Vacas González, S.; Miñarro, M.; Bosch, M.; Primo Millo, J.; Navarro Llopis, V. (2013). Studies on the Codling Moth (Lepidoptera: Tortricidae) Response to Different Codlemone Release Rates. ENVIRONMENTAL ENTOMOLOGY. 42(6):1383-1389. doi:10.1603/EN13114

V. Navarro-Llopis
Centro de Ecología Química Agrícola-
Instituto Agroforestal del Mediterráneo
Universitat Politècnica de València
Edificio 6C, Camino de Vera s/n 46022,
Valencia, Spain.
Phone: +34 963879058
Fax: +34 963879059
Email: vinallo@ceqa.upv.es

Studies on the codling moth (Lepidoptera: Tortricidae) response to different codlemone release rates

S. Vacas[1], M. Miñarro[2], M. D. Bosch [3], J. Primo[1] and V. Navarro-Llopis[1]

[1] Centro de Ecología Química Agrícola – Instituto Agroforestal del Mediterráneo (CEQA-IAM). Universitat Politècnica de València, edificio 6C, 5ª planta. Cmno de Vera s/n 46022 Valencia (Spain)

[2] Servicio Regional de Investigación y Desarrollo Agroalimentario. Les Baragañes, s/n. Apdo 13, Villaviciosa 33300, Asturias (Spain)

[3] Centre UdL-IRTA de Lleida, Rovira Roure 191, 25198 Lleida (Spain)

ABSTRACT

The response of the codling moth [*Cydia pomonella* L. (Lepidoptera: Tortricidae)] to different emission values of its main pheromone component, 8*E*,10*E*-dodecadien-1-ol (codlemone), was investigated in three field trials conducted in plots without mating disruption treatments. Moth catches obtained in traps baited with pheromone dispensers were correlated with the corresponding codlemone release rates by multiple regression analysis. In a preliminary trial conducted in Lleida (NE Spain), a decreasing trend of captures was observed based on increasing pheromone levels. After this, the pheromone release profiles of the pheromone dispensers were studied, in parallel with the field trials, by residual codlemone extraction and gas-chromatography quantification. In the trials carried out in Asturias (NW Spain), a correlation between trap catches and emission levels (within the range from 11 to 1078 μg/day) was found and fitted a logarithmic model. Captures followed a decreasing linear trend in the range of emission rates from 11 to 134 μg/day. Given that release values comprised between 11 and 67 μg/day did not lead to significantly different catches in traps, this emission range could be considered to develop effective formulations for attraction purposes when mating disruption is not acting in the environment.

KEYWORDS: *Cydia pomonella*, pheromone, mesoporous dispensers, release rate, mating disruption

55 The implementation of pheromone-delivery technologies in pest management programs requires
56 practical decisions on pheromone loads, blends, release rates and densities of dispensers. All
57 these aspects depend on each particular release device and potentially impact efficacy of the
58 control method (Weatherstone et al. 1985). Knowledge about optimum emission levels is a key
59 factor to improve the control methods based on the use of pheromones to attract insects to traps
60 or other kind of devices (monitoring, mass trapping, or 'attract-and-kill') because release rates
61 severely affect the attractiveness of the lure, and catches may decrease below and above this level
62 (Jacobson and Beroza 1964, Anshelevich et al. 1994, Zhang and Amalin 2005). In the same way,
63 a dispenser with an appropriate pheromone release rate is also necessary to achieve good mating
64 disruption efficiency and to extend its implementation. The cost of pheromone applied per
65 hectare is critical for mating disruption treatments; thus, pheromone emission from dispensers
66 must be controlled and optimized.
67 In the case of the codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae) control,
68 methods based on pheromones have become a cornerstone in orchard management programs
69 offering an alternative to conventional insecticides, together with the microbial control agents,
70 such as codling moth granulovirus (Miñarro and Dapena 2000, Arthurs et al. 2005) or
71 entomopathogenic nematodes (Lacey et al. 2006). From its discovery and synthesis, the main
72 component of the codling moth pheromone, 8*E*,10*E*-dodecadien-1-ol, codlemone (Roelofs et al.
73 1971), has been widely used for monitoring and implementing mating disruption as a
74 commercially viable pest management technique. In recent years, mating disruption is a
75 successful technique used to control codling moth on more than 160,000 ha worldwide (Witzgall
76 et al. 2008).
77 Although a few studies have reported on codling moth response to traps baited with increasing
78 pheromone loads (Kehat et al. 1994, Mitchell et al. 2008), emission rates were not assessed.

