实蝇觅食、交配和产卵行为相关的信息化合物研究及其应用进展*

温 强** 程晓琴** 李晓雪 王珊珊 姚志超 张宏宇***

（果蔬园艺作物种质创新与利用全国重点实验室，湖北洪山实验室，华中农业大学植物科学技术学院，中澳园艺和城市有害生物联合研究中心，城市与园艺昆虫学研究所，武汉 430070）

摘 要 实蝇是危害果实和蔬菜等园艺作物的一类具有毁灭性和检疫性的重要害虫，分布地区广、繁殖快，对果蔬产业造成了严重的经济损失。实蝇成虫产卵于寄主植物组织内，幼虫在组织内潜食，防治困难。信息化合物，包括虫源信息化合物、植物源信息化合物和其它来源的信息化合物，因具有活性高、专一性强等特点成为实蝇害虫绿色防控的首选策略。因此，本文系统综述了与实蝇成虫觅食、交配和产卵行为相关的虫源信息化合物、植物源信息化合物和其它来源信息化合物的研究进展及其在害虫防治中的应用现状，为实蝇害虫综合治理提供理论基础和指导。

关键词 实蝇；性信息素；植物挥发物；信息化合物；绿色防控

Progress in research on the application of semiochemicals related to the foraging, mating and oviposition behavior of the fruit fly

WEN Qiang** CHENG Xiao-Qin** LI Xiao-Xue WANG Shan-Shan YAO Zhi-Chao ZHANG Hong-Yu***

(National Key Laboratory for Germplasm Innovation & Utilization of Horticultural Crops, Hubei Hongshan Laboratory, College of Plant Science and Technology, Huazhong Agricultural University, China-Australia Joint Research Centre for Horticultural and Urban Pests, Institute of Urban and Horticultural Entomology, Wuhan 430070, China)

Abstract Fruit flies are destructive quarantine pests that harm horticultural crops. Their wide distribution and high fecundity cause large economic losses to the fruit and vegetable industry. Moreover, adult females lay their eggs within host plant tissue where the larvae feed making them difficult to control. Semiochemicals, including those derived from insects, plants, and other sources, due to their high activity and strong specificity, have become the preferred tools for the environmentally- friendly prevention and control of fruit flies. Therefore this review focuses on semiochemicals related to foraging, mating, and oviposition behavior and the application of these in pest control, and then provides guidance and a theoretical basis for the integrated management of Tephritidae fruit flies.

Key words fruit fly; sex pheromones; plant volatiles; semiochemicals; green prevention and control

实蝇（Tephritidae fruit fly）隶属双翅目（Diptera）实蝇科（Tephritidae），包含近 500 属约 5 000 种，是双翅目昆虫中最大的科之一，广泛分布于世界各地，而亚热带、温带及热带是其分布主要区域（李志红等，2013；高媛惠等，2016；Qin *et al.*, 2018）。实蝇科中的按实蝇属

*资助项目 Supported projects：云南省科技厅重大科技专项（202102AE090054）；财政部和农业农村部国家现代农业产业技术体系专项（CARS-26）；湖北洪山实验室资助

**共同第一作者 Co-first authors，E-mail：m17853680730@163.com；chengxq2018@163.com

***通讯作者 Corresponding author，E-mail：hongyu.zhang@mail.hzau.edu.cn

收稿日期 Received：2022-12-03；接受日期 Accepted：2023-01-28

（*Anastrepha*）、果实蝇属（*Bactrocera*）、腊实蝇属（*Ceratitis*）、绕实蝇属（*Rhagoltis*）和镞果实蝇属（*Zeugoacus*），其成虫在果实或蔬菜的果实组织内产卵，幼虫在果肉内部钻蛀取食危害，成为果蔬产业上的一类重要害虫（张宏宇和李红叶，2018）。

园艺作物在世界农业生产板块中占据重要份额（Ravichandra, 2014），大量产品因果实中隐藏的幼虫或卵导致果品不符合进出口检疫条例而严重影响其经济效益（Kibira *et al.*, 2015），如橘小实蝇 *B. dorsalis* 危害的果实每年对非洲造成的损失近 20 亿美元（Dohino *et al.*, 2017）。此外，实蝇成虫繁殖速度快，能随受害果蔬或其它媒介如包装袋等广泛传播扩散，极易形成爆发性危害，对果蔬的现代化产业健康发展造成危险性的冲击（王在凌等，2020）。因此，世界各地对实蝇严加防控，采取有力措施控制、遏制乃至根除该类害虫种群（Papadopoulos, 2014）。

对实蝇的防治主要是以诱杀为主，农业和化学防治为辅的综合治理（IPM）（张宏宇和李红叶，2018）。随着绿色发展理念逐步兴起，实蝇绿色防控技术迅速发展（Navarro-Llopis *et al.*, 2011），采用诱剂诱杀成为绿色防控技术的重要措施。常用诱剂主要为信息化合物诱剂（性信息素诱剂和类信息素诱剂）和食饵类诱剂。性信息素诱剂是以实蝇性信息素或其结构类似物为活性成分开发的具有引诱能力的诱剂（Witzgall *et al.*, 2010；Cui and Zhu, 2016），如实蝇在性成熟期释放的挥发性化学物质（Shelly *et al.*, 2014；李运娜，2018）。类信息素是来自于某些寄主植物的挥发物或代谢物等能引起昆虫趋向反应的物质（林嘉等，2021），如羽化后成虫因觅食补充营养、雌性寻找产卵寄主等生理特性会趋向于选择酵母或植物的挥发化合物（El-Ghany, 2019）。信息化合物具有活性高、专一性强且不会对非靶标生物造成负面影响等特点，相关技术备受重视，应用前景广阔（王留洋等，2022）。

本综述中，通过对国内外现有的相关文献分析，重点阐述了与实蝇觅食、交配和产卵行为相关的虫源信息化合物、植物源信息化合物和其它来源信息化合物的来源、生物活性行为测定方法、研究现状及其在害虫防治中的应用价值，为实蝇害虫综合治理提供理论基础及技术参考。

1　实蝇虫源信息化合物

昆虫信息化合物参与种内和种间的交流，影响其行为和生理反应（Tinsworth, 1990；Rodriguez and Niemeyer, 2005；Brezolin *et al.*, 2018）。来自昆虫虫体挥发物中的信息化合物，根据功能的不同，将其分为性信息素、寄主标记信息素、聚集信息素及利它素等信息素（Butenandt *et al.*, 1959；Guo *et al.*, 2020；Scolari *et al.*, 2021）。其中，性信息素对性成熟的成虫发挥着求偶和交配的生理作用；寄主标记信息素是指昆虫在寄主上产卵后，通过释放某种化学物质影响同种的排卵行为，从而减少在已经利用的资源上花费的时间和对有限宿主资源的竞争（Nufio and Papaj, 2001）。可见，信息化合物在昆虫成虫期发挥着至关重要的作用，如寻求食物、配偶和寄主定位等（Keeling *et al.*, 2004）。

实蝇性信息素主要来源于虫体和直肠腺，寄主标记信息素主要来自于虫体排泄物（表 1）。南美实蝇 *A. fraterculus* 雄虫虫体挥发物中的 α-蒎烯、柠檬烯、(Z)-3-壬烯-1-醇、(E,Z)-3,6-壬二烯-1-醇、α-法尼烯和(S,S)-(−)-epianastrephin 6 种主要物质可以触发雌虫的电生理反应，且在田间试验中证实对其雌虫有显著引诱效果（Milet-Pinheiro *et al.*, 2015）。柑橘大实蝇 *B. minax* 雌虫虫体挥发物(R)-(+)-柠檬烯对其雄虫具有强烈引诱力（张宏宇，2015；李运娜，2018）。此外，许多研究者对实蝇直肠腺挥发物分离后发现其对实蝇成虫有引诱行为反应（Haniotakis *et al.*, 1977；Mazomenos and Haniotakis, 1981；Carpita *et al.*, 2012；Canale *et al.*, 2015；Noushini *et al.*, 2019）。杨桃实蝇 *B. carambolae* 雄虫直肠腺挥发物 6-氧代-1-壬醇和 N-3-甲基丁基乙酰胺

表 1　实蝇虫源信息化合物

Table 1　Semiochemicals of Tetriphitidae from male/female borne

实蝇属 Genera	实蝇种 Species	信息素成分 Compounds	物质来源 Sources	行为效应[a] Behaviour	活性测定实验[b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
按实蝇属 *Anastrepha*	南美实蝇 *A. fraterculus*	α-蒎烯 α-Pinene；柠檬烯 Limonene；(Z)-3-壬烯-1-醇 (Z)-3-nonen-1-ol；(E,Z)-3,6-壬二烯-1-醇(E,Z)-3,6-nonadien-1-ol；α-法尼烯 α-Farnesene；(S,S)-(−)-epianastrephin	雄虫虫体 Male-borne	♀	+	+	+	Milet-Pinheiro *et al.*, 2015
	墨西哥实蝇 *A. ludens*	(Z)-3-壬烯醇 (Z)-3-nonenol；(Z,Z)-3,6-壬二烯醇 (Z,Z)-3,6-nonadienol)；(S,S)-(-)- epianastrephin	雄虫虫体 Male-borne	♀		+		Robacker and Hart, 1985
		2-（2,14-二甲基十五烷酰氨基）戊二酸 2-(2,14-Dimethylpentadecanoylamino) pentane-dioic acid	雌虫排泄物 Faeces from Female	♀		+		Aluja-Schuneman *et al.*, 2001
	西印度实蝇 *A. obliqua*	(Z)-3-壬烯醇 (Z)-3-nonenol；β-法尼烯 β-Farnesene	雄虫虫体 Male-borne	♀♂		+		López-Guillén *et al.*, 2011
	暗色实蝇 *A. serpentina*	2,5-二甲基吡嗪 2,5-dimethylpyrazine (DMP)；三甲基吡嗪 Trimethylpyrazine (TMP)；3,6-二氢-2,5-二甲基吡嗪 3,6-dihydro-2,5-dimeth- ylpyrazine (DHDMP)	雄虫虫体 Male-borne	♀	+	+		Robacker *et al.*, 2009
	加勒比实蝇 *A. suspensa*	Z-3-壬烯-1-醇 Z-3-nonen-1-ol；Z,Z-3,6-壬二烯-1-醇 Z,Z-3,6-nonadien-1-ol	雄虫虫体 Male-borne	♀		+		Nation, 1983
果实蝇属 *Bactrocera*	杨桃实蝇 *B. carambolae*	6-氧代-1-壬醇 6-oxo-1-nonanol；N-3-甲基丁基乙酰胺 N-3-methylbutyl acetamide	雄虫直肠腺 Male rectal gland	♀		+		Wee and Tan, 2005
	香蕉实蝇 *B. musae*	月桂酸乙酯 Ethyl laurate；丁酸乙酯 Ethyl butanoate；(E,E)-2,8-二甲基-1,7-二氧杂螺[5.5]十一烷 (E,E)-2,8-dimethyl-1,7-dioxaspiro[5.5]undecane	雄、雌虫直肠腺 Male/Female rectal gland	♀♂	+			Noushini *et al.*, 2019
	橄榄实蝇 *B. oleae*	(Z)-9-二十三烯 (Z)-9-tricosene	雄虫直肠腺 Male rectal gland	♀		+		Carpita *et al.*, 2012

续表 1 (Table 1 continued)

