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金龟甲性信息素的化学成分及其应用

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摘要: 金龟甲 Scarabaeidae 性信息素研究主要集中在丽金龟亚科 Rutelinae 和鳃金龟亚科 Melolonthinae。丽金龟亚科金龟甲的性腺由臀板和腹片顶端的上皮细胞组成, 其性信息素成分主要是脂肪酸衍生物; 而鳃金龟亚科金龟甲的性腺可以从腹部外翻, 性信息素成分主要是氨基酸衍生物和萜烯类化合物。一些存在地理或季节隔离的物种具有结构相同的性信息素成分, 但手性不同。在某些种类中, 性信息素成分的手性对映体可能具有行为拮抗作用。本文综述了金龟甲性信息素的化学结构与应用的新进展。

关键词: 金龟科; 丽金龟亚科; 鳃金龟亚科; 生殖隔离; 手性; 诱集

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Sex pheromones of scarab beetles and their application

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Abstract: The research on sex pheromone of beetle is mainly concentrated in the subfamilies Rutelinae and Melolonthinae. Sex pheromone gland of Rutelinae consists of epithelial cells that line the inner surfaces of the pygidium and two apical sternites. Their sex pheromone constituents are mainly fatty-acid derivatives. In marked contrast to Rutelinae, sex pheromone gland of Melolonthinae can evert from the abdominal tip, and their components are mainly amino acid derivatives and terpenoid compounds. Some scarab species that are geographically and/or seasonally isolated utilize the same sex pheromone components, but with different chirality. The chirality often plays an important role in the isolation of the communication channels of two species, where one enantiomer is utilized as sex pheromone by one species and the other is a behavioral antagonist against the other species. This paper summarized advances in chemical structure of sex pheromone and its application in management of scarab beetles.

Key words: Scarabaeidae; Rutelinae; Melolonthinae; reproductive isolation; chirality; trap

金龟科 Scarabaeidae 属鞘翅目 Coleoptera 多食亚目 Polyphaga 金龟总科 Scarabaeoidea, 是鞘翅目中数量较大的一个科。金龟科下分 13 亚科, 约 1 600 个属、27 000 种 (贾晨曦, 2014)。此类昆虫具有种类多、分布广、食性杂、生活隐蔽、适

应性强、生活史长短不一等特点, 是多种农作物、林木的主要害虫之一。成虫和幼虫均可危害, 成虫嗜好取食植物叶片, 对农作物和树木造成严重危害 (胡琼波, 2004; 滕小慧, 2018); 幼虫俗称蛴螬, 在土壤内长时间隐蔽生活, 为害多种农作

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物、林木等植物的地下幼嫩部分,如萌发的种子、幼根和地下茎(张美翠等,2014;陈博和陈磊,2016)。长期以来化学药剂一直是防治金龟的主要方法。然而,由于金龟的主要危害发生于隐藏在地下的幼虫期,药剂防治效果较差,且较为单一的药剂种类及不合理施用,极易导致金龟抗药性上升,不仅无法达到预期效果,还会残留于环境中(刘艳涛等,2019)。

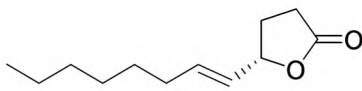
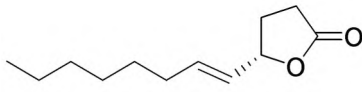
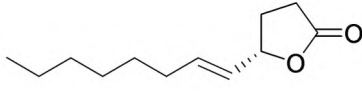
昆虫性信息素是由昆虫某一性别个体释放,被同种的异性个体感受并引起异性个体产生一定生殖行为反应的微量化学物质。应用昆虫性信息素防治害虫具有安全、高效且不伤害天敌等优点(张新慰等,2020),是近年来快速发展的一种害虫防治方法(张广智,2020)。目前,昆虫性信息素的研究与应用主要集中在鳞翅目的蛾类昆虫,其中尺蛾科、螟蛾科、夜蛾科和潜叶蛾科性信息素的生物合成及利用其性信息素开发性诱芯和田间监测技术已比较成熟(王博,2015;李洪明,2018;马涛等,2019;魏亮,2020;王洋等,2021),但对鞘翅目昆虫,尤其是金龟甲性信息素的研究还不够深入。关于金龟甲的研究,仅局限于生物学特性、生殖行为、性信息素成分鉴定等方面,在性信息素应用方面的研究还比较欠缺。上世纪70年代,首次出现金龟甲性信息素成分鉴定方面的报道,从新西兰肋翅鳃金龟 *Costalytra zealandica* 鉴定出性信息素成分苯酚(Henzell and Lowe, 1970; Tumlinson *et al.*, 1977)。随着气相色谱和触角电位联用技术的广泛应用,金龟科丽金龟亚科和鳃金龟亚科性信息素成分鉴定方面的研究取得了显著进展(龚恒亮等,2013)。目前,已鉴定出

