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植物精油的功能特性及在果蔬保鲜中的应用

Research progress on functional properties of plant essential oils and their applications in fresh keeping of fruits and vegetables

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摘要:文章简要概述了植物精油的提取技术,重点综述了植物精油的功能特性及植物精油在果蔬保鲜上的不同应用形式,包括精油纳米化、精油微胶囊化、精油联合物理技术等,并对植物精油在果蔬保鲜方面的发展方向进行了展望。

关键词:植物精油;提取技术;功能特性;果蔬保鲜

Abstract: The extraction technologies of plant essential oils were briefly summarized, and the functional characteristics of plant essential oils and the different application forms of plant essential oils in the preservation of fruits and vegetables were emphatically reviewed, including the essential oils nanocrystallization, the essential oils microencapsulation, and the essential oils combining with physical technologies and so on. This review could provide a theoretical basis for the further application of plant essential oils in the preservation of fruits and vegetables in the future.

Keywords: plant essential oils; extraction technologies; functional characteristics; fresh fruits and vegetables

新鲜果蔬在采收后依然有生命活动(如呼吸、新陈代谢等),且水分和溶质随贮藏时间的延长不断流失,极易导致质量损失、营养流失、食用质量变差和货架期缩短[1]。特别是鲜切果蔬因受到机械损伤,极易被微生物污染而发生劣变[2],导致其颜色、硬度、风味等发生改变,进而缩短鲜切果蔬的货架寿命[3]。在日常果蔬保鲜中,低温贮藏方便快捷、营养成分流失较少,但部分果蔬容易发生冷害,导致水分流失、理化活动异常及果蔬变质;气调贮藏通过调节气体比例控制果蔬呼吸,抑制有害菌增殖,但需要实时监控气体,能耗比较大[4]。因此,为延长果蔬的贮藏时间,通常会选择化学合成保鲜剂来延长果蔬的货架期。但若长期食用滥用化学保鲜剂的果蔬,可能对人体健康产生负面影响,甚至有致畸、致癌的风险,故天然保鲜剂取代化学保鲜剂成为一种必然趋势[5]。

植物精油是天然保鲜剂中的一种,含有丰富的活性物质赋予其广谱的抗氧化和抑菌等特性,可作为天然抗菌剂,抑制果蔬病原菌菌落增殖,达到延缓果蔬衰老和维持果蔬感官及营养品质的目的[6]。此外,与化学合成保鲜剂相比,植物精油具有绿色、环保、安全、无毒等优势,有广阔的应用前景[7]。因此,文章拟就植物精油的提取技术、功能特性及其在果蔬方面的应用进行综述,重点对其抗氧化、抑菌、抗炎、杀虫驱虫等特性及不同应用方式进行系统分析,以期为植物精油在果蔬保鲜上的应用提供依据。

1 植物精油的提取

植物的叶、花、果实、皮等部位通常含有较低或较高含量的精油,可通过不同的提取技术获得,工业上常采用传统的水蒸气蒸馏法或溶剂萃取法进行提取。但随着技术的不断发展,目前有关植物精油提取技术的研究比较成熟。由表1可知,提取技术对植物精油的提取率和组分有显著影响,且每种提取技术都各有优势和缺陷,实际生产中,需要根据植物来源、提取效率、提取目标组分等因素选择合适的提取技术。

