

Sex Pheromones of Scale Insects

Contents

- (A) What are scale insects?
- (B) Representative scale insects
- (C) Identification from Diaspididae species
- (D) Identification from Pseudococcidae species
- (E) Identification from Margarodidae species
- (F) References



Grouping by chemical structures

1. Acyclic compounds
2. Cyclic compounds
3. Polyketides (propanogenins)

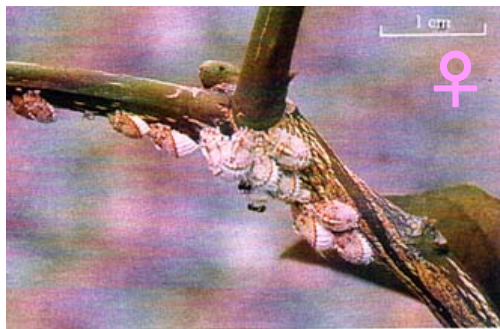
(A) What are scale insects?

Hemiptera: Homoptera {
 Psylloidea
 Aleyrodoidea
 Aphidoidea
 Coccoidea: scale insects
 (including 15-20 families)

Sexual heteromorphism

♀ : aptera (wingless), covered with wax

♂ : alata (winged), only front wings, without mouth part



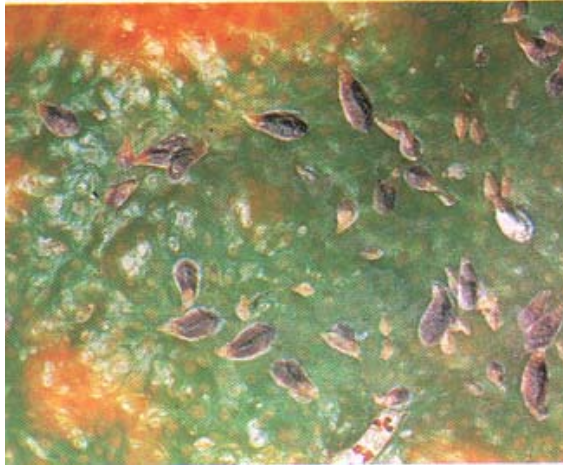
cottony cushion scale
Icerya purchasi



vedalia ladybird
Rodolia cardinalis

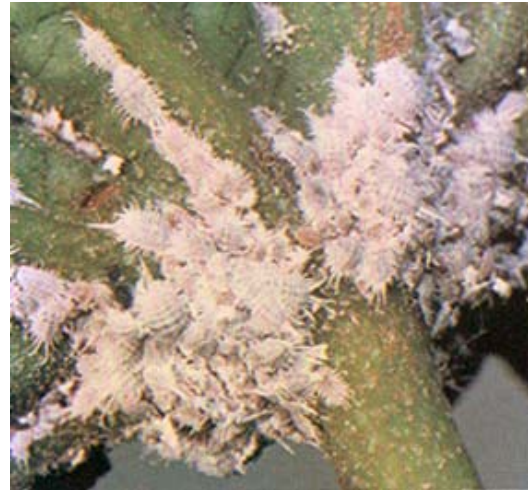
(B) Representative scale insects

Diaspididae



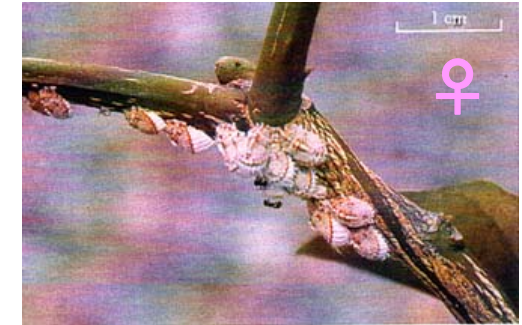
arrowhead scale
Unaspis yanonensis

Pseudococcidae



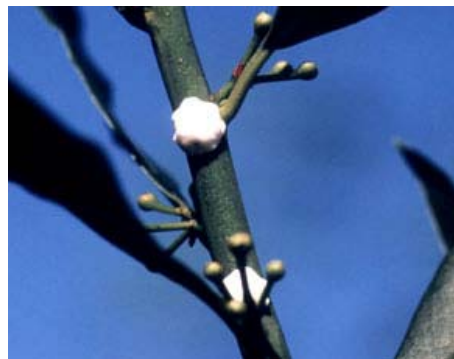
Comstock mealybug
Pseudococcus comstocki

Margarodidae



cottony cushion scale
Icerya purchasi

Coccidae



Japanese wax scale
Ceroplastes ceriferus



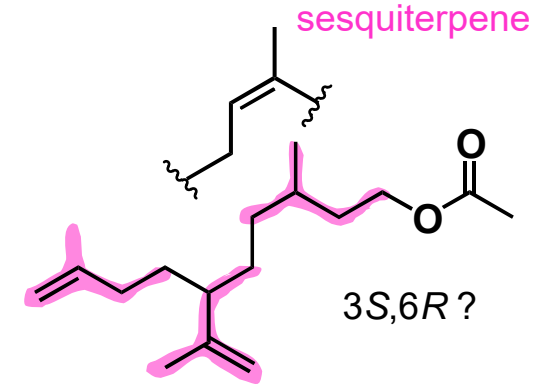
red wax scale
Ceroplastes rubens

(C) Diaspididae ①

i) California red scale (*Aonidiella aurantii*)

