鲜切蔬菜保鲜技术的研究进展

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摘　要: 鲜切蔬菜因符合生活快节奏而深受消费者欢迎, 产值逐年增长; 但由于鲜切蔬菜生理代谢活跃, 极易发生品质劣变和腐烂, 造成货架期很短, 为此国内外均加强了鲜切蔬菜保鲜技术的研发。本文分析了鲜切蔬菜在贮藏过程中的品质变化规律, 系统总结了鲜切蔬菜保鲜技术的研发进展, 特别是近几年一些新的保鲜技术研发动态, 简要讨论了鲜切蔬菜保鲜技术的发展趋势, 以期为鲜切蔬菜保鲜新技术的研发提供理论参考。

关键词: 鲜切蔬菜; 保鲜技术; 贮藏

Advances in postharvest technology of fresh-cut vegetables

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ABSTRACT: Fresh-cut vegetables have gained much more welcome from consumers since they are very suitable for the modern life. In recent years, the output of this industry of fresh-cut vegetables has increased rapidly. However, due to the active metabolism of fresh-cut vegetables, it is prone to quality deterioration and rot, resulting in a short shelf life. For this reason, the research and development of fresh-cut vegetable preservation technology has been strengthened at home and abroad. This paper reviewed the change in quality and development in preservation technology of fresh-cut vegetables during storage, especially some novel handlings in recent years, and then briefly discussed the trend of preservation technology of fresh-cut vegetables in the future, so as to provide a basis for the development of new technologies.

KEY WORDS: fresh-cut vegetables; preservation technology; storage

1　引　言

鲜切蔬菜, 又叫最小加工蔬菜, 是指新鲜蔬菜经过挑选整理、浸泡清洗、去皮切分、杀菌以及包装等过程, 成为一种便捷的新鲜蔬菜产品[1]。由于鲜切蔬菜食用方便, 而且同一包装可有不同种类蔬菜, 能满足消费者对不同口味蔬菜的要求, 深受消费者欢迎。近几年来, 国内外鲜切蔬菜生产规模和销售市场发展迅速。

鲜切蔬菜在国际上始于 50 年代, 主要以马铃薯为原料, 以后逐步扩展到胡萝卜、生菜、甘蓝、洋葱等。与完

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整的新鲜蔬菜相比, 由于去皮、切片或切丝和流通、销售等步骤, 鲜切蔬菜的生理代谢十分活跃, 易受病原菌侵染, 极易发生品质劣变和腐烂, 造成货架期很短; 因此, 各国对鲜切蔬菜保鲜技术的研发均十分重视。总体而言, 虽然各种保鲜措施能有效延长鲜切蔬菜的货架期, 但远不能满足消费者对高营养、优质感官品质的鲜切蔬菜产品的需求。

本文结合鲜切蔬菜在贮藏过程中的品质变化规律, 重点评述了鲜切蔬菜的保鲜技术研发的最新研究进展, 并讨论了鲜切蔬菜保鲜技术的发展趋势, 为鲜切蔬菜新的保鲜技术研发提供理论指导。

2 鲜切蔬菜在贮藏过程中的品质变化

2.1 外观变化

颜色、质地和风味是评价鲜切蔬菜的重要外观指标。其中, 颜色的变化最为直观, 但在不同鲜切蔬菜品种中表现不一样: 生菜、土豆、茄子[2]、荸荠[3]和莲藕[4]等容易发生褐变, 胡萝卜会出现"白腮红"[5]; 而番茄和洋葱发生半透明[6]。在蔬菜质地上主要体现为软化和木质化, 如黄瓜和洋葱的鲜切蔬菜会发生软化[2]; 而鲜切芦笋则会发生木质化[7]。风味也是评价鲜切蔬菜品质的关键因素。鲜切蔬菜在贮藏过程中常伴随着酸度、甜度、香气、辣味、涩味等口感上的变化。由于切割加工会加快鲜切蔬菜的呼吸速率, 因此, 消耗更多糖、酸和淀粉来维持其生命活动。此外, 鲜切蔬菜表面的汁液会阻塞气孔, 可能诱发无氧呼吸, 造成乙醇和乙醛的大量积累[8,9], 易使鲜切蔬菜发酸。品质变化多是因切分使蔬菜体内的酶与底物的区域化分布被打破, 酶与底物直接接触发生相应的生理生化反应所引起, 如酶促褐变、酶促细胞壁降解和次生物质代谢途径改变等。

2.2 营养物质变化

经鲜切加工处理的蔬菜容易发生营养成分的改变。研究表明, 鲜切菠菜在货架期内, 类黄酮和维生素 C 等抗氧化物质含量降低[10]。鲜切胡萝卜虽然在贮藏过程中维生素 C 含量降低, 但类胡萝卜素含量增加[11]; 而鲜切洋葱在 4 ℃和 50 ℃水中浸泡 5 min 后黄酮醇的损失量达到 17%~23%[12], 同样的鲜切番茄、西兰花和茄子在贮藏过程中黄酮醇的含量与未鲜切蔬菜相比显著降低[13]。与未切分洋葱相比, 鲜切洋葱的槲皮素含量与总酚含量较高, 但可溶性固形物含量降低[14]。鲜切紫甘蓝在货架期 7 d 内, 总花青苷和总硫代葡萄糖苷的损失率分别达到了 18.12%和 10.32%[15]。整体来讲, 鲜切蔬菜在贮藏过程中易发生营养物质的损失。

