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1 **Evaluation of the susceptibility to emamectin benzoate and lambda cyhalothrin in European**
2 **populations of *Cydia pomonella* (L.) (Lepidoptera: Tortricidae)**

3 Laura Depalo^a, Edison Pasqualini^a, Elias Jan^b, Russell Slater^b, Eve Daum^c, Christoph T. Zimmer^c,
4 Antonio Masetti^a

5 ^aAlma Mater Studiorum-Università di Bologna (UNIBO), Dipartimento di Scienze e Tecnologie Agro-
6 Alimentari (DISTAL), Viale G. Fanin 42, Bologna, 40127, Italy

7 ^b Syngenta Crop Protection AG, Rosentalstrasse 67, 4002 Basel, Switzerland

8 ^c Syngenta Crop Protection AG, Schaffhauserstrasse 101, 4332 Stein, Switzerland

9

10 **Abstract**

11 The codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) is one of the key pests of pome
12 fruit and walnut in almost all growing regions of the world and has developed resistance to several
13 insecticides. In this study, the susceptibilities of 15 codling moth populations to emamectin
14 benzoate and 9 populations to lambda cyhalothrin collected in five European countries were
15 measured by standard diet incorporation bioassays. Variation in susceptibility was observed
16 among populations, with LC₅₀ values ranging from 0.0017 to 0.0119 mg a.i./kg diet for emamectin
17 benzoate and from 0.033 to 0.292 mg a.i./kg diet for lambda cyhalothrin. Our results revealed only
18 small variations in emamectin benzoate susceptibility between populations, indicating no
19 selection of resistance to this active ingredient. Even though a wider range of responses was
20 detected for lambda cyhalothrin, our results also suggest that populations remain susceptible to
21 this insecticide. Based on pooled LC₉₅ evaluations, we propose the use of concentrations 0.02 mg
22 a.i./kg of diet for emamectin benzoate and 0.60 mg a.i./kg of diet for lambda cyhalothrin in order
23 to discriminate between resistant and susceptible individuals.

1 **Keywords** *Cydia pomonella*, codling moth, resistance monitoring, insecticide resistance,
2 emamectin benzoate, lambda cyhalothrin

3 **Introduction**

4 The codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) is one of the key pests of pome
5 fruit and walnut in almost all growing regions of the world. Codling moth has a high damage
6 potential and can cause total yield losses (Geier 1964, MacLellan 1976). Although non-chemical
7 control methods such as mating disruption, insect-proof nets and *Cydia pomonella* granulosis virus
8 (CpGV) are available, codling moth management mostly relies on chemical insecticides. The long-
9 term use of pesticides has selected populations resistant to insecticides with different modes of
10 action, including neurotoxic insecticides, insect growth regulators and granuloviruses (Bosch et al.
11 2018a).

12 Selection of resistant populations of codling moth can be dated back to the late 1920s, when
13 resistance to arsenate insecticides was reported in the USA (Hough 1928). Since 1990, there have
14 been reports of codling moth populations resistant to several insecticidal classes, including
15 neonicotinoids, benzoylureas, macrocyclic lactones and older compounds such as pyrethroids or
16 organophosphates (Reyes et al. 2007). Pesticide resistance is a major threat to pest control and
17 causes control failures in numerous cropping systems worldwide, thus proactive resistance
18 management is recommended to maximize the lifespan of pesticides. Monitoring pest
19 susceptibility can provide the basis to understand the status of insecticide resistance and to
20 develop a successful strategy to delay its occurrence (Roditakis et al. 2013).

21 Emamectin benzoate derives from a fermentation product of the soil microorganism *Streptomyces*
22 *avermitilis* (Burg et al. 1979). According to the IRAC Mode of Action (MoA) classification, it is
23 included in group 6 acting as an allosteric activator of glutamate-gated chloride channels in the
24 insect nervous system. Emamectin benzoate shows translaminar movement through the leaf

1 blade and has a residual activity on leaf-chewing lepidopteran species. However, residues on
2 foliage surfaces are rapidly broken-down by sunlight (Feely et al. 1992) and contact activity on
3 beneficial arthropods is limited to short periods (Depalo et al. 2017). This makes the use of
4 emamectin benzoate particularly suited for control of lepidopteran pests in IPM strategies.
5 Emamectin benzoate was registered in 2000 for codling moth control in Europe and other
6 countries (Ioriatti et al. 2009). To our knowledge no resistance of tortricid moths was previously
7 recorded to emamectin benzoate. However, a few cases have been reported for other lepidoptera
8 such as *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) from Pakistan (Ishtiaq et al. 2014,
9 Ahmad et al. 2018) and China (Che et al. 2015) and *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)
10 from China (Pu et al. 2010).