性信息素成分的金龟甲有20余种(王广利和孙凡,2005)。本文总结了已知的金龟甲性信息素成分的结构特点,并对金龟甲性信息素的应用进行了概述。

1 丽金龟亚科 Rutelinae 性信息素成分

丽金龟亚科的性信息素成分主要是脂肪酸衍生物,目前共鉴定出13种性信息素。异丽金龟属近源种之间性信息素差异不大,铜色丽金龟 *Anomala cuprea*、扁绿丽金龟 *Anomala octiescostata*、白毛绿丽金龟奇岛亚种 *Anomala albopilosa sakishimana*、*Anomala solida*、樱桃绿丽金龟 *Anomala daimiana* 和白毛绿丽金龟指名亚种 *Anomala albopilosa albopilosa* 性信息素中均含有(R,Z)-5-(\rightarrow -(辛-1-烯基)二氢呋喃-2-酮(Buibuilactone),铜色丽金龟、扁绿丽金龟、日本丽金龟 *Popillia japonica*、白毛绿丽金龟奇岛亚种和阿板丽金龟 *Anomala osakana* 释放的性信息素包含(R,Z)-5-(\rightarrow -(癸-1-烯基)二氢呋喃-2-酮(Japonilure),可见(R,Z)-5-(\rightarrow -(辛-1-烯基)二氢呋喃-2-酮和(R,Z)-5-(\rightarrow -(癸-1-烯基)二氢呋喃-2-酮是多种丽金龟性信息素的共有成分。铜色丽金龟、扁绿丽金龟和白毛绿丽金龟奇岛亚种释放这两种性信息素成分的比例存在种间差异(Tamaki *et al.*, 1985)。日本丽金龟的性信息素 R-Japonilure 的 S-对映体是阿板丽金龟的性信息素主要成分(Tumlinson *et al.*, 1977)。其它种性信息素成分见表1。

表1 丽金龟亚科性信息素
Table 1 Sex pheromones of Rutelinae

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
铜色丽金龟 <i>Anomala cuprea</i>	(R,Z)-5-(\rightarrow -(辛-1-烯基)二氢呋喃-2-酮 R-Buibuilactone		Larsson <i>et al.</i> , 1999
	(R,Z)-5-(\rightarrow -(癸-1-烯基)二氢呋喃-2-酮 R-Japonilure		
<i>Anomala solida</i>	(R,Z)-5-(\rightarrow -(辛-1-烯基)二氢呋喃-2-酮 (R)-Buibuilactone		Tóth <i>et al.</i> , 2003