Thus, trap catches have not been correlated with emission values and optimal release rates for attraction have not been proposed. Moreover, thresholds of pheromone concentration, and thus emission rates, needed for communication disruption of codling moth are not yet established with certainty. Many studies have reported mating disruption thresholds for codling moth based on the experimental results of efficient treatments (Cardé et al. 1977, Charmillot 1990, Knight 1995, Vickers et al. 1998). However, the minimum emission rate for effective mating disruption has not yet been established.

The aim of this study was to determine which maximum emission should be employed for monitoring purposes in orchards without a background level of pheromone. For this purpose, dose-response correlations were studied by comparing different codlemone release rates using traps baited with pheromone dispensers in three field trials conducted in two different provinces of Spain with different climates. Calculated emission rates were correlated by multiple regression analysis with their corresponding catches achieved.

Material and Methods

Pheromone Dispensers and Traps. New pheromone dispensers, with different loads and sizes, were elaborated based on the technology of inorganic molecular sieves (Corma et al. 1999, 2000). The dispenser matrix is sepiolite, a natural clay mineral with a high adsorptivity for organic molecules. Sepiolite is impregnated with the corresponding amount of pheromone in dichloromethane solution and different additives to give consistency and protect the dispenser against humidity. The impregnated material is then compressed in a cylindrical mold by means of a hydraulic press. The technology of mesoporous dispensers has been employed as part of the Adress System commercialized by Syngenta (Madrid, Spain) against *Ceratitis capitata* (Wiedemann) (Navarro- Llopis et al. 2007) or more recently, for mating disruption dispensers

against the California red scale (Vacas et al. 2009, 2010). The manufacturing process has been licensed to Ecologia y Protección Agrícola S.L. (Valencia, Spain) who has manufactured the dispensers for these trials.

Two mesoporous cylindrical tablets were formulated for the preliminary Lleida-2011 trial: C5 with 5 mg of pheromone load, 10 mm in diameter and 4 mm high; C30 loaded with 30 mg (13 mm diameter, 11 mm high). The C5 formulation was also employed in the trials carried out later in Asturias. A new mesoporous dispenser loaded with 50 mg of pheromone (C50) was included in the Asturias-May 2012 trial to obtain higher emission levels; these were also cylindrical tablets 13 mm in diameter and 11 mm high. The Asturias-July 2012 trial included a new formulation C1 loaded with 1 mg of pheromone (10 mm diameter, 3 mm high). Codlemone was employed as sex pheromone at 93% purity, provided by Bedoukian Research Inc. (Danbury, CA, USA).

The delta traps and sticky bases used in the trials were supplied by Sanidad Agrícola Econex, SL (Murcia, Spain). Each trap was baited with the corresponding pheromone dispensers, as described in the next section.

Field Trials

Preliminary Lleida-2011 Trial. The first field experiment was carried out in a 10 year-old 7-ha apple orchard located in the municipality of Bellpuig (province of Lleida – NE Spain; 41º 38’ N, 1º 2’E) in July and August 2011. The orchard cultivars were Royal Gala and Golden Suprema. Orchards received one ovicidal treatment (fenoxycarb) to control the first generation and four organophosphate insecticide applications throughout the season, using pheromone traps as indicators of the pest level. Orchards did not have mating disruption treatments. To evaluate the capture efficiency of different pheromone emission levels, five traps were used in five fully randomized blocks, baited with the following pheromone dispensers: (A5) 1x5-mg dispenser,

(A15) 3x5-mg dispensers, (A30) 1x30-mg dispenser, (A60) 2x30-mg dispensers, and (A90) 3x30-mg dispensers. Traps were hung in the canopy of apple trees at an approximate height of 2.5 m and were spaced at least 25 m apart, while blocks were placed 30 m away. Traps were rotated once a week in the block, and trials finished after two complete trap position rotations. Traps were placed in the field from 22 July 2011 to 29 August 2011.