2 植物精油的功能特性

2.1 抗氧化作用

植物精油中含有多种抗氧化活性成分,如芳樟醇[14]、

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表 1　植物精油提取技术比较

Table 1　Comparison of extraction technologies of plant essential oils

提取技术	植物来源	条件	提取率/%	提取组分种类/种	优缺点	参考文献
水蒸气蒸馏	云南小黄姜	料液比 1∶25 (g/mL),时间 2.5 h	1.44		操作方便,设备简单,但提取率低,热敏性化合物易分解	[8]
	杠香	料液比 1∶6 (g/mL),时间 5 h	0.90	39		[9]
超声波萃取法	狮头柑	超声功率 60 W,温度 50 ℃,时间 120 min	2.47	19	提取高效,方法简单,节能环保,可提取易热分解的精油	[10]
有机溶剂萃取法	神香草	提取溶剂为正己烷,料液比 1∶15 (g/mL),时间 4 h,温度 50 ℃	1.09		精油提取率高,但易生成乳浊液,需要二次提炼	[11]
CO_2超临界萃取法	杠香	压力 23 MPa,温度 55 ℃,时间 3 h	1.50	25	提取率高,但成本同样高	[9]
微波萃取法	肉桂	微波功率 450 W,时间 60 min	3.15	24	与水蒸气蒸馏法相比,得率提高了 35.78%	[12]
酶辅助法	琯溪蜜柚柚皮	纤维素酶 0.5%,温度 45 ℃,pH 值 4.0,时间 2 h	1.96		提取率比水蒸气蒸馏法高 180%	[13]

D-柠檬烯、*γ*-松油烯、*β*-蒎烯[15]、百里酚、香芹酚、丁香酚[16]等(图 1),其主要通过 4 个方面发挥抗氧化作用,从而达到果蔬保鲜的目的:① 植物精油通过降低呼吸速率、减少自由基的积累而延缓氧化伤害。有研究[17]发现,沉香精油清除羟基自由基的 IC_{50} 值为 0.45 mg/mL,清除超氧阴离子自由基的 IC_{50} 值为 2.53 mg/mL,且香茅精油对番木瓜保鲜时,番木瓜的呼吸峰值延迟、呼吸速率降低[18]。② 植物精油通过螯合金属离子实现抗氧化,如植物精油中的酚类物质与 Fe^{2+}、Cu^{2+} 等活泼金属离子螯合生成较稳定的配合物,从而减少自由基的生成[19]。③ 植物精油通过抑制脂质过氧化实现抗氧化,如植物精油中的香芹酚通过降低丙二醛的积累以延缓膜脂的过氧化,提高树莓的抗氧化作用[20]。④ 植物精油通过调控抗氧化酶活和抗氧化物含量实现抗氧化,如茴香精油可激活鲜切苋菜中过氧化物酶和超氧化物歧化酶[21];李子和等[22]复配的植物精油可提高马铃薯中还原型谷胱甘肽含量,降低过氧化氢物含量等,减缓衰老进程。

2.2　抑菌作用

植物精油中含有多种抑菌活性成分,如香芹酚、姜烯、*β*-倍半水芹烯、反式肉桂醛、香茅醇、香叶醇、松油烯-4-醇等(图 1),对金黄色葡萄球菌、灰霉、青霉等具有广谱的抑菌作用(表 2)。

植物精油可以通过以下 3 个方面发挥抑菌作用(图 2):① 破坏菌体的细胞壁和细胞膜的完整性、渗透性及膜脂质过氧化[28],致使营养物和代谢物不能正常通过,具体表现为菌体表面皱缩、出现溶解、不致密现象,甚至部分菌体外膜脱落、破裂等[29]。② 破坏蛋白和相关基因表达,如肉桂精油可影响金黄色葡萄球菌菌体蛋白的二