2.3 表面病原微生物

与完整的蔬菜相比, 鲜切蔬菜由于受到切分, 易发生汁液溢出。溢出液中的营养成分可为许多微生物提供了营养物质; 同时, 切割使得鲜切蔬菜暴露在外面积加大, 更有利于微生物的侵染。目前, 鲜切蔬菜上常见的病原微生物可分为致病菌和致腐菌。常见致病菌包括单核细胞增多性李斯特菌 (*Listeria monocytogenes*) 、沙门氏菌 (*Salmonella*[16]、大肠杆菌 O157:H7(*E. coli* O157:H7)[17]、志贺氏杆菌属 (*Shigella* spp.) 和金黄色葡萄球菌 (*Staphyloccocus aureus*)等[18]。最近, 美国多州还爆发了沙门氏菌疫情, 与食用受污染的黄瓜有关[19]。常见致腐菌主要有欧文氏菌 (*Erwinia* spp.) 、假单胞菌 (*Pseudomonas* spp.)[20]、好氧嗜温细菌、酵母菌和灰霉菌等[21]; 其中欧文氏菌和假单胞菌作为最为重要的 2 种病原菌, 具有分解果胶和水解蛋白质的活性, 可导致鲜切蔬菜的软腐发生[20]。陈湘宁等[22]对几种膜包装的鲜切蔬菜的腐败菌进行了分离, 结果表明在鲜切胡萝卜中的主要致腐菌为嗜麦芽糖寡养单胞菌(*Stenotrophomonas maltophilia*), 在鲜切紫甘蓝中致腐菌主要为荧光假单胞菌(*Pseudomonas fluorescens*), 在鲜切西兰花中的主要致腐菌为皱纹假单胞菌(*Pseudomonas corrugata*)。

3 鲜切蔬菜保鲜技术

3.1 物理方法

3.1.1 切分方式

鲜切蔬菜的切分大小、形状能直接影响到其贮藏效果, 因此, 可通过控制鲜切蔬菜的切分方式, 最大地减少损伤, 延长贮藏期。Del 等[23]对在低温贮藏下切片和切丝的胡萝卜进行了研究, 发现切丝比切片的胡萝卜呼吸速率高, 并且可溶性固形物和维生素 C 含量下降更快。Deza-Durand 等[24]研究了横切和纵切对生菜的保鲜效果的影响, 发现横切损伤程度严重, 能促进由脂氧合酶途径介导的香气成分的形成。Silveira 等[25]工作表明, 条状土豆上的微生物含量大于立方体状的土豆。Han 等[26]比较了大葱的三种切分方式(切片、切碎、切丝)对其贮藏效果的影响, 发现伤害程度的增加使得呼吸速率急剧上升, 并且造成辛辣味、可溶性固形物和抗坏血酸的含量降低。另外, Berno 等[27]还研究了紫洋葱的切厚片和切丁对其贮藏效果的影响, 表明切片更有利于呼吸速率、可溶性固形物、总酚等理化指标的稳定性。

3.1.2 低温与热激处理

适宜低温能降低鲜切蔬菜各项生命活动, 进而达到保鲜效果。Manzocco 等[28]研究表明, 鲜切生菜在 4 ℃低温下贮藏 7 d 内腐烂率小于 1%, 而当鲜切生菜在 12 ℃贮藏同样时间, 腐烂率则上升到 13%。Berno 等[29]研究了 0、5、10 和 15 ℃不同温度对鲜切紫洋葱的贮藏效果, 发现 0 ℃有利于营养物质和感官品质的保持, 表现为呼吸速率低, 总酚、花青素和槲皮素等含量变化小。侯茜等[30]对 0、5、10 ℃贮藏的鲜切黄瓜也进行了比较分析, 表明在 0 ℃条件下保鲜效果最好, 能够减少微生物污染数量, 维持可滴定

酸、可溶性蛋白和 Vc 等营养物质的含量，延长货架期。

除了低温贮藏外，热激预处理也应用于鲜切蔬菜保鲜。Rodoni 等[31]采用 45 ℃热水分别处理青辣椒条和红辣椒条 3 min，结果表明该处理能有效防止其颜色变化，减少失水量和腐烂率。Duarte-Sierra 等[32]对鲜切西兰花分别用 41 ℃热空气处理 180 min、47 ℃热空气处理 10 min，然后在 4 ℃下贮藏，发现两种热处理均能显著提高吲哚型葡萄糖酸盐和羟基肉桂酸的效价，增加抗氧化能力，能使贮藏期从 14 d 延长至 21 d。Paillart 等[33]工作表明，采用 45~47.5 ℃热水处理 30~180 s，可明显降低鲜切卷心莴苣的苯丙氨酸解氨酶(phenylalanine ammonia lyase, PAL)的活性，抑制卷心莴苣颜色变粉。另外，采用 100 ℃热水处理鲜切胡萝卜丝 45 s，可有效降低其呼吸速率，抑制微生物生长，使得保质期从原来的 7 d 延长至 10 d[34]。

