]	Ice water for 30 min	Inhibiting of fruit peel color and hardness decline
	Banana[41]	0 ℃ for 60 min	Inhibiting the activities of PME and PG, decaying softening
	Cucumber[42]	2 ℃ for 40 min	Weight loss, firmness and POD activity, CST achieved the most positive effect
CA	Cabbage[44]	7% O_2, 7% CO_2, 86% N_2	Reducing respiratory rate and POD activity, maintaining color, ascorbic acid, and chlorophyll
	Fresh-cut green bell pepper[45]	13%~14% O_2, 7% CO_2	Increasing monoterpenes, aldehydes ketones, sesquiterpenes, esters, furans, and pyrazine
	Green pepper[46]	5% O_2, 10% CO_2	Reducing respiration and inhibiting enzyme activity
1-MCP	Avocado[50]	0.93 mmol/m^3 for 1 min	Increasing the total flavonoids content and total antioxidant capacities
	Apple[51]	1.00 μL/L	Inhibiting internal ethylene concentration and maintaining hardness

表1(续表)

Methods	Materials	Treatments	Regulation effects
Ca	Fresh-cut mango[52]	0.136 mol/L for 2.5 min	$CaCl_2$ retarded mangos softening during storage, and the retardation was greater at higher calcium concentrations
	Fresh-cut 'Galia' melon[54]	0.4% for 1 min	Increasing tissue total Ca content, and maintaining a good firmness and a lower respiration rate
	Sweet cherry[55]	0.5% for 5 min	Reducing respiration rate, ascorbic acid degradation, and membrane lipid peroxidation, enhancing total phenolics content and total antioxidant capacity
NO	Peach[56]	Immersion in 15 μmol/L NO	Enhancing the activities of phenylalanine ammonia-lyase, and increasing the contents of total phenolics, flavonoids and lignin over the entire storage period
	Mango[57]	20 μL/L fumigation for 2 h	Inhibiting ethylene biosynthesis and respiration rate, and maintaining higher pulp firmness, springiness, cohesiveness, chewiness, adhesiveness, and stiffness.
	Banana[59]	40 μL/L fumigation for 3 h	Effecting on polygalacturonase and *MaPGs* gene expression, and retarding banana soften
Biological regulation	Fresh-cut papaya[69]	Microencapsulated beta-cyclodextrin + Trans-cinnamaldehyde + Chitosan + Pectin coating	Maintaining high firmness and better color, having better qualities
	Kinnow[71]	Isolation of yeasts from the uncorrupted surfaces of tomatoes, mangoes, lemons, and green peppers	Delaying decay and maintaining better qualities
	Fresh-cut pear[73]	Pseudomonas aeruginosa CPA-7	Reducing *L. monocytogenes* population

3 总结与展望

果蔬营养价值丰富,市场需求量大,但由于采后贮藏过程中极易失水软化,导致其腐烂霉变,从而显著降低食用价值和商品价值。因此,如何调控果蔬采后软化,抑制果蔬生理生化反应,是改善果蔬采后品质急需解决的问题。目前,已有大量关于果蔬采后软化调控方面的研究,主要集中在单一调控方法(如热激、UV-C、CaCl2、1-MCP等)对果胶及其相关降解酶的影响,关于复合调控方法的研究与应用仍较少,且其调控机制尚未明确。今后的研究应从分子水平上探讨各种调控方法,特别是复合调控方法,在采后果蔬软化中的调控途径及机制,确定适合各种果蔬采后软化的最佳调控方法,从而延长果蔬贮藏期。同时,要不断探索新的绿色、安全、高效的调控方法,为控制果蔬采后软化提供重要参考。

参考文献(References):

[1] SZYMAЙSKA-CHARGOT M, CHYLIЙSKA M, PIECZYWEK P M, *et al*. Tailored nanocellulose structure depending on the origin. Example of apple parenchyma and carrot root celluloses [J]. Carbohydrate Polymers, 2019, 210: 186-195.