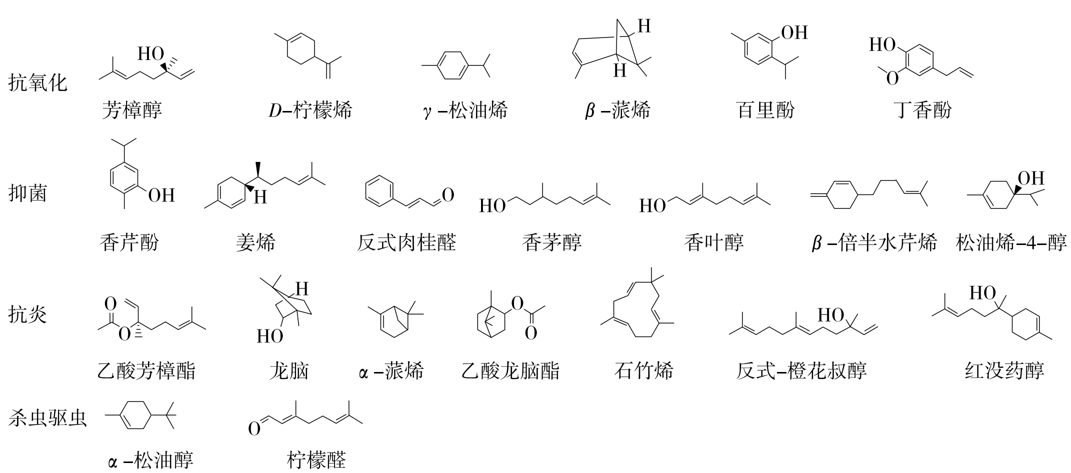

图 1　植物精油活性成分化学结构式

Figure 1　The chemical structures of bioactive compounds in plant essential oils

表 2 植物精油的抑菌作用

Table 2 Antimicrobial action of plant essential oils

植物精油	有效抑菌成分	菌落	参考文献
牛至精油	香芹酚	青霉、灰霉、腐霉、交链孢霉、李斯特菌	[23－24]
生姜精油	姜烯、β-倍半水芹烯	金黄色葡萄球菌、肺炎克雷伯菌	[25]
肉桂精油	反式肉桂醛	裂褶菌、暗色节菱孢、丝核菌等 12 种竹林病原真菌	[26]
香茅精油	香茅醇、香叶醇		
大蒜精油	二烯丙基硫化物		
互叶白千层精油	松油烯-4-醇		
迷迭香油	d-樟脑、二十烷、β-石竹烯、1,8-桉树脑等	金黄色葡萄球菌、铜绿假单胞菌和白色念珠菌	[27]

级和三级构象，进而影响菌体的结构及生长繁殖[30]；樟脑精油通过调控大肠杆菌基因的表达以抑制大肠杆菌的代谢和某些抗性反应，进而抑制大肠杆菌的生长[31]。③ 干扰菌体能量代谢过程，如香雪兰精油可诱导白色念珠菌的线粒体功能障碍，致使活性氧积累，菌体氧化还原失衡，从而达到抑菌的目的[32]。

2.3 抗炎作用

植物精油中含有多种抗炎活性成分，如乙酸芳樟酯[33－34]、倍半萜[35]、龙脑、α-蒎烯、乙酸龙脑酯、石竹烯、反式-橙花叔醇、红没药醇[36]等(图 1)，可通过调控炎症因子达到抗炎作用(图 3)，如苦橙叶精油和佛手柑精油均能显著降低细胞内炎症介质一氧化氮(NO)和肿瘤坏死因子-α(TNF-α)含量[34]。而在脂多糖诱导小鼠巨噬细胞的炎症模型中，紫茎泽兰精油能抑制白细胞介素-1β(IL-1β)、白细胞介素-6(IL-6)、白细胞介素-8(IL-8)蛋白分泌量及相关 mRNA 的表达，增加白细胞介素-10(IL-10)蛋白分泌量及相关 mRNA 的表达，这些相关炎症因子的表达量都与 Toll 样受体 4(TLR-4)蛋白表达水平增加有关，同时也与核转录因子(NF-κB)信号通路被抑制有关，其 IκBα 蛋白、p65 和 p50 胞浆蛋白等 NF-κB 信号通路中的关键蛋白表达水平增加[36]。此外，高小力等[35]研究发现沉香精油(10 μg/mL)通过降低 p-传感器和转录激活因子 3(p-STAT3)的蛋白表达水平，进而抑制炎症因子 IL-1β 和 IL-6 的产生来发挥抗炎作用。

2.4 杀虫驱虫作用

植物精油具有杀虫驱虫作用，对果蔬采前采后的常见病虫害，如烟粉虱、蚜虫、小菜蛾和甜菜夜蛾等具有较好的防控效果，其主要活性成分包括丁香酚、α-松油醇[37]、柠檬醛[38]等(图 1)。研究[39]发现薄荷精油对埃及伊蚊幼虫有驱杀作用，其 IC_{50} 值和 IC_{90} 值分别为 78.1，125.7 mg/L。植物精油对病虫害有不同的表现方式，如香樟精油对米象有较好的趋避效果；丁香精油对米象有较好的触杀作用；丁香及肉桂皮精油对米象有最高的熏蒸致死率，其中丁香精油熏蒸致死机理是对米象内谷胱甘肽-S-转移酶的诱导作用，抑制米象体内的羧酸酯酶酶活，且熏蒸处理时间越长、精油浓度越大，对酶活的抑制越强[40]。今后可深入研究精油趋避、触杀病虫害的机理。

