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植物中抗病原真菌的活性物质

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摘要 综述了近十年国内外公开报道的部分植物抗病原真菌的活性物质，这些物质主要包括萜类、生物碱类、黄酮类、酚类、醌类、苯丙素类、香豆素类和木脂素类等。侧重介绍了禾本科、豆科、蔷薇科、菊科和十字花科植物中抗病原真菌的活性物质的特点。提出了一些看法与建议。

关键词 植物，抗病原真菌，活性物质

Active Metabolites Against Phytopathogenic Fungi in Higher Plants

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Abstract A review was made of published literature in the recent years on the antifungal metabolites in higher plants. The metabolites mainly include terpenes, alkaloids, flavones, phenols, quinines, phenylpropanoids, coumarins and lignans. The characteristics of antifungal constituents in the families of Gramineae, Leguminosae, Rosaceae, Compositae and Cruciferae were emphasized. A brief conclusion and some suggestions for the further research of antifungal substances were also outlined.

Key words Higher plants, Anti-phytopathogenic fungi, Active metabolites

20世纪80年代以来，从保证食品安全、保护环境和克服有害生物抗性等共同关心的问题出发，科学工作者加大了从植物中寻找抗有害生物活性物质的研究力度。相对而言，在此类天然活性物质的研究中，杀虫物质的报道较多，而抗病的资料偏少，本文对有关植物中抗病原真菌的活性物质的研究作一概述。近十多年，人们对植物及其抗菌活性物质进行了较为深入的研究，研究范围涉及40多个科的1 000余种植物，发现了300多种新的抗植物真菌活性物质。从植物在农业生产中的地位出发，抗真菌活性物质的研究重点集中在主要粮食作物和经济作物上，如禾本科、豆科、蔷薇科和菊科等。同时，一些区域性的主要植物、特色植物和某些相关的民族药用植物也是研究者注意的对象。

1 植物及其抗真菌活性物质（表1）

1.1 禾本科植物水稻中的抗真菌活性物质

Grayer和Kokubun(2001)发现，水稻叶可产生许多固有抗菌物质（preformed或constitutive

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antifungal）或经诱导形成抗菌物质（induced antifungl 或 phytoalexin）。固有抗菌物质包括硅酸盐（酯）、以亚麻酸为母体的 12 个十八碳羟基脂肪酸(Kato *et al.*, 1993)、环氧脂肪酸和烷基间苯二酚(Suzuki *et al.*, 1996); 诱导产生的抗菌物质主要是黄烷酮和二萜类化合物。黄烷酮类的抗菌化合物有樱花苷(Kodama *et al.*, 1992)和4, 5, 7-三羟基黄烷酮, 二萜类的抗菌化合物有 momilactone A、稻叶素(oryzalexin)和植物卡生（phytocassane） (Koga *et al.*, 1995)等。

1.2 蔷薇科植物的抗真菌活性物质

Kokubun和Harborne(1994; 1995)用活性追踪与TLC生物自显影相结合的方法研究了130多种蔷薇科植物, 分离鉴定出 20 多个抗菌活性物质, 这些物质主要是异类黄酮、苯甲酸、联苯和二苯并呋喃类化合物。此外, 还有 3, 5- 二 - 氧 - 咖啡酰奎尼酸、对苯二酚葡萄糖苷以及在未成熟的油桃果中发现的7个三萜类物质(Lahlou *et al.*, 1999)。

1.3 豆科植物的抗真菌活性物质

豆科植物抗真菌活性物质主要是异类黄酮类物质, 如异黄酮、异黄烷酮、异黄烷、rotenoid、coumestan 和 coumaranochromone(Harborne and Baxter, 1999)等。Harborne(1999)曾系统分析比较过560多种豆科植物中的130多种不同抗真菌活性物质的构成特点, 并在属一级分类水平上, 提出了抗真菌活性物质化学分类的可能性。

1.4 十字花科植物的抗真菌活性物质

Pedras 等（2000）综述了十字花科植物中的 25 个抗菌物质：brassitin、cyclobrassinone、cyclobrassinin、1-methoxyspirobrassinin、1-methoxyspirobrassinol methylether、1-methylcamalexin、1-methoxyindole-3-carboxylate 和 sinalexin 等。有趣的是, 在 25 个抗菌物质中除1-Methoxyindole-3-carboxylate外, 其余24个全都是含硫吲哚化合物, 产生含硫抗菌物质似乎是十字花科的一个特点。