[2] YANG Z F, CAO S F, SU X G, *et al*. Respiratory activity and mitochondrial membrane associated with fruit senescence in postharvest peaches in response to UV-C treatment[J]. Food Chemistry, 2014, 161: 16-21.

[3] BASSO A, FÁTIMA R D, MOREIRA P M, *et al*. Effect of operational conditions on photocatalytic ethylene degradation applied to control tomato ripening[J]. Journal of Photochemistry & Photobiology A: Chemistry, 2018, 367: 294-301.

[4] MANSOURBAHMANI S, GHAREYAZIE B, ZARINNIA V, *et al*. Study on the efficiency of ethylene scavengers on the maintenance of postharvest quality of tomato fruit[J]. Journal of Food Measurement and Characterization, 2018, 12(2): 691-701.

[5] DUAN X W, CHENG G P, YANG E, *et al*. Modification of pectin polysaccharides during ripening of postharvest banana fruit [J]. Food Chemistry, 2008, 111(1): 144-149.

[6] DU S L, ZHANG J H, CHEN S Y, *et al*. The combined effect of 1-methylcyclopropene and citral suppressed postharvest grey mould of tomato fruit by inhibiting the growth of *Botrytis cinerea* [J]. Journal of Phytopathology, 2019, 167(2): 123-134.

[7] WALDRON K W. Plant structure and fruit and vegetable texture [J]. Texture in Food Solid Foods, 2004, 2(1): 241-258.

[8] BELAY Z A, CALEB O J, OPARA U L. Enzyme kinetics modelling approach to evaluate the impact of high CO_2 and super-atmospheric O_2 concentrations on respiration rate of pomegranate arils[J]. CyTA-Journal of Food, 2017, 15(4): 608-616.

[9] BRUMMELL D A. Cell wall disassembly in ripening fruit[J]. Functional Plant Biology, 2006, 33(2): 103-119.

[10] 白小东, 毕阳, 李永才, 等. 果蔬采后病害的潜伏侵染机理研究进展[J]. 食品科学, 2015, 36(7): 278-282.
BAI Xiaodong, BI Yang, LI Yongcai, *et al*. Mechanism of latent infection for postharvest diseases of fruits and vegetables [J]. Food Science, 2015, 36(7): 278-282.

[11] 李汴生, 苏芳萍, 朱悦夫, 等. 超高压处理对不同果蔬结构和性质的影响[J]. 高压物理学报, 2018, 32(3): 1-11.
LI Biansheng, SU Fangping, ZHU Yuefu, *et al*. Effect of high pressure processing on texture and quality of fruits and vegetables[J]. Chinese Journal of High Pressure Physics, 2018, 32(3): 1-11.

[12] CAMPS C. Singular approach to penetrometry by preprocessing of digitized force-displacement curves and chemometry: a case study of 12 tomato varieties[J]. Journal of Texture Studies, 2018, 49(4): 378-386.

[13] 张梦如, 杨玉梅, 成蕴秀, 等. 植物活性氧的产生及其作用和危害[J]. 西北植物学报, 2014, 34(9): 1916-1926.
ZHANG Mengru, YANG Yumei, CHENG Yunxiu, *et al*. Generation of reactive oxygen species and their functions and deleterious effects in plants[J]. Acta Botanica Boreali-Occidentalia Sinica, 2014, 34(9): 1916-1926.

[14] WANG Y, LI Y L, XU W D, *et al*. Exploring the effect of β-glucan on the biocontrol activity of *Cryptococcus podzolicus* against postharvest decay of apples and the possible mechanisms involved[J]. Biological Control, 2018, 121: 14-22.

[15] CHEN C Y, PENG X, ZENG R, *et al*. *Ficus hirta* fruits extract incorporated into an alginate-based edible coating for Nanfeng mandarin preservation[J]. Scientia Horticulturae, 2016, 202: 41-48.