Asturias-May 2012 Trial. Based on the preliminary results, we decided to perform a second field trial to test the existence of pheromone release thresholds that reduce trap catches by including higher emission rates. Six cider-apple orchards located in Asturias (NW Spain; 43º 30'N, 5º 30'W) were selected. All the orchards were managed following organic guidelines (Table 1). The distance between orchards varied between 150 m and 18.5 km. To evaluate the catch efficiency of the different emission levels, five traps with different pheromone dose were placed at each orchard. Pheromone dose in each one of the five traps per orchard was: C5 (1 x 5-mg dispenser), C20 (4 x 5-mg dispensers), C50 (1 x 50-mg dispenser), C100 (2 x 50-mg dispenser), and C200 (4 x 50-mg dispensers). The intertrap distance was at least 30 m. Traps were hung at 1.5 m above the ground, and were revised and rotated weekly from 10 May 2012 to 6 June 2012. The characteristics of each plot are described in Table 1.

Asturias-July 2012 Trial. The experiment was carried out in July and August 2012 in the same apple orchards and with the same methodology described above. The traps in each block were baited with a different pheromone dose and are referred to hereafter as C1 (1 x 1-mg dispenser), C3 (3 x 1-mg dispensers), C5 (1 x 5-mg dispenser), C10 (2 x 5-mg dispensers), and C20 (4 x 5-mg dispensers). Traps were placed on 11 July 2012, and the moths caught were counted weekly for five weeks.

Pheromone Release Profiles. Additional dispensers were simultaneously aged under field conditions in nearby areas of the trial orchards in Asturias, to be periodically gathered and analyzed to study their release profiles. The residual codlemone content was extracted at different aging dates. Three dispensers per ageing date were extracted by solvent extraction at 40ºC for 2 h, with magnetic agitation, in a particular volume of dichloromethane as follows: 2, 5 or 25 ml for dispensers C1, C5 and C50 respectively. Extracts were then analyzed by gas chromatography with a flame ionization detector (GC/FID), and pheromone content was quantified using *n*-heptadecane as the internal standard. After 1 hour of extraction, 0.5 ml of the internal standard solutions were added with the following concentrations: 1 mg/ml in extracts of dispensers C1 and 6 mg/ml in extracts of dispensers C5 and C50. All the analysis were performed using a Clarus®500 gas chromatograph (PerkinElmer Inc., Wellesley, USA) equipped with a ZB-5 (30 m × 0.25 mm × 0.25 mm) capillary column (Phenomenex Inc., Torrance, CA), maintained at 120ºC for 2 min and then raised by 20ºC/min to 260ºC, to be then maintained for 3 min. Temperature of the injection port was 250ºC, and FID detector was set at 300ºC. The carrier gas was helium at 1.5 ml/min.

Statistical Analysis. The quantified residual pheromone loads [P (mg)] for each dispenser were fit by polynomial regression with the independent variable *t* (number of ageing days). The first derivative of the resulting equations provided an estimation of the daily emission rate.

The captures recorded in each trap, as moths per trap and day, were transformed by sqrt (x) to normalize variance prior to applying a multifactor ANOVA (Fisher's LSD test at $P \leq 0.05$) to study the differences between trap catches according to three factors: week, block and emission level. Following the methodology applied in a previous study (Vacas et al. 2009), multiple or simple regression was used to study the relationship between catch data and the pheromone

emission rates tested. First, a two-way ANOVA was performed with catch data only with factors week and block. The residuals of this ANOVA did not account for variance due to the two factors week and block, and still provided evidence for variance due to the emission level factor. Thus, these residuals were employed in the regression analysis to obtain the correlation explaining the effect of the emission factor over trap catches. Statistical analyses were performed using the Statgraphics Centurion XVI package (StatPoint Technologies, Warrenton, VA, USA).

Results

Preliminary Lleida-2011 Trial. In our preliminary trial (Lleida-2011), population levels were very low throughout the study period; in fact, only 44 moths were captured in the 25 traps. Therefore, analysis of variance was performed with the total numbers of moths captured per trap and day throughout the trial for the different baited traps. No significant differences were found for emission factor ($F = 1.14$; $df = 4,16$; $P = 0.371$, in Fig. 1), whereas the block factor was significant ($F = 7.81$; $df = 4,16$; $P = 0.001$) due to the natural clumped distribution of the pest. Despite not being significant, the data suggest a trend of decreasing capture with increasing pheromone release rates. According to this result, we tested higher pheromone emission rates in the Asturias-May trial to confirm the decreasing trend in the number of captures.