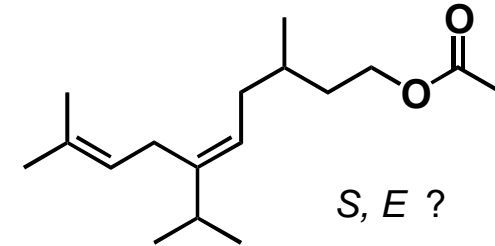
Roelofs *et al.*, 1977. *Nature*, **267**, 698

Roelofs *et al.*, 1978. *J. Chem. Ecol.*, **4**, 211



ii) Yellow scale (*Aonidiella citrina*)

Gieselmann *et al.*, 1979. *J. Chem. Ecol.*, **5**, 27

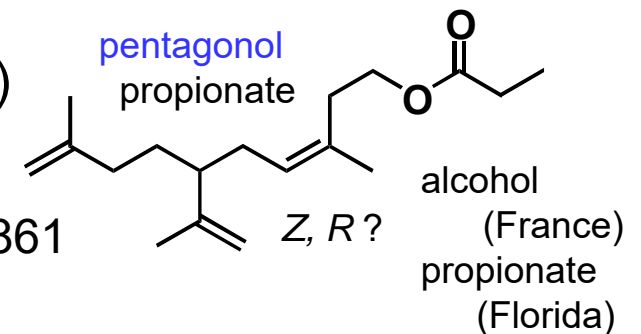


iii) White peach scale (*Psudaulascaspis pentagona*)

Heath *et al.*, 1979. *J. Chem. Ecol.*, **5**, 941

Einhorn *et al.*, 1983. *C. R. Acad. Sci., Ser. III*, **296**, 861

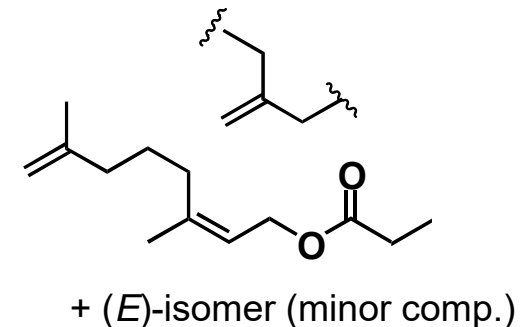
McLaughlin *et al.*, 1990. *J. Chem. Ecol.*, **16**, 749



iv) San Jose scale (*Quadraspidiotus perniciosus*)

Gieselmann *et al.*, 1979. *J. Chem. Ecol.*, **5**, 891

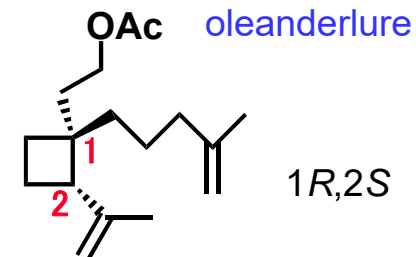
Anderson *et al.*, 1981. *J. Chem. Ecol.*, **7**, 695



(C) Diaspididae ②

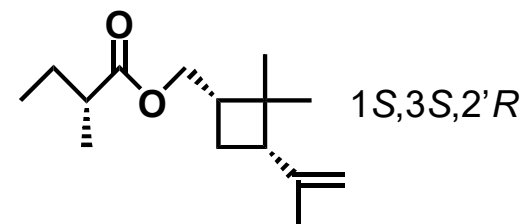
v) Oleander scale (*Aspidiotus nerii* = *A. hederiae*)

Einhorn *et al.*, 1998. PNAS, **95**, 9867



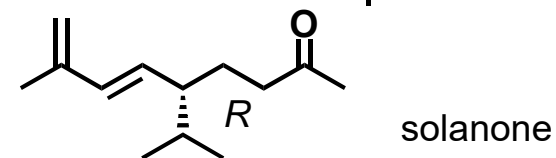
vi) *Acutaspis albopicta*

Millar *et al.*, 2012. *J. Econ. Entomol.*, **105**, 497



vii) *Aulacaspis murrayae*

Ho *et al.*, 2014. *J. Chem. Ecol.*, **40**, 379



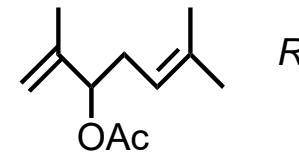
(D) Pseudococcidae ①

i) Comstock mealybug (*Pseudococcus comstocki*)

Negishi *et al.*, 1980. *Appl. Entomol. Zool*, **15**, 328

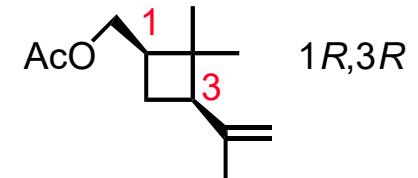
Bierl-Leonhardt *et al.*, 1980. *Life Science*, **27**, 399

