

ÍNDICE GENERAL.....	i
ÍNDICE DE FIGURAS.....	ix
ÍNDICE DE TABLAS.....	xv
LISTA DE ABREVIATURAS.....	xvii

ÍNDICE GENERAL

<u>INTRODUCCIÓN GENERAL</u>	1
1. Métodos de lucha contra plagas basados en semioquímicos	3
1.1 Las feromonas de insectos	4
1.2 Aislamiento e identificación de feromonas	6
1.3 Aplicación de las feromonas	7
1.3.1 Detección y seguimiento de poblaciones	7
1.3.2 Métodos directos de control	8
1.3.2.1 Captura masiva	8
1.3.2.2 Atracción y muerte/esterilización/infección	8
1.3.2.3 Confusión sexual	8
1.4 Ventajas del uso de las feromonas y dificultades para su desarrollo	9
1.5 Dispositivos emisores	10
1.6 Emisores basados en materiales porosos inorgánicos	13
2. EL PIOJO ROJO DE CALIFORNIA (<i>Aonidiella aurantii</i>)	16
2.1 Importancia y distribución	16
2.2 Biología de la plaga	17
2.3 Daños	18
2.4 Métodos de lucha	19
2.4.1 Métodos convencionales	19
2.4.2 Feromonas	21
3. EL BARRENADOR DEL ARROZ (<i>Chilo suppressalis</i>)	23
3.1 Importancia y distribución	23
3.2 Biología de la plaga	24
3.3 Daños	26
3.4 Métodos de lucha	26
3.4.1 Control químico	26
3.4.2 Feromonas	28
3.4.3 Otros	31
4. LA POLILLA DEL RACIMO (<i>Lobesia botrana</i>)	32
4.1 Importancia y distribución	32
4.2 Biología de la plaga	33

4.3 Daños.....	34
4.4 Métodos de lucha.....	34
4.4.1 Control químico.....	34
4.4.2 Control biológico.....	35
4.4.3 Feromonas.....	35
5. LA POLILLA DEL TOMATE (<i>Tuta absoluta</i>).....	38
5.1 Importancia y distribución.....	38
5.2 Biología de la plaga.....	39
5.3 Daños.....	40
5.4 Métodos de lucha.....	40
5.4.1 Control químico.....	40
5.4.2 Control biológico.....	41
5.4.3 Feromonas.....	41
6. LA MOSCA DEL OLIVO (<i>Bactrocera oleae</i>).....	44
6.1 Importancia y distribución.....	44
6.2 Biología de la plaga.....	44
6.3 Daños.....	45
6.4 Métodos de lucha.....	46
6.4.1 Control químico.....	46
6.4.2 Atrayentes y feromonas.....	46
6.4.3 Control biológico.....	48
7. LA MOSCA DEL MEDITERRÁNEO (<i>Ceratitis capitata</i>).....	49
7.1 Importancia y distribución.....	49
7.2 Biología de la plaga.....	49
7.3 Daños.....	50
7.4 Métodos de lucha.....	51
7.4.1 Control químico.....	51
7.4.2 Técnica del insecto estéril (TIE).....	52
7.4.3 Trampeo masivo.....	52
7.4.4 Feromonas.....	54
7.4.5 Control biológico.....	55
<u>JUSTIFICACIÓN Y OBJETIVOS.....</u>	59