11 Lambda cyhalothrin is a pyrethroid insecticide, i.e. a synthetic chemical analogue of pyrethrins
12 found in chrysanthemums (i.e. *Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids
13 have been widely used since the 1970s on many crops to control insect pests, including
14 Hemiptera, Coleoptera and Lepidoptera. The use of pyrethroid insecticides has increased in recent
15 years, probably due to the withdrawal of the organophosphate chlorpyrifos (He et al. 2008, Hites
16 2021). Since commercialization, pyrethroids have been largely used all over the world to control
17 codling moth, thus favoring the selection of resistant strains to this class of insecticides (Soleño et
18 al. 2008, Soleño et al. 2019). Lambda cyhalothrin has been available for the control of codling
19 moth since the 1980s (Roush et al. 1990) and populations resistant to lambda cyhalothrin have
20 been detected since 2000 in Europe (Bosch et al. 2018b), Northeastern China (Wei et al. 2020) and
21 North America (Mota-Sanchez et al. 2008).

22 In orchards where chemicals are widely used to decrease pest pressure and crop rotation is not
23 possible, insecticide resistance management (IRM) is crucial (Sparks et al. 2015). Regular
24 monitoring is the core of IRM and is essential to to manage insecticide resistance. Therefore, the

1 susceptibility of pests should be regularly assessed when any insecticide is used extensively. When
2 an a.i. is recommended for pests with known problems of resistance, proactive resistance
3 monitoring should be performed even before product commercialization.

4 In this 4-year survey we examined the susceptibility of 15 codling moth populations to emamectin
5 benzoate and 9 populations to lambda-cyhalothrin across five European countries. The aims of the
6 study were to (1) estimate lethal concentrations (LC_{50} and LC_{95}) for each population to both
7 insecticides; (2) check the occurrence of a potential shift in the responses of codling moth
8 populations to emamectin benzoate and lambda cyhalothrin; (3) provide an overall European
9 measure of susceptibility to these active ingredients for tracking possible future alterations in the
10 efficacy of the products.

11 **Materials and methods**

12 *Insects*

13 Codling moth populations were collected by means of cardboard trunk traps as mature diapausing
14 larvae from commercial orchards during 2015-2019. Populations tested against emamectin
15 benzoate were collected in from five EU Countries: Italy (7 populations), France (5), Belgium (1),
16 Spain (1) and Poland (1). Populations used for the assays with lambda cyhalothrin were collected
17 in France (4), Italy (4) and Belgium (1) (Table 1). None of the growers where collections were
18 made had reported any failure in controlling codling moth using insecticides.

19 Diapausing larvae were reared to adulthood and allowed to mate. Eggs were collected and newly
20 hatched larvae (F1) were used for the bioassays. Some populations were reared for one or two
21 generations to obtain enough offspring to complete bioassays for LC_{50} estimation.

22 The susceptible population was collected from an abandoned apple orchard in Lleida (Spain) in
23 1992. It has since been continuously reared in the laboratory without exposure to pesticides. This

population was kindly provided by the Institute for Food and Agricultural Research and Technology and University of Lleida (Spain).

Insecticides

Commercial formulation of emamectin benzoate (Affirm Opti[®] with 0.95% w/w = 9.5 g. active ingredient (a.i.)/kg formulated product) and of lambda cyhalothrin (Karate Zeon[®] 9.48% =100 g/L) were provided by Syngenta Crop Protection (Basel, Switzerland). The insecticides were mixed with distilled water to make up the serial dilutions needed for bioassays. Distilled water only was used for control groups.

Bioassays

Standard diet incorporated bioassays were carried out on newly hatched larvae (< 24 h) following the IRAC susceptibility test method 017 (www.irac-online.org). The meridic artificial diet Stonefly *Heliothis* Premix (Stonefly Industries Ltd., Bryan, TX) was used throughout the experiments. To study the concentration-response curves, serial dilution of formulated emamectin benzoate and lambda cyhalothrin were prepared and used to knead the diet. The final a.i. concentrations into the diet ranged from 0.0005 to 0.1 mg a.i./kg for emamectin benzoate and 0.01 and 10 mg a.i./kg for lambda cyhalothrin.

Experiments were carried out in 2-mL well plates, filling each well with approximately 0.5 g of diet, which was gently pressed to evenly fill the bottom of the well. A single newly hatched larva was placed in each well. The plates were then sealed with transparent ventilated adhesive lids to prevent escaping of larvae. Plates were incubated in rearing chambers at 25 ± 1 °C, $50 \pm 10\%$ RH and 16:8 (L:D) h photoperiod.