3.1.3 气调贮藏

Escalona 等[35]研究表明，采用 80 kPa O_2+10~20 kPa CO_2 气调包装可避免鲜切奶油生菜的发酵，并降低呼吸速率。Waghmare 等[36]研究发现，经次氯酸钠消毒后，应用 5% O_2+10% CO_2+85% N_2 气体包装，能使鲜切香菜在 5 ℃低温下贮藏 25 d，并降低表面微生物污染量，保持较好的颜色和硬度。Simón 等[37]工作表明，采用 7% CO_2+15% O_2 气体环境能够抑制鲜剥白芦笋的腐败，在 5 ℃低温下能够贮藏 14 d。Luna 等[38]报道，0.5~1.5 kPa O_2+98.5~99.5 kPa N_2 包装处理能维持鲜切罗马生菜中 Vc 含量，降低咖啡酸衍生物含量以及 PAL 和多酚氧化酶(polyphenol oxidase, PPO)的活性，抑制表面褐变发生。Shen 等[39]发现，4% O_2+2% CO_2+94% N_2 能有效地延缓鲜切土豆中的水分、维生素 C、色泽和硬度的损失，降低丙二醛含量和呼吸速率。Meng 等[40]用加压氩气(2~6 MPa)+5% O_2+ 8% CO_2 贮藏鲜切青椒，发现能减缓鲜切青椒中的水分、维生素 C、叶绿素含量的损失，较好地维持感官质量，同时减少了大肠杆菌、酵母菌和霉菌等微生物污染。另外，Meng 等[41]研究还表明，加压氩气(1.0 MPa)能够减缓鲜切黄瓜的水分、硬度、颜色、可溶性固形物和可滴定酸的损失，降低呼吸速率，并减少微生物污染数量。

3.1.4 紫外辐照

短波紫外光(ultraviolet-C, UV-C，波长 200~280 nm)能够通过破坏病原微生物的 DNA 或 RNA 的结构，从而达到杀灭病原微生物的目的。近些年来，UV-C 已被建议用作替代传统次氯酸钠的消毒处理。Martínez-Hernández 等[42]报道，采用 1.5、4.5、9.0 和 15 kJ/m^2 4 种剂量的 UV-C 处理鲜切西兰花，发现 1.5 和 4.5 kJ/m^2 这 2 种剂量处理能够提高鲜切西兰花的抗氧化性，降低表面微生物污染数量，有利于鲜切西兰花的物流保鲜。Wang 等[4]报道，鲜切藕片暴露于距离包装托盘 30 cm 的 75 W UV-C 灯下，持续暴光 1、5、10、20、40 min，然后在 4 ℃下贮藏 8 d，结果表明采用 5 和 10 min UV-C 处理能使 PPO 和过氧化物酶(Peroxidase, POD)失活，褐变程度最低。Huang 等[43]研究了 4.5 kJ/m^2 UV-C 处理对鲜切百合的品质影响，发现该处理能够降低淀粉酶的活性，增加抗氧化活性，减少鲜切百合褐变的发生。Gutiérreza 等[44]报道，应用 20 kJ/m^2 UV-C 处理鲜切芝麻菜，能通过增强抗坏血酸过氧化物酶(ascorbate peroxidase, APX)和过氧化氢酶(catalase, CAT)的活性，抑制活性氧产生，减少微生物污染，从而维持了较好的感官品质。

3.1.5 γ 射线与电子束辐射

辐照作为一种非热杀菌处理方法，但可能会导致品质的负面影响，如质地、风味和营养物质的损失。Mohácsi-Farkas 等[45]报道，采用 1.0、1.5 和 2 kGy 剂量的 γ 射线辐射处理鲜切番茄和胡萝卜，能够抑制鲜切番茄和胡萝卜表面的大肠杆菌、霉菌以及李斯特菌的污染数量，除了硬度以外，对感官品质影响不大；但会引起生育酚、类胡萝卜素等含量降低。Pinela 等[46]研究了 1、2、5 kGy γ 辐射对鲜切西洋菜在 4 ℃下贮藏的效果，发现以 2 kGy 处理对感官品质的效果最好。Fan 等[47]采用 0、1、2、3、4 kGy γ 射线辐照处理鲜切卷心莴苣，在 4 ℃下保存 14 d，确定 4 种剂量的 γ 射线处理均能降低鲜切卷心莴苣的褐变程度，抑制表面微生物数量的增加，但降低了维生素 C 的含量；其中，以 1 或 2 kGy 低剂量处理对整体感官品质的效果最好。另外，Gomes 等[48]报道，在 4 ℃低温下，应用 1、2、3 kGy 电子束辐照处理鲜切花椰菜，在 14 d 的实验期内，辐射处理能有效保持鲜切花椰菜的感官品质，减少鲜切花椰菜上的微生物污染数量，但未对颜色、硬度和失重等产生负面影响，其中以 3 kGy 电子束辐照处理效果最好。Joshi 等[19]还发现，采用 1.9 kGy 电子束辐射处理，抑制了鲜切黄瓜上的浦那沙门氏菌发生，并且在感官品质方面，只影响到鲜切黄瓜的硬度，但对其颜色、水分、营养成分含量没有明显的影响。