[16] DONG Y, ZHI H H, XU J, *et al*. Effect of methyl jasmonate on reactive oxygen species, antioxidant systems, and microstructure of chinese winter jujube at two major ripening stages during shelf life[J]. The Journal of Horticultural Science and Biotechnology, 2016, 91(3): 316-323.

[17] CHEN M Y, LIN H T, ZHANG S, *et al*. Effects of adenosine triphosphate (ATP) treatment on postharvest physiology, quality and storage behavior of longan fruit[J]. Food Bioprocess Technology, 2015, 8(5): 971-982.

[18] 陈昆松, 张上隆, 吕均良, 等. 脱落酸、吲哚乙酸和乙烯在猕猴桃果实后熟软化进程中的变化[J]. 中国农业科学, 1997, 30(2): 54-57.
CHEN Kunsong, ZHANG Shanglong, LV Junliang, *et al*. Variation of abscisic acid, indole 3 acetic acid and ethylene in kiwifruit during fruit ripening[J]. Scientia Agricutura Sinica, 1997, 30(2): 54-57.

[19] WANG N, CHEN H T, NONAKA S, *et al*. Ethylene biosynthesis controlled by NON-RIPENING: a regulatory conflict between wounding and ripening[J]. Plant Physiology and Biochemistry, 2018, 132: 720-726.

[20] GWANPUA S G, BUGGENHOUT S V, VERLINDEN B E, *et al*. Pectin modifications and the role of pectin-degrading enzymes during postharvest softening of Jonagold apples[J]. Food Chemistry, 2014, 158: 283-291.

[21] MASSOLO J F, FORTE L G, CONCELLÓA, *et al*. Effects of ethylene and 1-MCP on quality maintenance of fresh cut celery[J]. Postharvest Biology and Technology, 2019, 148: 176-183.

[22] BRUMMELL D A, HARPSTER M H. Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants[J]. Plant Molecular Biology, 2001, 47 (1-2): 311-339.

[23] HADFIELD K A, BENNETT A B. Polygalacturonases: many genes in search of a function[J]. Plant Physiology, 1998, 117 (2): 337-343.

[24] BRUMMELL D A, CIN V D, CRISOSTO C H, *et al*. Cell wall metabolism during maturation, ripening and senescence of peach fruit[J]. Journal of Experimental Botany, 2004, 55 (405): 2029-2039.

[25] WEN B, STRÖM A, TASKER A, *et al*. Effect of silencing the two major tomato fruit pectin methylesterase isoforms on cell wall pectin metabolism[J]. Plant Biology, 2013, 15(6): 1025-1032.

[26] FRY S C, DUMVILLE J C, MILLER J G. Fingerprinting of polysaccharides attacked by hydroxyl radicals *in vitro* and in the cell walls of ripening pear fruit[J]. Biochemical Journal, 2001, 357(3): 729-737.

[27] DUMVILLE J C, FRY S C. Solubilisation of tomato fruit pectins by ascorbate: a possible non-enzyme mechanism of fruit softening[J]. Planta, 2003, 217(6): 951-961.

[28] ZHANG Z S, WANG X M, ZHAO M X, *et al*. Free-radical degradation by $Fe^{2+}/Vc/H_2O_2$ and antioxidant activity of polysaccharide from Tremella fuciformis[J]. Carbohydrate Polymers, 2014, 112: 578-582.

[29] WANG Y, ZHANG X, ZHOU J Y, *et al*. Inhibitory effects of five antifungal substances on development of postharvest pathogen *Rhizopus oryzae*[J]. Journal of Agricultural Biotechnology, 2015, 23(1): 107-117.

[30] NAETS M, DAEL M V, VANSTREELS E, *et al*. To disinfect or not to disinfect in postharvest research on the fungal decay of apple[J]. International Journal of Food Microbiology, 2018, 266: 190-199.