Pheromone Release Profiles. The release profile of mesoporous dispenser C1 is depicted in Fig. 2A. Multiple linear regression performed with the mean residual pheromone values demonstrated that the quadratic effect was not statistically significant for C1 (significance of the quadratic coefficient: $P = 0.48$) and that the residual pheromone (mg) content fitted the linear model ($P < 0.001$, $R^2 = 0.98$) given by Equation 1. Thus, the slope of the linear model gave the emission rate of the dispenser, which was assumed constant and equal to 11.0 μg/day throughout

198 the study period. Likewise, the release profile of C5 (Fig. 2B) fitted the linear model in Equation
199 2 (P = 0.002, R^2 = 0.94; significance of quadratic coefficient: P = 0.10), corresponding to a mean
200 release value of 33.5 μg/day, throughout the study period. Finally, multiple linear regression
201 showed that the quadratic effect was not statistically significant for formulation C50 (significance
202 of the quadratic coefficient: P = 0.89), and that the residual codlemone content once again fitted a
203 linear model (Equation 3; P = 0.003, R^2 = 0.91). Thus, the emission rate of dispenser C50 given
204 by the slope of the linear model (Fig. 2C) was constant and equalled 269.5 μg/day.
205 $P_{C1} = 0.9485 - 0.0110 \cdot t$ (Eq. 1)
206 $P_{C5} = 5.2519 - 0.0335 \cdot t$ (Eq. 2)
207 $P_{C50} = 50.1351 - 0.2695 \cdot t$ (Eq. 3)
208
209 **Asturias 2012 Field Trials.** The sqrt-transformed catches were analyzed with multifactor-
210 ANOVA, considering the factors emission, week and block. None of the possible interactions
211 between factors resulted in statistically significant effects (week × block: F = 1.21; df = 15,59; P
212 = 0.29, week × emission: F = 0.92; df = 12,59; P = 0.54, block × emission: F =1.18; df = 20,59; P
213 = 0.30) and were disregarded from the final analysis. The emission factor was statistically
214 significant (F = 10.55; df = 4,106; P < 0.001), thus confirming the trend observed in Lleida-2011
215 trial. The higher the pheromone load, the fewer the catches obtained (Fig. 3A); the traps baited
216 with 5 mg dispensers trapped significantly more moths than those baited with 50 mg dispensers.
217 This suggests that the attractant power diminished with the emission level. Furthermore, the week
218 factor was statistically significant (F = 7.71; df = 3,106; P < 0.001), according to the pest
219 population dynamics, as well as the effect of the block factor (F = 5.32; df = 5,106; P < 0.001).
220 According to the release studies described before, each baited trap had a different emission
221 level. By considering release profiles of dispensers C5 and C50 and the calculated release rates

222 according to Eqs. 1 and 2, the emission factor could be considered a quantitative variable
223 according to the following correspondence: C5 = 33.5 μg/day, C20 = 134 μg/day, C50 = 269.5
224 μg/day, C100 = 539 μg/day, and C200 = 1078 μg/day. A strong relationship was found by the
225 regression analysis given the logarithmic model ($P = 0.003$, $R^2 = 0.96$) depicted in Fig. 4.
226 Accordingly, catches dropped almost linearly with increasing emission rates from 33.5 to 269.5
227 μg/day; then, they continued to lower slightly up to the highest studied release level of 1,078
228 μg/day (Fig. 4). Then, captures were reduced by 86%, as compared with traps baited with C5
229 dispensers.
230 Smaller pheromone doses were tested in July, and the number of moths trapped in C1, C3, C5
231 and C10 traps were not significantly different (Fig. 3B); only when traps were baited with four
232 C5 dispensers (C20) did mean captures start to decrease. The significance of the studied factors is
233 given by the following statistics obtained by multifactor-ANOVA: week $F = 13.88$; $df = 4,116$; P
234 < 0.001; block $F = 6.21$; $df = 5,116$; $P < 0.001$; and emission $F = 5.25$; $df = 4,116$; $P = 0.003$.
235 Only the interaction between week and block was statistically significant and the other factors
236 were consequently disregarded from the analysis (week × block: $F = 2.78$; $df = 20,116$; $P <$
237 0.001). This interaction resulted in a significant effect due to a reduction of captures in the block
238 number 3 during the last week of trial, while captures increased in the other plots.
239 By considering the aforementioned release profiles for dispensers C1 and C5, the emission
240 factor in this trial took the following values: C1 = 11 μg/day, C3 = 33 μg/day, C5 = 33.5 μg/day,
241 and C20 = 134 μg/day. The linearity of the decreasing attraction of *C. pomonella* to codlemone-
242 baited traps was confirmed by the multiple regression results depicted in Fig. 5 ($P < 0.001$, $R^2 =$
243 0.95). Thus, *C. pomonella* attraction could be promoted with codlemone emission rates up to 67
244 μg/day, while release rates above ca. 134 μg/day achieved significantly lower captures.
245