3 植物精油在果蔬保鲜中的应用

植物精油含有抗氧化、抑菌、抗炎、杀虫驱虫等功能特性的活性成分，因而可以将植物精油应用于果蔬保鲜，以期达到延长保鲜期的目的。其保鲜方式包括单精油直

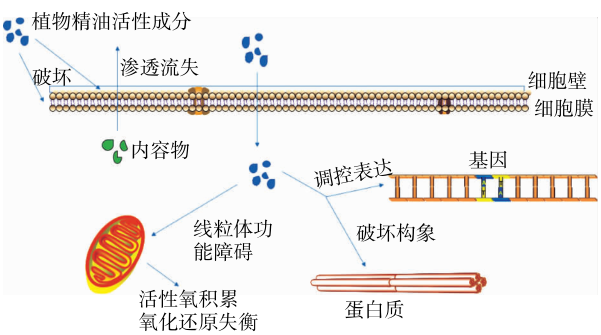

图 2 植物精油抑菌机制图[27]

Figure 2 The diagram of antibacterial mechanisms of plant essential oils

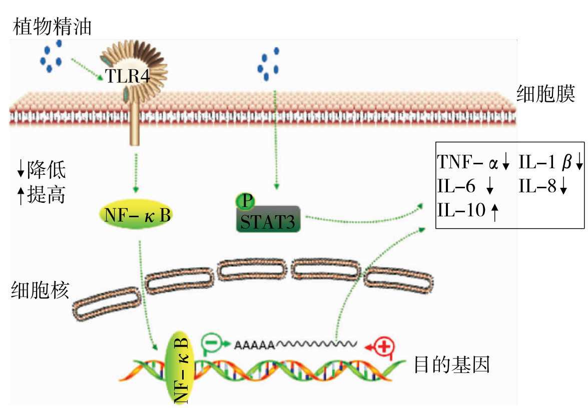

图 3 植物精油抗炎机制图[34,36]

Figure 3 The diagram of the anti-inflammatory mechanisms of plant essential oils

接保鲜,精油与保鲜剂复配保鲜,精油纳米保鲜,精油微胶囊保鲜,精油联合紫外光、微波、超声波等保鲜,精油与包装纸箱联用保鲜等。

3.1 单精油保鲜

单精油保鲜是指将植物精油以熏蒸、浸泡等处理方式对果蔬进行保鲜。其中精油熏蒸处理是将精油滴在滤纸片上,然后将滤纸片与果蔬放置在聚乙烯塑料袋中,实现精油对果蔬的熏蒸保鲜。李彦虎等[41]利用精油对双孢蘑菇进行熏蒸处理,常温条件下,花椒精油(0.1 mL/kg)和芥末精油(0.15 mL/kg)能抑制双孢蘑菇褐变,延缓腐烂,将货架期延长 2 d;低温贮藏条件下能减缓双孢蘑菇的失重率和呼吸强度,抑制子实体内多酚氧化酶活性,降低菇表面菌落总数,从而达到保鲜效果。精油浸泡处理是将果蔬浸泡在精油中,或者浸泡在一定浓度的精油溶液(含有适量的吐温-80 和蒸馏水)中,然后取出风干,置于包装袋或包装盒内保鲜。如将鲜切杭白菜浸泡在丁香精油(1 mL/L) 3 min 后装于塑料盒中,可使杭白菜表面的微生物增长缓慢,营养物质损失降低,货架期延长 6 d[42]。单精油保鲜操作方便、快捷,但果蔬经过熏蒸、浸泡处理后,精油易挥发,保鲜时间不长,且果蔬含有精油的刺激性气味,影响其售卖。