实蝇属 Genara	实蝇种 Species	信息素成分 Compounds	物质来源 Sources	行为效应[a] Behaviour	活性测定实验[b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
果实蝇属 *Bactrocera*	橄榄实蝇 *B. oleae*	1,7-二氧杂螺(5.5)十一烷 1,7-dioxaspiro(5.5) undecane	雌虫直肠腺 Female rectal gland	♂		+	+	Haniotakis *et al.*, 1977; Mazomenos and Haniotakis, 1981
		癸酸乙酯 Ethyl decanoate; 十六烷酸甲酯 Methyl hexadecanoate	雄、雌虫直肠腺 Male/Female rectal gland	♀♂	+	+		Canale *et al.*, 2015
		E-6-壬烯-1-醇 E-6-nonen-l-ol; 对异丙基甲苯 *p*-Cymene	雌虫虫体 Female-borne	♀		+	+	Gariboldi *et al.*, 1982
	桃实蝇 *B. zonata*	2-乙基-3,5,6-三甲基吡嗪 2-Ethyl-3,5,6-trimethylpyrazine; (E,E)-2,8-二甲基-1,7-二氧杂螺[5.5]十一烷 (E,E)-2,8-dimethyl-1,7-dioxaspiro[5.5] undecane; 十二烷酸乙酯 Ethyl dodecanoate	雄、雌虫虫体 Male/Female-borne	♀♂	+			Levi-Zada *et al.*, 2020
	番石榴实蝇 *B. correcta*	*β*-石竹烯 *β*-caryophyllene	雄虫直肠腺 Male-rectal gland	♂			+	Tokushima *et al.*, 2010; Wee *et al.*, 2018
		十二烷酸乙酯 Ethyl dodecanoate; 十四烷酸乙酯 Ethyl tetradecanoate; (E)-9-十六碳烯酸乙酯 Ethyl (E)-9-hexadecenoate; 十六烷酸乙酯 Ethyl hexadecanoate; (Z)-9-十八碳烯酸乙酯 Ethyl (Z)-9-octadecenoate; 辛醛 Octanal; N-(3-甲基丁基)乙酰胺 N-(3-methylbutyl) acetamide; (Z)-9-二十三烯 (Z)-9-tricosene; 十八碳烯酸乙酯 Ethyl octadecenoate; 二十烷酸乙酯 Ethyl eicosanoate	雌虫直肠腺 Female-rectal gland	♀♂		+		Zhang *et al.*, 2019
	橘小实蝇 *B. dorsalis*	2-烯丙基-4, 5-二甲氧基苯酚 2-allyl-4,5-dimethoxyphenol; 松柏醇 Coniferyl alcohol	雄虫虫体 Male-borne	♂			+	Nishida *et al.*, 1988

续表 1 (Table 1 continued)

实蝇属 Genera	实蝇种 Species	信息素成分 Compounds	物质来源 Sources	行为效应 [a] Behaviour	活性测定实验 [b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
果实蝇属 *Bactrocera*	柑橘大实蝇 *B. minax*	(R)-(+)-柠檬烯 (R)-(+)-Limonene	雌虫虫体 Female-borne	♂			+	张宏宇, 2015; 李运娜, 2018
		N-(3-甲基丁基)乙酰胺 N-(3-methyl-butyl) acetamide	雌虫虫体 Female-borne	♀♂	+			李明杰等, 2021
腊实蝇属 *Ceratitis*	地中海实蝇 *C. capitata*	(E) 6-壬烯酸甲酯 Methyl (E)-6-nonenoate；Ej-ó-nonen-l-ol	雄虫虫体 Male-borne	♀		+	+	Jacobson *et al.*, 1973
	纳塔尔实蝇 *C. rosa*	谷氨酸 Glutamic acid	雌虫排泄物 Faeces from female	♀		+		Cheseto *et al.*, 2018
	非洲芒果实蝇 *C. cosyra*	谷胱甘肽 Glutathione	雌虫排泄物 Faeces from Female	♀		+		Cheseto *et al.*, 2017
绕实蝇属 *Rhagoletis*	沙棘绕实蝇 *R. batava*	(-)-δ-庚内酯 (-)-δ-heptalactone	雄虫虫体 Male-borne	♀♂	+		+	Būda *et al.*, 2020
	欧洲樱桃实蝇 *R. cerasi*	十八烷酸 Octadecanoic；十九烷酸 Nonadecanoic；5,8,11,14,17-二十碳五烯酸 5,8,11,14,17-Eicosapentaenoic acid；5,8,11,14-二十碳五烯酸 5,8,11,14-Eicosatetraenoic acid；二十烷酸 Eicosanoic acid；二十烷酸 Heneicosanoic acid；4,7,10,13,16,19-二十二碳六烯酸 4,7,10,13,16,19-Docosahexenoic acid；二十二烷酸 Docosanoic acid	雄虫虫体 Male-borne	♀	+	+		Raptopoulos *et al.*, 1995
		N-[15 (β-吡喃葡萄糖基)-氧-8-羟基棕榈酰]牛磺酸 N-[15 (β-Glucopyranosyl)-oxy-8-hydroxypalmitoyl] taurine	雌虫排泄物 Faeces from Female	♀		+	+	Hurter *et al.*, 1987

a 表示信息化合物对实蝇的活性反应，其中 ♂ 代表物质对雄性有引诱活性反应； ♀ 代表物质对雌性有引诱活性反应； ♀♂ 代表物质对雌、雄两性有均有活性反应。

b 表示信息化合物对实蝇的活性行为反应的测定方式，其中 + 代表采取此类测定方式。表 2、表 3 同。

a represents the response of semiochemicals to Tetriphitidae spp., and ♂ represents the attractant active reaction to males; ♀ represents the attractant active reaction to females. ♀♂ represents the attractant active reaction to both sexes. b represents the determination method of semiochemicals's active behavioral response to Tetriphitidae spp., and + represents the adoption of such determination method. The same as table 2 and table 3.

对杨桃实蝇 *B. carambolae* 雌虫有显著引诱效果（Wee and Tan, 2005）。橄榄实蝇 *B. olea* 雌虫直肠腺挥发物中的1,7-二氧杂螺(5.5)十一烷对雄虫有显著引诱效果（Haniotakis *et al.*, 1977；Mazomenos and Haniotakis, 1981）。可见，实蝇虫体挥发物是发掘潜在性信息素的重要来源。此外，实蝇不仅在交配前释放利于求偶交配的性信息素，交配后的实蝇雌虫还会释放寄主标记信息素利于对寄主植物的占领，即寄主标记行为（Simões *et al.*, 1978；Li *et al.*, 2020）。Porter（1928）最早在苹果实蝇 *R. Pomonella* 的研究中对寄主标记行为进行了描述，之后 Prokopy（1972）和 Cirio 和 Italiana（1972）首次证实了苹果实蝇 *R. pomonella* 和核桃壳实蝇 *R. complete* 存在这种行为。随后许多研究者开始着力于实蝇寄主标记信息素的研究，并发现果实蝇属（*Bactrocera*）中的橘小实蝇 *B. dorsalis*，按实蝇属（*Anastrepha*）中的加勒比实蝇 *A. suspensa*、巴西番石榴实蝇 *A. sororcula* 及南美实蝇 *A. fraterculus* 等，腊实蝇属（*Ceratitis*）中的地中海实蝇 *C. capitata*、非洲芒果实蝇 *C. cosyra* 和纳塔尔实蝇 *C. rosa*，绕实蝇属（*Rhagoletis*）中的欧洲樱桃实蝇 *R cerasi* 4 种实蝇属中存在寄主标记行为（Wiesmann, 1937；Katsoyannos, 1975；Prokopy *et al.*, 1976, 1977, 1978, 1982；Simões *et al.*, 1978；Poloni and Silva, 1986；Hurter *et al.*, 1987；Selivon, 1991；Silva, 1991；Papaj *et al.*, 1992；Aluja *et al.*, 1993；Papaj and Aluja, 1993；Aluja-Schuneman *et al.*, 2001；Aluja and Diaz-Fleischer, 2006；Cheseto *et al.*, 2017；Cheseto *et al.*, 2018；Li *et al.*, 2020），然而真正被鉴定出的寄主标记信息素却较少（表 1）。墨西哥实蝇 *A. ludens*、非洲芒果实蝇 *C. cosyra*、纳塔尔实蝇 *C. rosa* 和欧洲樱桃实蝇 *R. cerasi* 的寄主标记信息素分别为 2-(2,14-二甲基十五烷酰氨基)戊二酸（Papaj and Aluja, 1993；Aluja-Schuneman *et al.*, 2001）、谷胱甘肽（Cheseto *et al.*, 2017）、谷氨酸（Cheseto *et al.*, 2018）和 N-[15(β-吡喃葡萄糖基)-氧-8-羟基棕榈酰]牛磺酸（Wiesmann, 1937；Katsoyannos, 1975；Hurter *et al.*, 1987）。

研究发现实蝇虫体或直肠腺中还产生聚集信息素（姜勇等, 2002；Guo *et al.*, 2020；Sun *et al.*, 2020；Wei *et al.*, 2022），能够引起同性或两性昆虫产生聚集行为反应（Noushini *et al.*, 2019；Zhang *et al.*, 2019；Būda *et al.*, 2020）。橄榄实蝇 *B. oleae* 雌虫虫体挥发物 E-6-壬烯-1-醇和对异丙基甲苯，室、内外活性行为测定表明对其雌虫有显著引诱效果（Gariboldi *et al.*, 1982）；西印度实蝇 *A. obliqua* 雄虫虫体挥发物中的(Z)-3-壬烯和β-法尼烯对其雌、雄成虫均有显著引诱效果（López-Guillén *et al.*, 2011）；番石榴实蝇 *B. correcta* 雌虫直肠腺挥发物（十二烷酸乙酯、十四烷酸乙酯、(E)-9-十六碳烯酸乙酯、十六烷酸乙酯、(Z)-9-十八碳烯酸乙酯、辛醛、N-(3-甲基丁基)乙酰胺、(Z)-9-二十三烯、十八碳烯酸乙酯、二十烷酸乙酯）对其两性成虫均有引诱效果（Zhang *et al.*, 2019）。

综上所述，实蝇信息化合物化学多样性高，包括酯类、醇类、醛类、羧酸类、环氧化物、酮和苯类化合物等。实蝇通过性信息素、聚集信息素等多种信息素作用于个体间通讯交流，利于其完成交配、产卵及寻找食物等行为和生理反应（Gut *et al.*, 2004；Rodriguez *et al.*, 2005；Wyatt, 2014；Brezolin *et al.*, 2018；巩雪芳等, 2018；Serrano *et al.*, 2019；李明杰等, 2021）。当前虽然大部分实蝇信息化合物在实验室内证实具有显著引诱效果，但未在田间进一步验证，无法实际应用于对实蝇的有效防治，这是实蝇信息化合物源诱剂开发应用中亟需解决的问题（林嘉等，2021；张栩浩，2022）。

2　实蝇植物源信息化合物

实蝇成虫需要补充营养和寻找寄主植物产卵，尤其是雌虫表现出对寄主植物挥发性成分的强烈反应和高度敏感性（王琼等，2014；张小娇等，2020）。因此，寄主植物或其他植物的次生代谢挥发性物是实蝇信息化合物的重要来源（表 2）。早在 1912 年，研究者就发现香茅 *Cymbopogon citratus* 中 4-烯丙基-1,2-二甲氧基苯（甲基丁香酚，ME）对桃实蝇 *B. zonata*、橘小实蝇 *B. dorsalis*

表 2　植物源实蝇信息化合物

Table 2　Semiochemicals of Tetriphitidae from plants

实蝇属 Genera	实蝇种 Species	信息类化合物 Compounds	物质来源 Sources	行为效应 [a] Behaviour	活性测定法 [b] Behavioural experiments		参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
按实蝇属 *Anastrepha*	墨西哥实蝇 *A. ludens*	1,8-桉叶素 1,8-cineole；己酸乙酯 Ethyl hexanoate；己醇 Hexanol	发酵佛手瓜 Fermented chapote fruit	♀♂		+	+	Robacker *et al.*, 1990
		辛酸乙酯 Ethyl octanoate；苯甲酸乙酯 Ethyl benzoate；4-萜品醇 4-terpineol；(-)-α-立方体苯 (-)-α-cubebene；orα-萜品醇 Orα-terpineol	发酵佛手瓜 Fermented chapote fruit	♀♂		+	+	Robacker *et al.*, 1992
		丙二醇 Propylene glycol；乙酸 Acetic acid；邻氨基苯甲酸甲酯 Methyl anthranilate；2-甲基丙酸乙酯 Ethyl 2-methylpropionate；3-甲基丁酸乙酯 Ethyl 3-methylbutyrate；2-甲基丁基丙酸酯 2-methylbutyl propionate	康科德葡萄 Concord grape	♀♂		+		Robacker *et al.*, 2011
		丁酸盐 Butyrate；(E)-3-己烯醇 (E)-3-hexenol；(Z)-3-己烯醇 (Z)-3-hexenol；己醇 Hexanol；己酸乙酯 Ethyl hexanoate；乙酸己酯 Hexyl acetate；(Z)-3-己烯基丁酸酯 (Z)-3-hexenyl butyrate；辛酸乙酯 Ethyl octanoate	番石榴 Guava	♀♂		+		Malo *et al.*, 2005