3.1.6 脉冲光

脉冲光处理是一种广泛研究的灭菌和消毒方法，常用于物体表面、包装和食品的灭菌。Valdivia-Nájar 等[49]报道，采用 4、6、8 J/cm^2 脉冲光处理鲜切番茄 4.5~6 ms，并在 5 ℃低温下贮藏 18 d，发现能明显减少鲜切番茄表面微生物数量，而且能促进番茄红素和总酚类化合物的积累；但会增强果胶甲基酯酶(pectin methylesterase, PME)和多聚半乳糖醛酸酶(polygalacturonase, PG)的活性，降低鲜切番茄的硬[50]。Oms-Oliu 等[51]应用 4、8、12、28 J/cm^2 处理鲜切蘑菇，发现高剂量脉冲光处理会导致维生素 C 和酚类物质的含量下降，PPO 活性增强，抗氧化能力降低；但 4.8 J/cm^2 低剂量脉冲光处理可延长鲜切蘑菇的保质期，同时不影响到抗氧化能力。不过，Ramos-Villarroel 等[52]工作表明，12 J/cm^2 脉冲光处理鲜切蘑菇，可抑制表面李斯特菌

和大肠杆菌的生长, 但会引起切面褐变。

3.1.7 等离子体

等离子体是继固体、液体、气体之后的第 4 种物质, 包括光子、自由电子、正离子、负离子、激发和非激发原子和分子, 这些粒子可以在相互复合过程中以可见光和紫外线的形式释放出能量, 起到杀菌作用。等离子体可通过电能、激光、微波、射频、磁场、交流电和直流电等多种形式产生。目前, 常用于产生等离子体的气体主要有空气、氧气、氮气或惰性气体[53]。Berardinelli 等[54]报道, 采用介质阻挡放电大气等离子体(空气作为工作气体, 电源电压 19.15 V)处理鲜切红菊苣, 发现 30 min 处理能减少李斯特菌和大肠杆菌的污染数量。Zhang 等[55]运用非热低压氧等离子体(13.56 MHz, 600 W)处理菠菜、莴苣、番茄和土豆 600 s, 发现对清除菠菜中的鼠伤寒杆菌 LT2 的效果优于 3% H_2O_2 洗涤处理。Bermúdez-Aguirre 等[56]研究发现, 采用大气压冷等离子体(电压 3.95~12.83 kV, 频率为 60 Hz)处理鲜切生菜和胡萝卜 10 min, 能使鲜切生菜和胡萝卜表面的大肠杆菌数量明显减少。另外, Andrasch 等[57]报道, 采用气体等离子体处理鲜切菊苣, 也能有效减少表面微生物污染数量。

3.2 化学方法

3.2.1 可食性被膜

可食性被膜通常以多糖、蛋白质、脂类等物质作为被膜剂, 采用喷洒、涂抹、浸泡等方式使其均匀分布于蔬菜表面, 形成一层被膜, 具有减少微生物侵染, 降低呼吸速率、水分蒸发等作用。Chitravathi 等[58]报道, 应用 5%虫胶涂膜能降低鲜切辣椒的水分、抗坏血酸和叶绿素的损失。Ranjitha 等[59]采用 0.75%和 1.5%低甲氧基果胶处理鲜切胡萝卜, 在 8℃下贮藏, 发现经处理后鲜切胡萝卜的货架期延长 5~7 d; 与未处理组相比, 低甲氧基果胶处理减少了鲜切胡萝卜的酚酸积累, 抑制了“白色腮红”现象发生, 同时降低了类黄酮含量, 减少了苦味和涩味等口感。Pushkala 等[60]研究表明, 用 0.2%壳聚糖、0.2%壳聚糖乳酸盐处理鲜切胡萝卜丝, 有利于胡萝卜丝的水分保持, 减少褐变率、降低呼吸速率和微生物污染, 可在 10 ℃低温下延长货架期至少 3 d。Ansorena 等[61]报道, 应用 2%壳聚糖或 0.75%羧甲基纤维素处理鲜切西兰花, 在 5 ℃下贮藏 18 d, 均能降低水分和抗坏血酸的损失以及微生物污染数量。另外, Ghidelli 等[62]研究了 5%大豆分离蛋白结合气调(80 kPa O_2)处理鲜切茄子, 发现该处理有利于保持鲜切茄子的硬度, 降低褐变率和失水率。