续表 1 Continued table 1

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
扁绿丽金龟 <i>Anomala octiescostata</i>	(R/Z)-5-(辛-1-烯基)二氢呋喃-2-酮 R-Buibuilactone		Leal <i>et al.</i> , 1994
	(R/Z)-5-(癸-1-烯基)二氢呋喃-2-酮 R-Japonilure		
东方异丽金龟 <i>Anomala orientalis</i>	(Z)-7-十三烯-2-酮 (Z)-tetradec-7-en-2-one		Zhang <i>et al.</i> , 1994
	(E)-7-十三烯-2-酮 (E)-tetradec-7-en-2-one		
	宣氏丽金龟 <i>Anomala schonfeldti</i>	(E)-2-壬烯-1-醇 2-(E)-nonenol	
红铜丽金龟 <i>Anomala rufocuprea</i>	(Z)-5-十四碳烯酸甲酯 methyl 5-(Z)-tetradecenoate		Tamaki <i>et al.</i> , 1985
阿板丽金龟 <i>Anomala osakana</i>	(S/Z)-5-(癸-1-烯基)二氢呋喃-2-酮 S-Japonilure		Leal <i>et al.</i> , 1994
白毛绿丽金龟 奇岛亚种 <i>Anomala albopilosa</i> <i>sakishimana</i>	(R/Z)-5-(辛-1-烯基)二氢呋喃-2-酮 R-Buibuilactone		Leal <i>et al.</i> , 1996
	(R/Z)-5-(癸-1-烯基)二氢呋喃-2-酮 R-Japonilure		
毛绿丽金龟 指名亚种 <i>Anomala albopilosa</i> <i>albopilosa</i>	(R/Z)-5-(辛-1-烯基)二氢呋喃-2-酮 R-Buibuilactone		Leal <i>et al.</i> , 1996
	(E)-2-壬烯醇 2-(E)-Nonenol		
	(E)-2-壬烯醛 2-(E)-Nonenal		
	苯甲酸甲酯 Methyl benzoate		
	樱桃绿丽金龟 <i>Anomala daimiana</i>	(R/Z)-5-(辛-1-烯基)二氢呋喃-2-酮 R-Buibuilactone	

续表 1 Continued table 1

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
	(E)-2-壬烯醇-1 2-(E)-nonenol		
分异发丽金龟 <i>Phyllopertha diversa</i>	1,3-二甲基-2,4-(1H,3H)-间二氮杂萘 1,3-Dimethyl-2,4-(1H,3H)-m-diazaraphthalene		Leal <i>et al.</i> , 1997
日本丽金龟 <i>Popillia japonica</i>	(R,Z)-5-(+)-(癸-1-烯基)二氢呋喃-2-酮 R-Japonilure		Tumlinson <i>et al.</i> , 1977
<i>Protaetia pryri pryri</i>	2,3-二羟基丙基异戊酸酯 2,3-Dihydroxypropyl isovalerate		Wakamura <i>et al.</i> , 2020

2 鳃金龟亚科 Melolonthinae 性信息素成分

鳃金龟亚科的性信息素成分主要为氨基酸衍生物或萜烯类化合物。以氨基酸衍生物作为性信息素成分是鳃金龟亚科区别于其它亚科的一个重要特点。鳃金龟亚科性信息素成分差异显著,除 *Holotrichia kiotonensis* 和 *Holotrichia loochooana loochooana*、*Phyllophaga crinita* 和 *Phyllophaga tristis* 有相同成分外,其它物种间性信息素成分的结构差异比较大。L-缬氨酸甲酯和 L-异亮氨酸甲酯是