续表 2 (Table 2 continued)

实蝇属 Genera	实蝇种 Species	信息类化合物 Compounds	物质来源 Sources	行为效应 [a] Behaviour	活性测定法 [b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
按实蝇属 *Anastrepha*	西印度实蝇 *A. obliqua*	丁酸乙酯 Ethyl butyrate；丁酸异丙酯 Isopropyl butyrate；己醇 Hexan-1-ol；丁酸丙酯 Propyl butyrate；丁酸异丁酯 Isobutyl butyrate；己酸乙酯 Ethyl hexanoate；丁酸异戊酯 Isopentyl butyrate；苯甲酸乙酯 Ethyl benzoate；辛酸乙酯 Ethyl octanoate	Mombin fruit	♀♂		+		Cruz-López *et al.*, 2006
		月桂烯 Myrcene；α-蒎烯 α-pinene；β-罗勒烯 β-ocimene	Amate mango; Coche mango; Ataulfo mango;	♀♂			+	Malo *et al.*, 2012
果实蝇属 *Bactrocera*	橘小实蝇 *B. dorsalis*	甲基丁香酚 Methyl eugenol	香茅 *Cymbopogon citratus*	♂		+		Howlett, 1912a, 1912b
		乙醇 Ethanol；乙酸乙酯 Ehyl acetate；己酸乙酯 Ethyl hexanoate；乙酸己酯 Hexyl acetate；乙酸芳樟酯 Linalyl acetate；壬酸乙酯 Ethyl nonanate；乙酸壬酯 Nonyl acetate；肉桂酸乙酯 Ethyl cinnamate；(E)-β-法尼烯 (E)-β-farnesene	榄仁树 *Terminalia catappa*	♀♂	+	+	+	Siderhurst *et al.*, 2006
		3-蒈烯 3-carene；β-石竹烯 β-caryophyllene；α-葎草烯 α-humulene	番石榴 Guava；芒果 Mango	♀		+		Jaleel *et al.*, 2019
		3-甲基丁酸甲酯 Methyl 3-methylbutanoate；乙酸丁酯 Butyl acetate；3-甲基丁基乙酸酯 3-methylbutyl acetate；乙酸己酯 Hexyl acetate	菠萝蜜假种皮 Arils of jackfruit	♀♂	+	+	+	Kamala Jayanthi *et al.*, 2021

续表 2 (Table 2 continued)

实蝇属 Genera	实蝇种 Species	信息类化合物 Compounds	物质来源 Sources	行为效应 [a] Behaviour	活性测定法 [b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
果实蝇属 *Bactrocera*	番石榴实蝇 *B. correcta*	3-蒈烯 3-carene；β-石竹烯 β-caryophyllene；α-葎草烯 α-humulene	番石榴 Guava；芒果 Mango	♀		+		Jaleel *et al.*, 2019
	桃实蝇 *B. zonata*	甲基丁香酚 Methyl eugenol	香茅 *Cymbopogon citratus*	♂		+		Howlett, 1912a, 1912b
	柑橘大实蝇 *B. minax*	壬醛 Nonanal；柠檬醛 Citral；柠檬烯 Limonene；芳樟醇 Linalool	冰糖橙 Bingtang sweet oranges；蜜桔 Satsumas mandarins；酸橙 Sour oranges	♀		+		Liu and Zhou, 2016
	昆士兰实蝇 *B. tryoni*	香叶酸甲酯 Methyl geranate；辛酸乙酯 Ethyl octanoate；己酸乙酯 Ethyl hexanoate；(Z)-3-己烯基丁酸酯 (Z)-3-hexenyl butyrate；苯甲酸甲酯 Methyl benzoate；苯甲酸异丁酯 Isobutyl benzoate	橘子 Orange；樱桃番石榴 Cherry guava；香蕉 Banana；斐济果 Feijoa fruit	♀	+			Mas *et al.*, 2020
镞果实蝇属 *Zeugodacus*	瓜实蝇 *Z. cucurbitae*	覆盆子酮 4-(4-Hydroxyphenyl)-2-butanone	兰花 Orchids	♂		+	+	Howse and Underwood, 2000；Tan, 2009
	瓜实蝇 *Z. cucurbitae*	(Z)-6-壬烯醛 (Z)-6-nonenal；(Z)-6-壬烯-1-醇 (Z)-6-nonen-1-ol；1-辛烯-3-醇 1-octen-3-ol；乙酸 Acetic acid；(E,Z)-2,6-壬二烯醛 (E,Z)-2,6-nonadienal；(E)-2-壬烯醛 (E)-2-nonenal；己醛 Hexanal；(E)-2-辛烯醛 (E)-2-octenal；1-己醇 1-hexanol	黄瓜 Cucumber	♀	+	+	+	Siderhurst and Jang., 2010

续表 2 (Table 2 continued)

实蝇属 Genera	实蝇种 Species	信息类化合物 Compounds	物质来源 Source	行为效应 [a] Behaviour	活性测定法 [b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
镞果实蝇属 *Zeugodacus*	瓜实蝇 *Z. cucurbitae*	α-蒎烯 α-pinene；1-辛烯-3-醇 1-octen-3-ol；对伞花烃 P-cymene；对乙基苯甲醛 P-ethyl-benzaldehyde；水杨酸甲酯 Methyl salicylate；对伞花烃-7-醇 P-cymen-7-ol	丝瓜 Ridge gourd	♀	+	+		Shivaramu *et al.*, 2022
腊实蝇属 *Ceratitis*	地中海实蝇 *C. capitata*	α-蒎烯 α-Copaene	荔枝 *Litchi chinensis*；垂叶榕 *Ficus benjamina*；鳄梨 Avocado；鳄梨 *Persea americana*	♂	+		+	Niogret *et al.*, 2011
绕实蝇属 *Rhagoletis*	苹果实蝇 *R. pomonella*	3-甲基丁烷-1-醇 3-methylbutan-1-ol；1-辛烯-3-醇 1-octen-3-ol；β-香叶烯 β-caryophyllene	开花山茱萸（北美山茱萸） Flowering dogwood (*Cornus florida*)	♀♂		+		Nojima *et al.*, 2003
		丁酸丁酯 Butyl butanoate；己酸丙酯 Propyl hexanoate；己酸丁酯 Butyl hexanoate；丁酸己酯 Hexyl butanoate；己酸戊酯 Pentyl hexanoate	苹果品种 Apple: Empire, Crispin, Cortland, Macintosh, Red Delicious	♀♂	+	+	+	Zhang *et al.*, 1999
		3-甲基丁-1-醇 3-methylbutan-1-ol；己酸丁酯 Butyl hexanoate；二氢-β-丙酮 Dihydro-β-ionone	绒毛红山楂 Downy red hawthorn (*Crataegus mollis*)	♀♂		+		Cha *et al.*, 2018
	西绕实蝇 *R. zephyria*	3-甲基丁烷-1-醇 3-methylbutan-1-ol；二甲基三硫 Dimethyl trisulfide；1-辛烯-3-醇 1-octen-3-ol；月桂烯 Myrcene；壬醛 Nonanal；芳樟醇 Linalool；(3E)-4，8-二甲基-1，3，7-壬三烯 (3E)-4,8-dimethyl-1,3,7-nonatriene；癸醛 Decanal；β-石竹烯 β-caryophyllene	雪莓果 Snowberry fruit	♀♂		+		Cha *et al.*, 2017

有明显引诱效果（Howlett *et al*., 1912a, 1912b）。随后研究发现甲基丁香酚存在于白鹤芋属 *Spathiphyyllum cannaefolium* 花（Chuah *et al*., 1996）、丁香（Qin *et al*., 2015），细辛（Liu *et al*., 2021）等在内的 400 多种植物中（Tan and Nishida, 2012），并相继发现甲基丁香酚对香蕉实蝇 *B. musae*、芒果实蝇 *B. occipialis*、菲律宾实蝇 *B. philippinensis* 等 81 种实蝇均有显著引诱效果（IAEA, 2003；Tan and Nishida, 2012；Cáceres *et al*., 2018）；兰花挥发物中覆盆子酮对瓜实蝇 *Z. cucurbitae* 雄虫有显著引诱效果（Howse and Underwood, 2000），而 Casanaginer 等（2003）通过大量实验筛选出引诱效果更好的衍生化合物 4-(对乙酰氧基苯基)-2-丁酮（诱蝇酮，覆盆子酮乙酸酯，Cue-lure，CL），其对近 50 多种实蝇均有引诱作用（IAEA, 2003），目前甲基丁香酚和诱蝇酮已经被广泛用于实蝇监测防治（IAEA, 2003）。

寄主植物果实挥发物对实蝇具有引诱效果。大量研究发现，墨西哥按实蝇 *A. ludens*、番石榴实蝇 *B. correcta*、苹果实蝇 *R. pomonella*、地中海实蝇 *C. capitata*、橘小实蝇 *B. dorsalis* 及柑橘大实蝇 *B. minax* 等实蝇对寄主植物气味有趋向行为反应，其中酯类、醇类、醛类、酸类、烯烃类以及萜类化合物能够引起实蝇的电生理反应，室内引诱活性测定试验证实其对实蝇有强烈的引诱效果（Niogret *et al*., 2011；Robacker *et al*., 2011；Liu and Zhou, 2016；Cha *et al*., 2018；Jaleel *et al*., 2019；Kamala Jayanthi *et al*., 2021）。发酵佛手瓜挥发物中的 1,8-桉叶素、己酸乙酯、己醇、辛酸乙酯、苯甲酸乙酯、4-萜品醇、(-)-α-立方体苯及 α-萜品醇对墨西哥实蝇 *A. ludens* 雌雄虫均有引诱效果（Robacker *et al*., 1990, 1992）；苹果挥发物丁酸丁酯、己酸丙酯、己酸丁酯、丁酸己酯和己酸戊酯混合物对苹果绕实蝇 *R. pomonella* 有显著引诱效果（Zhang *et al*., 1999）；芒果挥发物月桂烯、α-蒎烯和 β-罗勒烯对西印度按实蝇 *A. obliqua* 有显著引诱效果（Malo *et al*., 2012）；番石榴和芒果挥发物中 3-蒈烯、β-石竹烯、α-葎草烯在室内试验中对橘小实蝇 *B. dorsalis* 雌性显著引诱效果（Jaleel *et al*., 2019），而菠萝蜜假种皮挥发物 3-甲基丁酸甲酯、乙酸丁酯、3-甲基丁基乙酸酯和乙酸己酯混合物对橘小实蝇 *B.dorsalis* 雌、雄虫均有显著引诱效果（Kamala Jayanthi *et al*., 2021）。综上表明，来源于实蝇偏好寄主植物的挥发物成分是潜在信息化合物，然而基于寄主植物挥发物所开发的引诱剂在实蝇田间实际应用较少，无法达到有效控制实蝇危害的目的，这也从另一方面说明挥发物生物活性尚不稳定，仍需要对其作用机制进行深入研究，从而破解田间效果不稳定的难题。

3 实蝇的其他来源信息化合物

自然界中，昆虫与真菌之间存在着普遍的联系（Jonsell and Nordlander, 2004），真菌在昆虫的取食、交配等行为中存在一定影响（Guo *et al*., 2022；Meng *et al*., 2022）。研究报道，昆虫体内的微生物群产生的挥发性化合物在昆虫间的化学交流中发挥着重要作用，如参与昆虫信息化合物的生产过程（Engl and Kaltenpoth, 2018；Calcagnile *et al*., 2019）。

实蝇体内的肠道菌等微生物能产生信息化合物（表 3）。橘小实蝇 *B. dorsalis* 雄虫直肠中的芽孢杆菌，可协助雄虫合成对雌虫具有显著引诱效果的三甲基吡嗪（2,3,5-trimethylpyrazine，TMP）和四甲基吡嗪（2,3,5,6-tetramethylpyrazine，TTMP）（Ren *et al*., 2021）。此外实蝇肠道菌的代谢物也具有潜在引诱力，如橘小实蝇 *B. dorsalis* 肠道中的蜡样芽孢杆菌的代谢产物经室内外活性测试表明对橘小实蝇成虫具有显著引诱力（Wang *et al*., 2014）。同样酵母菌株挥发物中的异戊醇对橄榄实蝇 *B. oleae* 具有高引诱力，并在田间引诱试验中明确对其橄榄实蝇 *B. oleae* 成虫有显著引诱效果（Vitanović *et al*., 2020）。张栩浩（2022）从实蝇危害的果实和寄主植物叶片中分离的酵母菌，田间试验筛选出对南亚果实蝇 *Z. tau*、橘小实蝇 *B. dorsalis* 具有高引诱力的菌株，为进一步发掘信息化合物奠定基础。

