# 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, Δ = terminal] and/or other structures in the chain as follows, ≡ = 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 = primaly alcohol, OAc = acetate of alcohol, Ald = aldehyde, and one = ketone.

| Pheromone<br>Family and species of moth | Publication of synthesis |
|---|---|
| (1) Type I compounds | |
| 1-1) 1,3-Dienes | |
| E3,Z5-12:OAc<br>Tortricidae (*Phtheochroa cranaodes*) | Unelius, 1996; Park, 1998; Chong, 1999; Hodgson, 2007 |
| Z3,E5-14:OAc<br>Cossidae (*Holcocerus vicarius*) | Rossi, 1982; Doolittle, 1986 |
| E4,Z6-16:OAc<br>Stathmopodidae (*Stathmopoda masinissa*) | Nishida, 2003; Awalekar, 2020 |
| Z5,E7-12:OH and/or Z5,E7-12:Ald<br>Lasiocampidae (*Malacosoma disstria, Dendrolimus spectabilis,* etc.) | Chisholm, 1981; Ando, 1982; Bestmann, 1982; Trost, 1984; Gardette, 1984; Ando, 1985; Fiandanese, 1989; Khrimian, 2002 |
| E7,Z9-12:OAc<br>Tortricidae (*Lobesia botrana*) | Labovitz, 1975; Dressaire, 1980; Rossi, 1981; Ujvary, 1985; Gardette, 1984; Alexakis, 1988; Fiandanese, 1989; Yamamoto, 1989(c); Diego, 2006 |

| | |
|---|---|
| E8,E10-12:OH<br>Tortricidae (*Cydia pomonella*) | Descoins, 1972; Mori, 1974(a); Samain, 1978; Knox, 1981; Bloch, 1983; Yamada, 1983; Ando, 1985 |
| E8,Z10-14:Ald<br>Gracillariidae (*Cameraria ohridella*) | Figueiredo, 2007; Grodner, 2009 |
| E9,Δ11-12:OAc<br>Noctuidae (*Diparopsis castanea*) | Nesbitt, 1972; Mori 1974(a); Babler, 1977; [Wollenberg, 1979]; Rossi, 1981; Knox, 1981; Bloch, 1982; Yamada, 1983; Engman, 1985; Nagano, 2002; Cahiez, 2008 |
| Z9,Δ11-12:OAc<br>Noctuidae (*Diparopsis castanea*) | Gardette, 1984; Ishibashi, 1987 |
| Z9,E11-14:OAc<br>Noctuidae (*Spodoptera littoralis*) | Rossi, 1981; Gardette, 1984; Fiandanese, 1989 |
| E9,E11-14:OAc<br>Tortricidae (*Epiphyas postvittana*) | Knox, 1981; Bloch, 1983 |
| Z9,E11-16:Ald<br>Crambidae (*Diatraea saccharalis*) | Svirskaya, 1984(b); Tao, 2013 |
| E9,Z11-16:Ald<br>Pyralidae (*Acrobasis nuxvorella*) | Passaro, 2003; Figueiredo, 2007 |
| E10,Z12-16:OH<br>Bombycidae (*Bombyx mori*) | Negishi, 1973; Bestmann, 1977; Zweifel, 1978; Gardette, 1984; Alexakis, 1988; Fiandanese, 1989; Uenishi, 2000; Khrimian, 2002 |
| E10,E12-16:Ald<br>Noctuidae (*Earias insulana*) | Knox, 1981; Klug, 1982 |
| Z11,Z13-16:Ald<br>Pyralidae (*Amyelois transitella*)<br>Notodontidae (*Notodonta dromedaries* etc.) | Bishop, 1983; Gardette, 1984; Mori, 2009(c), Liu, 2019 |
| Z11,E13-16:OAc<br>Pyralidae (*Herpetogramma licarsisalis*) | Alexakis, 1988; Gibb, 2007 |
| 1-2) 1,4-Dienes | |
| E4,Z7-13:OAc<br>Gelechiidae (*Phthorimaea operculella*) | Voerman, 1978; Alexakis, 1978; Nishiyama, 1984; Yadav, 1986; Nonoshita, 1990;Hutzinger, 1995; Odinokov, 1997; Vakhidov, 2007; Pan, 2022 |
| Z9,E12-14:OAc | Jacobson, 1970; Bac, 1982; Kasymzhanova, 1992 |

Noctuidae (*Spodoptera eridania* etc.)
Pyralidae (*Cadra cautella,* etc.)