1982. *J. Chem. Ecol.*, **8**, 689



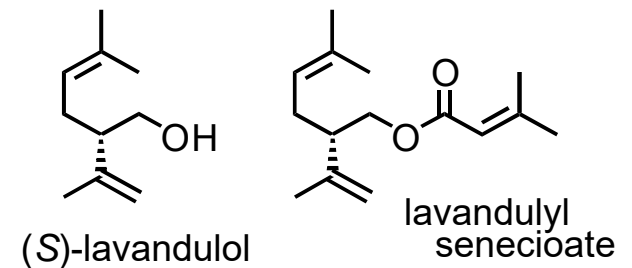
ii) Citrus mealybug (*Planococcus citri*)

Bierl-Leonhardt *et al.*, 1981. *Tetrahedron Lett.*, **22**, 389



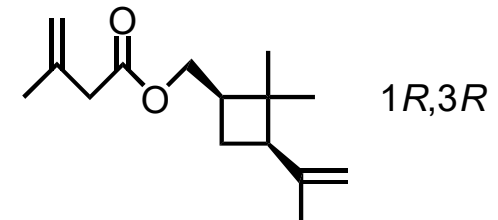
iii) Vine mealbug (*Planococcus ficus*)

Hinkens *et al.*, 2001. *Tetrahedron Lett.*, **42**, 1619



iv) Citriculus mealybug (*Pseudococcus cryptus*
= *P. citriculus*)

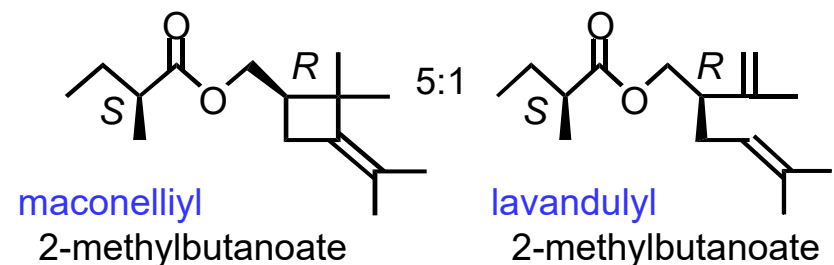
Arai *et al.*, 2003. *J. Chem. Ecol.*, **29**, 2213



v) Pink hibiscus mealybug

(*Maconellicoccus hirsutus*)

Zhang *et al.*, 2004. *PNAS*, 101, 9601

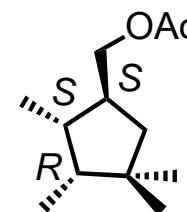


(D) Pseudococcidae ②

vi) Obscure mealybug (*Pseudococcus viburni*)

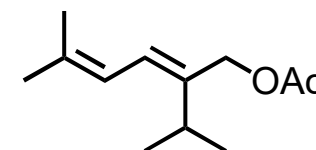
Millar *et al.*, 2005. *J. Chem. Ecol.*, **31**, 2999

Figadéra *et al.*, 2008. *Chem. Comm.*, 1106 (stereo)



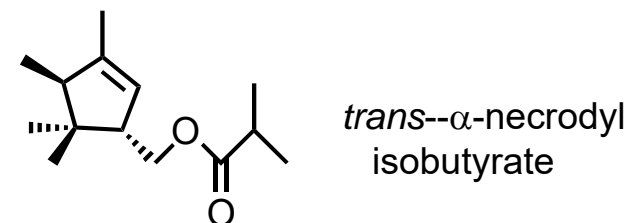
vii) Passionvine mealybug (*Planococcus minor*)

Ho *et al.*, 2007. *J. Chem. Ecol.*, **33**, 1986



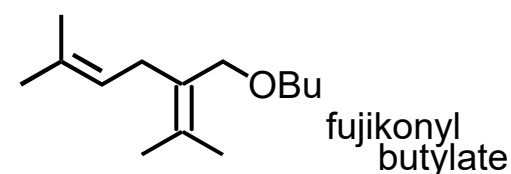
viii) Grape mealybug (*Pseudococcus maritimus*)

Figadère *et al.*, 2007. *Tetra. Lett.* **48**, 8434



ix) Japanese mealybug (*Planococcus kraunhiae*)

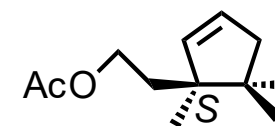
Sugie *et al.*, 2008. *Appl. Entmol. Zool.*, **43**, 369



x) Longtailed mealybug (*Phenacoccus longispinus*)

Millar *et al.*, 2009. *Org. Lett.*, **11**, 2683

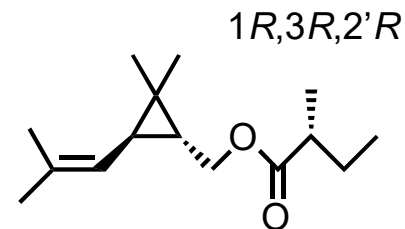
Ramesh *et al.*, 2013. *J. Org. Chem.*, **78**, 6281



(D) Pseudococcidae ③

xi) Madeira mealybug (*Phenacoccus madeirensis*)

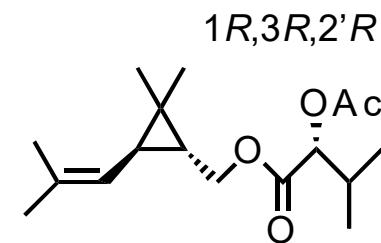
Ho *et al.*, 2009. *J. Chem. Ecol.*, **35**, 724



xii) Citrophilous mealybug (*Pseudococcus calceolariae*)

El-Sayed *et al.*, 2010. *Tetrahedron Lett.*, **51**, 1075

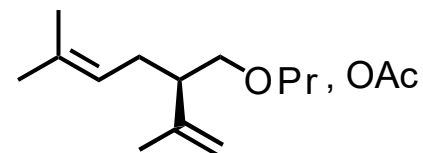
Unelius *et al.*, 2011. *J. Chem. Ecol.*, 37 166



xiii) Banana mealybug (*Dysmicoccus grassii*)

Alfonso *et al.*, 2012.