表 3　其他来源实蝇信息化合物

Table 3　Semiochemicals of Tetriphitidae from others

实蝇属 Genera	实蝇种 Species	信息类化合物 Compounds	物质来源 Sources	行为效应[a] Behaviour	活性测定法[b] Behavioural experiments			参考文献 References
					EAG or GC-EAD	Y 型嗅觉实验或室内网笼实验 Y-tube or Laboratory cage bioassays	田间试验 Field bioassays	
按实蝇属 *Anastrepha*	墨西哥实蝇 *A. ludens*	吲哚 Indole；2，5-二甲基吡嗪 2,5-dimethylpyrazine；2-苯乙醇 2-phenylethanol	来自墨西哥实蝇 *A. ludens* 中肠的肠杆菌 Enterobacter agglomerans isolated from the midgut of wild *A. ludens*	♀♂		+		Robacker *et al.*, 2004
果实蝇属 *Bactrocera*	橘小实蝇 *B. dorsalis*	三甲基吡嗪 2,3,5-trimethylpyrazine (TMP)；四甲基吡嗪 2,3,5,6-tetramethylpyrazine (TTMP)	来自橘小实蝇 *B. dorsalis* 雄性直肠中的芽孢杆菌 Bacillus species isolated from the *B.dorsalis* male rectum	♀	+	+		Ren *et al.*, 2021
	橄榄实蝇 *B. oleae*	异戊醇 Isoamyl alcohol	酵母菌株 Yeast strains	♀♂		+	+	Vitanović *et al.*, 2020
镞果实蝇属 *Zeugodacus*	瓜实蝇 *Z. cucurbitae*	氨 Ammonia；二甲基二硫醚 Dimethyl disulphide；甲氧基苯基肟 Methoxy phenyl oxime；2,2-二羟基-1-苯基乙烯酮 2,2-dihydroxy-1- phenyl ethenone；1,2-苯二甲酸的丁基-2-甲基丙基酯 Butyl-2-methylpropyl ester of 1,2-benzenedicarboxylic acid	来自瓜实蝇肠道和产卵器的肺炎克雷伯菌和阴沟肠杆菌 *Klebsiella pneumoniae* and *Enterobacter cloacae* from gut and ovipositor of *Z. cucurbitae*	♀♂		+		Sajan *et al.*, 2022

4 实蝇信息化合物应用进展

引诱剂诱杀是实蝇综合防治中的常用方法，可以有效监测和预警害虫爆发，同时还能与化学药剂（Toyzhigitova *et al.*, 2019）、诱捕器（Piñero *et al.*, 2006；张宏宇，2016）、诱虫灯（张宏宇，2018）等其它技术结合使用，并在实际应用中选择最佳诱杀点（李杖黎等，2012b），最大化诱剂诱杀效果。当前用于实蝇监测防治应用的饵剂主要是食物饵剂（Mazor *et al.*, 1987；Bateman and Morton, 1991；杜迎刚等，2017）和信息化合物饵剂如实蝇性信息素饵剂（Heuskin *et al.*, 2011）、植物源信息化合物诱剂（梁丹辉等，2016）。由于信息化合物具有选择性好、活性高和使用量少等优势，广泛用于对实蝇的监测和田间防治（Heuskin *et al.*, 2011；Park *et al.*, 2020），如基于 ME、CL 等信息化合物研制的实蝇高效饵剂（Economopoulos and Haniotakis, 2019；Ballo *et al.*, 2020）。田间应用中，信息素化合物表现出高效引诱特性，但因其易挥发、持效期短的缺点，极大降低了应用效果，因此实蝇信息化合物开发应用中如何延长持效期是亟需解决的关键问题（赵锦年等，2011；李运娜，2018）。

缓释技术是延缓信息化合物释放速度和持效期的有效手段。通过特定材料或方法控制昆虫信息化合物缓慢释放，能有效防治虫害，减少农药使用，降低环境污染和农业成本（严力等，2019）。利用层状氢氧化锌作为载体材料开发了昆虫信息素己烯酸的控释配方，延缓信息素释放速率（Ahmad *et al.*, 2015）；将信息素 1，7-二氧螺环 5.5 十一烷封装成聚 L-乳酸微粒，显著延长其持效期至四周（Zisopoulou et al., 2020）；基于信息素月桂烯开发的正十八烷壳聚糖复合膜，具有良好的控释效果的同时还能依据昆虫的昼夜节律有规律性释放（Li *et al.*, 2022）。传统缓释技术主要有固体信息素制剂、微胶囊、缓释微球等（陈秀琴等，2021；李学琳，2021；马涛等，2022），其中固体材料制剂应用广泛。如凝胶类制剂（李文芳，2017；马海泉，2021）、无机吸附材料（李运娜，2018）、浸渍绳、PVC 管（相会明等，2022）、橡胶芯等材料结合信息化合物通过包裹或模压制成缓释饵剂（Golub *et al.*, 1983；Môttus *et al.*, 1997；Atterholt *et al.*, 1999；Johansson *et al.*, 2001；Selina *et al.*, 2008）。在实蝇缓释技术中，主要应用于甲基丁香酚、诱蝇酮等信息化合物。如基于 ME 和 Cue-lure 两种活性物质开发的水凝胶缓释剂对橘小实蝇 *B. dorsalis*、南亚果实蝇 *Z. tau* 具有良好的引诱效果（马海泉，2021）。随着纳米技术发展，具有缓释特性的纳米材料不断应用于信息化合物的缓释剂型研究中。糠醇胺-介孔二氧化硅材料对甲基丁香酚进行改性，研制出效果好、寿命长的环保型缓释剂，为信息化合物缓释剂型研究提供新的方向（Chen *et al.*，2019，2020）。目前市面上，基于信息素开发的产品有北京中捷四方生物科技有限公司生产橘小实蝇 *B. dorsalis* 诱芯、瓜实蝇 *Z. cucurbitae* 诱芯和地中海实蝇 *C. capitata* 诱芯（http://www.youbuqi.cn/chanpin/syyx/310.html），南京新安中绿生物科技有限公司生产的橘小实蝇 *B. dorsalis* 膏剂（胶条）和柑橘大实蝇 *B. minax* 膏剂（http://www.smartagribio.com）等产品（表 4）。

此外，信息化合物还能与物理防控如色板、灯光诱杀，化学农药和其他饵剂如食物饵剂结合使用，发挥各自优势，提高害虫防治效果（林明光等，2013；王波等，2013；郭峰等，2020）。3%甲氨基阿维菌素苯甲酸盐与甲基丁香酚混配使用显著增强橘小实蝇 *B. dorsalis* 的诱杀效果（张艳等，2013）；Naled 90%：甲基丁香酚 = 20%：80%的配比获得的诱杀剂对桃实蝇 *B. zonta* 诱杀效果显著优于其他杀虫剂，且对桃实蝇 *B. zonata* 有效防控时期长达 8 周（Ghanim *et al.*, 2010）。此外市面上有北京中捷四方生物科技有限公司、漳州英格尔科技公司等生产的实蝇信息素粘虫板产品（陈海燕等，2018）。总而言之，信息化合物在实际应用中与多种措施结合可提高诱杀效果，是信息化合物应用于实蝇害虫绿色防控和综合治理的重要方向。

表 4　已用于实蝇监测与防治的实蝇信息化合物及其产品

Table 4　Semiochemicals and products used for monitoring and controlling Tetriphitidae

信息化合物 Compounds	饵剂 Lures	防治对象 Insect pests	生产公司或参考文献 Companies or references
4-烯丙基-1,2-二甲氧基苯 4-Allyl-1,2-dimethoxybenzene	诱蝇醚 ME Methyl eugenol	杨桃实蝇 *B. carambolae*；胡桃实蝇 *B. caryeae*；番石榴实蝇 *B. correcta*；橘小实蝇 *B. dorsalis*；斯里兰卡实蝇 *B. kandiensis*；香蕉实蝇 *B. musae*；芒果实蝇 *B. occipitalis*；木瓜实蝇 *B. papayae*；菲律宾实蝇 *B. philippinensis*；瘤胫实蝇 *B. tuberculata*；三带实蝇 *B.* umbrosa；黄侧条实蝇 *B. xanthodes*；桃实蝇 *B. zonata*	Pipef, 2002
	橘小实蝇引诱剂 Attractants of *B. dorslis*	橘小实蝇 *B. dorsalis*	中捷四方（北京）生物科技有限公司 Beijing Pherobio Technology Co., Ltd.
	橘小实蝇膏剂/胶条（诱芯）Ointment / gum strips (lure core) of *B. dorsalis*	橘小实蝇 *B. dorsalis*	南京新安中绿生物科技有限公司 Nanjing Xinan SinoGreen Biological Technology Co. Ltd
	柑橘小实蝇诱剂 Attractants of *B. dorslis*	橘小实蝇 *B. dorsalis*	河南爱树科技发展有限公司 Henan LoveTree Technology Development Co.,Ltd
	橘小实蝇诱芯 Attractants of *B. dorslis*	橘小实蝇 *B. dorsalis*	北京依科曼生物技术股份有限公司 Beijing Ecoman Biological Technology Co. Ltd
	橘小实蝇诱芯 Attractants of *B. dorslis*	橘小实蝇 *B. dorsalis*	泉州市绿普森生物科技有限公司 Quanzhou Lvpusen Biotech Co.，Ltd.
(R)-(+)-柠檬烯 (R)-(+)-Limonene	(R)-(+)-柠檬烯 (R)-(+)-Limonene	柑橘大实蝇 *B. minax*	张宏宇，2015；李运娜，2018
4-(乙酰氧基苯基)-2-丁酮 4-(p-Acetoxyphenyl)-2-butanone	瓜实蝇引诱剂 Attractants of *Z. cucurbitae*	瓜实蝇 *Z. cucurbitae*	河南爱树科技发展有限公司 Henan LoveTree Technology Development Co.,Ltd
	瓜实蝇膏剂（诱芯）Ointment / gum strips (lure core) of *Z. cucurbitae*	瓜实蝇 *Z. cucurbitae*	南京新安中绿生物科技有限公司 Nanjing Xinan SinoGreen Biological Technology Co. Ltd
	瓜实蝇引诱剂 Attractants of *Z. cucurbitae*	瓜实蝇 *Z. cucurbitae*	中捷四方（北京）生物科技有限公司 Beijing Pherobio Technology Co., Ltd.