3.2.2 植物精油

植物精油是植物体内的次生代谢产物, 被认为是一种天然防腐剂, 具有抗菌、抗病毒、抗氧化等作用。Scollard 等[63]报道, 采用百里香精油和马鞭草酮处理鲜切生菜, 能显著抑制生菜表面的李斯特菌污染数量。Viacava 等[64]工作表明, 含百里香精油的 β-环糊精微囊处理鲜切生菜, 可明显减少肠杆菌、酵母和霉菌的污染, 同时有利于保持其抗氧化性和色泽。Karagözlü 等[65]研究发现, 0.08 ml/L 薄荷精油和罗勒精油处理能有效抑制鲜切生菜和马齿苋中的鼠伤寒杆菌和大肠杆菌 O157:H7 污染; 同样 0.05%丁香精油和丁香酚处理能抑制鲜切生菜的 PAL、PPO 和 POD 的活性, 延缓鲜切生菜的褐变和软化的发生[66]。Myszka 等[67]工作表明, 富含 *β*-石竹烯的胡椒精油(2.8~5 μL/mL)能减少鲜切生菜上的荧光假单胞菌污染数量, 从而减少鲜切蔬菜的腐烂率。Valeria Rizzo 等[68]用 0.5%迷迭香精油处理鲜切土豆片, 在 4 ℃下贮藏 11 d, 发现可抑制嗜温性细菌和肠杆菌的生长, 并保持鲜切土豆的抗坏血酸、总酚的含量和抗氧化性。牛至精油聚乙烯醇微囊(牛至精油:聚乙烯=3:5)处理鲜切生菜, 在 20 ℃下贮藏 5 d, 能有效抑制霉菌、酵母和总嗜温需氧菌的生长, 同时也有利于色泽和质地的保持[69]。Do-Hee 等[70]报道, 采用 1%松叶精油有利于鲜切生菜中的抗氧化酶活性和总酚含量的保持, 并抑制褐变发生。

3.2.3 电解水

电解水是指 NaCl、KCl 等稀盐溶液放置在有隔膜的电解槽中进行电解, 在电解槽阳极生成的是酸性电解水, 含有次氯酸、氯气等有效氯; 阴极生成的是碱性电解水, 不含有效氯; 而在无隔膜电解槽中电解得到的则成为微酸性电解水, 同样含有次氯酸, 但氯气含量很低[71]。其中, 酸性和微酸性电解水常用于果蔬杀菌消毒。Mansur 等[72]报道, 将鲜切甘蓝在 40 ℃微酸性电解水(含 5 mg/L 有效氯)中浸泡 3 min, 在 4 ℃和 7 ℃低温环境下贮藏, 可有效降低鲜切甘蓝中的李斯特菌和一些致腐败菌的污染, 延长保质期 4~6 d。Koide 等[73]发现, 采用 45 ℃微酸性电解水(含 23 mg/L 有效氯)处理鲜切胡萝卜, 在 18 ℃下贮藏, 能够降低总需氧菌、霉菌和酵母菌的数量, 对鲜切胡萝卜的外观和抗坏血酸、β-胡萝卜素含量无明显的影响, 推荐作为一种有效的消毒方法。与次氯酸钠溶液(pH 9.6, 含约 150 mg/L 有效氯)处理鲜切卷心菜相比, 采用 20~22 ℃的微酸性电解水(pH 6.1, 含 20 mg/L 有效氯)杀菌效果更好, 菌落总数减少约 1.5 log CFU/g, 霉菌和酵母菌减少约 1.3 log CFU/g[74]。Tomás-Callejas 等[75]还报道, 用 5 ℃中性和酸性电解水(含 40、70、100 mg/L 有效氯)处理鲜切京水菜 2 min, 均能抑制鲜切京水菜表面微生物污染, 增加抗氧化性和具有护色(保绿)的作用; 进一步研究表明, 将菊苣和生菜浸泡于中性电解水(含 100 mg/L 有效氯)中 5 min, 能使嗜温性细菌和肠杆菌数量减少 1.7 log CFU/g[76]。Navarro-Rico 等[77]指出, 中性和酸性电解水(含 70 和 100 mg/L 有效氯)处理鲜切西兰花能够提高抗氧化性, 降低微生物污染数量, 能在 5 ℃下贮藏 19 d。此外, 1%柠檬酸和 50 ℃的碱性电解水复合处理 3 min, 也能减少鲜切胡萝卜中的细菌、真菌约 3.7~4 log CFU/g[78]。

3.2.4　臭　氧

臭氧能作用于微生物的生物膜、核酸、酶、芽孢外壳和病毒衣壳, 起到杀灭微生物的作用。臭氧被认为是一种安全无毒、可以直接接触食物表面的消毒剂。Alwi 等[79]报道, 在含 19.26 mg/m^3 臭氧中暴露 6 h, 有助于减少鲜切甜椒的食源性病原菌。Alexopoulos 等[80]用 0.5 mg/L 臭氧水溶液(向水中连续通入臭氧气体, 以维持 0.5 mg/L 浓度)处理鲜切生菜和甜椒 15 min, 能明显减少微生物污染。Zhang 等[81]研究表明, 采用 0.18 mg/L 臭氧水处理鲜切芹菜, 能够有效抑制多酚氧化酶活性和呼吸速率; 同时, 能使微生物含量降低 1.69 Log CFU/g。Chauhan 等[82]应用 10 mg/L 臭氧水结合气调(2% O_2+8% CO_2+90% N_2)处理鲜切胡萝卜, 在 6 ℃下贮藏 30 d; 结果表明, 该处理降低了呼吸和乙烯释放率, 同时抑制 PPO 和 POD 的活性, 减轻鲜切胡萝卜的木质化程度。