1.5 菊科植物的抗真菌活性物质

Alvarez-Castellanos等(2001)用茼蒿(*Chrysanthemum coronarium* L.)花精油对12种植物病原菌进行抗菌试验, 均表现出抗真菌活性, 精油的主要化学成分为 2- 莰烷醇（29.2%）、α- 蒎烯（14.8%）、β- 蒎烯（9.5%）和 lyratyl acetate(9.8%)。Skaltsa 等（2000）从矢车菊(*Centaurea cyanus* L.)中分离到大叶香叶内酯、elumanolide、eudesmanolide 和桉叶烷对 9 种植物病原真菌有抑制作用。Maatooq 等（1996）发现灰白银胶菊×绒毛银胶菊中的银胶菊酮、8- 氧 - 灰白银胶菊酮、8- 氧 - 去甲 - 灰白银胶菊酮和假虎刺酮等倍半萜内酯对黑曲霉与烟曲霉有抗真菌活性。Takasugi 和 Masuda（1996）用假单胞菌诱导 *Polymnia sonchifolia* 产生出 3 个 4' - 羟基苯乙酮类化合物有抗 *Bipolaris leersiae* 的活性。有人用 $CuCl_2$ 诱导向日葵产生香豆素、7- 羟基 -6- 甲基香豆素和三脉泽兰素等抗真菌活性物质。

表 1 摘录了自 1993 年以来部分其他植物抗病原真菌活性物质的主要研究报道。

2 植物抗病原真菌活性物质的化学分类

从表1可见, 植物的抗真菌活性物质在化学分类上绝大多数都属于次生代谢产物, 主要包括萜类、生物碱类、黄酮类、酚类、醌类、苯丙素类、香豆素和木脂素等类型, 其分子量通常在 1 000 Da 以下。

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2.1 萜类

植物体内具有抗真菌活性的萜类化合物, 多是单萜、倍半萜、二萜和三萜。

Picman (1984)用 45 种萜类化合物对 *Mioroporium cookei*、*Trichophytom mentagrophytes* 和 *Fusarium* spp. 进行抗菌试验, 发现62%以上的倍半萜化合物对其中的两种真菌呈一定的抗菌活性, 近 50%的萜类化合物具有很强的抗菌活性, 对镰刀菌有弱抑制作用的为 13%。Wedge 等 (2000)用 36 种天然和半合成的倍半萜内酯对 *Collectotrichum acutatum*、*C.fragariae*、*C. gloeosporiodes*、*Fusarium oxysporum*、*Botrylis cinerea* 和 *Phomopsis* sp.进行了抗菌试验, 结果证明大多数化合物均有一定程度的抗菌生物活性, 有些呈现出很强的抗菌活性。

二萜类的抗真菌活性化合物。Haraguchi（1996）发现存在于沟果非洲砂仁(*Aframomum aulacocarpos* Pellegr ex Koechlin)、红豆蔻(*Alpinia galanga* Rosc)和姜(*Zingiber officinale* (L.) Willd.)中的二萜化合物——非砂仁二醛, 可强力抑制金色青霉菌的生长。水稻中的二萜化合物植物卡生（phytocassane）A、B、C、D、E (Koga *et al.*, 1995)以及稻叶素 E 和稻叶素 F(Kato *et al.*, 1993), 可抑制稻瘟病菌（*Magnaporthe grisea*）芽孢生长。

2.2 芳香族类抗真菌活性物质

植物体内的芳香族类抗真菌化合物, 最典型的是酚和醌。赵纯森等（1994）从厚朴落叶中分离出两种联苯酚类化合物——厚朴酚和厚朴酚, 对多种植物病原真菌具有较高的离体和活体抗真菌活性。水稻幼苗经诱导产生的一种烷基间苯二酚（Suzuki *et al.*, 1996）, 具有抗稻瘟病的活性。萘醌是一类有效的抗真菌活性物质, 独丽花(*Moneses uniflora* Gray)中的萘醌——梅笠草素（Saxena *et al.*, 1996） 对黄曲霉与烟曲霉有抑制作用。北极花破布木(*Cordia linnaei* Stearin)根中的破布木醌 B、E、G 和 H 及破布木(*Cordia curassavica*)中的破布木醌 J 和 K 对瓜枝孢有抗真菌活性(Ioset *et al.*, 1998)。此外, Suresh 等(2003) 从喜马大黄(*Rheum emodi*)中分离出 3 种新的萘醌—— revandchinone-1、revandchinone-3 和 revandchinone-4 对 *Rhizopus oryzae* 和 *Asperigillus niger* 有抗真菌活性。