续表 4 (Table 4 continued)

信息化合物 Compounds	饵剂 Lures	防治对象 Insect pests	生产公司或参考文献 Companies or references
4-(乙酰氧基苯基)-2-丁酮 4-(p-Acetoxyphenyl)-2-butanone	诱蝇酮 CL Cue-lure	瓜实蝇 *Z. cucurbitae*；大洋洲橘实蝇 *B. curvipennis*；汤加实蝇 *B. facialis*；基尔基实蝇 *B. kirki*；小昆士兰实蝇 *B. neohumeralis*；斐济实蝇 *B. passiflorae*；昆士兰实蝇 *B. tryoni*；南瓜实蝇 *Z. tau*	Pipef, 2002
	瓜实蝇诱芯 Lure core of *Z. cucurbitae*	瓜实蝇 *Z. cucurbitae*	北京依科曼生物技术股份有限公司 Beijing Ecoman Biological Technology Co. Ltd
2-甲基-4-氯环己烷羧酸特丁基酯 Tert-butyl 4-chloro-2-methylcyclohexane-1-carboxylate	地中海实蝇引诱剂 Attractants of *C. capitata*	地中海实蝇 *C. capitata*	中捷四方（北京）生物科技有限公司 Beijing Pherobio Technology Co., Ltd.
	TML（trimedlure）	纳塔尔实蝇 *C. rosa*；马斯卡林实蝇 *C. catoirii*	Pipef, 2002
α-紫罗兰醇 α-Ionol	Latilure	辣椒实蝇 *B. latifrons*	Pipef, 2002
碳酸氢铵 Ammonium Bicarbonate	碳酸氢铵 Ammonium Bicarbonate	橄榄实蝇 *B. oleae*； 苹果实蝇 *R. pomonella*	Pipef, 2002
螺酮缩醇(1,7-二旋氧杂[5.5]十一烷) 1,7-Dioxaspiro(5.5)undecane	螺环缩酮 Spiroketal	橄榄实蝇 *B. oleae*	Pipef, 2002
乙酸铵 Ammonium acetate	乙酸铵 Ammonium acetate	西美绕实蝇 *R. indifferens*；黑樱桃实蝇 *R. fausta*；核桃壳实蝇 *R. completa*；东部樱桃实蝇 *R. cingulata*；欧洲樱桃实蝇 *R. cerasi*	Pipef, 2002
乙酸松油酯 α-terpinyl acetate	乙酸松油酯 Terpinyl acetate	非洲芒果实蝇 *C. cosyra*	Pipef, 2002
己酸丁酯 Butyl hexanoate	己酸丁酯 Butyl hexanoate	苹果实蝇 *R. pomonella*	Pipef, 2002
碳酸铵 Ammonium carbonate	碳酸铵 Ammonium carbonate	欧洲樱桃实蝇 *R. cerasi*；东部樱桃实蝇 *R. cingulata*；黑樱桃实蝇 *R. fausta*；西美绕实蝇 *R. indifferens*	Pipef, 2002

5　展望

实蝇信息化合物在实蝇监测和防治工作中发挥着重要的作用（李咏玲等，2010；Scolari *et al.*, 2021）。当前实蝇信息化合物研究多着眼于虫体、寄主植物等，而寄主植物挥发物中被证实有效的物质多为混合物（Kamala Jayanthi *et al.*, 2021），效果不稳定、应用难度大，阻碍了实蝇信息化合物的推广应用。未来研究中，从实蝇生态位或生物习性出发，扩展信息化合物的来源，如实蝇虫体排泄物和肠道菌等（Ren *et al.*, 2021；Scolari *et al.*, 2021），或许有稳定的活性物质，促进信息化合物的发掘。

目前实蝇信息化合物的活性研究多局限于室内实验，是因为信息化合物在室外实验的效果不理想，难以开展大田实验，是亟待解决重点难题。由于室外温度、紫外线、雨水、大风等环境因素造成的影响，导致信息化合物的持效期短，效果差（Gallego *et al.*, 2008；Kaur *et al.*, 2021）。有研究表明利用物理缓释（李运娜 2018；马海泉, 2021）、化学缓释（张瑜，2017；Muskat and Patel, 2021）、纳米材料包裹（Chen *et al.*, 2020；Li *et al.*, 2022）等多种方式可显著提高信息化合物的持效期。此外，与化学农药、物理防控技术和其他饵剂相结合，如甲基丁香酚和诱蝇酮这两种广泛用于实蝇防控的物质，因其引诱雄性实蝇的专性特性（Beroza *et al.*, 1960；IAEA, 2003；Park *et al.*, 2020），可在此基础上和其他对雌性有显著引诱能力的物质相结合，开发雌雄双诱型诱剂，达到“1+1>2”的效果（张艳等，2013；Royer and Mayer, 2018；张宏宇，2018；郭峰等，2020）。因此，未来研究应不断完善实蝇害虫综合防控体系，提高实蝇防控效率，保障果蔬产品经济效益。

参考文献 (References)

Ahmad R, Hussein MZ, Kadir WRWA, Sarijo SH, Hin TYY, 2015. Evaluation of controlled-release property and phytotoxicity effect of insect pheromone zinc-layered hydroxide nanohybrid intercalated with hexenoic acid. *Journal of Agricultural and Food Chemistry*, 63(51): 10893–10902.

Aluja M, Diaz-Fleischer F, 2006. Foraging behavior of *Anastrepha ludens*, *A. obliqua*, and *A. serpentina* in response to feces extracts containing host marking pheromone. *Journal of Chemical Ecology*, 32(2): 367–389.

Aluja M, Jácome I, Birke A, Lozada N, Quintero G, 1993. Basic patterns of behavior in wild *Anastrepha striata* (Diptera: Tephritidae) flies under field-cage conditions. *Annals of the Entomological Society of America*, 86(6): 776–793.

Aluja-Schuneman MR, Díaz-Fleischer F, Edmunds AJF, Hagmann L, 2001. Isolation, structural determination, synthesis, biological activity and application as control agent of the host marking pheromone (and derivatives thereof) of the fruit flies of the type *Anastrepha* (Diptera: Tephritidae). United States, Patent: US6555120, 2001-07-25.

Atterholt CA, Delwiche MJ, Rice RE, Krochta JM, 1999. Controlled release of insect sex pheromones from paraffin wax and emulsions. *Journal of Controlled Release*, 57(3): 233–247.

Ballo S, Demissie G, Tefera T, Mohamed SA, Khamis FM, Niassy S, Ekesi S, 2020. Use of para-pheromone methyl eugenol for suppression of the mango fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Southern Ethiopia. *Sustainable Management of Invasive Pests in Africa*, 20(1): 203–217.

Bateman MA, Morton TC, 1991. The importance of ammonia in proteinaceous attractants for fruit flies. *Australian Journal of Agricultural Research*, 32(6): 883–903.

Beroza M, Alexander BH, Steiner LF, Mitchell WC, Miyashita DH, 1960. New synthetic lures for the male melon fly. *Science*, 131(3406): 1044–1045.

Brezolin AN, Martinazzo J, Muenchen DK, de Cezaro AM, Rigo AA, Steffens C, Steffens J, Blassioli-Moraes MC, Borges M, 2018. Tools for detecting insect semiochemicals: A review. *Analytical and Bioanalytical Chemistry*, 410(17): 4091–4108.

Būda V, Blažytė-Čereškienė L, Radžiutė S, Apšegaitė V, Stamm P, Schulz S, Aleknavi˘cius D, Mozūraitis R, 2020. Male-produced (−)-δ-heptalactone, pheromone of fruit fly *Rhagoletis batava* (Diptera: Tephritidae), a sea buckthorn berries pest. *Insects*, 11(2): 138–151.

Butenandt VA, Beckmann R, Stamm D, Hecker E, 1959. Über den sexual-lockstoff des seidenspinners *Bombyx mori*—reindarstellung und konstitution. *Zeitschrift für Naturforschung*, 14(2): 283–284.

Cáceres C, Meza JS, Hendrichs J, Vreysen MJ, 2018. Different methods of methyl eugenol application enhance the mating success of male oriental fruit fly (Dipera: Tephritidae). *Scientific Reports*, 8(1): 1–8.

Calcagnile M, Tredici SM, Talà A, Alifano P, 2019. Bacterial semiochemicals and transkingdom interactions with insects and

plants. *Insects*, 10(12): 441–471.

Canale A, Benelli G, Germinara GS, 2015. Behavioural and electrophysiological responses to overlooked female pheromone components in the olive fruit fly, *Bactrocera oleae* (Diptera: Tephritidae). *Chemoecology*, 25(3): 147–157.

Carpita A, Canale A, Raffaelli A, Saba A, Benelli G, Raspi A, 2012. (Z)-9-tricosene identified in rectal gland extracts of *Bactrocera oleae* males: First evidence of a male-produced female attractant in olive fruit fly. *Naturwissenschaften*, 99(1): 77–81.

Casanaginer V, Oliver JE, Jang E, Carvalho L, 2003. Syntheses and behavioral evaluations of fluorinated and silylated analogs of rasp-berry ketone as attractants for the melon fly, *Bactrocera cucurbitae* (Coquillett). *Journal of Entomological Science*, 38(1): 111–119.

Cha DH, Olsson SB, Yee WL, Goughnour RB, Hood GR, Mattsson M, Schwara D, Feder JL, Linn Jr CE, 2017. Identification of host fruit volatiles from snowberry (*Symphoricarpos albus*), attractive to *Rhagoletis zephyria* flies from the western United States. *Journal of Chemical Ecology*, 43(2): 188–197.

Cha DH, Powell TH, Feder JL, Linn CE, 2018. Identification of a new blend of host fruit volatiles from red downy hawthorn, *Crataegus mollis*, attractive to *Rhagoletis pomonella* flies from the northeastern United States. *Journal of Chemical Ecology*, 44(7): 671–680.

Chen HY, Chen LS, Shen ZC, Zhou HJ, Hao L, Xu H, Zhou XH, 2020. Synthesis of mesoporous silica post-loaded by methyl eugenol as an environment-friendly slow-release bio pesticide. *Scientific Reports*, 10(1): 6108–6120.

Chen HY, Li JC, Shen ZC, Zhou HJ, Hao L, Xu H, Zhou XH, 2019. One-step synthesis of methyl eugenol/Schiff base mesoporous silica nanoparticles sustained-release performance with high lure efficiency. *Journal of Sol-Gel Science and Technology*, 92(1): 723–735.

Chen HY, Lin ZF, Qin S, Wang HH, Pan F, Ji XC, 2018. Evaluation on trapping effect of different color board and 4 kinds of fruit fly sticky board on *Bactrocera dorsalis* adults. *China Tropical Agriculture*, 1: 43–44, 48. [陈海燕, 林珠凤, 秦双, 王海洪, 潘飞, 吉训聪, 2018. 不同颜色粘板及 4 种实蝇类害虫粘板诱捕橘小实蝇成虫效果的评价. 中国热带农业, 1: 43–44, 48.]

Chen XQ, Liu QQ, He YX, Liu BP, Qiu LM, 2021. The preparation and application of nanoscale sex attractant lures against *Spodoptera frugiperda*. *Journal of Southern Agriculture*, 52(3): 626–631. [陈秀琴, 刘其全, 何玉仙, 刘必炮, 邱良妙, 2021. 草地贪夜蛾性诱剂纳米诱芯的制备及其应用. 南方农业学报, 52(3): 626–631.]

Cheseto X, Kachigamba DL, Ekesi S, Ndung'u M, Teal PEA, Beck JJ, Torto B, 2017. Identification of the ubiquitous antioxidant tripeptide glutathione as a fruit fly semiochemical. *Journal of Agricultural and Food Chemistry*, 65(39): 8560–8568.

Cheseto X, Kachigamba DL, Ekesi S, Ndung'u M, Teal PEA, Beck JJ, Torto B, 2018. Identification of glutamic acid as a host marking pheromone of the African fruit fly species *Ceratitis rosa* (Diptera: Tephritidae). *Journal of Agricultural and Food Chemistry*, 66(38): 9933–9941.

Chuah CH, Ooi LE, Yong HS, Goh SH, 1996. New male fruitfly attractants from spadix of *Spathiphyllum cannaefolium* (Araceae). *Biochemical Systematics and Ecology*, 24(3): 189–193.

Cirio U, Italiana SE, 1972. Osservazioni sul comportamento di ovideposizione della *Rhagoletis completa* Cresson (Diptera, Trypetidae) in laboratorio//Proceedings of the Atti del IX Congresso Nazionale Italiano di Entomologia. Tipografia Bertelly Picardi, Siena, Italy: 21–25 June 1972. 99–117.

Cruz-López L, Malo EA, Toledo J, Virgen A, Del Mazo A, Rojas JC, 2006. A new potential attractant for *Anastrepha obliqua* from *Spondias mombin* fruits. *Journal of Chemical Ecology*, 32(2): 351–365.

Cui GZ, Zhu JJ, 2016. Pheromone-based pest management in China: Past, present, and future prospects. *Journal of Chemical Ecology*, 42(7): 557–570.

Dohino T, Hallman GJ, Grout TG, Clarke AR, Follett PA, Cugala DR, Minh Tu D, Murdita W, Hernandez E, Pereira R, Myers SW, 2017. Phytosanitary treatments against *Bactrocera dorsalis* (Diptera: Tephritidae): Current situation and future prospects. *Journal of Economic Entomology*, 110(1): 67–79.

Du YG, Ji QE, Chen JH, Lai ZX, 2017. Effects of protein on the reproduction of *Bactrocera dorsalis* (Hendel). *Jiangsu Agricultural Sciences*, 45(4): 73–75. [杜迎刚, 季清娥, 陈家骅, 赖钟雄, 2017. 蛋白质对橘小实蝇生殖的影响. 江苏农业科学, 45(4): 73–75.]

Economopoulos AP, Haniotakis GE, 2019. Advances in attractant and trapping technologies for tephritids//Calkins CO, Bloem K, Bloem S, Chambers DL(eds). Fruit Files and the Sterile Insect Technique. Boca Raton: CRC Press. 57–66.