3.2.5　其它化学方法

除了上面提及的目前常用的化学处理之外, 近年来已发现其它一些化学处理对鲜切蔬菜也具有较好的保鲜效果, 显示出一定的发展前程。表 1 总结了不同化学处理方式、蔬菜种类以及保鲜效果。

表 1　不同化学处理对鲜切蔬菜的保鲜效果
Table 1　Effects of different chemical treatments on storage of fresh-cut vegetables

处理	切菜种类	作用效果	参考文献
二氧化氯(3、5 mg/L)	生菜	降低大肠杆菌污染	[83]
二氧化氯(10、50 和 100 mg/L)	莲藕	抑制褐变	[84]
二氧化氯(3 mg/L)	红甜菜	减少 *E. coli* O157:H7 交叉污染, 但对沙门氏菌无效	[85]
二氧化氯(3 mg/L)+次氯酸钠(100 mg/L)	莴苣	降低表面微生物数量, 不影响感官品质	[86]
乳清蛋白浓缩物(14、28 mg/L)	生菜	抑制 PPO 活性, 降低褐变程度	[87]
乳清脱膜渗透浓缩物[3% (*V*:*V*)]	番茄	提高抗氧化性和总酚含量	[88]
乳清蛋白(23.5 g/L)+果胶(5.9 g/L)+山梨醇(11.8 g/L)	土豆、胡萝卜	减少微生物量, 保持水分、酚类物质和类胡萝卜素含量	[89]
纳米碳酸钙(30 g/100 g)+低密度聚乙烯(56 g/100 g)包装	山药	减少酵母和霉菌数量, 降低褐变、总酚和丙二醛含量	[90]
海藻酸钙(4%)负载银-蒙脱石(100 mg/L)纳米颗粒	胡萝卜	降低腐败微生物量, 维持感官品质	[91]
半胱氨酸[0.5、1.0、2.0%(*W*:*W*)]	土豆	抑制酶促褐变	[92]
半胱氨酸(0.1%、0.3%、0.5%、1.0%)	洋蓟	减少组织褐变和黄化	[93]
半胱氨酸(0.5%)	秋葵	降低发黑程度和酚类物质含量	[94]
含银(0.001%~1.0%)聚乳酸薄膜	辣椒	使 4 log CFU 的沙门氏菌灭活	[95]
1-MCP(1 μL/L)	西兰花	延缓开花和叶绿素降解, 减少腐败	[96]
1-MCP(1.5 mg/L)+亚氯酸钠(100 mg/L)	香菜	减少病原菌含量, 降低腐烂率	[97]
2, 4-表油菜素内酯(80 nmol/L)	莲藕	降低酚类物质、丙二醛含量, 降低 PPO、PAL、LOX 活性	[98]
草酸(1、3 mmol/L)	芦笋	降低切口脱水率, 保持感官品质和主要生物活性物质	[99]
过氧乙酸(25、80、150 和 250 mg/L)	胡萝卜、卷心菜、生菜、韭菜	不同程度降低四种切菜上的微生物污染, 胡萝卜的微生物减少量最高(0.5–3.5 log CFU/g), 韭菜最低(0.4–1.4 log CFU/g)	[100]
水杨酸(1、2、4 mmol/L)	荸荠	延缓褐变, 保持营养成分	[3]
抗坏血酸(10 mmol/L)、阿魏酸(10 mmol/L)	荸荠	阿魏酸抑制褐变, 但抗坏血酸无效; 阿魏酸间接抑制 PAL 活性, 两者均能抑制 PPO 和 POD 的活性	[101]
硫化氢(10、15、20 μL/L)	莲藕	降低产氧率和 H_2O_2 含量, 提高了莲藕片的抗氧化能力	[102]
过氧化氢(0.15%、0.3%、0.6%、0.9%)	荸荠	抑制褐变, 降低 POD、PPO、PAL 的活性	[103]