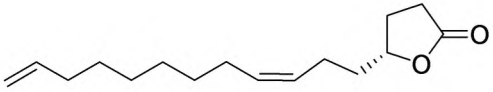
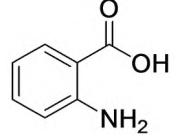
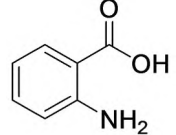
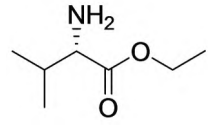
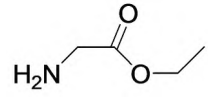
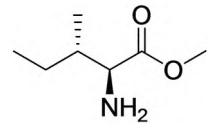
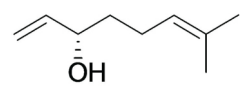
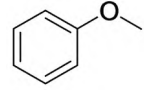
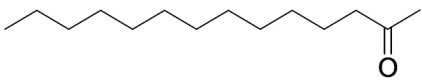
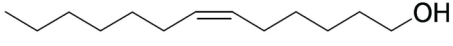
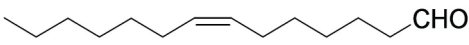
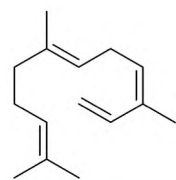
Phyllophaga anxia 的性信息素成分 (Zhang *et al.*, 1997)。*Phyllophaga eleman* 和 *Phyllophaga viciana* 的性信息素成分相近,主要由 N-乙酰基 L-异亮氨酸甲酯、N-甲酰 L-异亮氨酸甲酯和 L-异亮氨酸甲酯组成 (Leal, 1998)。乙偶姻 (R)-Acetoin 是 *Amphimallon solstitiale* 的性信息素,对于成群婚飞的雄成虫有很强的吸引作用 (Tolasch *et al.*, 2003)。*Phyllophaga crinita* 的性信息素是 2-甲基(聚硫甲基)-安息香酸盐 Methyl 2-(methylthio)benzoate, 这是首次报道金龟甲性信息素成分中含有硫基团 (Robbins *et al.*, 2003)。其它种性信息素成分见表 2。

表 2 鳃金龟亚科性信息素

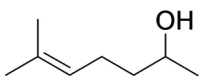
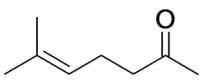
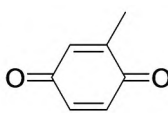
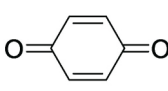
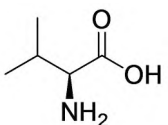
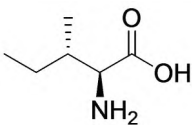
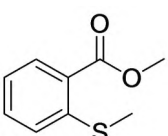
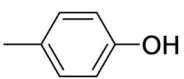
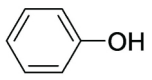
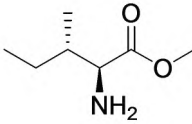
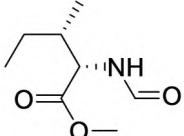
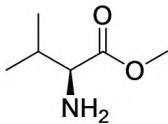
Table 2 Sex pheromones of Melolonthinae

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
欧洲鳃角金龟 <i>Amphimallon majalis</i>	1,4-苯并二恶烷-2-羧酸丙酯 Propyl 1,4-benzodioxan-2-carboxylate		Megovern <i>et al.</i> , 1970
<i>Amphimallon solstitiale</i>	乙偶姻 (R)-Acetoin		Tolasch <i>et al.</i> , 2003
新西兰肋翅 鳃角金龟 <i>Costelytra zealandica</i>	苯酚 Phenol		Henzell and Lowe, 1970

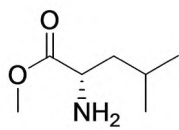
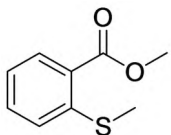
续表 2 Continued table 2

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
黑七鳃金龟 <i>Heptophylla picea</i>	(R,Z)-7,15-十六碳二烯-4-内酯 (R,Z)-7,15-Hexadecadiene-4-lactone		Kuwahara <i>et al.</i> , 1997
<i>Holotrichia kiotonensis</i>	邻氨基苯甲酸 2-Amino-benzoic acid		Oike <i>et al.</i> , 2017
<i>Holotrichia loochooana loochooana</i>	邻氨基苯甲酸 2-Amino-benzoic acid		Yasui <i>et al.</i> , 2003
华北大黑鳃金龟 <i>Holotrichia oblita</i>	脯氨酸乙酯 Proline ethyl ester		王惠等,1997
	甘氨酸乙酯 Glycine ethyl ester		
暗黑鳃金龟 <i>Holotrichia parallela</i>	L-异亮氨酸甲酯 L-Methyl isoleucine		Leal,1992
	R(-)-芳樟醇 R(-)-Linalool		
<i>Holotrichia reynaudi</i>	茴香醚 Anisole		Ward <i>et al.</i> , 2001
<i>Hoplia equina</i>	十四碳酮 2-Tetradecanone		Weber <i>et al.</i> , 2005
<i>Lichnanthe vulpine</i>	(Z)-7-Hexadecenol		Robbins <i>et al.</i> , 2006
	(Z)-7-Hexadecenal		
<i>Maladera matrida</i>	(Z,E)-α-Farnesene		Falach <i>et al.</i> , 2003