2.3 黄酮类抗真菌活性物质

黄酮类物质是植物体内广泛存在的一类抗菌物质。孪花蟛蜞菊(*Wedelia biflora* (Linn.))中的黄酮—— 3, 3′- 二甲基槲皮素(Miles *et al.*, 1993), 对茄子镰刀菌和寄生曲霉有抑制作用。灰叶(*Tephrosia purpurea* (L.) Pers.)中黄酮——披针灰叶素B(Chang *et al.*, 1997)可抑制病原体孢子和菌核发芽, 对蓼白粉病和小麦散黑粉菌有作用。甜香杨梅(*Myrica gale*) L.、宾州杨梅(*Myrica pensylvanica* L.)和锯齿杨梅(*Myrica serrata* Lamarck)中的2′, 4′-二羟基-6′-甲氧基-3′, 5′-二甲基查耳酮(Gafner *et al.*, 1996b), 在TLC上对瓜枝孢菌最小抑制生长量为6 mg。王锦亮等(1995）发现云南血竭(*Dracaena cochinchensis* (Lour.) Chen)中的查耳酮——岩棕素A, 其2.5%滤纸片在培养平板上的抑菌圈直径大小枝孢嗜果仓霉为15.0 mm, 禾谷镰刀菌龙血树变种、禾谷镰刀云南变种及出芽短梗霉均为 11.0 mm。此外, Garo 等（1996）证明(2*S*)-4′- 羟基 -7- 甲氧基黄烷、(2*S*)-7, 4′-二羟基-3′-甲氧基黄烷和(±)-7, 4′-二羟基-3′-甲氧基黄烷, 对瓜枝孢和立枯丝核菌有抑制作用。

2.4 含硫或含氮抗真菌活性物质

含硫或含氮化合物包括生物碱、胺及酰胺类等物质, 它们是植物体内具有抗菌活性的典型物质。在含硫化合物中, Greger 等（1994）发现狭叶山小桔(*Glycomis angustifolia* Lindl)中的