Discussion

The present work has employed different mesoporous dispensers, with pheromone loads ranging from 1 to 50 mg, as tools to study the codling moth response to different codlemone emission rates. Our preliminary trial suggested a decreasing trend of captures in accordance with increasing pheromone loads within the range 5-90 mg. This response has been previously reported in the literature: Kehat et al. (1994) found increasing catches of codling moth males with increasing pheromone doses, within the 0.1–100 μg range, but a 5,000 μg load was significantly less attractive than 100 or 1,000 μg loaded on a rubber septum. Similarly, Mitchell et al. (2008) showed that by increasing the load from 1 to 10 mg, the mean number of male moths captured decreased, while no differences were observed within the 0.01-0.1mg range. The same response was observed in the wind tunnel assays performed to develop an attract-and-kill strategy (Lösel et al. 2000). Maximal captures were achieved at a concentration of 0.065% codlemone in a 100 μl droplet, and a reduction of more than 50% in the average number of moths trapped was obtained with pheromone concentrations that were 10 times higher (0.65%). However, all these works address insect responses based on the initial pheromone loads of the dispensers, which do not provide a conclusive idea about actual pheromone release as it is highly affected by dispenser type. For example, Critchley et al. (1997) demonstrated that 1 mg-loaded polyethylene vials caught significantly more moths than rubber septa with the same amount of ingredient. In fact, rubber dispensers have non-linear kinetics, which means that emission can greatly vary between the beginning and the end of their lifespan and even on the same day due to temperature (Domínguez-Ruíz et al. 2008).

In the present work, field trap catches and pheromone release profiles of the dispensers employed were studied simultaneously and correlated to verify the existence of an optimum release value for attraction or whether the decreasing trend observed becomes asymptotic at

higher release rates. Although field trials were conducted in representative plots, the statistical analysis performed takes the block factor as a fixed factor, and therefore results obtained are valid only in the areas where trials were conducted. For this reason, field trials were conducted in the two main apple growing areas of Spain; nevertheless, these results should be validated in regions with different conditions and population levels.

In our experiments, it was found that emission rates within the range 11-67 μg/day did not lead to significantly different catches in monitoring traps. At higher values, however, moth catches decreased significantly. Nevertheless, the effect of very low emission rates (< 11 μg/day) remains uncertain; probably, a positive relationship could be observed with increasing release rates in a much lower range. With the data obtained, the multiple regression highlights a pronounced drop in captures with codlemone emissions up to 269 μg/day, which continue slightly decreasing up to the highest release level studied, that of 1,078 μg/day (only 2 moths were captured in the 6 traps with this codlemone emission during the 4-week trial). This result was possibly due to sensory adaption or sensory overload effect in the vicinity of the lure, a mechanism that has been proposed for mating disruption (Cardé and Minks 1995).

Although the minimum rate for effective mating disruption has not been established with certainty, estimates vary widely and range from 2 to 40 mg/ha/h (Cardé et al. 1977, Charmillot 1990, Vickers et al. 1998), and may vary in any case depending on population density, tree size and other environmental factors (Howell et al. 1990; McDonough et al. 1992). The aforementioned mating disruption pheromone doses correspond to the individual dispenser release rates within the 29-240 μg/day range, applied at 1,000-2,000 dispensers/ha. The dispensers described by Angeli et al. (2007) fall within this emission range (mean ca. 56 μg/day); however, these pheromone emission rates are 10-50 times lower than those of several other commonly used dispensers for the conventional mating disruption of *C. pomonella*, with reported

294 mean release values from 0.6 to 3 mg/day (Brown et al. 1992, Knight 1995, Tomaszewska et al.
295 2005, Femenia 2011). These efficient mating disruption dispensers agree with the results
296 presented herein as captures were virtually zero in the traps baited with codlemone dispensers
297 releasing at a rate ca. 1 mg/day.

