

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; Rossi, 1983; Trost, 1984; Gardette, 1984; Ando, 1985; Brown, 1986; Huang, 1987; Stille, 1987(a); Stille, 1987(b); Fiandanese, 1989; Khrimian, 2002
E7,Z9-12:OAc	Tortricidae (<i>Lobesia botrana</i>)	Roelofs, 1973; Labovitz, 1975; Negishi, 1977; Bestmann, 1979; Dressaire, 1980; Rossi, 1981(a); Ideses, 1982; Tsuboi, 1982; Ujvary, 1985; Gardette, 1984; Cuvigny, 1987; Alexakis, 1988;

- E8,E10-12:OH
Tortricidae (*Cydia pomonella*)
- E8,Z10-14:Ald
Gracillariidae (*Cameraria ohridella*)
- 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*)
- Z9,E11-16:Ald
Crambidae (*Diatraea saccharalis*)
- E9,Z11-16:Ald
Pyralidae (*Acrobasis nuxvorella*)
- E10,Z12-16:OH
Bombycidae (*Bombyx mori*, *Bombyx mandarina*)
- E10,E12-16:Ald
Noctuidae (*Earias insulana*)
- Z11,Z13-16:Ald
Pyralidae (*Amyelois transitella*)
- Fiandanese, 1989; Yamamoto, 1989(c); Odinkov, 1993(a);
Kukovinets, 2000; Diego, 2006; Cahiez, 2017
- Descoins, 1972; Mori, 1974(a); Bestmann, 1978; Samain, 1978;
Knox, 1981; Naoshima, 1980; 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
- Nesbitt, 1972; Mori 1974(a); Babler, 1977; [Wollenberg, 1979];
Babler, 1979; Mandai, 1979; Bestmann, 1979; Yasuda, 1979;
Rossi, 1981(a); Knox, 1981; Bloch, 1982; Ranganathan, 1982;
Yamada, 1983; Ochiai, 1983; Engman, 1985; Ishibashi, 1985;
Yamada, 1986; Penhoat, 1986; Nagano, 2002; Cahiez, 2008
- Rossi, 1981(b); Ochiai, 1983; Michelot, 1983; Balezina, 1984;
Gardette, 1984; Ishibashi, 1987
- Tamaki, 1973; Goto, 1975; Hall, 1975; Bestmann, 1979; Lin, 1980;
Rossi, 1981(a); Ratovelomana, 1981; Gardette, 1984;
Cuvigny, 1987; Björkling, 1987; Fiandanese, 1989;
Yadav, 1989
- Knox, 1981; Bloch, 1983; Björkling, 1987
- Svirskaya, 1984(b); Svatoš, 2001; Tao, 2013
- Svirskaya, 1984(b), Millar, 1996; Passaro, 2003; Figueiredo, 2007
- 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;
Odinkov, 1993(b); Uenishi, 2000; Khrimian, 2002
- Knox, 1981; Klug, 1982; Yadav, 1989
- Coffelt, 1979; Sonnet, 1980; Arai, 1982; Bishop, 1983; Michelot, 1983;
Gardette, 1984; Furber, 1986; Mori, 2009(c); Liu, 2019

Notodontidae (*Notodonta dromedaries* etc.)