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表 1 部分植物抗菌

Table 1 The selected antifungal compounds

科 Family	**种** Species	**器官** Organ	**化合物** Compound
Euphorbiaceae	*Bridelia reusa*	Stem bark	(*E*)-4-(1,5-dimethyl-3-oxo-1-hexenyl)benzoic acid
Rutaceae	*Glycosmis pentaphylla*	Leaf	Illukumbin B
	Dictamnus dasycarpus	Root bark	Isofraxinellone
	Coleonema pulchellum	Root	Precolpuchol
	Zanthoxylum andentum	Stem bark	8-acetonyldihydrontidine
Solanaceae	*Withania coagulans*	Whole plant	17 β-hydroxywithanolide K
Guttifereae	*Hypericum brasiliense*	Stem, Root	Hyperbrasilone
Polygalaceae	*Polygala fruticosa*	Leaf, Root bark	Frutinone A
Gentianaceae	*Gentiana tibetica*	Root	Ethyl *N*-docosanoylanthranilate
Pyrolaceae	*Moneses uniflora*	Aerial part	8-chlorochimphilin
Musaceae	*Musa acuminata*	Rhizome	Musanolone C
Boraginaceae	*Cordia linnaei*	Root	Cordiaquinone B
	Heliotropium floridum	Aerial part	3′-acetyltrachelanthamine
Cyperaceae	*Mariscus psilostachys*	Whole plant	(±)-5, 4′-dihydroxy-7, 3′-dimethoxy-flavanone
Agvaceae	*Dracaena cochinchinensis*	Resin	7-hydroxy-4′-methoxy-flavan
			Loureirin A
Piperaceae	*Piper aduncum*	Leaf	Methyl 8-hydroxy-2, 2-dimethyl-2H-chromene-6carboxylate
	P. tuberculatum		8(*Z*)-*N*-(12,13,14-trimethoxycinnamoyl)-△^{3}-pyridin-2-one
			Arboreumine
Umbelliferae	*Apium graveolens*	Stem	Columbianetin
	Diplolophium buchanani	Leaf	*Trans*-isoelemicin
			Oxypeucedanin hydrate
Caricaceae	*Carica papaya*	Fruit	3′-5′-dimethoxy-4′-hydr-(2-hydroxy) acetophenone
Labiatae	*Salvia tomentosa*	Aerial part	Dehydroabietic acid
Acanthaceae	*Hypoestes serpens*	Root	Fusicoserpenol
			Dolobeserpenoic acid
Berberidaceae	*Podophyllum hexandrum*	Leaf	Picropodopyllone
Combretaceae	*Terminalia belerica*	Fruit rind	7-Hyhroxy-3′, 4′-（methylenedioxy）flavane
Myrsinaceae	*Rapanea melanophloeos*	Leaf	Sakurasosaponin
Myristicaceae	*Virola olrifera*	Aril	Oleiferin F
	V. urinamensis	Root	2-hydroxy-7,4′-dimethoxyisoflavone
Polygonaceae	*Polygonum hydropiper*	Bud	Tadeonal
	Rheum emodi	Rhizome	Revandchinone-1
			Revandchinone-3
Dipsacaceae	*Cephalaria transsylvanica*	Flower	TanssylvanosideA
Canellaceae	*Canella winterana*	Stem bark	Warburqanal
Celastraceae	*Bhesa paniculata*	Wood	Anofinic acid
Bignoniaceae	*Newbouldia laevis*	Root	(2*R*)-5-methoxydehydroiso- α -lapachone
Myricaceae	*Myrica serrata*	Leaf	Aurentiacin A
Liliaceae	*Veratrum taliense*	Root	Neoverataline A
			Neoverataline B
Pineceae	*Pseudolarix kaempferi*	Stem bark	Pseudolaric acid B
Phytolacaceae	*Petiveria alliacea*	Root	Dibenzyl tetrasulphide
			Benzylhydroxymethyl sulpide
			Di(benzyltrithio) methane
Araceae	*Lysichitum americanum*	Leaf	2-(4-methoxyphenyl)-1-nitroethane
			2-(4-hydroxylphenayl)-1-nitroethane
Lauraceae	*Persea americana*	Fruit	(*E,Z,Z*)-1-acetoxy-2-hydroxy-4oxo-heneicosa-5,12,15-triene