续表 2 Continued table 2

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
<i>Megaplatypus mutatus</i>	(+)-Sulcatol		Funes ,2009
	6-甲基-5-庚烯-2-酮 Sulcatone		
欧洲鳃金龟 <i>Melolontha melolontha</i>	甲苯醌 Toluquinone		Reinecke <i>et al.</i> ,2006
	1,4-对苯醌 1,4-Benzoquinone		
六月鳃金龟 <i>Phyllophaga anxia</i>	L-缬氨酸 L-Valine		Alm ,2004
	L-异亮氨酸甲酯 L-Methyl isoleucine		
<i>Phyllophaga crinita</i>	2-(甲基硫代)苯甲酸甲酯 Methyl 2-(methylthio) benzoate		Robbins <i>et al.</i> , 2003
<i>Phyllophaga cuyabana</i>	对甲苯酚 <i>p</i> -Cresol		Leal <i>et al.</i> , 2003
	苯酚 Phenol		
<i>Phyllophaga elenans</i>	L-异亮氨酸甲酯 L-Methyl isoleucine		Oehlschlager <i>et al.</i> ,2003
<i>Phyllophaga georgiana</i>	N-Formyl L-isoleucine methyl ester		Robbins <i>et al.</i> , 2009
	Valine methyl ester		

续表 2 Continued table 2

物种 Species	化学组分 Chemical component	化学结构 Chemical structure	参考文献 Reference
<i>Phyllophaga lanceolata</i>	L-leucine methyl ester		Nojima <i>et al.</i> , 2003
<i>Phyllophaga tristis</i>	2-(甲基硫代)苯甲酸甲酯 Methyl 2-(methylthio) benzoate		Robbins <i>et al.</i> , 2011

鳃金龟释放的信息化学物质可以直接作为性信息素发挥作用, 或者作为性信息素前体物质, 快速转化为性信息素后发挥作用。这些性信息素成分大多都具有杀菌作用, 可能是由原始的防卫机制进化而来的 (Leal, 1997)。鳃金龟 *Cyclocephala lurida* 雄虫触角对幼虫和雌性成虫的提取物中的一种共有成分具有电生理反应, 该成分能够激发 *C. lurida* 雄虫的交配前的婚飞行为 (Leal, 1998)。因此性信息素可能在幼虫阶段发挥某种替代作用, 在发育成熟的雄虫中消失, 但在雌性成虫中仍然保留, 目前尚不清楚幼虫时期就开始产生性信息素的原因 (Leal, 1998)。鳃金龟性信息素的这种特点或许可以揭示昆虫信息素的进化途径 (Haynes and Potter, 1995)。

3 金龟甲生殖隔离机制

在金龟科中, 不同物种利用同一种物质作为性信息素的现象普遍存在, 其避免种间的交叉吸引的方法主要有两种, 一种是利用分子结构的手性, 另一种是利用交配时间和地理分布的差异。

手性化合物是化学分子结构上镜像对称又不能完全重合的化合物 (龚恒亮等, 2013)。在金龟科中, 大多数物种的性信息素都是单一组分, 且有些物种的信息素成分存在立体异构现象。因此, 手性异构体成为了这些金龟实现物种间生殖隔离的重要化学信息物质。有些种类的丽金龟具有相同的性信息素物质, 但空间构型不同, 利用手性性信息素对映体实现种间生殖隔离。如日本丽金龟和阿板丽金龟在日本普遍发生, 生态分布区重叠, 且性信息素都是 (R, Z)-5-(+)-(癸-1-烯基)二氢呋喃-2-酮 (刘孟英, 1997)。但两个物种利用信