[31] URBAN L, CHARLES F, ALCANTARA D M, *et al*. Understanding the physiological effects of UV-C light and exploiting its agronomic potential before and after harvest[J]. Plant Physiology and Biochemistry, 2016, 105: 1-11.

[32] ZHU P K, LI Q W, AZAD S M. Fungal gene mutation analysis elucidating photoselective enhancement of UV-C disinfection efficiency toward spoilage agents on fruit surface[J]. Frontiers in Microbiology, 2018, 9: 1141.

[33] GUTIÉRREZ D R, CHAVES A R, RODRÍGUEZ D C. Use of UV-C and gaseous ozone as sanitizing agents for keeping the quality of fresh-cut rocket (*Eruca sativa mill*)[J]. Journal of Food Processing and Preservation, 2016, 41(3): 1-13.

[34] JANISIEWICZ W J, TAKEDA F, GLENN D, *et al*. Dark period following UV-C treatment enhances killing of *Botrytis cinereal* conidia and controls gray mold of strawberries[J]. Phytopathology, 2016, 106(4): 386-394.

[35] CHISARI M, BARBAGALLO R N, SPAGNA G, *et al*. Improving the quality of fresh-cut melon through inactivation of degradative oxidase and pectinase enzymatic activities by UV-C treatment[J]. International Journal of Food Science and Technology, 2011, 46(3): 463-468.

[36] MANSOURBAHMANI S, GHAREYAZIE B, KALATEJARI S, *et al*. Effect of post-harvest UV-C irradiation and calcium chloride on enzymatic activity and decay of tomato (*Lycopersicon esculentum* L.) fruit during storage[J]. Journal of Integrative Agriculture, 2017, 16(9): 2093-2100.

[37] MAXIN P, WEBER R W S, PEDERSEN H L, *et al*. Control of a wide range of storage rots in naturally infected apples by hot-water dipping and rinsing[J]. Postharvest Biology and Technology, 2012, 70: 25-31.

[38] GLOWACZ M, MOGREN L M, READE J P H, *et al*. Can hot water treatments enhance or maintain postharvest quality of spinach leaves[J]. Postharvest Biology and Technology, 2013, 81: 23-28.

[39] HONG P, HAO W N, LUO J J, *et al*. Combination of hot water, *Bacillus amyloliquefaciens* HF-01 and sodium bicarbonate treatments to control postharvest decay of mandarin fruit[J]. Postharvest Biology and Technology, 2014, 88: 96-102.

[40] CHEN J, LIU X X, LI F F, *et al*. Cold shock treatment extends shelf life of naturally ripened or ethylene-ripened avocado fruits[J]. PloS One, 2017, 12(12): 14-16.

[41] ZHANG H Y, YANG S Y, JOYCE D C, *et al*. Physiology and quality response of harvested banana fruit to cold shock[J]. Postharvest Biology and Technology, 2010, 55(3): 154-159.

[42] YANG Z, CHEN M F, CHEN A Q, *et al*. Analysis about heat transfer of vegetable during cold shock treatment and preservation quality after storage[J]. International Journal of Food Engineering, 2017, 13(3): 1-13.

[43] 黄宇斐, 乔勇进, 刘晨霞, 等. 气调对西兰花贮藏效果与品质的影响[J]. 食品与机械, 2017, 33(6): 114-200.
HUANG Yufei, QIAO Yongjin, LIU Chenxia, *et al*. Effect of

controlled atmosphere on preservation and freshness storage of broccoli[J]. Food & Machinery, 2017, 33(6): 114-200.

[44] ZHU Z W, WU X W, GENG Y, *et al*. Effects of modified atmosphere vacuum cooling (MAVC) on the quality of three different leafy cabbages[J]. LWT-Food Science and Technology, 2018, 94: 190-197.

[45] RANJITHA K, SUDHAKAR R D V, SHIVASHANKARA K S, *et al*. Effect of pretreatments and modified atmosphere packaging on the shelf life and quality of fresh-cut green bell pepper [J]. Journal of Food Science and Technology, 2015, 52(12): 7872-7882.

