

Synthetic studies on female sex pheromones of lepidopteran insects

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The pheromones are classified into (1) type I compounds, (2) type II compounds, (3) methyl-branched compounds, and (4) non-branched other compounds.

The chemical formulae are symbolized by

- 1) the number before the hyphen giving the position of double bond(s) [$Z = (Z)$ -configuration, $E = (E)$ -configuration, $\Delta =$ terminal] and/or other structures in the chain as follows, \equiv = triple bond, epo = *cis*-epoxy ring, tepo = *trans*-epoxy ring, and Me = branched methyl group,
- 2) the number before the colon giving the carbon atoms in the straight chain skeleton,
- 3) the words after the colon giving the functional groups as follows, H = hydrocarbon, OH = primary alcohol, OAc = acetate of alcohol, Ald = aldehyde, and one = ketone.

Pheromone	Family and species of moth	Publication of synthesis
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<u>(1) Type I compounds</u>		
1-1) 1,3-Dienes		
E3,Z5-12:OAc	Tortricidae (<i>Phtheochroa cranaodes</i>)	Unelius, 1996; Park, 1998; Simonelli, 1998; Chong, 1999; Yadav, 2000; Ragoussis, 2004; Hodgson, 2007
Z3,E5-14:OAc	Cossidae (<i>Holcocerus vicarius</i>)	Doolittle, 1976; Rossi, 1982; Doolittle, 1986; Huang, 1987
E4,Z6-16:OAc	Stathmopodidae (<i>Stathmopoda masinissa</i>)	Nishida, 2003; Awalekar, 2020
Z5,E7-12:OH and/or Z5,E7-12:Ald	Lasiocampidae (<i>Malacosoma disstria</i> , <i>Dendrolimus spectabilis</i> , etc.)	Chisholm, 1981; Ando, 1982; Bestmann, 1982(a); Rossi, 1983; Trost, 1984; Gardette, 1984; Ando, 1985; Brown, 1986; Huang, 1987; Stille, 1987(a); Stille, 1987(b); Fiandanese, 1989; Khrimian, 2002
Z7, Δ 9-10:OH or E7, Δ 9-10:OH	Limacodidae (<i>Parasa lepida</i> , <i>Monema flavescens</i>)	Islam, 2009

- E7,Z9-12:OAc
Tortricidae (*Lobesia botrana*)
- E8,E10-12:OH
Tortricidae (*Cydia pomonella*)
- E8,Z10-14:Ald
Gracillariidae (*Cameraria ohridella*)
- E8,Z10-15:OAc
Pyralidae (*Acrobasis vaccinii*)
- E9,Δ11-12:OAc
Noctuidae (*Diparopsis castanea*)
- Z9,Δ11-12:OAc
Noctuidae (*Diparopsis castanea*)
- Z9,E11-14:OAc
Noctuidae (*Spodoptera littoralis*,
Spodoptera litura)
- E9,E11-14:OAc
Tortricidae (*Epiphyas postvittana*)
- E9,Z11-15:Ald and Z9,Z11-15:Ald
Sphingidae (*Dolbina tancrei*)
- Z9,E11-16:Ald
Crambidae (*Diatraea saccharalis*)
- E9,Z11-16:Ald
- Roelofs, 1973; Labovitz, 1975; Negishi, 1977; Bestmann, 1979;
Cassani, 1980; Dressaire, 1980; Ratovelomanana, 1981;
Rossi, 1981(a); Ideses, 1982; Tsuboi, 1982; Ujvary, 1985;
Gardette, 1984; Cuvigny, 1987; Alexakis, 1988; Fiandanese, 1989;
Yamamoto, 1989(c); Odinokov, 1993(a); Kukovinets, 2000;
Diego, 2006; Cahiez, 2017
- Descoins, 1972; Mori, 1974(a); Bestmann, 1978; Samain, 1978;
Knox, 1981; Naoshima, 1980(a); Babler, 1982; Bloch, 1983;
Yamada, 1983; Ando, 1985; Chisholm, 1985; Yamada, 1986;
Penhoat, 1986; Shakova, 1996; Chourreu, 2021
- Svatoš, 1999; Hoskovec, 2000; Francke, 2002; Figueiredo, 2007;
Grodner, 2009; Chourreu, 2020
- Chavan, 2005
- Nesbitt, 1973; Mori 1974(a); Tanaka, 1975; Babler, 1977;
[Wollenberg, 1979]; Babler, 1979; Mandai, 1979;
Bestmann, 1979; Yasuda, 1979; Rossi, 1981(a); Knox, 1981;
Tsai, 1981; Bloch, 1982; Ranganathan, 1982; Yamada, 1983;
Ochiai, 1983; Engman, 1985; Ishibashi, 1985; Yamada, 1986;
Penhoat, 1986; Nagano, 2002; Cahiez, 2008
- Nesbitt, 1973; Rossi, 1981(b); Tsai, 1981; Ochiai, 1983; Michelot, 1983;
Balezina, 1984; Gardette, 1984; Ishibashi, 1987
- Tamaki, 1973; Goto, 1975; Hall, 1975; Bestmann, 1979; Cassani, 1980
Lin, 1980; Rossi, 1981(a); Ratovelomana, 1981; Gardette, 1984;
Cuvigny, 1987; Björckling, 1987; Fiandanese, 1989;
Yadav, 1989
- Knox, 1981; Bloch, 1983; Björckling, 1987
- Millar, 1996; Uehara, 2013
- Svirskaya, 1984(b); Svatoš, 2001; Tao, 2013
- Svirskaya, 1984(b), Millar, 1996; Passaro, 2003; Figueiredo, 2007