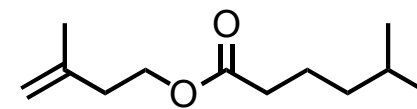
J. Agric. Food Chem., **60**, 11959



(R)-lavandulyl propionate

xiv) Matsumoto mealybug (*Crisicoccus matsumotoi*)

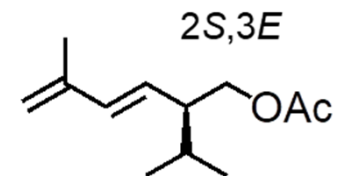
Tabata *et al.*, 2012. *Naturwissenschaften*, **99**, 567



xv) Grey pineapple mealybug (*Dysmicoccus neobrevipes*)

Tabata & Ichiki, 2015. *J. Chem. Ecol.*, **41**, 194

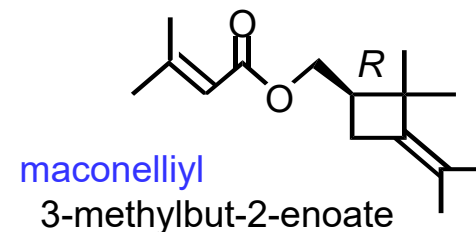
Tabata & Ohno, 2015. *Appl. Entomo. Zool.*, **50**, 341



(D) Pseudococcidae ④

xvi) Cotton mealybug (*Phenacoccus solenopsis*)

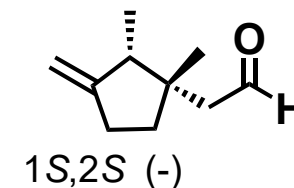
Tabata & Ichiki, 2016. *J. Chem. Ecol.*, **42**, 1193



xvii) Pinapple mealybug (*Dysmicoccus brevipes*)

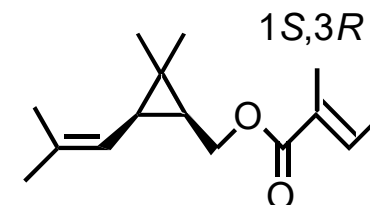
Tabata *et al.*, 2017. *J. R. Soc. Interface*, **14**, 20170027

Mori & Tabata, 2017. *Tetrahedron*, **73**, 6530-6541



xviii) Striped mealybug (*Ferrisia virgata*)

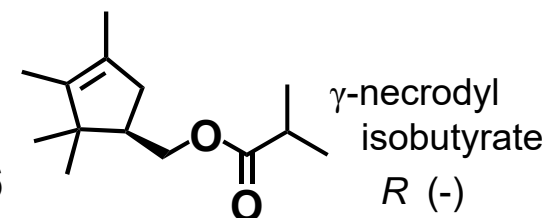
Tabata & Ichiki, 2017. *J. Chem. Ecol.*, **43**, 745-752



xix) Spherical mealybug (*Nipaecoccus viridis*)

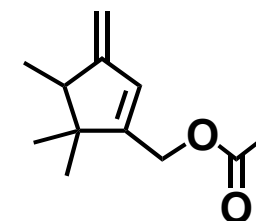
Levi-Zada *et al.*, 2019. *J. Chem. Ecol.*, **45**, 455

Levi-Zada *et al.*, 2021. *J. Agric. Food Chem.*, **69**, 3026



xx) *Delottococcus aberiae*

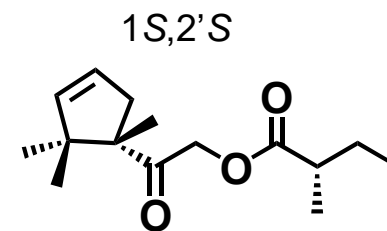
Vacas *et al.*, 2019. *J. Agric. Food Chem.*, **67**, 9441



(D) Pseudococcidae ⑤

xxi) Aerial root mealybug (*Pseudococcus baliteus*)

Tabata *et al.*, 2020. *Tetrahedron Lett.*, **61**, 151802



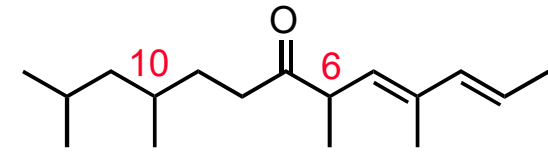
(E) Margarodidae ①

i) Japanese black pine bast scale

(*Matsucoccus matsumurae*)

Lanier *et al.*, 1989. *J. Chem. Ecol.*, **15**, 1645

Hibbard *et al.*, 1991. *J. Chem. Ecol.*, **17**, 89



6R,10R ? matsuone

ii) Red pine scale (*M. resinosae*)

Lanier *et al.*, 1989. Hibbard *et al.*, 1991.