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
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
Z9,E12-14:OAc Noctuidae (<i>Spodoptera eridania</i> etc.) Pyralidae (<i>Cadra cautella</i> , etc.)	Jacobson, 1970; Su, 1973; Bac, 1982; Cuvigny, 1987; Kasymzhanova, 1992
1-3) 1,5-Dienes E3,Z7-14:OAc Gelechiidae (<i>Symmetrischema tangolias</i>)	Griepink, 1995; Ragoussis, 2008; Awalekar, 2021
Z7,Z11-16:OAc and/or Z7,E11-16:OAc Gelechiidae (<i>Pectinophora gossypiella</i> , <i>Sitotroga cerealella</i>)	Sonnet, 1974; Bierl, 1974; Mori, 1974(b); Su, 1974; Anderson, 1975; Mori, 1975; Bestmann, 1976; Sonnet, 1976; Michelot, 1983; Ishihara, 1984; Joshi, 1984; Svirskaya, 1984(a); Andelic, 1985; Ducoux, 1992; D'yakonov, 2017
1-4) Other dienes E2,Z13-18:OAc and/or E2,Z13-18:Ald Sesiidae (<i>Vitacea polistiformis</i> , etc) Cossidae (<i>Zeuzera pyrina</i>)	Schwarz, 1983; Voerman, 1984; Yamaoka, 1985; Frérot, 1986; Tonini, 1986; Hukumoto, 1998; Hoskovec, 1990; Takikawa, 1997; Capdevila, 1999; Ishmuratov, 2000; Grodner, 2006; Naka, 2006; Islam, 2007
E3,Z8 -14:OAc Gelechiidae (<i>Scrobipalpuloides absoluta</i>)	Griepink, 1996; Svatoš, 1996; Cabezas, 2019
Z3,Z13-18:OAc and/or E3,Z13-18:OAc Sesiidae (<i>Synanthedon exitiosa</i> <i>Synanthedon pictipes</i> , etc.)	Tumlinson, 1974; Uchida, 1978; Voerman, 1979; Ebata, 1979; Uchida, 1979; Voerman, 1979; Doolittle, 1980; Gardette, 1983(b); Svirskaya, 1984(a); Vinczer1985; Zhang, 1986;

	E6,Z11-16:OAc and E6,Z11-16:Ald Saturniidae (<i>Antheraea polyphemus</i>)	Yamamoto, 1989(a); Hoskovec, 1990; Moret, 1991; Capdevila, 1999; Naka, 2006; Armstrong-Chong, 2004 Kochansky, 1975; Kochansky, 1977; Tomida, 1983; Tomida, 1986
1-5)	Trienes E3,Z8,Z11-14:OAc Gelechiidae (<i>Scrobipalpuloides absoluta</i>) E4,E6,Z10-16:OAc and E4,Z6,Z10-16:OAc Gracillariidae (<i>Conopomorpha cramerella</i>) E4,E6,Z11-16:Ald Saturniidae (<i>Samia cynthia</i>) E4,Z7,Z10-13:OAc Gelechiidae (<i>Phthorimaea operculella</i>) Z7,Z11,E13-16:Ald Gracillariidae (<i>Phyllocnistis citrella</i>) Z9,E11,Δ13-14:Ald Pyralidae (<i>Ectomyelois ceratoniae</i>) Elachistidae (<i>Stenoma cecropia</i>) E10,E12,Z14-16:OAc or E10,E12,Z14-16:Ald Crambidae (<i>Glyphodes pyloalis</i>) Sphingidae (<i>Manduca sexta</i>)	Attygalle, 1996; Hungerford, 1998; Cabezas, 2019 Beevor, 1986; Yen, 1992; Huang, 2017 Bestmann, 1989; Tomida, 1993 Voerman, 1978; Pan, 2022 Leal, 2006; Moreira, 2006; Vang, 2008 Baker, 1989; Millar, 1990(a); Tellier, 1990; Tellier, 1991(a); Zagatti, 1996 Ando, 1988; Doolittle, 1990; Tellier, 1991(b); Chen, 2000
1-6)	Tetraenes 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>) ≡11,Z13-16:OAc Notodontidae (<i>Thaumetopoea pityocampa</i>)	Millar, 2008; Hoddle, 2009; Zou, 2010 Camps, 1981; Camps, 1983; Gardette, 1983(a); Rossi, 1983; Shani, 1983; Stille, 1987

(2) Type II compounds

Z3,Z6,Z9-19:H and/or Z3,Z6,Z9-21:H
Geometridae (*Ascotis selenaria*, etc.)
Erebidae (*Anticarsia gemmatalis*, etc.)