[46] 李素清，张艳梅，秦文. 青椒气调贮藏工艺研究[J]. 食品工业科技，2014，35(1): 318-322.
LI Suqing, ZHANG Yanmei, QIN Wen. Study on CA storage technology of green peppers[J]. Science and Technology of Food Industry, 2014, 35(1): 318-322.

[47] HU Z J, TANG C X, HE Z B, *et al*. 1-Methylcyclopropene (MCP)-Containing cellulose paper packaging for fresh fruit and vegetable preservation: a review[J]. BioResources, 2017, 12(1): 2234-2248.

[48] 刘超超，魏景利，徐玉亭，等. 苹果 3 个早熟品种果实发育后期硬度及其相关生理指标的初步研究[J]. 园艺学报，2011，38(1): 133-138.
LIU Chaochao, WEI Jingli, XU Yuting, *et al*. Preliminary study on firmness and related physiological indices of three early-ripening apple cultivar during late development of the fruit [J]. Acta Horticulturae Sinica, 2011, 38(1): 133-138.

[49] HADFIELD K A, ROSE J K, YAVER D S, *et al*. Polygalacturonase gene expression in ripe melon fruit supports a role for polygalacturonase in ripening-associated pectin disassembly[J]. Plant Physiology, 1998, 117(2): 363-373.

[50] ZHANG Z K, HUBER D J, RAO J P. Antioxidant systems of ripening avocado (*Persea americana* Mill.) fruit following treatment at the preclimacteric stage with aqueous 1-methylcyclopropene[J]. Postharvest Biology and Technology, 2013, 76: 58-64.

[51] WATKINS C B, NOCK J F. Rapid 1-methylcyclopropene (1-MCP) treatment and delayed controlled atmosphere storage of apples[J]. Postharvest Biology and Technology, 2012, 69: 24-31.

[52] NGAMCHUACHIT P, SIVERTSEN H K, MITCHAM E J, *et al*. Effectiveness of calcium chloride and calcium lactate on maintenance of textural and sensory qualities of fresh-cut mangos [J]. Journal of Food Science, 2014, 79(5): 786-794.

[53] SAFTNER R A, CONWAY W S, SAMS C E. Effects of postharvest calcium and fruit coating treatments on postharvest life, quality maintenance, and fruit-surface injury in 'Golden Delicious' apples[J]. Journal of the American Society for Horticutural Science, 1998, 123(2): 294-298.

[54] SILVEIRA A C, AGUAYO E, CHISARI M, *et al*. Calcium salts and heat treatment for quality retention of fresh-cut 'Galia' melon[J]. Postharvest Biology and Technology, 2011, 62(1): 77-84.

[55] WANG Y, XIE X B, LONG L E. The effect of postharvest calcium application in hydro-cooling water on tissue calcium content, biochemical changes, and quality attributes of sweet cherry fruit[J]. Food Chemistry, 2014, 160: 22-30.

[56] LI G J, ZHU S H, WU W X, *et al*. Exogenous nitric oxide induces disease resistance against *Monilinia fructicola* through activating the phenylpropanoid pathway in peach fruit[J]. Journal of the Science of Food and Agriculture, 2017, 97(9): 3030-3038.

[57] ZAHARAH S S, SINGH Z. Mode of action of nitric oxide in inhibiting ethylene biosynthesis and fruit softening during ripening and cool storage of 'Kensington Pride' mango[J]. Postharvest Biology and Technology, 2011, 62(3): 258-266.

[58] CORPAS F J, PALMA J M. Nitric oxide on/off in fruit ripening [J]. Plant Biology, 2018, 20(5): 805-807.

[59] 吴斌，郭芹，王刚霞，等. 一氧化氮处理对香蕉多聚半乳糖醛酸酶及 MaPGs 基因表达的影响[J]. 生物技术进展，2014，4(1): 30-35.
WU Bin, GUO Qin, WANG Gangxia, *et al*. Effects of nitric oxide treatment on polygalacturonase activity and expression of MaPGs genes in harvested banana fruit during storage[J]. Current Biotechnology, 2014, 4(1): 30-35.