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活性物质

in higher plants

分子式 Formula	**化合物类别** Class	**病原菌** Pathogen	**文献** Reference
$C_{15}H_{18}O_3$	Bisabolane sesquiterpene	*Cladosporium cladosporioides*	Jayasinghe *et al.*, 2003
$C_{12}H_{13}NOS$	Organic sulfide	*C. cladosporioides*	Greger *et al.*, 1994
$C_{14}H_{16}O_3$	Benzofuran	*C. cucumerinum*	Zhao *et al.*, 1998
$C_{14}H_{16}O_2$	Phenol	*C. cucumerinum*	Brader *et al.*, 1997
$C_{24}H_{23}NO_5$	Benzophenanthrene alkaloid	*C. cladosporioide*s	Nissanka *et al.*, 2001
$C_{28}H_{38}O_6$	Steroidal lactone	*Pleurotus ostreatus*	Choudhary *et al.*, 1995
$C_{16}H_{16}O_4$	Phenol	*C. cucumerinum*	Rocha *et a*l, 1994
$C_{16}H_{18}O_4$	Coumarin	*C. cucumerinum*	Rahalison *et al.*, 1994
$C_{31}H_{53}NO_3$	Anthranilic acid derivative	*Aspergillus flavus*	Tan *et al.*, 1998
$C_{12}H_9CLO_2$	Organic halid	*Fusarium tricuictum*	Saxena *et al.*, 1996
$C_{19}H_{14}O_2$	Phenalenone	*F. oxysporum*	Luis *et al.*, 1995
$C_{21}H_{26}O_3$	Naphthoquinone	*C. cucumerinum*	Ioset *et al.*, 1998
$C_{17}H_{29}NO_5$	Pyrolizidine alkoloid	*F. moniliforme*	Reina *et al.*, 1997
$C_{17}H_{16}O_6$	Flavan	*C. cucumerinum*	Garo *et al.*, 1996
$C_{16}H_{16}O_3$	Flavan	*C. carpophilum*	**王锦亮等，**1995
$C_{17}H_{18}O_4$	Chalcone	*Aureobasidium pullulans*	
$C_{13}H_{14}O_4$	Chromene	*Penicillium oxalicum*	Orjala *et al.*, 1993
$C_{17}H_{19}NO_5$	Amide	*C. sphaerospermum*	Navickiene *et al.*, 2000
$C_{25}H_{40}N_2O_5$	Amide	*C. sphaerospermum*	Vasques *et al.*, 2002
$C_{14}H_{14}O_4$	Coumarin	*Botrytis cinerea*	Afek *et al.*, 1995
$C_{12}H_{16}O_3$	Phenylpropanoid	*C. cucumerinum*	Marston and Hostettmann, 1995
$C_{16}H_{16}O_6$	Furocoumarin	*C. cucumerinum*	
$C_{10}H_{12}O_5$	Acetophenone	*Collectotrichum gloeosporioides*	Echeverri *et al.*, 1997
$C_{20}H_{28}O_2$	Diterpenoid	*Pyricularia grisea*	San Feliciano *et al.*, 1993
$C_{20}H_{34}O_2$	Diterpenoid	*C. cucumerinum*	
$C_{23}H_{38}O_4$	Diene	*Collectotrichum gloeosporioides*	Domergue *et al.*, 2000
			Rasoamiarnjanahary *et al.*, 2003
$C_{20}H_{30}O_2$	Diterpenoid	*C. cucumerinum*	
$C_{22}H_{20}O_8$	Lignan	*Pleurotus ostreatus*	Atta-Ur-Rahman *et al.*, 1995
$C_{16}H_{14}O_4$	Flavane	*P. expansum*	Valsaraj *et al.*, 1997
$C_{60}H_{98}O_{27}$	Trierpenoidal glycoside	*C. cucumerinum*	Ohtani *et al.*, 1993
$C_{20}H_{24}O_5$	Lignan	*C. cladosporioides*	Sartorelli *et al.*, 1998
$C_{17}H_1O_{54}$	Isoflavone	*C. cladosporioides*	Lopes *et al.*, 1999
$C_{15}H_{22}O_2$	Sesquiterpenoid	*Mucor mucedo*	Taniguchi, 1993
$C_{34}H_{46}O_6$	Oxanthrone ester	*Rhizopus oryzae*	Suresh *et al.*, 2003
$C_{37}h_{54}O_5$	Anthraquinone ester		
$C_{53}H_{86}O_{22}$	Trierpenoidal glycoside	*Aspergillus oryzae*	Kirmizigul and Anil, 1994
$C_{15}H_{22}O_3$	Sesquiterpenoid	*Sclerotinia libertiania*	Taniquchi, 1993
$C_{12}H_{12}O_3$	Benzopyran	*C. cucumerinum*	Harrison *et al.*, 1995
$C_{16}H_{14}O_4$	Naphthoquinone	*C. cucumerinum*	Gafner *et al.*, 1996a
$C_{17}H_{16}O_4$	Chalcone	*C. cucumerinum*	Gatner *et al.*, 1996b
$C_{27}H_{41}NO_8$	Steriodal alkaloide	*Phytophthora capisis*	Zhou *et al.*, 2003
$C_{27}H_{41}NO_9$			
$C_{21}H_{26}O_7$	Diterpenoid	*Aspergillus flavus*	Li *et al.*, 1995
$C_{14}H_{14}S_4$	Polysulphide	*C. cladosporioides*	Benevides *et al.*, 2001
$C_8H_{10}S_6$			
$C_{15}H_{16}S_6$			
$C_9H_{11}O_3N$	Nitro compound	*Fusarium oxysporum*	Hanawa *et al.*, 2000
$C_9H_{11}O_3N$	Nitro compound		
$C_{23}H_{38}O_4$	Diene	*Collectotrichum gloeosporioides*	Domergue *et al.*, 2000

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含硫生物碱——甲基达布林有中等抗真菌活性。存在于北京油菜(*Brassica campestris* L. ssp. *pekinensis*)与欧洲油菜(*B. napus* L.)中的环芸苔宁碱和甲基油菜素, 对31种以上植物的致病真菌显示出中等抗真菌活性(Takasugi *et al.*, 1988)。在含氮化合物中, Harborne 和 Baxter (1993)发现存在于许多植物中的胺类化合物有抗真菌作用, 如spermdine和spermidin可抑制青霉菌孢子的萌发。Navickiene 等(2000)从 *Piper hispidum* 和 *Piper tubericulatum* 中分离到 10 种酰胺化合物, 对 *C. sphaerospermum* 的最低抑制剂量为 0.1~5 mg。