El-Ghany NMA, 2019. Semiochemicals for controlling insect pests. *Journal of Plant Protection Research*, 59(1): 1–11.

Engl T, Kaltenpoth M, 2018. Influence of microbial symbionts on insect pheromones. *Natural Product Reports*, 35(5): 386–397.

Gallego D, Galián J, Diez JJ, Pajares JA, 2008. Kairomonal responses of *Tomicus destruens* (Col., Scolytidae) to host volatiles α-pinene and ethanol. *Journal of Applied Entomology*, 132(8): 654–662.

Gao YH, Gai YP, Li B, Zhang LJ, Chen K, Li HP, 2016. Analysis of

fruit flies intercepted in entry quarantine during 2013-2014. *Plant Quarantine*, 30(5): 68–71. [高媛惠, 盖云鹏, 李斌, 张利军, 陈克, 李惠萍, 2016. 我国口岸截获实蝇疫情分析. 植物检疫, 30(5): 68–71.]

Gariboldi P, Jommi G, Rossi R, Vita G, 1982. Studies on the chemical constitution and sex pheromone activity of volatile substances emitted by *Dacus oleae*. *Experientia*, 38(4): 441–444.

Ghanim NM, Moustafa SA, El-Metwally MM, Afia YE, Salman MS, Mostafa ME, 2010. Efficiency of some insecticides in male annihilation technique of peach fruit fly, *Bactrocera zonata* (Saunders) under Egyptian conditions. *Egyptian Academic Journal of Biological Sciences, F. Toxicology and Pest Control*, 2(1): 13–19.

Golub M, Weatherston J, Benn MH, 1983. Measurement of release rates of gossyplure from controlled release formulations by mini-airflow method. *Journal of Chemical Ecology*, 9(3): 323–333.

Gong XF, Xie SA, Che XR, Lu SJ, Lu N, 2018. Relationship between insect pheromone and host volatiles in green control and research progress review. *Shaanxi Forest Science and Technology*, 46(5): 91–98. [巩雪芳, 谢寿安, 车显荣, 吕淑杰, 吕妮, 2018. 昆虫信息索与寄主挥发物在绿色防控中的关系及研究进展. 陕西林业科技, 46(5): 91–98.]

Guo F, Zhao RN, Yao MY, 2020. The trapping effect of combined using insecticidal lamp and attractant against *Actinidia chinensis Bactrocera dorsalis*. *China Plant Protection*, 40(10): 56–59. [郭峰, 赵如娜, 姚明勇, 李太美, 吴学三, 姜霖, 陈文龙, 2020. 杀虫灯与引诱剂组合使用对猕猴桃橘小实蝇的诱捕效果. 中国植保导刊, 40(10): 56–59.]

Guo QY, Yao ZC, Cai Z, Bai S, Zhang HY, 2022. Gut fungal community and its probiotic effect on *Bactrocera dorsalis*. *Insect Science*, 29(4): 1145–1158.

Guo XJ, Yu QQ, Chen DF, Wei JN, Yang PC, Yu J, Wang XH, Kang L, 2020. 4-Vinylanisole is an aggregation pheromone in locusts. *Nature*, 584(7822): 584–588.

Gut LJ, Stelinski LL, Thomson DR, Miller JR, 2004. Behaviour-modifying chemicals: Prospects and constraints in IPM//Integrated Pest Management: Potential, Constraints and Challenges. Wallingford UK: CABI Publishing. 73–121.

Haniotakis GE, Mazomenos BE, Tumlinson IH, 1977. A sex attractant of the olive fruit fly, *Dacus oleae*, and its biological activity under laboratory and field conditions. *Entomologia Experimentalis et Applicata*, 21(2): 81–87.

Heuskin S, Verheggen FJ, Haubruge E, Wathelet JP, Lognay G, 2011. The use of semiochemical slow-release devices in integrated pest management strategies. *Biotechnologie, Agronomie, Société et Environnement*, 15(3): 459–470.

Howlett FM, 1912a. Chemical reactions of fruit-flies. *Transactions of the Royal Entomological Society of London*, 6(3): 297–305.

Howlett FM, 1912b. The effect of oil of citronella on two species of Dacus. *Transactions of the Royal Entomological Society of London*, 60(2): 412–418.

Howse PE, Underwood KL, 2000. Environmentally-safe pest control using novel bioelectrostatic techniques: initial results and prospects for area-wide usage//Tan KH(ed.). Area-wide Control of Fruitflies and Other Insect Pests. Joint Proceedings of the International Conference on Area-wide Control of Insect Pests and the Fifth International Symposium on Fruit Flies of Economic Impor- tance. Malaysia. 295–299.

Hurter J, Boller EF, Städler E, Blattmann B, Buser HR, Bosshard NU, Damm L, Kozlowski MW, Schöni R, Raschdorf F, Dahinden R, Schlumpf E, Fritz H, Richter WJ Schreiber S, 1987. Oviposition-deterring pheromone in *Rhagoletis cerasi*: Purification and determination of the chemical constitution. *Experientia*, 43(2): 157–164.

IAEA, 2003. Trapping guidelines for area-wide fruit fly programmes. Vienna: IAEA. 36–38.

Jacobson M, Ohinata K, Chambers DL, Jones WA, Fujimoto MS, 1973. Insect sex attractants. 13. isolation, identification, and synthesis of sex pheromones of the male Mediterranean fruit fly. *Journal of Medicinal Chemistry*, 16(3): 248–251.

Jaleel W, He Y, Lü L, 2019. The response of two *Bactrocera* species (Diptera: Tephritidae) to fruit volatiles. *Journal of Asia-Pacific Entomology*, 22(3): 758–765.

Jiang Y, Lei CL, Zhang SN, 2002. The aggregation pheromones of insects. *Acta Entomologica Sinica*, 45(6): 822–832. [姜勇, 雷朝亮, 张钟宁, 2002. 昆虫聚集信息素. 昆虫学报, 45(6): 822–832.]

Johansson BG, Anderbrant OLLE, Simandl J, Avtzis ND, Salvadori C, HedenstrÖm E, HÖgberg HE, 2001. Release rates for pine sawfly pheromones from two types of dispensers and phenology of *Neodiprion sertifer*. *Journal of Chemical Ecology*, 27(4): 733–745.

Jonsell M, Nordlander G, 2004. Host selection patterns in insects breeding in bracket fungi. *Ecological Entomology*, 29(6): 697–705.

Kamala Jayanthi PD, Saravan Kumar P, Vyas M, 2021. Odour cues from fruit arils of artocarpus heterophyllus attract both sexes of oriental fruit flies. *Journal of Chemical Ecology*, 47(6): 552–563.

Katsoyannos BI, 1975. Oviposition-deterring, male-arresting, fruit-marking pheromone in *Rhagoletis cerasi*. *Environmental Entomology*, 4(5): 801–807.

Kaur K, Sharma S, Gupta R, Munikrishnappa VKT, Chandel M,

Ahamed M, Singal NK, Bakthavatsam N, Gorantla M, Muthusamy E, Shanmugam V, 2021. Nanomaze lure: Pheromone sandwich in graphene oxide interlayers for sustainable targeted pest control. *ACS Applied Materials & Interfaces*, 13(41): 48349–48357.

Keeling CI, Plettner E, Slessor KN, 2004. Hymenopteran semiochemicals//Schulz S(ed.). The Chemistry of Pheromones and Other Semiochemicals I. Berlin, Heidelberg: Springer. 133–177.

Kibira M, Affognon H, Njehia B, Muriithi B, Mohamed SB, Ekesi S, 2015. Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya. *African Journal of Agricultural and Resource Economics*, 10(4): 343–353.

Levi-Zada A, Levy A, Rempoulakis P, Fefer D, Steiner S, Gazit Y, Nestle D, Yuval B, Byers JA, 2020. Diel rhythm of volatile emissions of males and females of the peach fruit fly *Bactrocera zonata*. *Journal of Insect Physiology*, 120(1): 1–10.

Li H, Ren L, Xie MX, Gao Y, He MY, Hassan B, Lu YY, Cheng DF, 2020. Egg-surface bacteria are indirectly associated with oviposition aversion in *Bactrocera dorsalis*. *Current Biology*, 30(22): 1–9.

Li MJ, Yu HY, Hu A, Wang WL, Wang SS, 2021. Identification and bioassay of components of the aggregation pheromones of *Protaetia brevitarsis* Lewis. *Chinese Journal of Applied Entomology*, 58(4): 900–910. [李明杰, 于海洋, 胡安, 王威龙, 王少山, 2021. 白星花金龟聚集信息素的分离鉴定及引诱效果. 应用昆虫学报, 58(4): 900–910.]

Li WF, 2017. The perparation of *Diablo gill* beetil sex pheromone synergistic sustained-ralease gels. Master theses. Qingdao: Qingdao University of Science and Technology. [李文芳, 2017. 暗黑鳃金龟性信息素增效缓释凝胶剂的研制. 硕士学位论文. 青岛: 青岛科技大学.]

Li X, Wen Y, Zhang YL, Ge ZQ, 2022. Pheromone enclosed in halloysite with n-octadecane releases rhythmically under simulated diurnal temperature. *Applied Clay Science*, 217: 106386.

Li XL, 2021. Evaluation on the biological activity and stability of sex pheromone microcapsules of *Dendrolimus punctatus* Walker in the forest. *Guangxi Plant Protection*, 2021(3): 1–4. [李学琳, 2021. 马尾松毛虫性信息素微胶囊林间生物活性及稳定性评价. 广西植保, 2021(3): 1–4.]

Li YL, Han FS, Zhang JT, 2010. Review on insect sex pheromone. *Journal of Shanxi Agricultural Sciences*, 38(6): 51–54. [李咏玲, 韩福生, 张金桐, 2010. 昆虫性信息素研究综述. 山西农业科学, 38(6): 51–54.]

Li YN, 2018. The study on sex pheromone and baits of *Bactrocera minax*. Master theses. Wuhan: Huazhong Agricultural University. [李运娜, 2018. 柑橘大实蝇性信息素及其饵剂研究. 硕士学位论文. 武汉: 华中农业大学.]

Li ZH, Jiang F, Ma XL, Fang Y, Sun ZZ, Qing YJ, Wang QL, 2013. Review on prevention and control techniques of Tephritidae invasion. *Plant Quarantine*, 27(2): 1–10. [李志红, 姜帆, 马兴利, 方焱, 孙壮志, 秦誉嘉, 王巧玲, 2013. 实蝇科害虫入侵防控技术研究进展. 植物检疫, 27(2): 1–10.]

Li ZL, Guo YC, Zheng WW, Yuan JS, Qi XH, Zhang H, 2012a. Control efficiency based on trapping points distribution of *Bactrocera* (*Tetradacus*) *minax* (Enderlein). *Journal of Huazhong Agricultural University*, 31(6): 710–712. [李杖黎, 郭元成, 郑薇薇, 袁建设, 齐小慧, 张宏宇, 2012b. 诱杀点分布对柑橘大实蝇诱杀效果的影响. 华中农业大学学报, 31(6): 710–712.]

Liang DH, ChenR, Zhou Q, 2016. Responsiveness of *Bactrocera dorsalis* (Hendel) adult to different colours and odorants. *Life Science Research*, 20(1): 36–39, 62. [梁丹辉, 陈冉, 周琼, 2016. 橘小实蝇成虫对不同颜色和气味物质的趋性反应. 生命科学研究, 20(1): 36–39, 62.]

Lin J, Yang DQ, Hao XX, Cai PM, Ji QE, 2021. Advance on the attractants of Tephritid fruit flies. *Journal of Environmental Entomology*, 43(6): 1398–1407. [林嘉, 杨德庆, 郝旭兴, 蔡普默, 季清娥, 2021. 实蝇引诱剂研究进展. 环境昆虫学报, 43(6): 1398–1407.]

Lin MG, Zhang Y, Wang XJ, Zeng L, 2013. Trapping effect of methyl eugenol and protein bait on *Bactrocera dorsalis* (Hendel) in Hainan carambola orchard. *Northern Horticulture*, 2013(16): 131–134. [林明光, 张艳, 汪兴鉴, 曾玲, 2013. 甲基丁香酚和蛋白饵剂对海南杨桃园橘小实蝇诱控效果研究. 北方园艺, 2013(16): 131–134.]