Conner, 1980; Becker, 1983; Heath, 1983; Underhill, 1983; Baker, 1984;
Liu, 1984; Bestmann, 1985; Mangold, 1987; Langlois, 1990;
Ando, 1993; Yadav, 1998(a); Wang, 2007; Davies, 2007

Δ 1,Z3,Z6,Z9-19:H
Geometridae (*Operophtera brumata*)

Roelofs, 1982; Huang, 1983; Jain, 1983(b); Baker, 1984; Viala, 1991;
Pohnert, 2000; Yamamoto, 2008

Δ 1,Z3,Z6,Z9-21:H
Erebidae (*Utetheisa ornatix*)

Huang, 1983; Jain, 1983(a); Yamamoto, 2008

Z3,Z6,Z9,E11-19:H
Geometridae (*Alsophila pometaria*)

Wong, 1984; Yamamoto, 2008

Z3,Z6,Z9,Z12-20:H
Geometridae (*Thalassodes immissaria*)

Yamakawa, 2011(a); Langseter, 2012

epo3,Z6,Z9-19:H (3S,4R) and (3R,4S)
Geometridae (*Ascotis selenaria*)

Becker, 1990; Millar, 1990(b); [Ando 1993]; Soulie, 1995; Qin, 1997

Z3,epo6,Z9-18:H (6S,7R)
Geometridae (*Ectropis obliqua*)

Yu, 2017; Xu, 2017

Z3,epo6,Z9-19:H (6S,7R)
Geometridae (*Erannis defoliaria*)

Mori, 1991(c); [Ando 1993]; Qin, 1997

Z6,epo9-19:H (9S,10R)
Geometridae (*Ennomos subsignaria*)

Millar, 1991; MaGee, 2011; Zhou, 2024(a)

Z6,epo9-21:H (9S,10R)
Erebidae (*Phragmatobia fuliginosa*, etc.)
(9R,10S)
Erebidae (*Teia anartoides*, 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 (*Lymantria mathura*, etc.)

[Ando 1993]; Qin, 1997; Khrimian, 2004

Z3,Z6,epo9-21:H (9S,10R)
Erebidae (*Hyphantria cunea*, *Oraesia excavata* etc)

Mori, 1981; Mori, 1986; Pougny, 1987; [Bell, 1993]; [Ando 1993];
Qin, 1997; Zhang, 1999; Nakanishi, 2005

Δ 1,Z3,Z6,epo9-21:H (9S,10R)
Erebidae (*Hyphantria cunea*, 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 (*Leucoma salicis*)

epo3,epo6,Z9-21:H (3S,4R,6S,7R)
Erebidae (*Perina nuda*)

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

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

Yamamoto, 1999; [Yamazawa, 2001]; [Lizarraga, 2001]; Muto, 2003(a)
Wimalaratne, 2004

Yamamoto, 1999; [Yamazawa, 2001]

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*)

Δ 1,Me10,Me14-18:H (10S,14S)
Lyonetiidae (*Lyonetia prunifoliella*)

Δ 1,Me14-18:H (S)
Lyonetiidae (*Lyonetia clerkella*)

Dasaradhi, 1987

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

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

Mori, 1991(a); Taguri, 2012; Li, 2013; Yu, 2023

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

Lamers, 2003; Cao, 2013

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; 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; Mori, 1986; Fukusaki, 1991; Keinan, 1992;
Brevet, 1992; Hu, 1999; Koumbis, 2005; Inkster, 2005;

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; Hjalmarsson, 1985; Sankaranarayanan, 1995; Geresh, 1998;
Chow, 2001

Me10,Me14-15:OisoBu (R)
Erebidae (*Arna pseudoconspersa*)

Ichikawa, 1995; Sun, 2017(a); Sun, 2024

3-4) Secondary alcohols

Me5-17:7-OH (5R,7R)
Erebidae (*Miltachrista calamine*)

Yamakawa, 2011(b); Muraki, 2014; Yuan, 2022

Me6,Me10,Me14-15:2-OH (2R,6R,10R)
Pyralidae (*Corcyra cephalonica*, *Aphomia sociella*)

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
Erebidae (*Orgyia pseudotsugata*)

Smith, 1975; Akermark, 1978; Nishiyama, 1984 Larson, 1985;
Dasaradhi, 1987; Jones, 2006

Z6,E8-21:11-one
Erebidae (*Orgyia pseudotsugata*, *O. vetusta*)

Muto, 2003(b); Jury, 2003; Comeskey, 2004

Z6,Z9-21:11-one
Erebidae (*Orgyia leucostigma*, *Teia anartoides*)

Mayo, 2022

Z7-19:11-one (Z12-19:9-one)
+ Z7-20:11-one (Z13-20:10-one)

Naoshima, 1981; Yadagiri, 1983; Yamashita, 1988

Carposinidae (*Carposina sasakii*)

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