	Pyralidae (<i>Acrobasis nuxvorella</i>)	
E10,E12-14:OAc	Tortricinae (<i>Amorbia cuneana</i>) Gracillariidae (<i>Phyllonorycter crataegella</i>)	Bestmann, 1978; McDonough, 1982; Ferrao, 1998
E10,Z12-16:OH	Bombycidae (<i>Bombyx mori</i> , <i>Bombyx mandarina</i>)	Butenandt, 1961; Negishi, 1973; Normant, 1975; Bestmann, 1977; Zweifel, 1978; Kuwahara, 1979; Tsuboi, 1982; Miyaura, 1983 Gardette, 1984; Stille, 1987(b); Alexakis, 1988; Fiandanese, 1989; Odinokov, 1993(b); Uenishi, 2000; Khrimian, 2002
E10,E12-16:Ald	Noctuidae (<i>Earias insulana</i>)	Knox, 1981; Klug, 1982; Yadav, 1989
Z11,Δ13-14:Ald and Z11,Δ13-14:OAc	Tortricinae (<i>Argyrotaenia spheropa</i>)	Legrand, 2004
Z11,Z13-16:Ald	Pyralidae (<i>Amyelois transitella</i>) Notodontidae (<i>Notodonta dromedaries</i> etc.)	Coffelt, 1979; Sonnet, 1980; Arai, 1982; Bishop, 1983; Michelot, 1983; Gardette, 1984; Furber, 1985; Furber, 1986; Mori, 2009(c); Liu, 2019
E11,E13-16:Ald	Crambidae (<i>Hellula undalis</i>)	Arai, 1982; Lo, 1986; Yamada, 1986
Z11,E13-16:OAc	Pyralidae (<i>Herpetogramma licarsisalis</i>)	Lo, 1986; Alexakis, 1988; Gibb, 2007
Z13,E15-18:Ald	Notodontidae (<i>Micromelalopha siversi</i>)	Liu, 2021
1-2) 1,4-Dienes		
E4,Z7-13:OAc	Gelechiidae (<i>Phthorimaea operculella</i>)	Voerman, 1978; Alexakis, 1978; Nishiyama, 1984; Yadav, 1986; Nonoshita, 1990; Hutzinger, 1995; Odinokov, 1997; Vakhidov, 2007; Pan, 2022
Z7,Z10-16:Ald	Cossidae (<i>Chilecomadia valdiviana</i>)	Herrera, 2016
Z9,E12-14:OAc	Noctuidae (<i>Spodoptera eridania</i> etc.)	Jacobson, 1970; Su, 1973; Bestmann, 1974; Bac, 1982; Cuvigny, 1987; Kasymzhanova, 1992