CAPÍTULO I "The first account of the mating disruption technique for the control of California Red Scale, <i>Aonidiella aurantii</i> Maskell (Hemiptera: Diaspididae) using new biodegradable dispensers".....	65
I.1 Introduction	66
I.2 Material and methods	68
I.2.1 Field trials	68
<i>I.2.1.1 First trial year</i>	68
<i>I.2.1.2 Second trial year</i>	69
I.2.2 Evaluation of treatment efficacy	69
I.2.3 Mesoporous pheromone dispenser	70
I.2.4 Pheromone release profiles	70
I.2.5 Statistical analysis	71
I.3 Results	72
I.3.1 Dose-response trial: 2006	72
<i>I.3.1.1 Male catches</i>	72
<i>I.3.1.2 Fruit damage</i>	73
<i>I.3.1.3 Pheromone release profiles</i>	74
I.3.2 Dose-response trial: 2007	75
<i>I.3.2.1 Male catches</i>	75
<i>I.3.2.2 Fruit damage</i>	76
<i>I.3.2.3 Pheromone release profiles</i>	77
I.4 Discussion	78
CAPÍTULO II "Mating disruption of California red scale, <i>Aonidiella aurantii</i> Maskell (Hemiptera: Diaspididae), using biodegradable mesoporous pheromone dispensers".....	85
II.1 Introduction	86
II.2 Material and methods	88
II.2.1 Mesoporous dispenser and device	88
II.2.2 Experimental design	89
<i>II.2.2.1 Trial 1</i>	90
<i>II.2.2.2 Trial 2 and 3</i>	90
II.2.3 Evaluation of treatment efficacy	91
II.2.4 Pheromone release profiles	92
II.2.5 Statistical analysis	93
II.3 Results	93

II.3.1 Efficacy trials.....	93
<i>II.3.1.1. Male catches.....</i>	93
<i>II.3.1.2. Fruit damage.....</i>	96
II.3.2. Pheromone release profiles.....	99
II.4 Discussion.....	100

CAPÍTULO III “Different strategies to apply mating disruption for controlling *Aonidiella aurantii* Maskell (Hemiptera: Diaspididae)..... 105

III.1 Introduction.....	106
III.2 Material and methods.....	108
III.2.1 Mesoporous dispenser and device.....	108
III.2.2 Experimental design.....	108
III.2.3 Evaluation of treatment efficacy.....	110
III.2.4 Pheromone release profiles.....	111
III.2.5 Statistical analysis.....	111
III.3 Results.....	112
III.3.1 Efficacy of the different strategies.....	112
<i>III.3.1.1 Male catches.....</i>	112
<i>III.3.1.2 Fruit damage.....</i>	114
III.3.2 Pheromone release profiles.....	115
III.4 Discussion.....	116

CAPÍTULO IV “Studies on the development of a mating disruption system to control the tomato leaf miner, *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae).....121

IV.1 Introduction.....	122
IV.2 Material and methods.....	124
IV.2.1 Mesoporous pheromone dispensers.....	124
IV.2.2 Containment level trials.....	124
<i>IV.2.2.1 Low-containment trial.....</i>	124
<i>IV.2.2.2 High-containment trial.....</i>	125
IV.2.3 Efficacy trials.....	126
<i>IV.2.3.1 First trial: 2009.....</i>	126
<i>IV.2.3.2 Second trial: 2010.....</i>	127
IV.2.4 Evaluation of treatment efficacy.....	128
IV.2.5 Pheromone release profiles.....	128
IV.2.6 Statistical analysis.....	129

IV.3 Results.....	130
IV.3.1 Low-containment level trial: El Perelló 2008.....	130
IV.3.2 High-containment level trial: Paiporta 2009.....	132
IV.3.3 Efficacy trial: Alicante 2009.....	134
IV.3.4 Efficacy trial: Paiporta 2010.....	136
IV.3.5 Pheromone release profiles.....	138
IV.4 Discussion.....	140
CAPÍTULO V “Study on the optimum pheromone release rate for attraction of <i>Chilo suppressalis</i> Walker (Lepidoptera: Pyralidae)”.....	147
V.1 Introduction.....	148
V.2 Material and methods.....	149
V.2.1 Pheromone dispensers and traps.....	149
V.2.1.1 Standard dispenser.....	149
V.2.1.2 Mesoporous dispenser.....	150
V.2.1.3 Funnel traps.....	150
V.2.1.4 Light traps.....	150
V.2.2 Field trial.....	150
V.2.3 Pheromone release rates.....	151
V.2.4 Statistical analysis.....	152
V.3 Results.....	153
V.3.1 Pheromone release rates.....	153
V.3.2 Field trial.....	154
V.3.2.1 Population dynamics.....	154
V.3.2.2 Trap catches.....	157
V.4 Discussion.....	159
CAPÍTULO VI “Effect of sex pheromone emission on the attraction of <i>Lobesia Botrana</i>”.....	165
VI.1 Introduction.....	166
VI.2 Material and methods.....	167
VI.2.1 Pheromone dispensers and traps.....	167
VI.2.2 Field trial.....	168
VI.2.3 Pheromone emission rates.....	168
VI.2.4 Statistical analysis.....	169
VI.3 Results.....	170