1-3) 1,5-Dienes

| | |
|---|---|
| E3,Z7-14:OAc<br>Gelechiidae (*Symmetrischema tangolias*) | Ragoussis, 2008; Awalekar, 2021 |
| Z7,Z11-16:OAc and/or Z7,E11-16:OAc<br>Gelechiidae (*Pectinophora gossypiella, Sitotroga cerealella*) | Sonnet, 1974; Mori, 1974(b); Su, 1974; Anderson, 1975; Ishihara, 1984; Svirskaya, 1984(a); Ducoux, 1992; D'yakonov, 2017 |

1-4) Other dienes

| | |
|---|---|
| E2,Z13-18:Ald and/or E2,Z13-18:OAc<br>Sesiidae (*Vitacea polistiformis*, etc) | Hukumoto, 1998; Hoskovec, 1990; Grodner, 2006; Naka, 2006; Islam, 2007 |
| E3,Z8 -14:OAc<br>Gelechiidae (*Scrobipalpuloides absoluta*) | Cabezas, 2019 |
| Z3,Z13-18:OAc and/or E3,Z13-18:OAc<br>Sesiidae (*Synanthedon exitiosa Synanthedon pictipes*, etc.) | Voerman, 1979; Doolittle, 1980; Gardette, 1983(b); Svirskaya, 1984(a); Yamamoto, 1989(a); Hoskovec, 1990; Naka, 2006; Armstrong-Chong, 2004 |
| E6,Z11-16:OAc and E6,Z11-16:Ald<br>Saturniidae (*Antheraea polyphemus*) | Kochansky, 1977 |

1-5) Trienes

| | |
|---|---|
| E3,Z8,Z11-14:OAc<br>Gelechiidae (*Scrobipalpuloides absoluta*) | Cabezas, 2019 |
| E4,E6,Z10-16:OH and E4,Z6,Z10-16:OH<br>Gracillariidae (*Conopomorpha cramerella*) | Huang, 2017 |
| E4,E6,Z11-16:Ald<br>Saturniidae (*Samia cynthia*) | Tomida, 1993 |
| E4,Z7,Z10-13:OAc<br>Gelechiidae (*Phthorimaea operculella*) | Voerman, 1978; Pan, 2022 |
| Z7,Z11,E13-16:Ald<br>Gracillariidae (*Phyllocnistis citrella*) | Leal, 2006; Moreira, 2006; Vang, 2008 |

Z9,E11,Δ13-14:Ald — Baker, 1989; Millar, 1990; Tellier, 1990; Tellier, 1991(a)
Pyralidae (*Ectomyelois ceratoniae*)
Elachistidae (*Stenoma cecropia*)

E10,E12,Z14-16:OAc or E10,E12,Z14-16:Ald — Ando, 1988; Doolittle, 1990; Tellier, 1991(b); Chen, 2000
Crambidae (*Glyphodes pyloalis*)
Sphingidae (*Manduca sexta*)

1-6) Tetraenes

Z7,Z13,Z16,Z19-22:OisoBu — Khrimian, 2008
Erebidae (*Euproctis chrysorrhoea*)

1-7) 1,3-Enynes

Z9,≡11,Δ13-14:Ald — Hoddle, 2009; Zou, 2010
Elachistidae (Stenoma catenifer)

≡11,Z13-16:OAc — Gardette, 1983(a); Camps, 1983; Shani, 1983
Notodontidae (*Thaumetopoea pityocampa*)

(2) Type II compounds

Z3,Z6,Z9-19:H and/or Z3,Z6,Z9-21:H — Conner, 1980; Becker, 1983; Baker, 1984; Underhill, 1983; Bestmann, 1985; Mangold, 1987; Langlois, 1990; Ando, 1993 Yadav, 1998(a); Wang, 2007; Davies, 2007
Geometridae (*Ascotis selenaria*, etc.)