298 The use of pheromone dispensers for monitoring purposes allows following population
299 dynamics, detecting the presence of adults, assessing mating disruption efficacy, and even
300 establishing timings and thresholds for control measures. Yet the pheromone release rates should
301 be standardized for many of these purposes. The application of synthetic pheromone in a mating
302 disruption program may change the relative attraction of pheromone lures; consequently,
303 monitoring dispensers loaded with 1 mg of pheromone can prove unreliable indicators of efficacy
304 (Thomson et al. 2001), giving false negatives when used in a mating disruption environment. In
305 this case, the sensitivity of pheromone traps can be improved by baiting traps with stronger lures
306 (i.e. 10 mg of pheromone lures) to establish a high emission point source within a pheromone
307 treated area (Charmillot 1990, Calkins et al. 2003). This applies not only to mating disruption
308 efficacy assessments, but also in general to establish when control measures should be adopted.
309 Insect response to the attractant can decrease below and above a particular emission interval
310 (Jacobson and Beroza 1964, Roelofs et al. 1977, Howse 1998, Zhang and Amalin 2005);
311 therefore, establishing treatment thresholds, according to trap catches, without including the
312 actual release rates of the dispensers or employing suboptimal emission rates may result in
313 underestimated population levels.

314 Attract-and-kill or attract-and-remove strategies are being studied as alternatives to mating
315 disruption treatments (Charmillot et al. 2000, Lösel et al. 2000, Krupke et al. 2002, Reinke et al.
316 2012). As mentioned before, knowledge about optimum release rates is essential for control
317 methods based on pheromones as attractants. When there is no pheromone background, the

emission range reported in this work (11-67 μg/day) could be considered to develop effective formulations for attraction purposes because commercial dispensers can be designed in accordance with this value for better pheromone use.

Acknowledgements

We thank Alejandro Núñez for field assistance in Asturias and farm owners for allowing us to work in their orchards.

References cited

Angeli, G., G. Anfora, M. Baldessari, G. S. Germinara, F. Rama, A. De Cristofaro, and C. Ioriatti. 2007. Mating disruption of codling moth *Cydia pomonella* with high densities of Ecodian sex pheromone dispensers. J. Appl. Entomol. 131: 311–318.

Anshelevich, L., M. Kehat, E. Dunkelblum, and S. Greenberg. 1994. Sex pheromone traps for monitoring the European vine moth, *Lobesia botrana* – Effect of dispenser type, pheromone dose, field aging of dispenser, and type of trap on male captures. Phytoparasitica 22: 281–290.

Arthurs, S. P., L. A. Lacey, and R. Fritts Jr. 2005. Optimizing use of Codling moth granulovirus: effects of application rate and spraying frequency on control of Codling moth larvae in Pacific Northwest apple orchards. J. Econ. Entomol. 98(5): 1459-1468.

Brown, D. F., A. L. Knight, J. F. Howell, C. R. Sell, J. L. Krysan, and M. Weiss. 1992. Emission characteristics of a polyethylene pheromone dispenser for mating disruption of codling moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 85: 910-917.

Calkins, C. O., and R. J. Faust. 2003. Overview of area-wide programs and the program for suppression of codling moth in the western USA directed by the United States Department of Agriculture-Agricultural Research Service. Pest Manag. Sci. 59:601–604.

Cardé, R. T., T. C. Baker, and P.J. Castrovillo. 1977. Disruption of sexual communication in *Laspeyresia pomonella* (codling moth), *Grapholitha molesta* (oriental fruit moth) and *G. prunivora* (lesser appleworm) with hollow fiber attractant sources. Ent. Exp. Appl. 22: 280-288.

Cardé, R. T., and A. K. Minks. 1995. Control of moth pests by mating disruption: successes and constraints. Ann. Rev. Entomol. 40: 559-585.

Charmillot, P. J. 1990. Mating disruption technique to control codling moth in Western Switzerland. In Ridgway, R.L., R.M. Silverstein, and M.N. Inscoe (eds.), Behavior-modifying chemicals for insect management. Marcel Dekker Inc., New York, NY, USA, p. 165-182.

Charmillot, P. J., D. Hofer, and D. Pasquier. 2000. Attract and kill: a new method for control of the codling moth *Cydia pomonella*. Entomol. Exp. Appl. 94: 211–216.