续表 1

处理	切菜种类	作用效果	参考文献
过氧化氢(0.4 mg/L)+ 银(5 mg/L)	生菜	显著降低假单胞菌、肠杆菌、酵母和霉菌的数量	[104]
百里香、黑孜然、鼠尾草、迷迭香、月桂叶纯露(50 g 原料+0.5 L 水, 蒸馏 1 h)	胡萝卜	降低鼠伤寒杆菌和大肠杆菌含量	[105]
百里香、夏香薄荷、牛至纯露(100 g 原料+1 L 水, 蒸馏得到 250 mL 纯露)	番茄、黄瓜	降低 *E. coli* O157:H7 含量	[106]
大蒜素(2、10 g/L)	莴苣	有助于色泽和营养成分的保持	[107]
皂树皮提取物(10.24 mg/mL)、N^{α} -月桂酰-L-精氨酸乙酯(10.24 mg/mL)	菊苣	N^{α}-月桂酰-L-精氨酸乙酯具有很强的抗菌活性, 但皂树皮提取物的抑菌活性较弱	[108]
绿茶提取物(0.25 g/100 mL)	生菜	抑制褐变	[109]
马齿苋提取物[0.05%(*W*:*W*)]	土豆	抑制 POD、PPO、PAL 的活性	[110]
氧化白藜芦醇(0.01%)+抗坏血酸水包油微乳(0.05%)	莲藕	具有很强的抗氧化效果, 抑制褐变	[111]
精氨酸(100 mmol/L)	生菜	抑制褐变, 使货架期延长 1 倍	[112]
一氧化氮(205、410 mg/m^3)	生菜	显著抑制了切割表面褐变	[113]
一氧化碳(175 μL/L)	莲藕	抑制 POD、PPO 的活性, 减轻褐变程度	[114]
乙醇(0.5%)	茴香	显著减少茎和鞘切面的褐变	[115]
乙醇(30%)+抗坏血酸(30 g/L)	莲藕	抑制褐变, 减少微生物污染	[116]
酪氨酸酶抑制剂(1000 U/mL)	莲藕	抑制 PPO 活性, 增强 SOD 活性和增加抗坏血酸、谷胱甘肽含量	[117]
鳕鱼肽[0.1%(*W*:*W*)]	土豆	抑制 PPO、POD 和 PAL 的活性, 减少总酚积累	[118]

3.3 生物方法

3.3.1 噬菌体

噬菌体能有效感染宿主细菌, 导致宿主细菌的裂解死亡。近年来, 噬菌体已经被当作一种新型、环保的保鲜剂, 应用在食品领域。Abuladze 等[119]报道, 采用一种噬菌体混合物(ECP-100, 含有 3 种可裂解大肠杆菌 O157:H7 的噬菌体), 来处理鲜切番茄和菠菜, 在处理 120 h 后番茄中的大肠杆菌 O157:H7 数量降低 94%, 在 24 h 后菠菜中的大肠杆菌 O157:H7 数量降低 100%。Sharma 等[120]在新鲜小黄瓜上接种沙门氏菌(每根黄瓜 5 log CFU), 并喷洒 3.2 mL 磷酸盐缓冲液(对照)或 10 log CFU/mL 沙门氏菌特异性的噬菌体制剂(Salmo Fresh), 于 10 ℃或 22 ℃下贮藏, 结果发现, 在 10 ℃条件下贮藏 24 h, 经噬菌体处理的黄瓜上的沙门氏菌数量为 1.72 log CFU, 显著低于对照组的 3.20 log CFU; 在 22 ℃下贮藏 1 天, 处理组比对照组减少 2.37 log CFU。Boyacioglu 等[121]采用 *E. coli* O157:H7 特异性的噬菌体制剂(EcoShield^{TM})处理鲜切菠菜和生菜, 于 4 ℃或 10 ℃下贮藏 15 d, 发现噬菌体混合物 EcoShield^{TM} 能有效减少鲜切菠菜和生菜的大肠杆菌污染数量; 进一步研究表明, 气调处理(5% O_2、35% CO_2、60% N_2)能增强 EcoShield^{TM} 的防腐效果。Guenther 等[122]报道, 用噬菌体的 A511 和 P100 分别处理鲜切卷心菜, 均能降低鲜切卷心菜上的李斯特菌污染数量, 且在 3×10^6~10^8 PFU/g 范围内, 随着使用的噬菌体浓度升高, 能增加防治李斯特菌污染效果。Sharma 等[123]用大肠杆菌 O157:H7 特异性的噬菌体混合物(ECP-100)处理鲜切生菜, 于 4 ℃下贮藏, 发现处理组在第 0、1、2 d 的大肠杆菌 O157:H7 数量分别为 0.72、0.22 和 0.58 log CFU/cm^2, 明显低于对照组的 2.64、1.79 和 2.22 log CFU/cm^2。Magnone 等[124]研究表明, 采用 EcoShield BC(FDA 批准用于杀灭牛肉绞碎加工中的 *E. coli* 0157:H7 的商品制剂, 含 3 种噬菌体的混合物)处理鲜切西兰花, 于 10 ℃下贮藏 24 h 后, 噬菌体混合物能使花椰菜中大肠杆菌 0157:H7 的数量减少 99.5%, 并且在 5 d 和 7 d 后, 减少量分别维持在 99%和 97%。

3.3.2 生防菌(拮抗菌)

在许多类型的微加工食品中, 存在细菌微生物群落。细菌间由于存在拮抗作用, 可利用一些细菌来防控鲜切蔬菜上的有害细菌。乳酸菌是一种常见的拮抗菌。据报道, 乳酸菌通过竞争营养和分泌具有抗菌活性的物质, 包括有机酸、过氧化物和抗菌多肽来抑制一些病原菌生长。Cálix-Lara 等[125]报道, 商品用乳酸菌制剂 LactiGuard^{TM} 可作为抗菌剂用来处理菠菜, 经处理过的菠菜上的大肠杆菌 O157:H7 和沙门氏菌的污染数量明显下降。Siroli 等[126]从