Liu F, Ali T, Liu Z, 2021. Comparative transcriptomic analysis reveals the effects of drought on the biosynthesis of methyleugenol in *Asarum sieboldii* Miq. *Biomolecules*, 11(8): 1233–1248.

Liu L, Zhou Q, 2016. Olfactory response of female *Bactrocera minax* to chemical components of the preference host citrus volatile oils. *Journal of Asia-Pacific Entomology*, 19(3): 637–642.

López-Guillén G, López LC, Malo EA, Rojas J, 2011. Olfactory responses of *Anastrepha obliqua* (Diptera: Tephritidae) to volatiles emitted by calling males. *Florida Entomologist*, 94(4): 874–881.

Ma HQ, 2021. Study on controlled-release formulations of pheromone and food bait for fruit fly. Master theses. Wuhan: Huazhong Agricultural University. [马海泉, 2021. 实蝇信息素的缓释剂及食物饵剂的研发. 硕士学位论文. 武汉: 华中农业大学.]

Ma T, Yang XC, Lin N, Wen XJ, Wang S, 2022. Preparation, sustained release and field mating disruption of *Grapholitha molesta* sex pheromone microcapsule. *Journal of South China*

Agricultural University, 43(2): 77–86. [马涛, 杨兴翠, 林娜, 温秀军, 王偲, 2022. 梨小食心虫性信息素微胶囊的制备、缓释及野外迷向效果. 华南农业大学学报, 43(2):77–86.]

Malo EA, Cruz-López L, Toledo J, Del Mazo A, Virgen A, Rojas JC, 2005. Behavioral and electrophysiological responses of the Mexican fruit fly (Diptera: Tephritidae) to guava volatiles. *Florida Entomologist*, 88(4): 364–371.

Malo EA, Gallegos-Torres I, Toledo J, Valle-Mora J, Rojas JC, 2012. Attraction of the west Indian fruit fly to mango fruit volatiles. *Entomologia Experimentalis et Applicata*, 142(1): 45–52.

Mas F, Manning LA, Singlet M, Butler R, Mille C, Suckling DM, 2020. Electrophysiological and behavioral responses of Queensland fruit fly females to fruit odors. *Journal of Chemical Ecology*, 46(2): 176–185.

Mazomenos BE, Haniotakis GE, 1981. A multicomponent female sex pheromone of *Dacus oleae* Gmelin: Isolation and bioassay. *Journal of Chemical Ecology*, 7(2): 437–444.

Mazor M, Gothilf S, Galun R, 1987. The role of ammonia in the attraction of females of the Mediterranean fruit fly to protein hydrolysate baits. *Entomologia Experimentalis et Applicata*, 43(1): 25–29.

Meng LX, Xia CX, Jin ZX, Zhang HY, 2022. Investigation of gut bacterial communities of Asian citrus psyllid (*Diaphorina citri*) reared on different host plants. *Insects*, 13(8): 694.

Metcalf, R, 1990. Chemical ecology of Dacinae fruit flies (Diptera: Tephritidae). *Annals of Entomological Society of America*, 83(6): 1017–1030.

Milet-Pinheiro P, Navarro D, De Aquino NC, Ferreira LL, Tavares RF, da Silva RDCC, Lima-Mendonça A, Vaníčková L, Mendonça AL, Do Nascimento RR, 2015. Identification of male-borne attractants in *Anastrepha fraterculus* (Diptera: Tephritidae). *Chemoecology*, 25(3): 115–122.

Môttus E, Nômm V, Williams IH, Liblikas I, 1997. Optimization of pheromone dispensers for diamondback moth *Plutella xylostella*. *Journal of Chemical Ecology*, 23(9): 2145–2159.

Muskat LC and Patel AV, 2021. Innovations in semiochemical formulations. *Entomologia Generalis*, 42(2): 231–249.

Nation JL, 1983. Sex pheromone of the Caribbean fruit fly: Chemistry and field ecology//Proceedings of the 5th International Congress of Pesticide Chemistry, Kyoto, Japan: 109–110.

Navarro-Llopis V, Vacas S, Sanchis J, Primo J, Alfaro C, 2011. Chemosterilant bait stations coupled with sterile insect technique: An integrated strategy to control the Mediterranean fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology*, 104(5): 1647–1655.

Niogret J, Montgomery WS, Kendra PE, Heath RR, Epsky ND, 2011. Attraction and electroantennogram responses of male Mediterranean fruit fly to volatile chemicals from Persea, Litchi and Ficus wood. *Journal of Chemical Ecology*, 37(5): 483–491.

Nishida R, Tan KH, Serit M, Lajis NH, Fukami H, 1988. Accumulation of phenylpropanoids in the rectal glands of males of the oriental fruit fly, *Dacus dorsalis*. *Experientia*, 44(6): 534–536.

Nojima S, Linn C, Roelofs W, 2003. Identification of host fruit volatiles from flowering dogwood (*Cornus florida*) attractive to dogwood-origin *Rhagoletis pomonella* flies. *Journal of Chemical Ecology*, 29(10): 2347–2357.

Noushini S, Perez J, Park SJ, Holgate D, Jamie I, Jamie J, Taylor P, 2019. Rectal gland chemistry, volatile emissions, and antennal responses of male and female banana fruit fly, *Bactrocera musae*. *Insects*, 11(1): 32–44.

Nufio CR, Papaj DR, 2001. Host marking behavior in phytophagous insects and parasitoids. *Entomologia Experimentalis et Applicata*, 99(3): 273–293.

Papadopoulos NT, 2014. Fruit fly invasion: Historical, biological, economic aspects and management//Shelly T, Epsky N, Jang E, Reyes-Flores J, Vargas R (eds.). Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Dordrecht: Springer. 219–252.

Papaj DR, Aluja M, 1993. Temporal dynamics of host-marking in the tropical tephritid fly, *Anastrepha ludens*. *Physiological Entomology*, 18(3): 279–284.

Papaj DR, Averill AL, Prokopy RJ, Wong TTY, 1992. Host-marking pheromone and use of previously established oviposition sites by the Mediterranean fruit-fly (Diptera, Tephritidae). *Journal of Insect Behavior*, 5(5): 583–598.

Park SJ, De Faveri SG, Cheesman J, Hanssen BL, Cameron DN, Jamie IM, Taylor PW, 2020. Zingerone in the flower of *Passiflora maliformis* attracts an Australian fruit fly, *Bactrocera jarvisi* (Tryon). *Molecules*, 25(12): 2877.

Piñero JC, Jácome I, Vargas R, Prokopy RJ, 2006. Response of female melon fly, *Bactrocera cucurbitae*, to host-associated visual and olfactory stimuli. *Entomologia experimentalis et Applicata*, 121(3): 261–269.

Pipef R, 2002. Fruit Fly Pests of the Word // Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture. Scientific Advisory Services Pty Ltd. Http://www-naweb.iaea.org/nafa/.

Poloni YJ, Silva MT, 1986. Considerations on the reproductive of *Anastrepha pseudoparallela* Loew 1873 (Diptera: Tephritidae) //

Fruit flies : Proceedings of the Second International Symposium. Kolymbari, Greece: Elsevier Science Publishers. 16–21.

Porter BA, 1928. The apple maggot. *Technical Bulletins*, 26(8): 349–358.

Prokopy RJ, 1972. Evidence for a marking pheromone deterring repeated oviposition in apple maggot flies. *Environmental Entomology*, 1(4): 326–332.

Prokopy RJ, Greany P, Chambers D, 1977. Oviposition-deterring pheromone in *Anastrepha suspensa*. *Environmental Entomology*, 6(2): 463–465.

Prokopy RJ, Malavasi A, Morgante JS, 1982. Oviposition deterring pheromone in *Anastrepha fraterculus* flies. *Journal of Chemical Ecology*, 8(4): 763–771.

Prokopy RJ, Reissig WH, Moericke V, 1976. Marking pheromones deterring repeated oviposition in *Rhagoletis* flies. *Entomologia Experimentalis et Applicata*, 20(2): 170–178.

Prokopy RJ, Ziegler JR, Wong TTY, 1978. Deterrence of repeated oviposition by fruit-marking pheromone in *Ceratitis capitata* (Diptera: Tephritidae). *Journal of Chemical Ecology*, 4(1): 55–63.

Qin Y, Yang X, Leng P, Hu Z, 2015. Analysis of floral volatile components from 6 Syringa plants collected by dynamic headspace sampling by ATD-GC/MS. *Acta Botanica Boreali-Occidentalia Sinica*, 35(10): 2078–2088.

Qin YJ, Krosch MN, Schutze MK, Zhang Y, Wang XX, Prabhakar CS, Susanto A, Hee AKW, Ekesi S, Badji K, Khan M, Wu JJ, Wang QL, Yan G, Zhu LH, Zhao ZH, Liu LJ, Clarke AR, Li ZH, 2018. Population structure of a global agricultural invasive pest, *Bactrocera dorsalis* (Diptera: Tephritidae). *Evolutionary Applications*, 11(10): 1990–2003.

Raptopoulos D, Haniotakis G, Koutsaftikis A, Kelly D, Mavraganis V, 1995. Biological activity of chemicals identified from extracts and volatiles of male *Rhagoletis cerasi*. *Journal of Chemical Ecology*, 21(9): 1287–1297.

Ravichandra NG, 2014. Horticulture and its role in the national economies//Horticultural Nematology. New Delhi: Springer. 1–3.

Ren L, Ma Y, Xie MX, Lu YY, Cheng DF, 2021. Rectal bacteria produce sex pheromones in the male oriental fruit fly. *Current Biology*, 31(10): 2220–2226.

Robacker DC, Aluja M, Cossé AA, Sacchetti P, 2009. Sex pheromone investigation of *Anastrepha serpentina* (Diptera: Tephritidae). *Annals of the Entomological Society of America*, 102(3): 560–566.

Robacker DC, Hart WG, 1985. (Z)-3-nonenol, (Z,Z)-3,6-nonadienol and (S,S)-(-)-epianastrephin: Male produced pheromones of the Mexican fruit fly. *Entomologia Experimentalis et Applicata*, 39(2): 103–108.

Robacker DC, Lauzon CR, He X, 2004. Volatiles production and attractiveness to the Mexican fruit fly of *Enterobacter agglomerans* isolated from apple maggot and Mexican fruit flies. *Journal of Chemical Ecology*, 30(7): 1329–1347.

Robacker DC, Massa MJ, Sacchetti P, Bartelt RJ, 2011. A novel attractant for *Anastrepha ludens* (Diptera: Tephritidae) from a concord grape product. J*ournal of Economic Entomology*, 104(4): 1195–1203.

Robacker DC, Moreno AM, Garcia JA, Flath RA, 1990. A novel attractant for Mexican fruit fly, *Anastrepha ludens*, from fermented host fruit. *Journal of Chemical Ecology*, 16(10): 2799–2815.

Robacker DC, Warfield WC, Flath RA, 1992. A four-component attractant for the Mexican fruit fly, *Anastrepha ludens* (Diptera: Tephritidae), from host fruit. *Journal of Chemical Ecology*, 18(7): 1239–1254.

Rodriguez LC, Niemeyer HM, 2005. Integrated pest management, semiochemicals and microbial pest-control agents in Latin American agriculture. *Crop Protection*, 24(7): 615–623.

Royer JE, Mayer DG, 2018. Combining cue-lure and methyl eugenol in traps significantly decreases catches of most *Bactrocera*, *Zeugodacus* and *Dacus* species (Diptera: Tephritidae: Dacinae) in Australia and Papua New Guinea. *Journal of Economic Entomology*, 111(1): 298–303.

Sajan JV, Subramanian S, Sharma K, 2022. Attractancy potential of bacterial volatiles from symbiotic bacteria of wild population of *Zeugodacus cucurbitae* Coquillett (Diptera: Tephritidae). *Phytoparasitica*, 50(2): 411–421.

Scolari F, Valerio F, Benelli G, Papadopoulos NT, Vaníčková L, 2021. Tephritid fruit fly semiochemicals: Current knowledge and future perspectives. *Insects*, 12(5): 1–56.

Selina OE, Chinarev AA, Obukhova PS, Bartkowiak A, Bovin NV, Markvicheva EA, 2008. Alginate-chitosan microspheres for the specific sorption of antibodies. *Russian Journal of Bioorganic Chemistry*, 34(4): 468–474.