息素化学结构的手性异构巧妙地避免了种间的交叉引诱: 日本丽金龟雌虫只产生 R-Japonilure, 微量 S 异构体即可对雄虫产生趋避作用 (Tumlinson *et al.*, 1977); 阿板丽金龟只利用 S-Japonilure 为性信息素, 雄虫对 R 对映体具有趋避反应 (Leal, 1996)。因此, 手性结构的相互拮抗机制在金龟甲性信息素的化学信息通讯中具有重要的生物学意义。同时, 手性结构对处于同一生态位的不同种金龟性信息素的活性也有拮抗作用。日本丽金龟和红铜丽金龟 *Anomala rufocuprea* 常在日本混合发生, 前者的性信息素 R-Japonilure 不影响后者的交配行为, 但后者的性信息素 Methyl 5-(Z)-tetradecenoate 对前者性信息素的活性有抑制作用 (Leal, 1996)。铜色丽金龟的性信息素由 R-Buibuilactone 和 R-Japonilure 组成, S-Buibuilactone 可抑制 R-Japonilure 对雄虫的引诱作用 (Larsson *et al.*, 1999)。

东方丽金龟 *Blitopertha orientalis* 和东方异丽金龟的性信息素均为 (Z)-7-十三烯-2-酮和 (E)-7-十三烯-2-酮, 但前者分布于美国, 后者分布于日本 (Zhang *et al.*, 1994)。扁绿丽金龟和铜色丽金龟性信息素成分均为 R-Buibuilactone 和 R-Japonilure, 在日本均有分布, 但发生期不同, 前者成虫期主要在早春, 而后者成虫期却在夏天 (Leal *et al.*, 1993a; Leal *et al.*, 1994a; Leal *et al.*, 1994b)。交配时间的不同是具有相同性信息素成分的金龟之间产生生殖隔离的另一重要因素。铜色丽金龟的性信息素释放量和交配活动在日落前达到峰值; 白毛绿丽金龟指名亚种的性信息素释放量和交配活动则在日落后达到顶峰 (Leal *et al.*, 1996a)。 *Cyclocephala borealis* 和 *Cyclocephala lurida* 也是通过成虫活跃时间的差异来实现种间生殖隔离。

Cyclocephala lurida 主要在夜间 11 点之前活动, *C. borealis* 则在午夜之后 (Potter, 1980)。

4 应用研究

金龟甲性信息素有高效的引诱作用, 仅有少数几种金龟甲性信息素在田间应用成功, 如日本丽金龟 *Popillia japonica*、暗黑鳃金龟 *Holotrichia parallela* 引诱剂 (张艳玲等, 2004; 鞠倩等, 2014)。1 mg 苯酚对新西兰肋翅鳃角金龟具有非常明显的引诱效果 (Harper *et al.*, 2017); 剂量为 1 mg 和 20 mg 的 (*E*)-2-壬烯-1-醇在田间对宣氏丽金龟 *A. schonfeldti* 的引诱效果无显著性差异 (Hasegawa *et al.*, 1993); 聚乙烯管可以延长性信息素的引诱时间, 使用聚乙烯管装载 12 mg (*R*)-2-丁醇诱集 *Dasylepida ishigakiensis* 的持效期长达 167 d, 对照组持效期仅 28 d (Wakamura *et al.*, 2009); 六月鳃金龟的性信息素缬氨酸甲酯和异亮氨酸甲酯对食叶鳃金龟属的多种 (约 59 种) 金龟具有引诱作用, 该研究揭示了一种性信息素的多态现象 (Robbins *et al.*, 2006a)。(Z)-7-十四碳烯-2-酮和 (*E*)-7-十四碳烯-2-酮以 93:7 的比例混合对东方异丽金龟有明显的引诱效果, 显著降低了田间的种群密度, 降低率可达 92% (Polavarapu *et al.*, 2002)。人工合成的 R-Japonilure 对日本丽金龟雄虫有显著的诱集作用, 引诱效果和雌虫引诱效果相当, 但它的 (*S*)-对映体能显著降低 R-Japonilure 对雄虫的诱集能力 (Leal, 1996)。高效性诱剂的研发依赖于田间反复诱集、筛选的实验基础上, 对其各成分配比进行不断调整, 最后得到引诱效果最佳且应用方便的诱剂。丽金龟亚科丽金龟属多数金龟有相同的性信息素成分 (表 1), 可以利用此特性开发广谱型引诱剂。