鲜切生菜上共分离出 15 株乳酸菌，其中有 5 株确定为植物乳杆菌；在分离得到的菌株中，干酪乳杆菌(v4b4)和植物乳杆菌(v7b3 和 v4b5)对肠炎链球菌 E5、单核细胞增多性李斯特菌 Scott A 和大肠杆菌 555 有着明显的抑制效果。Johnston 等[127]报道，从鲜切的生菜和菠菜中共分离得到 495 种大肠杆菌 O157:H7 的拮抗菌，通过产酸实验和蛋白酶敏感实验，发现约 17%拮抗菌产抗菌肽和大约 16%拮抗菌产酸作为其部分抑制活性。Oliveira 等[128]先后从鲜切生菜中分离筛选了 112 个拮抗菌株，其中，假单胞菌菌株 M309M309 只减少大肠杆菌 O157:H7 的污染数量；而革兰氏假单胞菌 CPA-7 菌株与乳酸链球菌素的复合使用则降低了单核细胞增多性李斯特菌的污染数量。该项研究提出了生物防治的潜力，但需要与其它处理结合使用，以提高其效果。Schuenzel 等[129]进一步从鲜切西兰花、卷心菜、胡萝卜、生菜、洋葱等中筛选出 1180 株菌株，分别测试它们对金黄色葡萄球菌 ATCC 27664、大肠杆菌 O157:H7 E009、单核细胞增多性李斯特菌 LCDC81-861 和蒙特维多沙门氏菌等病原菌的抗菌活性；其中 37 株菌株(3.22%)至少对一种试验病原菌具有不同程度的抑制活性，而且多种菌株对这四种病原菌均有抑制作用，显示出生防菌应用的潜在前景。

3.3.3　细菌素

细菌素是指某些细菌在代谢过程中产生的对其它细菌尤其是与其亲缘关系比较近的细菌具有抑制或杀灭作用的蛋白质或肽类物质。细菌素对真核细胞无毒副作用，而且能被肠道消化蛋白酶消化，对正常菌群无影响；因此，被认为对人和动物安全[130]。Martínez-Hern 等[131]报道，使用 0.250 g/L 乳酸链球菌素、50 g/L 乳铁蛋白和水解乳铁蛋白处理鲜切茴香，并以 150 mg/L 次氯酸钠处理作为对照，发现水解乳铁蛋白对嗜冷菌的抑制效果最好，乳酸链球菌素处理对嗜中温、肠杆菌科、乳酸杆菌、酵母和霉菌的抑制力高于次氯酸钠处理。McManamon 等[132]指出，鲜切生菜在 4 ℃条件下贮藏 7 d, 2.5、5 mg/kg 乳酸链球菌素 A 处理减少了单核细胞增多性李斯特菌污染数量，并在贮藏前 5 d 保持了较好的感官品质。Federico 等[133]用乳铁蛋白 B 处理鲜切生菜，并在 4 ℃下贮藏 4 d，能使鲜切生菜的腐烂率降低 36%。Song 等[134]报道，采用 1%乳酸溶液+1%壳聚糖+64 μg/mL 乳酸链球菌素+250 μg/mLε-聚赖氨酸复合处理鲜切胡萝卜，能降低鲜切胡萝卜的呼吸速率、维生素 C 损失，减少微生物污染数量。Allende 等[135]以 5 种乳酸菌各自生产的细菌素(乳酸链球菌素 Z、植物乳杆菌素 C、乳酸菌素 481、凝固素和片球菌素)对鲜切生菜进行处理，发现能显著降低单核细胞增多性李斯特菌的存活率。

4　总结与展望

与完整的新鲜蔬菜相比，鲜切蔬菜由于经历去皮、切片或切丝等加工和后续的运输、流通、销售等步骤，表现出与完整蔬菜不同而自身特有的生理代谢和品质变化规律，极易发生色泽、质地和风味的劣变和营养物质的下降，严重的则失去商品价值；因此，需要加强鲜切蔬菜的品质劣变和病害防控等理论研究，包括揭示鲜切蔬菜品质控制的内外部因素，解析鲜切蔬菜的品质劣变的复杂网络及交互作用，明确维持品质关键步骤和关键调控因子，为解决目前鲜切蔬菜保鲜的技术难题提供新知识，并为技术研发提供理论支撑。

我国鲜切蔬菜市场发展迅速。其中，生菜、胡萝卜、土豆、西兰花等作为大宗蔬菜，目前在品质劣变和病害防控研究最多，对应的保鲜技术也比较完备；而莲藕、荸荠、山药等特色蔬菜则深受到我国消费者青睐，虽然研究起步时间比较晚，但发展较快。

鲜切蔬菜保鲜技术开发将以安全无毒、环保高效为核心，需要注重物理、化学、生物等方式的有效结合，特别是脉冲光、等离子体、生物技术等一些新技术的应用，并结合低温精准控制和自发气调包装，形成综合保鲜技术体系，并建立技术标准；同时进一步完善鲜切蔬菜冷链物流，并结合高效的保鲜技术手段，进而达到保持品质、延长货架期的目标。

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