Shi *et al.*, 1995. *Tetrah. Lett.*, **36**, 7201

(6R,10R)-matsuone

iii) Black pine bast scale (*M. thunbergiana*)

Lanier *et al.*, 1989. Hibbard *et al.*, 1991.

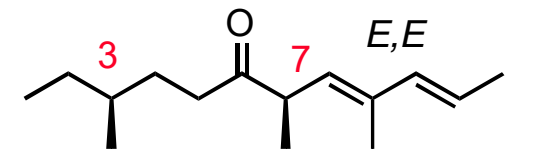
Park *et al.*, 1994. *J. Chem. Ecol.*, **20**, 2185

(6R,10R)-matsuone

iv) Maritime pine scale (*M. feytaudi*)

Einhorn *et al.*, 1990. *Tetrah. Lett.*, **31**, 6633

Jactel *et al.*, 1994. *J. Chem. Ecol.*, **20**, 2159



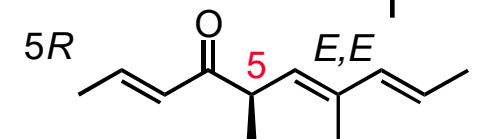
3S,7R

Z,E

v) Israeli pine bast scale (*M. josephi*)

Dunkelblum *et al.*, 1993. *Tetrah. Lett.*, **34**, 2805

Dunkelblum *et al.*, 1995. *J. Chem. Ecol.*, **21**, 849



5R

E:Z=3:1

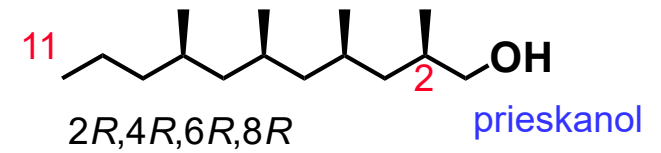
Z,E

(E) Margarodidae ②

vi) *Margarodes prieskaensis*

Burger *et al.*, 2017. *J. Chem. Ecol.*, **43**, 94

Me₂,Me₄,Me₆,Me₈₋₁₁:OH



(F) References ①

Diaspididae

- Acutaspis albopicta*
- Aonidiella aurantii* California red scale
- Aonidiella citrina* yellow scale
- Aspidiotus nerii* = *A. hederae* oleander scale
- Aulacaspis murrayae*
- Psudaulascaspis pentagona* white peach scale
- Quadraspidotus perniciosus* San Jose scale
- Millar *et al.*, 2012. *J. Econ. Entomol.*, **105**, 497
- Roelofs *et al.*, 1977. *Nature*, **267**, 698
Roelofs *et al.*, 1978. *J. Chem. Ecol.*, **4**, 211
- Gieselmann *et al.*, 1979. *J. Chem. Ecol.*, **5**, 27
- Einhorn *et al.*, 1998. *PNAS*, **95**, 9867
- Ho *et al.*, 2014. *J. Chem. Ecol.*, **40**, 379
- Heath *et al.*, 1979. *J. Chem. Ecol.*, **5**, 941
Einhorn *et al.*, 1983. *C. R. Acad. Sci., Ser. III*, 296, 861
McLaughlin *et al.*, 1990. *J. Chem. Ecol.*, **16**, 749
- Gieselmann *et al.*, 1979. *J. Chem. Ecol.*, **5**, 891
Anderson *et al.*, 1981. *J. Chem. Ecol.*, **7**, 695

(F) References ②

Pseudococcidae

- Crisicoccus matsumotoi* [Matsumoto mealybug] Tabata *et al.*, 2012. *Naturwissenschaften*, **99**, 567
- Delottococcus aberiae* Vacas *et al.*, 2019. *J. Agric. Food Chem.*, **67**, 9441
- Dysmicoccus brevipes* [pineapple mealybug] Tabata *et al.*, 2017. *J. R. Soc. Interface*, **14**, 20170027
Mori & Tabata, 2017. *Tetrahedron*, **73**, 6530-6541
- Dysmicoccus grassii* Alfonso *et al.*, 2012. *J. Agric. Food Chem.*, **60**, 11959
- Dysmicoccus neobrevipes* [grey pineapple mealybug] Tabata & Ichiki, 2015. *J. Chem. Ecol.*, **41**, 194
Tabata & Ohno, 2015. *Appl. Entomo. Zool.*, **50**, 341
- Ferrisia virgate* [striped mealybug] Tabata & Ichiki, 2017. *J. Chem. Ecol.*, **43**, 745
- Maconellicoccus hirsutus* [hibiscus mealybug] Zhang *et al.*, 2004. *PNAS*, **101**: 9601
- Nipaecoccus viridis* [spherical mealybug] Levi-Zada *et al.*, 2019. *J. Chem. Ecol.*, **45**, 455
Levi-Zada *et al.*, 2021. *J. Agric. Food Chem.*, **69**, 3026
- Phenacoccus madeirensis* [Madeira mealybug] Ho *et al.*, 2009. *J. Chem. Ecol.*, **35**, 724
- Phenacoccus solenopsis* [cotton mealybug] Tabata & Ichiki, 2016. *J. Chem. Ecol.*, **42**, 1193
- Planococcus citri* [citrus mealybug] B.-Leonhardt *et al.*, 1981. *Tetrahedron Lett.*, **22**, 389
- Planococcus ficus* [vine mealbug] Hinkens *et al.*, 2001. *Tetrahedron Lett.*, **42**, 1619
- Planococcus kraunhiae* [Japanese mealybug] Sugie *et al.*, 2008. *Appl. Entomol. Zool.*, **43**, 369