植食性金龟甲在植物上进行聚集、取食、交配或产卵等行为, 植物挥发物为其这些行为提供了不可或缺的信息。植物挥发物与性信息素混配可显著增强引诱效果。比如植物源引诱剂丁子香酚与日本丽金龟性信息素 R-Japonilure 混合, 引诱效果相比单一使用性信息素提高了 2~3 倍 (Ladd, 1986); 植物挥发物乙酸-反-2-己烯酯与暗黑鳃金龟性信息素异亮氨酸甲酯、芳樟醇混合比单一使用性信息素有更高的诱捕率, 且在比例为 1:5 时引诱率最高, 增效率达 175% (Ju *et al.*, 2017)。植物挥发物顺-3-己烯醇可显著提高

Melolontha melolontha 性信息素甲苯醌的引诱效果, 在 10:1 时的效果比单用性信息素提升了 10 倍; 顺-3-己烯醇也可显著提高性信息素 1, 4-Benzoquinone 对 *M. hippocastani* 的引诱效果, 在 10:1 时效果提升了 2 倍 (Reinecke *et al.*, 2006)。扁绿丽金龟性信息素与植物挥发物乙酸叶醇酯、苯甲醛、苯乙醛、苯甲醇、苯乙醇、苯乙腈和苯甲酸甲酯以 4:8:14:3:5:19:11 的比例混用后可显著增强引诱效果 (Tamaki, 1984; Leal *et al.*, 1994c); 红铜丽金龟性信息素 (*Z*)-5-十四碳烯酸甲酯与植物挥发性物质邻氨基苯甲酸甲酯混合使用比单独使用性信息素提高了 5 倍的引诱效果 (Imai *et al.*, 1997)。这些都表明了将性信息素与植物挥发物结合应用的前景广阔。

5 问题与展望

性信息素是有害生物综合防治策略 (Integrated pest management, IPM) 中的重要途径之一, 越来越受到世界各国的关注。目前已鉴定出的金龟甲性信息素主要集中于丽金龟亚科和鳃金龟亚科, 但依然还有大量危害农林果木及农作物的金龟的性信息素未被鉴定。已鉴定的金龟性信息素应用范围较窄, 成功应用田间防治的引诱剂屈指可数。金龟甲性信息素产品少的主要原因一是性信息素中各微量成分的比例难以确定, 比例不当会严重影响引诱效果; 二是人工合成路线复杂, 成本较高, 这些都严重影响到金龟性信息素的鉴定及田间应用, 亟需掌握金龟性信息素成分最佳配比, 提高合成效率、降低成本, 加速金龟性信息素商品化, 使其成为农业生产上一种便捷高效的防治手段。

利用昆虫性信息素控制其为害已成为全球生物防治的重要举措。近年来随着分子生物学技术的快速发展, 如触角转录组及嗅觉基因分析、性信息素受体蛋白基因克隆及原核表达等技术的快速应用, 国内外有关金龟性信息素的报道逐年增多。借助分子生物学技术可以进一步开展性信息素的生物合成、嗅觉感受机理等方面的研究。

丽金龟亚科不同属之间的性信息素成分具有重叠现象, 如无法确定某种金龟的性信息素成分时, 可借鉴已鉴定的金龟性信息素成分, 利用标准品进行电生理反应和田间试验, 进而缩小性信息素的范围, 降低性信息素组分的鉴定难度; 也

可利用该特征防治不同属的金龟，扩大金龟性信息素的应用范围，以期在有害生物综合防治过程中发挥更大的作用。

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