Δ1,Z3,Z6,Z9-19:H — Huang, 1983; Jain, 1983(b); Baker, 1984; Viala; 1991; Pohnert, 2000 Yamamoto, 2008
Geometridae (*Operophtera brumata*)

Δ1,Z3,Z6,Z9-21:H — Jain, 1983(a); Yamamoto, 2008
Erebidae (*Utetheisa ornatrix*)

Z3,Z6,Z9,E11-19:H — Yamamoto, 2008
Geometridae (*Alsophila pometaria*)

Z3,Z6,Z9,Z12-20:H — Yamakawa, 2011(a); Langseter, 2012
Geometridae (*Thalassodes immissaria*)

epo3,Z6,Z9-18:H (3*S*,4*R*) and (3*R*,4*S*) — [Ando 1993]; Soulie, 1995; Qin, 1997
Geometridae (*Ascotis selenaria*)

Z3,epo6,Z9-18:H (6*S*,7*R*) — Yu, 2017; Xu, 2017

Geometridae (*Ectropis obliqua*)

Z3,epo6,Z9-19:H (6*S*,7*R*) — Mori, 1991(c); [Ando 1993]; Qin, 1997
Geometridae (*Erannis defoliaria*)

Z6,epo9-19:H (9*S*,10*R*) — MaGee, 2011; Zhou, 2024(a)
Geometridae (*Ennomos subsignaria*)

Z6,epo9-21:H (9*S*,10*R*) — Brevet, 1992; [Bell, 1993]; [Ando 1995]; Zhang, 2000
Erebidae (*Phragmatobia fuliginosa*, etc.)
(9*R*,10*S*) — Muto, 2003(b); Zhou, 2024(a)
Erebidae (*Teia anartoides,* etc.)
Z3,Z6,epo9-19:H (9*S*,10*R*) — [Ando 1993]; Qin, 1997; Khrimian, 2004
Erebidae (*Lymantria mathura,* etc.)

Z3,Z6,epo9-21:H (9*S*,10*R*) — Mori, 1981; Mori, 1986; Pougny, 1987; [Bell, 1993]; [Ando 1993]; Qin, 1997; Nakanishi, 2005
Erebidae (*Estigmene acrea, Hyphantria cunea*, etc)

Δ1,Z3,Z6,epo9-21:H (9*S*,10*R*) — Mori, 1989; Yadav, 1998(b); Nakanishi, 2005; Che, 2005; Yamakawa, 2012
Erebidae (*Hyphantria cunea,* etc.)

Z3,epo6,epo9-21:H (6*R*,7*S*,9*R*,10*S*, leucomalure) — Yamamoto, 1999; [Yamazawa, 2001]; [Lizarraga, 2001]; Muto, 2003(a) Wimalaratne, 2004
Erebidae (*Leucoma salicis*)

epo3,epo6,Z9-21:H (3*S*,4*R*,6*S*,7*R*) — Yamamoto, 1999; [Yamazawa, 2001]
Erebidae (*Perina nuda*)

tepo4,Z6,Z9-19:H — [Yamamoto, 2013]; Kang, 2007
Geometridae (*Bupalus piniarius*)

Z6,Z9,tepo11-21:H (11*S*,12*S*, posticlure) — Wakamura, 2001; Muto, 2001; Fernandes, 2002; Kang, 2007; Fernandes, 2007
Erebidae (*Orgyia postica*)

(3) Methyl-branched compounds

3-1) Hydrocarbons

Me2-17:H — Dasaradhi, 1987
Erebidae (*Holomelina aurantiaca* etc.)