(F) References ③

Pseudococcidae

Planococcus maritimus [grape mealybug]

Planococcus minoor [passionvine mealybug]

Pseudococcus baliteus [aerial root mealybug]

Pseudococcus calceolariae [citrophilous mealybug]

Pseudococcus comstocki [comstock mealybug]

Pseudococcus cryptus [citrus mealybug]
(= *P. citriculus*)

Pseudococcus longispinus [longtailed mealybug]

Pseudococcus viburni [obscure mealybug]

Figadère *et al.*, 2007. *Tetrahedron Lett.*, **48**, 8434

Ho *et al.*, 2007. *J. Chem. Ecol.*, **33**, 1986

Tabata *et al.*, 2020. *Tetrahedron Lett.*, **61**, 151802

El-Sayed *et al.*, 2010. *Tetrahedron Lett.*, **51**, 1075

Negishi *et al.*, 1980. *Appl. Entomol. Zool.*, **15**, 328

Bierl-Leonhardt *et al.*, 1980. *Life Sciences*, **27**, 399

Bierl-Leonhardt *et al.*, 1982. *J. Chem. Ecol.*, **8**, 689

Arai *et al.*, 2003. *J. Chem. Ecol.*, **29**, 2213

Millar *et al.*, 2009. *Org. Lett.*, **11**, 2683

Ramesh *et al.*, 2013. *J. Org. Chem.*, **78**, 6281

Millar *et al.*, 2005. *J. Chem. Ecol.*, **31**, 2999

Figadéra *et al.*, 2008. *Chem. Comm.*, 1106

(F) References ④

Margarodidae

Margarodes prieskaensis

Burger *et al.*, 2017. *J. Chem. Ecol.*, **43**, 94

Matsucoccus feytaudi [martime pine scale]

Einhorn *et al.*, 1990. *Tetrah. Lett.*, **31**, 6633
Jactel *et al.*, 1994. *J. Chem. Ecol.*, **20**, 2159

Matsucoccus josephi [Israeli pine bast scale]

Dunkelblum *et al.*, 1993. *Tetrah. Lett.*, **34**, 2805
Dunkelblum *et al.*, 1995. *J. Chem. Ecol.*, **21**, 849

Matsucoccus matsumurae [Japanese pine bast scale]

Lanier *et al.*, 1989. *J. Chem. Ecol.*, **15**, 1645
Hibbard *et al.*, 1991. *J. Chem. Ecol.*, **17**, 89
Mendel *et al.*, 2004. *Biolog. Control*, **30**, 134

Matsucoccus resinosae [red pine scale]

Lanier *et al.*, 1989. *J. Chem. Ecol.*, **15**, 1645
Hibbard *et al.*, 1991. *J. Chem. Ecol.*, **17**, 89
Shi *et al.*, 1995. *Tetrah. Lett.*, **36**, 7201

*Matsucoccus thunbergiana*e [black pine red scale]

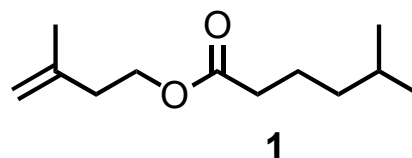
Lanier *et al.*, 1989. *J. Chem. Ecol.*, **15**, 1645
Hibbard *et al.*, 1991. *J. Chem. Ecol.*, **17**, 89
Park *et al.*, 1994. *J. Chem. Ecol.*, **20**, 2185

1. Acyclic compounds

See compound numbers in Zou & Millar, 2015
(*Nat. Prod. Rep.*, **32**, 10.1039/c4np00143e)

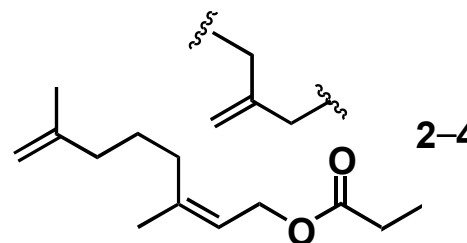
1-1. Hemiterpenol

Matsumoto mealybug



1-2. Esters of geraniol isomer

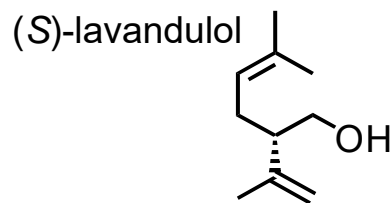
San Jose scale



+ (*E*)-isomer (minor comp.)