VI.3.1 Pheromone emission rates.....	170
VI.3.2 Field trial: Trap catches.....	172
VI.4 Discussion.....	175
CAPÍTULO VII “Response of two tephritid species, <i>Bactrocera oleae</i> and <i>Ceratitis capitata</i> , to different emission levels of pheromone and parapheromone”.....	183
VII.1 Introduction.....	184
VII.2 Material and methods.....	186
VII.2.1 Olive fruit fly.....	186
VII.2.1.1 Traps and pheromones.....	186
VII.2.1.2 Field trial.....	186
VII.2.2 Mediterranean fruit fly.....	187
VII.2.2.1 Traps and pheromones.....	187
VII.2.2.2 Field trial.....	187
VII.2.3 Release rates.....	188
VII.2.4 Statistical analysis.....	189
VII.3. Results.....	189
VII.3.1 Release rates.....	189
VII.3.2 Field trial.....	191
VII.3.2.1 Trap catches.....	191
VII.3.2.2 Olive fruit fly.....	193
VII.3.2.3 Mediterranean fruit fly.....	194
VII.4 Discussion.....	196
CAPÍTULO VIII “Solid phase microextraction of volatile emissions of <i>Ceratitis capitata</i> (Wiedemann) (Diptera: Tephritidae): Influence of fly sex, age and mating status”.....	203
VIII.1 Introduction.....	204
VIII.2 Material and methods.....	206
VIII.2.1 Insects.....	206
VIII.2.2 Collection of volatiles.....	207
VIII.2.3 Detection and identification of volatiles.....	208
VIII.2.4 Statistical analysis.....	209
VIII.3 Results and Discussion.....	210
VIII.3.1 Overview of identified compounds.....	210
VIII.3.2 Data pretreatment.....	216

VI.3.4 PCA: Score plots.....	216
VI.3.5 PCA: Loading plots.....	219
VI.3.6 ANOVA results.....	222
VI.3.7 Relationship between emission pattern and reported blends.....	225
VI.4 Conclusions.....	226
 <u>DISCUSIÓN GENERAL</u>	229
<u>CONCLUSIONES</u>	253
<u>REFERENCIAS</u>	259