Me2,Me5-17:H (S) + Me5,Me11-17:H (5*R*,11*S*) — [Gries, 1991]; Li, 1993; Mori, 1996; Wang, 2023
Geometridae (*Lambdina fiscellaria*)

Me5,Me9-15:H (5*S*,9*R*) — Kuwahara, 2000; Moreira, 2003; [Zarbin, 2004]; Mori, 2008
Lyonetiidae (*Perileucoptera coffeella*)

| | |
|---|---|
| Me5,Me9-17:H (5*S*,9*S*)<br>Lyonetiidae (*Leucoptera malifoliella*) | Mori, 1991(a); Taguri, 2012; Li, 2013; Yu, 2023 |
| Me7-17:H (S) + Me7,Me11-17:H (meso)<br>Geometridae (*Lambdina athasaria, L. pellucidaria*) | Shirai, 1999; Diaz, 2000; Enders, 2002; [Chow, 2004]; Nagano, 2007 |
| Me9-19:H (*S*)<br>Erebidae (*Alabama argillacea*) | Lamers, 2003; Cao, 2013 |
| Δ1,Me10,Me14-18:H (10*S*,14*S*)<br>Lyonetiidae (*Lyonetia prunifoliella*) | Tamagawa, 1999; [Nakamura, 2000(a)]; Summeren, 2005; Taguri, 2014; Yu, 2023 |
| Δ1,Me14-18:H (*S*)<br>Lyonetiidae (*Lyonetia clerkella*) | [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 (7*R*,8*S*, (+)-disparlure)<br>Erebidae (*Lymantria dispar*) | Iwaki, 1974; Mori, 1981; Mori, 1986; Fukusaki, 1991; Keinan, 1992; Brevet, 1992; Hu, 1999; Koumbis, 2005; Inkster, 2005; Garg, 2017; Gwon, 2024 |
| 3-3) Esters of primary alcohol and acid | |
| Me3,Me13-15:Ate with Me2-5:3-OH (3*R*,13*R*,1'*S*)<br>Psychidae (*Clania variegata*) | Mori, 2009(b); Mori, 2010; Taguri, 2013; Sun, 2017(b); Wang, 2024 |
| Me10-12:OAc (*R*)<br>Tortricidae (*Adoxophyes honmai*) | Suguro, 1979; Hjalmarsson, 1985; Sankaranarayanan, 1995; Geresh, 1998; Chow, 2001 |
| Me10,Me14-15:OisoBu (*R*)<br>Erebidae (*Arna pseudoconspersa*) | Ichikawa, 1995; Sun, 2017(a); Sun, 2024 |
| 3-4) Secondary alcohols | |
| Me5-17:7-OH (5*R*,7*R*)<br>Erebidae (*Miltachrista calamine*) | Yamakawa, 2011(b); Muraki, 2014; Yuan, 2022 |
| Me6,Me10,Me14-15:2-OH (2*R*,6*R*,10*R*)<br>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*) | [Yamamoto, 2007]; [Do, 2009]; Mori, 2009(a); [Taguri, 2010]; |

| | |
|---|---|
| + Me6,Me14-18:2-one<br>Erebidae (*Lyclene dharma*) | Shikichi, 2012; Zhou, 2024(b) |

(4) Non-branched other compounds

4-1) Esters of secondary alcohols

| | |
|---|---|
| 17:7-OPr (*S*) + 17:8-OPr (*S*)<br>Erebidae (*Barsine expressa*) | Fujii, 2013 |
| Z12-17:2-OAc (*S*)<br>Tineidae (*Kermania pistaciella*) | Gries, 2006; Britton, 2009 |

4-2) Ketones

| | |
|---|---|
| Z6-21:11-one<br>Erebidae (*Orgyia pseudotsugata*) | Smith, 1975; Akermark, 1978; Nishiyama, 1984 Larson, 1985; Dasaradhi, 1987; Jones, 2006 |
| Z6,E8-21:11-one<br>Erebidae (*Orgyia pseudotsugata*, *O. vetusta*) | Muto, 2003(b); Jury, 2003; Comeskey, 2004 |
| Z6,Z9-21:11-one<br>Erebidae (*Orgyia leucostigma, Teia anartoides*) | Mayo, 2022 |
| Z7-19:11-one (Z12-19:9-one)<br>+ Z7-20:11-one (Z13-20:10-one)<br>Carposinidae (*Carposina sasakii*) | Naoshima, 1981; Yadagiri, 1983; Yamashita, 1988 |

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