Corma, A., J. Muñoz-Pallarés, and E. Primo-Yúfera. 1999. Production of semiochemical emitters having a controlled emission speed which are based on inorganic molecular sieves. World Patent WO9944420.

Corma, A., J. Muñoz-Pallarés, and E. Primo-Yúfera. 2000. Emitter of semiochemical substances supported on a sepiolite, preparation process and applications. World Patent WO0002448.

Critchley B. R., D. R. Hall, D. I. Farman, L. J. McVeigh, M. A. O. A. Mulaa and P. Kalama. 1997. Monitoring and mating disruption of the maize stalkborer, Busseola fusca, in Kenya with pheromones. Crop Prot. 16: 541–548.

Domínguez-Ruíz, J., J. Sanchis, V. Navarro-Llopis, and J. Primo. 2008. A new long-life trimedlure dispenser for Mediterranean fruit fly. J. Econ. Entomol. 101: 1325-1330.

Femenia, B. 2011. Desenvolupament d'emissors degradables de les feromones de *Lobesia botrana* Denis i Schiffermüller i *Cydia pomonella* Linnaeus (Lepidoptera:Tortricidae) per a la tècnica de confusió sexual. Avaluació de la seua eficàcia al camp. PhD thesis, Universidad Politécnica de Valencia, Valencia, Spain.

Howell, J.F., R. S. Schmidt, D. R. Horton, S. U. K Khattak, and L. D. White. 1990. Codling moth: male moth activity in response to pheromone lures and pheromone-baited traps at different elevations within and between trees. Environ. Entomol. 19: 573-577.

Con formato: Español (España)

Con formato: Español (España)

Howse, P. E. 1998. Pheromones and behavior. In P. E. Howse, I. Stevens and O. Jones (eds.), Insect Pheromones and their Use in PestManagement, Chapman & Hall, London, UK, pp. 1–130.

Jacobson, M., and M. Beroza. 1964. Insect attractants. Sci. Am. 211: 20–27.

Kehat, M., L. Anshelevich, E. Dunkelblum, P. Fraishtat, and S. Greenberg. 1994. Sex pheromone traps for monitoring the codling moth: effect of dispenser type, field aging of dispenser, pheromone dose and type of trap on male captures. Entomol. Exp. Appl. 70: 55-62.

Knight, A. L. 1995. Evaluating pheromone emission rate and blend in disrupting sexual communication of codling moth (Lepidoptera: Tortricidae). Environ. Entomol. 24: 1396-1403.

Krupke, C. H., B. D. Roitberg, and G. J. R. Judd. 2002. Field and laboratory responses of male codling moth (Lepidoptera: Tortricidae) to a pheromone-based attract-and-kill strategy. Environ. Entomol. 31: 189-197.

Lacey, L. A., S. P. Arthurs, T. R. Unruh, H. Headrick, and R. Fritts. 2006. Entomopathogenic nematodes for control of codling moth (Lepidoptera: Tortricidae) in apple and pear orchards: Effect of nematode species and seasonal temperatures, adjuvants, application equipment, and post-application irrigation. Biol. Control 37: 214–223.

Lösel P. M., G. Penners, R. P. J. Potting, D. Ebbinghaus, A. Elbert, and J. Scherkenbeck. 2000. Laboratory and field experiments towards the development of an attract and kill strategy for the control of the codling moth, *Cydia pomonella*. Entomol. Exp. Appl. 95: 39-46.

McDonough, L. M., W. C. Aller and A. L. Knight. 1992. Performance characteristics of a commercial controlled release dispenser of sex pheromone for control of codling moth (*Cydia pomonella*) by mating disruption. J. Chem. Ecol. 18: 2177– 2189.

Miñarro, M., E. Dapena. 2000. Control de *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) con granulovirus y confusión sexual en plantaciones de manzano de Asturias. Bol. San. Veg. Plagas 26: 305-316.

Mitchell V. J., L. A. Manning, L. Cole, D. M. Suckling, and A. M. El-Sayed. 2008. Efficacy of the pear ester as a monitoring tool for codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) in New Zealand apple orchards. Pest Manag. Sci. 64:209–214.