1-3. Esters of lavandulol and analogus

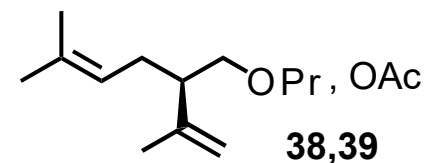
vine mealbug



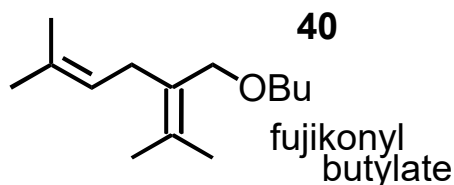
pink hibiscus mealybug



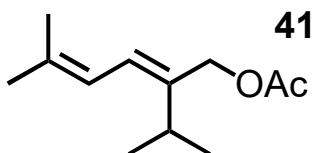
banana mealybug



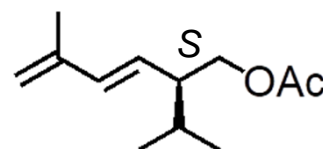
Japanese mealybug



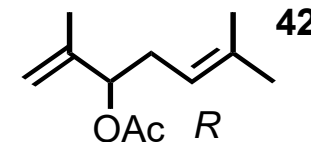
passionvine mealybug



grey pineapple mealybug

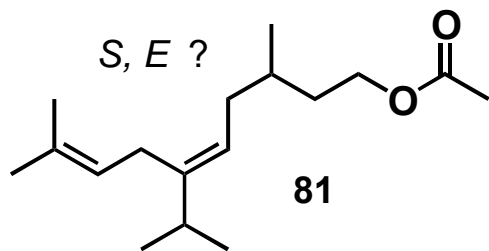


comstock mealybug

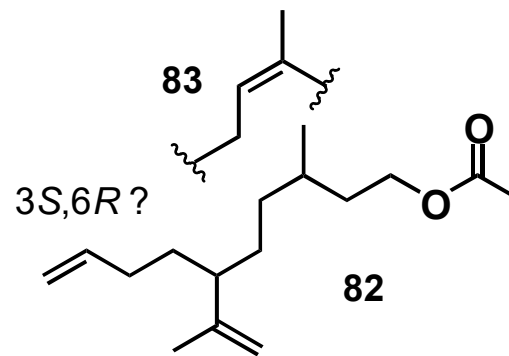


1-4. Esters of sesquiterpenols and analogus

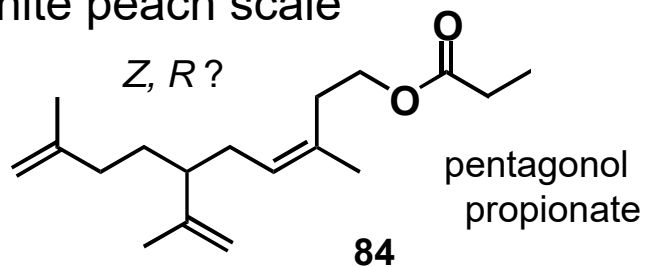
yellow scale



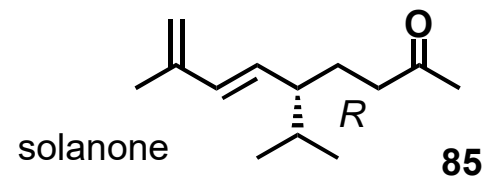
California red scale



white peach scale



Aulacaspis murrayae

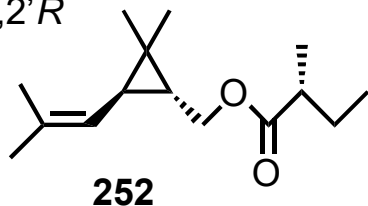


2. Cyclic compounds

2-1. Cyclopropane-containing pheromones

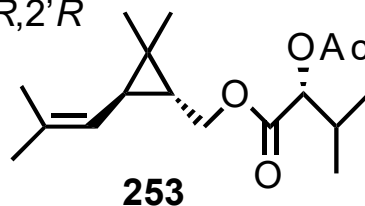
Madeira mealybug

1*R*,3*R*,2'*R*



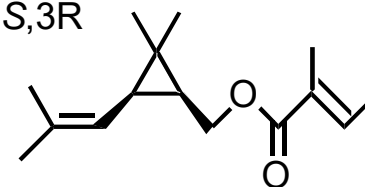
citrophilous mealybug

1*R*,3*R*,2'*R*



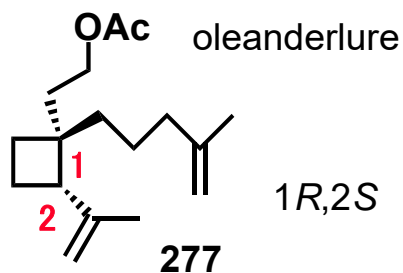
striped mealybug

1*S*,3*R*

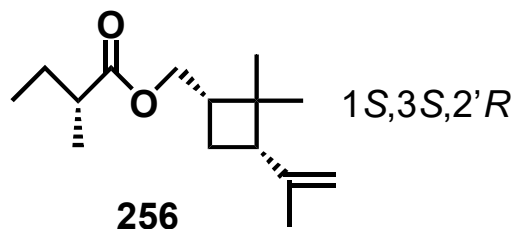


2-2. Cyclobutane-containing pheromones