ÍNDICE DE FIGURAS

Introducción

Figura 1.1 Imagen del apareamiento de la polilla de la seda, <i>Bombyx mori</i> L.....	5
Figura 1.2 Túnel de viento (izq.) y olfatómetro en Y (dcha.) para ensayos biológicos de comportamiento.....	6
Figura 1.5.1 Tipos de cinéticas de emisión.....	11
Figura 1.5.2 Emisor de tipo <i>rubber septa</i>	12
Figura 1.6.1 Estructura de la sepiolita.....	14
Figura 1.6.2 Imágenes de emisores mesoporosos. Emisor para confusión sexual de <i>Lobesia botrana</i> (izq.) y emisor de acetato amónico para <i>Ceratitis capitata</i> (dcha.).....	15
Figura 2.2.1 Hembra adulta junto a dos <i>crawlers</i> (izq.) y macho adulto (dcha.) de <i>Aonidiella aurantii</i>	17
Figura 2.2.2 Hembra joven con pigidio extendido (izq.) y hembra grávida con <i>crawlers</i> (dcha.).....	18
Figura 2.3.1 Imagen de fruto atacado por piojo rojo de California.....	19
Figura 2.4.2.1 Moléculas componentes de la feromona de <i>Aonidiella aurantii</i>	21
Figura 2.4.2.2 Imagen de trampa pegajosa para el seguimiento de poblaciones de <i>Aonidiella aurantii</i>	22
Figura 2.4.2.3 Imagen del emisor TCB-RSD (Red Scale Down®).....	22
Figura 3.2.1 Imágenes del adulto, larva y puestas de <i>Chilo suppressalis</i>	25
Figura 3.3.1 Daños en espiga de segunda generación de <i>Chilo suppressalis</i> y larva en el interior de una caña.....	26
Figura 3.4.2.1 Molécula del (Z)-11-hexadecenal, componente mayoritario de la feromona de <i>Chilo suppressalis</i>	29
Figura 3.4.2.2 Emisor para confusión sexual de <i>Chilo suppressalis</i> Selibate®CS..	29
Figura 4.2.1 Imágenes del adulto y larva de <i>Lobesia botrana</i>	33
Figura 4.3.1 Daños de primera y tercera generación provocados por <i>Lobesia botrana</i> en racimos.....	34
Figura 4.4.3.1 Molécula del acetato de (<i>E,Z</i>)-7,9-dodecadieno, componente mayoritario de la feromona de <i>Lobesia botrana</i>	36
Figura 4.4.3.2 Emisor para confusión sexual de <i>Lobesia botrana</i> del tipo tubo de polietileno.....	37

Figura 5.2.1 Estadios larvarios (izq.) y pupas (dcha.) de <i>Tuta absoluta</i>	39
Figura 5.3.1 Insectos adultos (izq.) y planta de tomate gravemente atacada por <i>Tuta absoluta</i>	40
Figura 5.4.3.1 Molécula del acetato de (3E,8Z,11Z)-tetradecatrienilo, componente mayoritario de la feromona de <i>Tuta absoluta</i>	42
Figura 6.2.1 Pupas de <i>Bactrocera oleae</i> en el interior del fruto (izq.) e insecto adulto (dcha.).....	45
Figura 6.4.2.1 Molécula del 1,7-dioxaspiro[5.5]undecano, feromona de la hembra de <i>Bactrocera oleae</i>	47
Figura 6.4.2.2 Trampa pegajosa amarilla para seguimiento de poblaciones de <i>Bactrocera oleae</i>	47
Figura 7.2.1 Dimorfismo sexual en <i>Ceratitis capitata</i>	50
Figura 7.4.3.1 Mosquero para captura masiva de <i>Ceratitis capitata</i> y sistema de quimioesterilización Adress®.....	53

Capítulo I

Figure I.1 Male CRS catches per trap per day during the 2006 trial for pheromone treated plots, D8 and D20, and the untreated plot.....	72
Figure I.2 Mean percentage of damaged fruits observed inside the untreated and pheromone treated plots, D8 and D20, at the end of the 2006 season.....	73
Figure I.3 Relation between the amount of residual pheromone (in mg) and days of field exposure for the two types of dispensers (D8 and D20) tested in the 2006 trial.....	74
Figure I.4 Male CRS catches per trap per day during the 2007 trial for pheromone treated plots, D50 and D100, and the untreated plot.....	75
Figure I.5 Mean \pm SE percentage of damaged fruit inside the untreated and pheromone treated plots, D50 and D100, at the end of the 2007 season.....	76
Figure I.6 Relation between the amount of residual pheromone (in mg) and day of field exposure for the two types of dispensers (D50 and D100) tested in the 2007 trial.....	77

Capítulo II

Figure II.1 Male CRS catches per trap per week, in monitoring sticky traps, for mating disruption treated plots and control plots in Trial 1.....	94
---	----