3.2 精油简单复配保鲜

精油简单复配是指精油与常用的涂膜保鲜剂简单混合后形成稳定的复配液体系,再将复配液以涂膜、浸泡等方式应用于果蔬保鲜。由于常用的保鲜剂的涂膜透气性、物理和力学性能较差[43],当添加植物精油后,能与精油中酚类物质的官能团相互作用,可提高涂膜的阻隔性和抗氧化性能,还可降低膜的含水率、水溶胀率和溶解度[44],使果蔬色泽、硬度、质地等品质较好地保持,降低营养物的损失(表 3)。与单精油保鲜相比,复配保鲜能延长精油作用时间,更能显著提高果蔬贮藏保鲜效果,但果蔬表面依然会存有精油刺激性气味,可能呈现负面的感官评分。

3.3 精油纳米乳液、纳米薄膜保鲜

纳米乳液是粒径为 10～100 nm 的胶体分散体系[50],植物精油在添加果胶、玉米醇溶蛋白、吐温-80 等表面活性剂后[51],经搅拌、超声、均质等混合形成植物精油纳米乳液。精油纳米乳化不仅可提高精油的稳定性、抗氧化、抑菌等特性[52],还可取代氯基消毒杀菌剂,减少环境污染[53]。李子和等[22]将吐温-80 与复配的 4 种精油(孜然精油、莳萝精油、芫荽精油、葛缕子精油)纳米乳化,随后将制得的乳液雾化处理马铃薯,发现纳米乳化后的精油能调控抗氧化酶酶活及抗氧化物质含量,延长休眠期,抑制马铃薯发芽。

除了将纳米乳液以液态形式作用于果蔬外,还可通过溶剂蒸发法,使纳米乳液成膜,用于包装保鲜果蔬。Chi 等[54]制备含有佛手柑精油的聚乳酸纳米复合膜用于包装芒果,发现贮藏期间,该复合膜能延缓芒果颜色、总酸度、维生素 C 和微生物性质的有害变化,延长芒果采后寿命 15 d。此外,还可利用植物精油的抑菌特性制备具有抗菌性能的 pH 指示剂纤维素纳米纤维包装薄膜[55],显著降低精油对果蔬感官品质的影响。与精油简单复配相比,植物精油纳米化使精油形成众多的纳米颗粒,可提高精油的分散性,具有一定的缓释作用,进行果蔬保鲜时,能降低果蔬表面刺激性气味,延长保鲜时间,但纳米乳液处理耗能较大,在果蔬保鲜中的应用范围较窄。

3.4 精油微胶囊保鲜

精油微胶囊化是指将精油包裹制得微小粒子,形成小胶囊,如壳聚糖和羧甲基纤维素钠作为壁材的精油胶囊,能较好地保留精油的缓释、包封效率和结构稳定性[56]。以 4%牛至精油为芯材,明胶、阿拉伯胶为壁材,芯壁比为 1∶1 的牛至精油微胶囊为例[57],水通过壁材进入微胶囊内部后,溶解微胶囊内部的精油形成高浓度的溶液,该溶液通过壁材释放到微胶囊外部[58],从而使精油缓慢作用于杏果实,降低空气中精油的刺激性气味,延长保鲜时间。Yin等[59]将芒果在海藻酸钠溶液和含肉桂精

表 3　植物精油简单复配的果蔬保鲜

Table 3　Simple combination of plant essential oils for the preservation of fruits and vegetables

复配物质	果蔬	处理方式	贮藏温度/℃	效果	参考文献
黄皮精油、壳聚糖	番木瓜	涂膜 1 min	25	果失重率下降,硬度保持较好,腐烂时间延长	[45]
留兰香精油、羧甲基纤维素	草莓	浸泡 5 min	4±1	水分流失显著降低,外观、颜色、质地和整体可接受性等保持较高水平,货架期延长 12 d	[46]
百里香/牛至精油、海藻酸钠	鲜切木瓜	浸泡	4	pH 变化减缓,衰老延缓	[47]
百里香/牛至精油、海藻酸钠	鲜切苹果、鲜切哈密瓜	浸泡 2 min	4	呼吸速率减缓,硬度、色泽等品质被有效保持,细菌、霉菌和酵母菌菌落数等降低	[48]
肉桂精油、伊枯草菌素 A	樱桃番茄	浸泡 10 min	30	可滴定酸、维生素 C 和还原糖等损失降低	[49]