- Pyralidae (*Cadra cautella*, etc.)
 E11,E14-18:Ald Ho, 1996
 Endromidae (*Andraca bipunctata*)
- 1-3) 1,5-Dienes
 E3,Z7-14:OAc Griepink, 1995; Ragoussis, 2008; Awalekar, 2021
 Gelechiidae (*Symmetrischema tangolias*)
 Z7,Z11-16:OAc and/or Z7,E11-16:OAc
 Gelechiidae (*Pectinophora gossypiella*,
Sitotroga cerealella)
 E10,E14-16:Ald Yan, 2014
 Crambidae (*Omphisa anastomosalis*)
- 1-4) Other dienes
 E2,Z13-18:OAc and/or E2,Z13-18:Ald
 Sesiidae (*Vitacea polistiformis*, etc)
 Cossidae (*Zeuzera pyrina*)
 E3,Z8 -14:OAc Griepink, 1996; Svatoš, 1996; Cabezas, 2019
 Gelechiidae (*Scrobipalpuloides absoluta*)
 Z3,Z13-18:OAc and/or E3,Z13-18:OAc
 Sesiidae (*Synanthedon exitiosa*
Synanthedon pictipes, etc.)
 E4,E10-12:OAc Gries, 1993
 Gracillariidae (*Phyllonorycter mespilellus*)
 E6,Z11-16:OAc and E6,Z11-16:Ald
 Saturniidae (*Antheraea polyphemus*)
 E6,Z11-18:Ald
 Saturniidae (*Actias luna*)
 1-5) Trienes
 Kochansky, 1975; Kochansky, 1977; Bestmann, 1981; Tomida, 1983;
 Wang, 1984; Tomida, 1986
 Millar, 2016

E3,Z8,Z11-14:OAc Gelechiidae (<i>Scrobipalpuloides absoluta</i>)	Attygalle, 1996; Hungerford, 1998; Cabezas, 2019
E4,E6,Z10-16:OAc and E4,Z6,Z10-16:OAc Gracillariidae (<i>Conopomorpha cramerella</i>)	Beevor, 1986; Yen, 1992; Huang, 2017
E4,E6,Z11-16:Ald Saturniidae (<i>Samia cynthia</i>)	Bestmann, 1989; Tomida, 1993
E4,Z7,Z10-13:OAc Gelechiidae (<i>Phthorimaea operculella</i>)	Voerman, 1978; Pan, 2022
Z7,Z11,E13-16:Ald Gracillariidae (<i>Phyllocnistis citrella</i>)	Leal, 2006; Moreira, 2006; Vang, 2008
Z9,E11,Δ13-14:Ald Pyrilidae (<i>Ectomyelois ceratoniae</i>) Elachistidae (<i>Stenoma cecropia</i>)	Baker, 1989; Millar, 1990(a); Tellier, 1990; Tellier, 1991(a); Zagatti, 1996
E10,E12,Z14-16:OAc or E10,E12,Z14-16:Ald Crambidae (<i>Glyphodes pyloalis</i>) Sphingidae (<i>Manduca sexta</i>)	Ando, 1988; Doolittle, 1990; Tellier, 1991(b); Chen, 2000
1-6) Tetraenes E4,E6,Z11,Z13-16:Ald Saturniidae (<i>Callosamia promethean</i>)	Gago, 2013
Z7,Z13,Z16,Z19-22:OisoBu Erebidae (<i>Euproctis chrysorrhoea</i>)	Khrimian, 2008
1-7) 1,3-Enynes Z9, ≡ 11, Δ13-14:Ald Elachistidae (<i>Stenoma catenifer</i>)	Millar, 2008; Hoddle, 2009; Zou, 2010
≡11,Z13-16:OAc Notodontidae (<i>Thaumetopoea pityocampa</i>)	Camps, 1981; Camps, 1983; Gardette, 1983(a); Rossi, 1983; Shani, 1983; Stille, 1987
<u>(2) Type II compounds</u>	
Z3,Z6,Z9-19:H and/or Z3,Z6,Z9-21:H Geometridae (<i>Ascotis selenaria</i> , etc.) Erebidae (<i>Anticarsia gemmatalis</i> , etc.)	Conner, 1980; Becker, 1983; Heath, 1983; Underhill, 1983; Baker, 1984; Liu, 1984; Bestmann, 1985(a); Mangold, 1987; Langlois, 1990; Ando, 1993; Yadav, 1998(a); Wang, 2007; Davies, 2007