2.5 苯丙素类抗真菌活性物质

苯丙素中的香豆素和木脂素是植物重要的抗真菌活性物质。(1) 香豆素：灌木酮 A 和非巴洛素对瓜枝孢、去甲蟛蜞菊内酯对黑曲霉、欧前胡酚对盘长状刺盘孢、弯孢霉菌和青霉菌有较强抗真菌活性 (Marston and Hostettmann, 1995); (2)木脂素：产油肉豆蔻(*Virola oleifera* (Schott) Smith)中的木脂素——产油肉豆蔻素 G 和 H (Sartorelli *et al.*, 1998) 抑制芽枝状枝孢和球孢枝孢生长的最低剂量为 10~25 mg。鬼臼(*Podophyllum emodi* Wall.var.*chinense* Sprague)中的木脂素——4′-O-去甲去氢鬼臼毒素对糙皮侧耳有抗真菌作用(Atta-Ur-Rahman *et al.*, 1995)。

2.6 其他抗真菌活性物质

Arnone 等(1993)发现桉杯伞烯A和B, 在浓度50 mg·mL^{-1}时, 对芽枝状枝孢呈抗真菌活性。姜烯酮 A 在 10 mg·mL^{-1} 时, 完全抑制 *Pyricularia oryzae* 生长。Zhao 等 (1998) 测定白鲜 *Dictamnus dasycarpus* Turcz.中的柠檬苦素——6β-羟基栾皮酮, 在TLC板上, 抑制瓜枝孢生长的最小剂量为 5 mg。Phay 等(1999)证明威尔士洋葱中的十八碳-3-羟基吲哚可抑制 *Fusarium oxysporum* 蛋白质的合成。Wang 和 Ng (2002)从猕猴桃中分离出类似于奇异果甜蛋白的单链蛋白 (21 kDa), 有抗 *Botrytis cinerea* 和抑制 *Mycosphaerella arachidicola* 与 *Corpinus comatus* 的活性。

3 结语

从以上的研究结果可以得出以下几点结论：(1)具有抗菌活性物质的植物呈现出多样性; (2)植物抗菌活性物质的分布呈现出多样性; (3)植物抗菌活性物质的类别呈现出多样性; (4)在众多的植物抗菌活性物质中, 萜类、酚醌类、黄酮类、含硫与含氮生物碱类和香豆素等化合物是主要类型; (5)植物抗菌活性物质的活性大小 (MIC 值) 通常为 0.1~100 mg。

植物次生代谢物质是生物间, 特别是植物与昆虫、植物与微生物之间协同进化的产物, 是新物质不断生成的基源。据估计全球约有 50 万种植物, 作过化学成分研究的仅占 10%, 已知的植物次生代谢产物有 40 万种, 鉴定分子结构的仅有 1 万多种。因此, 植物源农药的研发具有巨大的空间和广阔的前景, 我国已利用除虫菊成功开发出高效拟杀虫菊酯。著名的巴斯夫公司和先正达公司都以热带雨林中的 *Oudemansiella muscida* 和 *Strobilurus teuacellus* 的抗菌物质β-甲基丙烯酸酯类化合物为模版开发出了杀菌谱广、药效高、对环境和非靶标生物友善的系列杀菌剂。随着对植物抗菌活性物质的化学与分子生物学研究的深入, 安全、高效和环保农药的开发将会不断呈现出新的突破。值得提及的是, 由于滥用化学合成农药导致食品安全的问题越来越突出, 因此, 研究植物源抗菌物质防治果蔬采后病害具有很重要的意义。

植物抗菌活性物质的研发, 首先应从复杂的植物体中分离提纯单体, 明确其组成、结构和性

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质；其次是分析生源途径、遗传特性、构效关系和作用机理；最后是利用先导化合物通过化学改性开发出系列产品。深入研究植物抗菌活性物质的分子机制，运用基因工程手段调节其产出，更是有效利用植物活性物质的新途径。植物抗真菌活性物质的研究属边缘交叉学科，必须有多学科的协作。充分利用相关的植物资源与活性产物数据库，组合经典与现代方法进行活性测试筛选、物质分离提纯和鉴定是提高研究准确性和工作效率的重要手段。

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