油微胶囊液中进行交替浸泡沉淀，得到有 5 层覆膜的芒果，其 pH 值、硬度、呼吸速率、维生素 C 含量等变化均得到改善。此外，室温条件下芥末精油微胶囊可替代部分杀菌剂，与 0.8 或 0.9 倍浓度咪鲜胺结合处理荔枝时，其保鲜效果与咪鲜胺单独保鲜无明显差异[60]。与精油纳米乳化相比，精油微胶囊能进一步延长精油的作用时间、减缓气味的散发，可部分或完全替代杀菌保鲜剂，但因壁材、精油及其浓度的选择、成本的控制、繁琐的操作等其他因素，导致精油微胶囊在果蔬保鲜中的应用不广泛。

3.5 精油联合物理保鲜

果蔬常用的物理保鲜技术有低温、紫外光、微波、超声波、气调等，虽然有操作简单、安全、应用广等优点，但是物理处理会造成果蔬组织的损伤，蛋白质、果胶等营养成分的分解和流失[61]。而植物精油联合物理技术保鲜时，果蔬的保鲜时间比物理技术单独处理要好，还可降低对果蔬品质的伤害。研究[62]发现百里香精油与气调技术联用时，草莓的保鲜期比单独用气调保鲜延长了 4 d 以上；与单独微波处理相比，西兰花经肉桂精油清洗后用 300 W 微波处理 40 s，其维生素 C、总酚、总黄酮含量等得到有效保持，叶绿素分解减缓[63]。但是植物精油联合物理技术保鲜仍会有植物精油的特殊气味残留，需将精油纳米化或胶囊化。

3.6 精油涂布包装纸箱保鲜

将精油纳米化或胶囊化后喷涂于包装纸箱上，使纸箱具有抗氧化、抑菌等特性，当果蔬封装于该纸箱后，既避免精油直接接触果蔬而造成感官及品质的降低，又可提供封闭的、狭窄的、良好的保鲜环境，是未来果蔬贮藏保鲜的一种新趋势。Buendía-moreno 等[64]将香芹酚、牛至、肉桂按重量比 70∶10∶20 制成精油混合物随后加入一定量的 β-环状糊精等其他物制成纳米胶囊的水性丙烯酸乳液，将该乳液喷涂到包装纸箱上对番茄进行保鲜，结果发现，8 ℃贮藏 6 d 后，番茄的硬度几乎不受影响，未引起显著的水分流失，且感官质量也并未产生负面影响；当香芹酚、牛至、肉桂以质量比 70∶10∶20 有效地封装在 β-环状糊精后，喷涂于纸箱上对甜椒进行贮藏保鲜，使其在 8 ℃下的货架期延长 18 d[65]。此外，将 4% 百里香精油、吐温-80、大豆分离蛋白形成的纳米乳剂涂布于箱坯内壁并用其盛装草莓，结果发现，箱内草莓表面的菌落数减少，能在一定程度上维持草莓感官质量和硬度指标[66]。

4 结论及展望

植物精油因其具有抗氧化、抑菌、抗炎、杀虫驱虫等功能特性而被逐渐应用于果蔬保鲜中。现植物精油在果蔬保鲜中的应用方式主要是单精油保鲜、精油简单复配保鲜、精油乳化保鲜、精油微胶囊化保鲜、精油联合物理保鲜、精油与纸箱联用保鲜等。但单精油保鲜、精油简单复配保鲜等方式会使果蔬带有植物精油的刺激性气味而影响消费者接受度，导致植物精油应用有所限制，故植物精油需经过一定的处理以降低或掩盖气味，如精油微胶囊化、纳米乳化等技术，在达到果蔬保鲜的同时能降低消费者对植物精油刺激性气味的排斥，提高消费者的购买欲。后续需在提高植物精油稳定性、减少挥发、缓慢释放等方面进行积极创新。为了保证植物精油被摄食后在人体中的安全性，还需大量的临床试验，从而使植物精油在果蔬保鲜方面得到更广泛的应用。

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