Selivon D, 1991. Alguns aspectos do comportamento de *Anastrepha striata* Schiner e *Anastrepha bistrigata* Bezzii (Diptera: Tephritidae). Master thesis. Sao Paulo, Brazil: University of São Paulo.

Serrano JM, Mc Elfresh JS, Zou Y, Millar JG, 2019. ldentification of aggregation-sex pheromone components for at"living fossil", the false click beetle, *Palaeoxenus dohrni* Horn (Coleoptera: Eucnemidae). *Journal of Chemical Ecology*, 45(4): 366–370.

Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R, 2014. Trapping and the detection, control, and regulation of Tephritid

fruit flies. New York, London: Springer, Dordrecht. 15–172.

Shivaramu S, Parepally SK, Chakravarthy AK, Pagadala Damodaram KJ, Kempraj V, 2022. Ridge gourd volatiles are attractive to gravid female melon fly, *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae). *Journal of Applied Entomology*, 146 (5): 539–546.

Siderhurst MS, Jang EB, 2006. Female-biased attraction of oriental fruit fly, *Bactrocera dorsalis* (Hendel), to a blend of host fruit volatiles from *Terminalia catappa* L. *Journal of Chemical Ecology*, 32(11): 2513–2524.

Siderhurst MS, Jang EB, 2010. Cucumber volatile blend attractive to female melon fly, *Bactrocera cucurbitae* (Coquillett). *Journal of Chemical Ecology*, 36(7): 699–708.

Silva JG, 1991. Biologia e comportamento de *Anastrepha grandis* (Macquart, 1846) (Diptera: T ephritidae). Master thesis. Sao Paulo, Brazil: University of São Paulo.

Simões MH, Polloni YJ, Pauludetti MA, 1978. Biologı´a de algunas especies de *Anastrepha* (Diptera: Tephritidae) en laborato´rio// III Latin-American Entomology Congress. Proceedings: Contrib Uted Papers-Abstracts. Ilheus, Brazil. 431–436.

Sun RR, Li XW, Zhang JM, Zhang YJ, Zhang LM, LÜ YB, 2020. Comparison of two types of aggregation pheromone dispensers for trapping *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Chinese Journal of Applied Entomology*, 57(1): 181–188. [孙冉冉, 李晓维, 章金明, 张治军, 张立猛, 吕要斌, 2020. 西花蓟马聚集信息素组分在两种载体中的释放规律及引诱效果. 应用昆虫学报, 57(1): 181–188.

Tan KH, 2009. Fruit fly pests as pollinators of wild orchid// Proceedings of the 7th International Symposium on Fruit Flies of Eco-nomic Importance. Salvador, Brazil. 195–206.

Tan KH, Nishida R, 2012. Methyl eugenol: Its occurrence, distribution, and role in nature, especially in relation to insect behavior and pollination. *Journal of Insect Science*, 12(56): 1–74.

Tinsworth EF, 1990. Regulation of pheromones and other semiochemicals in the United States// Ridgway RL, Silverstein RM, Inscoe MN(eds.). Behavior-Modifying Chemicals for Insect Management: Applications of Pheromones and Other Attractants. New York: Marcel Dekker Inc. 569–603.

Tokushima I, Orankanok W, Tan KH, Ono H, Nishida R, 2010. Accumulation of phenylpropanoid and sesquiterpenoid volatiles in male rectal pheromonal glands of the guava fruit fly, *Bactrocera correcta*. *Journal of Chemical Ecology*, 36(12): 1327–1334.

Toyzhigitova B, Yskak S, Lozowicka B, Kaczyński P, Dinasilov A, Zhunisbay R, Wolejko E., 2019. Biological and chemical protection of melon crops against *Myiopardalis pardalina* Bigot. *Journal of Plant Diseases and Protection*, 126(4): 359–366.

Vitanović E, Aldrich JR, Boundy-Mills K, Čagalj M, Ebeler SE, Burrack H, Zalom FG, 2020. Olive fruit fly, *Bactrocera oleae* (Diptera: Tephritidae), attraction to volatile compounds produced by host and insect-associated yeast strains. *Journal of Economic Entomology*, 113(2): 752–759.

Wang B, Yang Y, Huang JC, Chen JH, 2013. Toxicity of pesticides in protein bait to *Bactrocera dorsalis*. *Journal of South China Agricultural University*, 34(1): 37–40. [王波, 杨莹, 黄居昌, 陈家骅, 2013. 橘小实蝇蛋白饵剂中添加农药的室内毒力测定. 华南农业大学学报, 34(1): 37–40.]

Wang HX, Jin L, Peng T, Zhang HY, Chen QL, Hua YJ, 2014. Identification of cultivable bacteria in the intestinal tract of *Bactrocera dorsalis* from three different populations and determination of their attractive potential. *Pest Management Science*, 70(1): 80–87.

Wang LY, Yang CX, Guo BB, Zhe DM, Mei XD, Yang XL, Ning J, 2022. Research progress and application prospects on insect sex pheromone. *Chinese Journal of Pesticide Science*, 24(5): 997–1016. [王留洋, 杨超霞, 郭兵博, 折冬梅, 梅向东, 杨新玲, 宁君, 2022. 昆虫性信息素研究进展与应用前景. 农药学学报, 24(5): 997–1016.]

Wang Q, Li WZ, Chen HJ, Gong DF, Hu JJ, Guo S, Yuan GH, 2014. Progress of plant-derived fruit fly attractants. *Insect Research in Hua Zhong Area*, 10: 144–152. [王琼, 李为争, 陈汉杰, 龚东风, 胡晶晶, 郭帅, 原国辉, 2014. 实蝇类植物源引诱剂研究进展. 华中昆虫研究, 10: 144–152.]

Wang ZL, Xu J, Zhang RZ, 2020. Global distribution and invasion of important quarantine fruit flies of China. *Journal of Biosafety*, 29(3): 164–169. [王在凌, 徐婧, 张润志, 2020. 中国重要检疫性实蝇的全球分布和入侵情况. 生物安全学报, 29(3): 164–169.]

Wee SL, Chinvinijkul S, Tan K, Nishida R, 2018. A new and highly effective male lure for the guava fruit fly *Bactrocera correcta*. *Journal of Pest Science*, 91(2): 691–698.

Wee SL, Tan KH, 2005. Female sexual response to male rectal volatile constituents in the fruit fly, *Bactrocera carambolae* (Diptera: Tephritidae). *Applied Entomology and Zoology*, 40(2): 365–372.

Wei R, Wu JY, Zhang XW, Liu XY, Yang S, Wei XY, Diao HN, Cui JY, 2022. Research progress on application of insect pheromone to green prevention and control of pest. *Heilongjiang Agricultural Sciences*, 2022(12): 95–99. [魏然, 吴俊彦, 张习文, 刘显元, 杨树, 位昕禹, 刁鹤男, 崔杰印, 2022. 昆虫信息素应用于害虫绿色防控的研究进展. 黑龙江农业科学, 2022(12): 95–99.]

Wiesmann R, 1937. Die orientierung der kirschfliege, *Rhagoletis*

cerasi L., bei der eiablage. *Landw. Jahrb. Schweiz*, 51(1): 1080–1109.

Witzgall P, Kirsch P, Cork A, 2010. Sex pheromones and their impact on pest management. *Journal of Chemical Ecology*, 36(1): 80–100.

Wyatt TD, 2014. Pheromones and Animal Behavior: Chemical Signals and Signatures. England, Cambridge: Cambridge University Press.1–378.

Xiang HM, Diao HL, Li XW, Zhao ZG, Ma RY, 2022. Comparison of the pheromone release rate and degree of mating disruption achieved using four different types of pheromone dispenser to control the oriental fruit moth. *Chinese Journal of Applied Entomology*, 59(2): 311–317. [相会明, 刁红亮, 李先伟, 赵志国, 马瑞燕, 2022. 梨小食心虫性信息素在四种载体中释放速率及田间迷向率研究. 应用昆虫学报, 59(2): 311–317.]

Yan L, Li ZR, Han GZ, 2019. Research progress on controlled release technology for insect pheromones. *Chinese Journal of Applied Chemistry*, 36(10): 1099–1108. [严力, 李卓睿, 韩国志, 2019. 昆虫信息素缓释技术的研究进展. 应用化学, 36(10): 1099–1108.]

Zhang A, Linn C, Wright S, Prokopy R, Reissig W, Roelofs W, 1999. Identification of a new blend of apple volatiles attractive to the apple maggot, *Rhagoletis pomonella*. *Journal of Chemical Ecology*, 25(6): 1221–1232.

Zhang HY, 2015. A sex pheromone for *Bactrocera minax*. China, Patent. 105145557. 2015-12-16. [张宏宇, 2015. 一种柑桔大实蝇性信息素. 中国, 专利号：105145557. 2015-12-16.]

Zhang HY, 2016. A device for trap-and-kill fruit fly pests. China, Patent: ZL201620011742.9. 2016-01-01. [张宏宇, 2016. 一种实蝇类害虫诱杀装置. 中国, 专利号: ZL201620011742.9. 2016-01-07.]

Zhang HY, 2018. A multifunctional insect killing device that integrates physical and chemical. China, Patent: CN201820177567.X. 2018-02-01. [张宏宇, 2018. 一种理化一体多功能杀虫装置. 中国, 专利号: CN201820177567.X. 2018-02-01.]

Zhang HY, Li HY, 2018. Color Atlas for Green Controls of Citrus Diseases and Insect Pests. Beijing: China Agriculture Press. 116–118. [张宏宇, 李红叶, 2018. 柑橘病虫害绿色防控彩色图谱. 北京: 中国农业出版社. 116–118.]

Zhang XG, Wei CM, Miao J, Zhang XJ, Wei B, Dong WX, Xiao C, 2019. Chemical compounds from female and male rectal pheromone glands of the guava fruit fly, *Bactrocera correcta*. *Insects*, 10(3), 78–88.

Zhang XH, 2022. Study of yeast-based lure for *Bactrocera dorsalis* and *Zeugodacus tau*. Master theses. Wuhan: Huazhong Agricultural University. [张栩浩, 2022. 橘小实蝇和南亚果实蝇酵母菌源引诱剂研究. 硕士学位论文. 武汉: 华中农业大学.]

Zhang XJ, Qian C, Yang LS, Liu HC, Li CY, Dong WX, 2020. Behavioral responses of sexually immature, mature virgin, and mated, guava fruit flies to host plant odor. *Chinese Journal of Applied Entomology*, 57(1): 166–172. [张小娇, 钱诚, 杨六三, 刘洪翠, 李成云, 董文霞, 2020. 不同生理状态的番石榴实蝇对寄主气味的行为反应. 应用昆虫学报, 57(1): 166–172.]

Zhang Y, 2017. The study of the semioche mical and dispensers of *Monochamus alternatus*. Master theses. Guangdong: South China Agricultural University. [张瑜, 2017. 松墨天牛信息化学物质与缓释载体研究. 硕士学位论文. 广东: 华南农业大学.]

Zhang Y, Lin MG, Wang XJ, Li F, Shi J, Zeng L, 2013. Effects of different insecticides added with methyl eugenol and protein bait on trapping and killing *Bactrocera dorsalis*. *South China Fruits*, 42(3): 72–74. [张艳, 林明光, 汪兴鉴, 黎奋, 石晶, 曾玲, 2013. 甲基丁香酚和蛋白饵剂添加不同杀虫剂诱杀橘小实蝇的效果. 中国南方果树, 42(3): 72–74.]

Zhao JN, Jiang P, Zhang XY, Lin YH, Huang ZG, He YY, 2011. Study on the slow-release attractant for *Monochamus alternatus* and its attractive effect. *Forest Research*, 24(3): 350–356. [赵锦年, 蒋平, 张星耀, 林云华, 黄照岗, 何玉友, 2011. 松褐天牛缓释型引诱剂及其引诱效果研究. 林业科学研究, 24(3): 350–356.]

Zisopoulou SA, Chatzinikolaou CK, Gallos JK, Ofrydopoulou A, Lambropoulou DA, Psochia E, Bikiaris DN, Nanaki SG, 2020. Synthesis of dacus pheromone, 1,7-dioxaspiro 5.5 undecane and its encapsulation in PLLA microspheres for their potential use as controlled release devices. *Agronomy-Basel*, 10(7): 1053–1067.