Figure II.2 Male CRS catches per trap per week, in monitoring sticky traps, for mating disruption treated plots and control plots in Trial 2.....	95
Figure II.3 Male CRS catches per trap per week, in monitoring sticky traps, for mating disruption treated plots and control plots in Trial 3.....	95
Figure II.4 Mean percentage of damaged fruits observed inside the different plots: oil control, mating disruption (MD) and MD+oil treatment, for Trial 1.....	97
Figure II.5 Mean percentage of damaged fruits observed inside the different plots: untreated, oil control, mating disruption (MD) and MD+oil treatment, for Trial 2.....	98
Figure II.6 Mean percentage of damaged fruits observed inside the different plots: untreated, oil control, mating disruption (MD) and MD+oil treatment, for Trial 3.....	98
Figure II.7 Relationship between the remaining amount of pheromone in the mesoporous dispensers (mg) and the corresponding days of field exposure.....	99

Capítulo III

Figure III.1 Sketch showing the arrangement of the 11 plots in the field with the corresponding strategies.....	109
Figure III.2 Population dynamics of <i>Aonidiella aurantii</i> shown as males per trap per week (MTW) captured on the different mating disruption plots and the untreated plots.....	113
Figure III.3 Mean percentage of damaged fruits observed in the different plots. Bars labelled with the same letter do not differ significantly (ANOVA test P>0.05).....	114
Figure III.4 Evolution of the remaining load of pheromone on the mesoporous Dispensers (mg) versus time (days in orchard).....	116

Capítulo IV

Figure IV.1 Arrangement of the different plots inside the greenhouse for the 2009 efficacy trial (Alicante, Spain).....	127
Figure IV.2a Captures of <i>Tuta absoluta</i> , as moths per trap and day (MTD), in commercial monitoring traps for pheromone treated plots (T80 and T20) and the Reference plot.....	131
Figure IV.2b Damage level obtained in the mentioned plots (low-containment trial 2008), as percentage of plants with <i>T. absoluta</i> live stages (eggs, pupae or larvae).....	131

Figure IV.3a Captures of <i>T. absoluta</i> , as moths per trap and day (MTD), in commercial monitoring traps for the pheromone treated plot and the Reference plot with conventional chemical treatments.....	133
Figure IV.3b Damage level obtained in the mentioned plots (high-containment trial 2009), as percentage of plants with TLM live stages (eggs, pupae or larvae).....	133
Figure IV.4a Average captures of <i>T. absoluta</i> , as moths per trap and day (MTD), In commercial monitoring traps for the pheromone treated plots and the Reference plot with conventional chemical treatments.....	135
Figure IV.4b Damage level obtained in the mentioned plots (efficacy trial 2009), as percentage of plants with TLM live stages (eggs, pupae or larvae).....	135
Figure IV.5a Average captures of <i>T. absoluta</i> , as moths per trap and day (MTD), in commercial monitoring traps for the pheromone treated plots and the Reference plots with conventional chemical treatments.....	137
Figure IV.5b Damage level obtained in the mentioned plots (efficacy trial 2010), as percentage of plants with TLM live stages (eggs, pupae or larvae).....	137
Figure IV.6a Release profiles of (3E,8Z,11Z)-tetradecatrienyl acetate (TDTA), the major <i>T. absoluta</i> pheromone component of T80 dispenser from low containment trial 2008.....	139
Figure IV.6b Release profiles of (3E,8Z,11Z)-tetradecatrienyl acetate (TDTA), the major <i>T. absoluta</i> pheromone component of T20 dispenser from low containment trial 2008.....	139
Figure IV.6c Release profiles of (3E,8Z,11Z)-tetradecatrienyl acetate (TDTA), the major <i>T. absoluta</i> pheromone component of T60 dispenser from high containment trial 2009.....	139
Figure IV.6d Release profiles of (3E,8Z,11Z)-tetradecatrienyl acetate (TDTA), the major <i>T. absoluta</i> pheromone component of T80 dispenser from efficacy trials 2009-2010.....	139

Capítulo V

Figure V.1 Release profile of Z11-16:Ald, the major <i>C. suppressalis</i> pheromone component, from the two kinds of dispensers tested.....	154
Figure V.2 Population dynamics of <i>C. suppressalis</i> in trial area according to the total number of moth catches recorded in 8 light traps.....	155
Figure V.3 Moth catches per trap per day (MTD) along the growing season of the rice for each type of baited trap.....	155