[60] RODRIGUEZ-ARZUAGA M, PIAGENTINI A M. New antioxidant treatment with yerba mate (*Ilex paraguariensis*) infusion for fresh-cut apples: modeling, optimization, and acceptability [J]. Food Science and Technology International, 2017, 24(3): 223-231.

[61] 王石华. 复合保鲜剂处理对丽江雪桃贮藏防褐保鲜的影响[J]. 北方园艺，2016，(3): 125-129.
WANG Shihua. Effect of compound preservative treatment on fresh-keeping and inhibit browning of lijiang snow peach during storage[J]. Northern Horticulture, 2016, (3): 125-129.

[62] WAGHMARE R B, ANNAPURE U S. Effects of hydrogen peroxide, modified atmosphere and their combination on quality of minimally processed cluster beans[J]. Journal of Food Science and Technology, 2017, 54(11): 3658-3665.

[63] PARREIDT T S, MÜLLER K, SCHMID M. Alginate-based edible films and coatings for food packaging applications[J]. Foods, 2018, 7(10): 1-38.

[64] 宋晓雪，胡文忠，毕阳，等. 鲜切果蔬软化机理及其调控的研究进展[J]. 食品工业科技，2013，34(4): 397-400.
SONG Xiaoxue, HU Wenzhong, BI Yang, *et al*. Research progress in softening mechanism and regulation of fresh-cut fruits and vegetables[J]. Science and Technology of Food Industry, 2013, 34(4): 397-400.

[65] WU Q, TAO X Y, AI X Z, *et al*. Effect of exogenous auxin on aroma volatiles of cherry tomato (*Solanum lycopersicum* L.) fruit during postharvest ripening[J]. Postharvest Biology and Technology, 2018, 146: 108-116.

[66] LI J Y, TAO X Y, LI L, *et al*. Comprehensive RNA-Seq analysis on the regulation of tomato ripening by exogenous auxin [J]. Plos One, 2016, 11(5): 25-27.

[67] SUN Y F, LIANG B, WANG J, *et al*. SlPti4 affects regulation of fruit ripening, seed germination and stress responses by modulating ABA signaling in tomato[J]. Plant and cell physiology, 2018, 59(10): 1956-1965.

[68] 赵瑞平，兰凤英，孙丰梅，等. 采前涂膜处理对宣化牛奶葡萄贮藏生理及品质的影响[J]. 食品科学，2011，32(10): 274-278.
ZHAN Ruiping, LAN Fengying, SUN Fengmei, *et al*. Effect of preharvest coating treatment on physiology and quality of grape during storage[J]. Food Science, 2011, 32(10): 274-278.

[69] BRASIL I M, GOMES C, PUERTA-GOMEZ A, *et al*. Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya[J]. LWT-Food Science and Technology, 2012, 47(1): 39-45.

[70] 张慜，冯彦君. 果蔬生物保鲜新技术及其研究进展[J]. 食品与生物技术学报，2017，36(5): 449-455.
ZHANG Min, FENG Yanjun. New bio-preservation technology of fruits & vegetables and its research progress[J]. Journal of Food Science and Biotechnology, 2017, 36(5): 449-455.

[71] HABIBA, NOREEN R, ALI S A, *et al*. Evaluation of biocontrol potential of epiphytic yeast against postharvest *Penicillium digitatum* rot of stored Kinnow fruit (*Citrus reticulata*) and their effect on its physiochemical properties[J]. Postharvest Biology and Technology, 2019, 148: 38-48.

[72] XU L, DU Y. Effects of yeast antagonist in combination with UV-C treatment on postharvest diseases of pear fruit[J]. Biocontrol, 2011, 57(3): 451-461. (下转第 517 页)