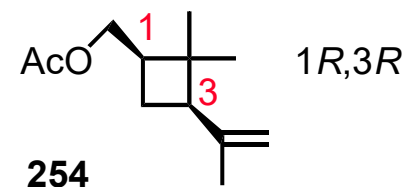
oleander scale



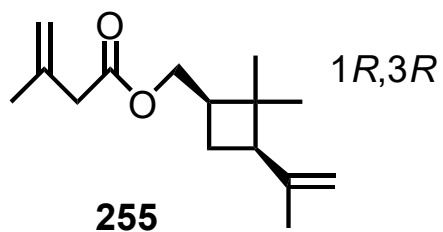
Acutaspis albopicta



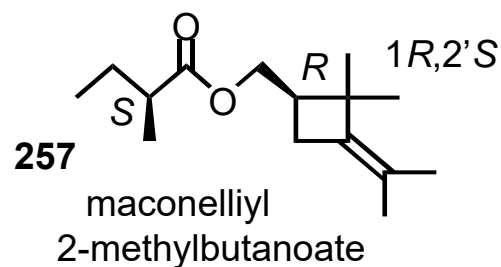
citrus mealybug



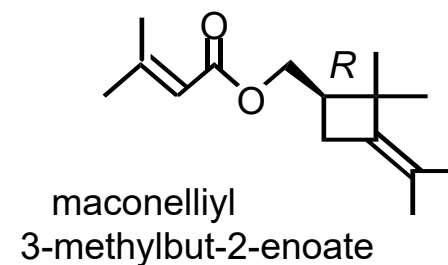
citriculus mealybug



pink hibiscus mealybug

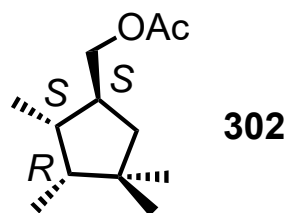


cotton mealybug

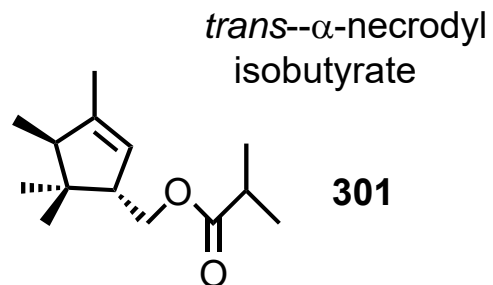


2-3. Cyclopenta(e)ne-containing pheromones

obscure mealybug



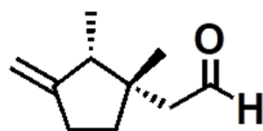
grape mealybug



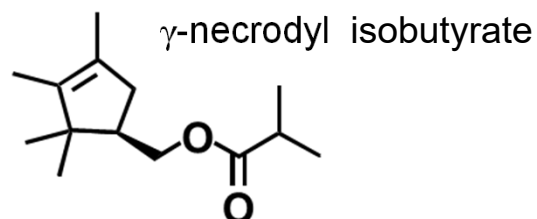
longtailed mealybug



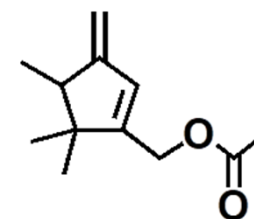
pineapple mealybug



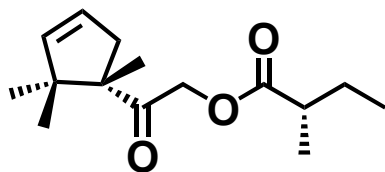
spherical mealybug



Delottococcus aberiae



aerial root mealybug

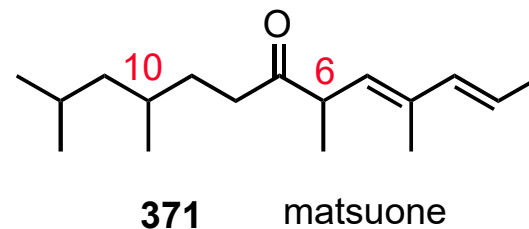


3. Polyketides (propanogenins)

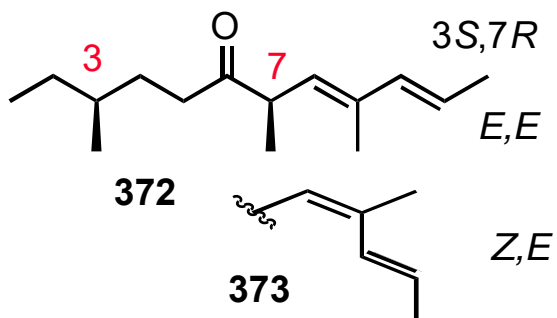
Japanese black pine bast scale $6R,10R$?

red pine scale $(6R,10R)$ -matsuone

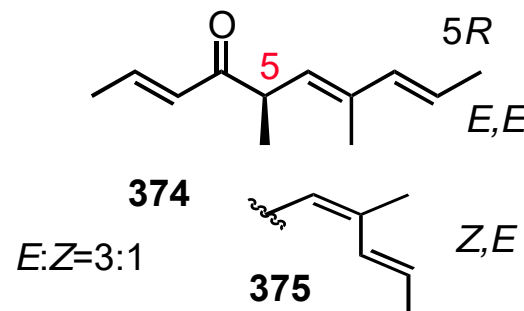
black pine bast scale $(6R,10R)$ -matsuone



maritime pine scale



Israeli pine bast scale



Margarodes prieskaensis

$Me_2, Me_4, Me_6, Me_8-11:OH$