Figure V.4. Means and 95% LSD intervals corresponding to factor emission, from the ANOVA carried out with data in Table V.1.....	159
---	-----

Capítulo VI

Figure VI.1 Release profiles of (<i>E,Z</i>)-7,9-dodecadienyl acetate, the major <i>Lobesia botrana</i> pheromone component, from the three kinds of dispenser tested.....	172
Figure VI.2 Average number of moths caught per trap and week (MTW) for each of five types of baited trap, with t the day of inspection.....	173
Figure VI.3 Scatter plot and fitted regression model (equation 7) of $\sqrt{N_c}$ – ASB vs. SRE (square root of emission).	174

Capítulo VII

Figure VII.1 Release dynamics of spiroacetal from commercial polyethylene dispensers.....	190
Figure VII.2 Release dynamics of trimedlure from commercial mesoporous dispensers.....	191
Figure VII.3 Average Olive fruit fly catches per trap per week obtained in yellow PVC sticky boards baited with commercial spiroacetal dispensers.....	192
Figure VII.4 Average Mediterranean fruit fly catches per trap per week obtained in Moskisan® traps baited with mesoporous TML dispensers.....	192
Figure VII.5 Captures of <i>B. oleae</i> and 95% LSD intervals corresponding to factor emission for spiroacetal release rates. Curve represents the quadratic model that best fits the mean values of captures according to emission rates.....	195
Figure VII.6 Captures of <i>C. capitata</i> and 95% LSD intervals corresponding to factor emission for trimedlure release rates. Interval overlapping indicates the lack of a maximum attraction value.....	195

Capítulo VIII

Figure VIII.1a Score plot (t[1] vs. t[2]) for the first and second principal components obtained from the emission matrix.....	217
Figure VIII.1b Score plot (t[2] vs. t[1]) for the PCA using male's observations.....	217
Figure VIII.1c Score plot (t[2] vs. t[1]) for the PCA using female's data.....	217
Figure VIII.2 Loading plot ($p[1]^3$ vs. p[2]) for the PCA carried out with the emission matrix, corresponding to the score plot in Figure VIII.1a	220

Figure VIII.3 Loading plot ($p[2]$ vs. $p[1]$) for the PCA carried out using female's observations, corresponding to the score plot in Figure VIII.1c	221
Figure VIII.4 Loading plot ($p[2]$ vs. $p[1]$) for the PCA carried out using male's observations, corresponding to the score plot in Figure VIII.1b	221
Figure VIII.5 Interaction plot and 95% LSD intervals of 10 ANOVAs conducted with factor sex (males: thicker solid lines; females: thinner dashed lines) and factor age \times status with 4 variants (v3: virgin 3-d old; v9: virgin 9-d old; m3: mated 3d old; m9: mated 9-d old).....	223

ÍNDICE DE TABLAS

Tabla 1 Categorías de semioquímicos.....	4
 <u>Capítulo I</u>	
Table I.1 Mean±SE males per trap per week for each dispenser during the whole season and over separate flights in the 2007 trial.....	76
 <u>Capítulo II</u>	
Table II.1 Mean and SE males per trap per day, mating disruption index (MDI) and statistical parameters obtained by analysis of variance (ANOVA), during 2 nd and 3 rd flights. Means in a row followed by the same letter are not significantly different (ANOVA test, $P>0.05$).....	96
 <u>Capítulo III</u>	
Table III.1 Mean ± SE males per trap per day (MTD), mating disruption index (MDI), and statistical parameters obtained by analysis of variance (ANOVA).....	113
 <u>Capítulo V</u>	
Table V.1. Number of catches of <i>C. suppressalis</i> in traps baited with pheromone dispensers.....	156
 <u>Capítulo VI</u>	
Appendix VI	179
 <u>Capítulo VIII</u>	
Table VIII.1 Compounds detected in the experiments of medfly emissions According to sex, age and mating status.....	214
Table VIII.2. Summary overview of the four principal components (PC) obtained from the emission matrix.....	218