Δ1,Z3,Z6,Z9-19:H Geometridae (<i>Operophtera brumata</i>)	Roelofs, 1982; Bestmann, 1982(b); Huang, 1983; Jain, 1983(b); Baker, 1984; Viala, 1991; Pohnert, 2000; Yamamoto, 2008
Δ1,Z3,Z6,Z9-21:H Erebidae (<i>Utetheisa oratrix</i>)	Huang, 1983; Jain, 1983(a); Yamamoto, 2008
Z3,Z6,Z9,E11-19:H Geometridae (<i>Alsophila pometaria</i>)	Wong, 1984; Yamamoto, 2008
Z3,Z6,Z9,Z12-20:H Geometridae (<i>Thalassodes immissaria</i>)	Yamakawa, 2011(a); Langseter, 2012
epo3,Z6,Z9-19:H (3S,4R) and (3R,4S) Geometridae (<i>Ascotis selenaria</i>)	Becker, 1990; Millar, 1990(b); [Ando 1993]; Soulie, 1995; Qin, 1997
Z3,epo6,Z9-18:H (6S,7R) Geometridae (<i>Ectropis obliqua</i>)	Yu, 2017; Xu, 2017
Z3,epo6,Z9-19:H (6S,7R) Geometridae (<i>Erannis defoliaria</i>)	Millar, 1986; Mori, 1991(c); [Ando 1993]; Qin, 1997
Z6,epo9-19:H (9S,10R) Geometridae (<i>Ennomos subsignaria</i>)	Millar, 1991; MaGee, 2011; Zhou, 2024(a)
Z6,epo9-21:H (9S,10R) Erebidae (<i>Phragmatobia fuliginosa</i> , etc.) (9R,10S) Erebidae (<i>Teia anartoides</i> , etc.)	Rollin, 1986; Millar, 1991; Brevet, 1992; [Bell, 1993]; [Ando 1995]; Zhang, 1999; Zhang, 2000 Millar, 1991; Muto, 2003(b); Zhou, 2024(a)
Z3,Z6,epo9-19:H (9S,10R) Erebidae (<i>Lymantria mathura</i> , etc.)	[Ando 1993]; Qin, 1997; Khrimian, 2004
Z3,Z6,epo9-21:H (9S,10R) Erebidae (<i>Hyphantria cunea</i> , <i>Oraesia excavata</i> etc)	Mori, 1981; Mori, 1986; Pougny, 1987; [Bell, 1993]; [Ando 1993]; Qin, 1997; Zhang, 1999; Nakanishi, 2005
Δ1,Z3,Z6,epo9-21:H (9S,10R) Erebidae (<i>Hyphantria cunea</i> , etc.)	Mori, 1989; [Nikoleva, 1993]; Yadav, 1998(b); Nakanishi, 2005; Che, 2005; Yamakawa, 2012
Z3,epo6,epo9-21:H (6R,7S,9R,10S, leucomalure) Erebidae (<i>Leucoma salicis</i>)	Yamamoto, 1999; [Yamazawa, 2001]; [Lizarraga, 2001]; Muto, 2003(a) Wimalaratne, 2004
epo3,epo6,Z9-21:H (3S,4R,6S,7R) Erebidae (<i>Perina nuda</i>)	Yamamoto, 1999; [Yamazawa, 2001]

tepo4,Z6,Z9-19:H
Geometridae (*Bupalus piniarius*)

Z6,Z9,tepo11-21:H (11S,12S, posticlure)
Erebidae (*Orgyia postica*)

Kang, 2007; [Yamamoto, 2013]

Wakamura, 2001; Muto, 2001; Fernandes, 2002; Kang, 2007;
Fernandes, 2007

(3) Methyl-branched compounds

3-1) Hydrocarbons

Me2-17:H
Erebidae (*Holomelina aurantiaca* etc.)

Me2,Me5-17:H (S) + Me5,Me11-17:H (5R,11S)
Geometridae (*Lambdina fiscellaria*)

Me5,Me9-15:H (5S,9R)
Lyonetiidae (*Perileucoptera coffeella*)

Me5,Me9-17:H (5S,9S)
Lyonetiidae (*Leucoptera malifoliella*)

Me7-17:H (S) + Me7,Me11-17:H (meso)
Geometridae (*Lambdina athasaria*, *L. pellucidaria*)

Me9-19:H (S)
Erebidae (*Alabama argillacea*)

Δ1,Me10,Me14-18:H (10S,14S)
Lyonetiidae (*Lyonetia prunifoliella*)

Δ1,Me14-18:H (S)
Lyonetiidae (*Lyonetia clerkella*)

Naoshima, 1980(b); Dasaradhi, 1987

[Gries, 1991]; Li, 1993; Mori, 1996; Wang, 2023

Kuwahara, 2000; [Liang, 2000]; Moreira, 2003; [Zarbin, 2004]; Mori, 2008

[Kovalev, 1991]; Mori, 1991(a); Tamagawa, 1999; [Liang, 2000];
Taguri, 2012; Li, 2013; Yu, 2023

[Gries, 1994]; Shirai, 1999; Diaz, 2000; Enders, 2002; [Chow, 2004];
Nagano, 2007

Lamers, 2003; Cao, 2013

[Gries, 1997(b)]; Tamagawa, 1999; [Nakamura, 2000(a)]; Summeren, 2005;
Taguri, 2014; Yu, 2023