Reinke, M.D., J. R. Miller, and L. J. Gut. 2012. Potential of high-density pheromone-releasing microtraps for control of codling moth *Cydia pomonella* and obliquebanded leafroller *Choristoneura rosaceana*. Physiol. Entomol. 37: 53-59.

Roelofs, W. L., A. Comeau, A. Hill,and G. Milicevic. 1971. Sex attractant of the codling moth: characterization with electroantennogram technique. Science 174:297-99.

Roelofs W. L., M.J. Gieselmann, A. M. Cardé, H. Tashiro, D. S. Moreno et al. 1977. Sex pheromone of California red scale, *Aonidiella aurantii*. Nature 267: 698–699.

Thomson, D., J. Brunner, L. Gut, G. Judd, and A. Knight. 2001. Ten years implementing codling moth mating disruption in the orchards of Washington and British Columbia: starting right and managing for success. IOBC wprs Bull. 24: 23-30.

Tomaszewska, E., V. R. Hebert, J. F. Brunner, V. P. Jones, M. Doerr, and R. Hilton. 2005. Evaluation of pheromone release from commercial mating disruption dispensers. J. Agric. Food Chem. 53: 2399-2405.

Vacas, S., C. Alfaro, V. Navarro-Llopis, M. Zarzo, and J. Primo. 2009. Study on the optimum pheromone release rate for attraction of *Chilo suppressalis* (Lepidoptera: Pyralidae). J. Econ. Entomol. 102: 1094-1100.

Vickers, R. A., W. G. Thwaite, D. G. Williams, and A. H. Nicholas. 1998. Control of codling moth in small plots by mating disruption: alone and with limited insecticide. Entomol. Exp. Appl. 86: 229–239.

Weatherston, I., D. Miller, and J. Lavoie-Dornik. 1985. Capillaries as controlled release devices for insect pheromones and other volatile substances – a reevaluation: part II. Predicting release rates from Celcon and Teflon capillaries. J. Chem. Ecol. 11: 967–978.

Witzgall, P., L. Stelinski, L. Gut, and D. Thomson. 2008. Codling moth management and chemical ecology. Ann. Rev. Entomol. 53: 503-22.

Zhang, A., and D. Amalin. 2005. Sex pheromone of the female pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae): biological activity evaluation. Environ. Entomol. 34: 264-270.

Figure legends

Fig. 1. Mean ± SE number of moths caught per trap and day (MTD) for each of the five types of baited trap (A5, A15, A30, A60 and A90) tested in preliminary trial Lleida-2011. Bars labelled with the same letter are not significantly different (LSD test at $P > 0.05$).

Fig. 2. Release profiles of 8*E*,10*E*-dodecadien-1-ol (codlemone) from the C1 (A), C5 (B) and C50 (C) mesoporous dispenser employed in field trials carried out in Asturias (2012). Fitted linear models (Eqs. 1-3) describe the mean pheromone content of the dispenser [codlemone (mg)] vs. time (days of ageing). Three replicates were extracted per ageing time.

Fig. 3. Mean ± SE number of moths caught per trap and day (MTD) for each of the five types of baited trap tested in trials Asturias-May (A) and Asturias-July (B). Bars labelled with the same letter are not significantly different (LSD test at $P > 0.05$).

Fig. 4. Fitted regression (logarithmic) model, for trial Asturias-May data, of residuals vs. emission rates. The dependent variable is the residuals from the ANOVA applied to capture data (MTD) according to factors week and block.

Fig. 5. Fitted regression (linear) model, for trial Asturias-July data, of residuals vs. emission rates. The dependent variable is the residuals from the ANOVA applied to capture data (MTD) according to factors week and block.

454 **Tables**

455

456 **Table 1. Description for Asturias trial orchards**

Orchard	Municipality	Size (ha)	Age (years)	Insecticide treatments
1	Villaviciosa	1.1	11	Granulovirus + Neem*
2	Villaviciosa	0.5	5	Granulovirus + Neem*
3	Villaviciosa	0.9	15	Granulovirus + Neem*
4	Nava	1.1	15	None
5	Villaviciosa	2.0	8	Granulovirus + Neem*
6	Sariego	0.7	14	None

457 *Granulovirus (Madex, Andermatt Biocontrol) was sprayed against the
458 codling moth, and neem (NeemAzal-T/S, Trifolio GmbH) against the rosy
459 apple aphid, *Dysaphis plantaginea* Pass.

460