[Sugie, 1984]; [Manabe, 1985]; Kato, 1985; Mori, 1985; Sonnet, 1987;
[Yamamoto, 1989(b)]; Sankaranarayanan, 1995; Kharisov, 2003;
Zhang, 2013; Ishmuratov, 2013; Wei, 2020; He, 2021; He, 2022

3-2) Epoxides

Me2,epo7-18:H (7R,8S, (+)-disparlure)
Erebidae (*Lymantria dispar*)

Iwaki, 1974; Mori, 1981; [Koumaglo, 1984]; [Chan, 1985]; Mori, 1986;
Fukusaki, 1991; Keinan, 1992; Brevet, 1992; Hu, 1999;
Marshall, 1999; Koumbis, 2005; Inkster, 2005; Garg, 2017;
Gwon, 2024; [Vasian, 2025]

3-3) Esters of primary alcohol and acid

Me3,Me13-15:Ate with Me2-5:3-OH (3R,13R,1'S)
Psychidae (*Clania variegata*)

Mori, 2009(b); Mori, 2010; Taguri, 2013; Sun, 2017(b); Wang, 2024

- Me10-12:OAc (R)
Tortricidae (*Adoxophyes honmai*)
Suguro, 1979; [Horiike, 1982]; Sonnet, 1982(a); [Sonnet, 1982(b)];
Hjalmarsson, 1985; Sankaranarayanan, 1995; Geresh, 1998;
Chow, 2001
- Me10,Me14-15:OisoBu (R)
Erebidae (*Arna pseudoconspersa*)
Ichikawa, 1995; Zhao, 1998; Sun, 2017(a); Sun, 2024
- 3-4) Secondary alcohols
- Me5-17:7-OH (5R,7R)
Erebidae (*Miltochrista calamine*)
Yamakawa, 2011(b); Muraki, 2014; Yuan, 2022
- Me6,Me10,Me14-15:2-OH (2R,6R,10R)
Pyralidae (*Corcyra cephalonica*, *Aphomia sociella*)
[Hall, 1987]; Mori, 1991(b); Nakamura, 2000(b), Shafikov, 2011
- 3-5) Ketones
- Me6-18:2-one (S) + Me14-18:2-one (S)
+ Me6,Me14-18:2-one
Erebidae (*Lyclene dharmia*)
[Yamamoto, 2007]; [Do, 2009]; Mori, 2009(a); [Taguri, 2010];
Shikichi, 2012; Zhou, 2024(b)
- (4) Non-branched other compounds
- 4-1) Esters of secondary alcohols
- 17:7-OPr (S) + 17:8-OPr (S)
Erebidae (*Barsine expressa*)
Fujii, 2013
- Z12-17:2-OAc (S)
Tineidae (*Kermania pistaciella*)
Gries, 2006; Britton, 2009
- 4-2) Ketones
- Z6-21:11-one and/or Δ 1,Z6-21:11-one
Erebidae (*Orgyia pseudotsugata*)
Smith, 1975(a); Smith, 1975(b); Mori, 1977; Akermark, 1978; Smith, 1978;
Fetizon, 1978; Kondo, 1979; Trost, 1981; Fernández, 1983;
Hernández, 1983; Murata, 1983; Pramod, 1983; Reddy, 1983;
Sonnet, 1983; Ito, 1984; Naoshima, 1984; Ousset, 1984;
Nishiyama, 1984; Wang, 1984; Bestmann, 1985(b); Larson, 1985;
Mundy, 1985; Wenkert, 1985; Reddy, 1986; Dasaradhi, 1987;
Reddy, 1987; Muto, 2003(b); Jones, 2006
- Z6,E8-21:11-one
Gries, 1997(a); Muto, 2003(b); Jury, 2003; Comeskey, 2004

Erebidae (*Orgyia pseudotsugata*, *O. vetusta*)
Z6,Z9-21:11-one
Erebidae (*Orgyia leucostigma*, *Teia anartoides*)
Z7-19:11-one (Z12-19:9-one)
and/or Z7-20:11-one (Z13-20:10-one)
Carposinidae (*Carposina sasakii*)

Gries, 1997(a); Mayo, 2022

Tamaki, 1977; Tamada, 1978; Naoshima, 1981; Yoshida, 1982;
Hernández, 1983; Kang, 1983; Yadagiri, 1983; Sonnet, 1983;
Ito, 1984; Kang, 1984; Lee, 1984; Bestmann, 1985(b);
Kang, 1985; Wenkert, 1985; Yamashita, 1988;
Ramiandrasoa, 1990

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