Mortality was scored four days after placement of larvae in the wells. Larvae were considered dead if not reacting to the touch with a fine brush. When larvae were visibly affected and unable to upright themselves when flipped on their back, they were scored as moribund. Dead and moribund

larvae were both considered as observed responses. Larvae that could not be found at mortality checks were not included in the number of tested subjects.

For each codling moth population, six evenly spaced concentrations of the insecticides were used along with a negative control to calculate preliminary LC values. Emamectin benzoate was tested at 0.001, 0.003, 0.01, 0.03, 0.1, 0.3 mg/kg; Lambda-cyhalothrin was tested at 0.01, 0.03, 0.10, 0.30, 1, 3 mg/kg. The preliminary results were used to optimize a second (and in some cases a third) set of concentrations more precisely aiming at final LC estimation. These results were used to optimize a second (and in some cases a third) set of concentrations more precisely aiming at final LC estimation. A total of 48 codling moth larvae were tested for each concentration.

Statistical analysis

Probit regressions including intercept, slope, LC₅₀, LC₉₅ and associated 95% confidence limits (CLs) were run using IBM SPSS Statistics ver. 23 (Chicago, IL, USA). If Pearson goodness-of-fit test detected significant deviation for probit models, a heterogeneity factor was used in the calculation of 95% confidence limits (CLs). Natural response rate was included as a parameter in each probit regression to account for mortality in the control groups of each population. The proportion of dead larvae in the controls was used as the initial value to estimate the natural response rate in each model (https://www.ibm.com/docs/en/SSLVMB_28.0.0/pdf/IBM_SPSS_Regression.pdf).

The ratio test was used to compare LCs of different populations (Depalo et al. 2016, Robertson et al. 2017).

Resistance ratios (RR) were calculated comparing each LC₅₀ of any tested population to the LC₅₀ of the most susceptible field population (RR-F), to the LC₅₀ of the laboratory colony (RR-L) and to the pooled LC₅₀ values (RR-P).

Results

Emamectin benzoate

1 Only limited variation in susceptibility to emamectin benzoate was detected among the 15 field-
2 collected populations, with LC₅₀ values ranging from 0.0017 mg a.i./kg diet for Vaucluse (France) to
3 0.0119 mg a.i./kg diet for Villanova de Belpuig (Spain). The LC₉₅ values for the codling moth field
4 populations ranged from 0.0071 to 0.0361 mg a.i./kg diet (Table 2).

5 The LC₅₀ of the colony reared in the laboratory since 1992 (for up to 100 generations) was 0.0068
6 (0.0040-0.0106) mg a.i./kg diet, and it was not the most susceptible of the populations tested.
7 Indeed, based on the results of LC ratio test, the LC₅₀s of populations from Vaucluse and Le Pont
8 de Cè were significantly lower than the laboratory strain. The pooled LC₅₀ and LC₉₅ values were
9 0.0050 mg a.i./kg diet and 0.0213 mg a.i./kg diet, respectively.

10 The RR-Fs (compared to the most sensible field population) ranged from 1.2 to 7.0, RR-Ls
11 (compared to the laboratory population) ranged from 0.3 to 1.8, RR-Ps (compared to the pooled
12 LC₅₀ values) ranged from 0.3 to 2.4. All populations can be considered susceptible to emamectin
13 benzoate as all RRs were below tenfold, providing no indication of resistance (Table 2).

14 *Lambda cyhalothrin*

15 A small range of variation was recorded among 8 out of the 9 field populations tested with lambda
16 cyhalothrin. The LC₅₀ values of these eight susceptible populations ranged from 0.033 mg a.i./kg
17 diet for Le Ponts de Cè (France) to 0.292 mg a.i./kg diet for Grisolles (France). The LC₉₅ values
18 ranged from 0.104 to 2.91 mg a.i./kg diet (Table 3). The value of LC₅₀ of laboratory colony was
19 0.049 (0.044-0.055) mg a.i./kg diet, and the laboratory population was not the most susceptible.
20 The LC₅₀s of populations from Baricella, Ghibullo and Le Pont de Cè were not significantly different
21 from the laboratory population, while LC₅₀s of the other populations were significantly higher than
22 the laboratory strain.

23 The pooled LC₅₀ and LC₉₅ calculated excluding data of the L'Isle sur la Sorgue were 0.080 mg a.i./kg
24 diet and 0.594 mg a.i./kg diet, respectively. Among the susceptible populations, the RR-Fs ranged

from 1.4 to 8.8, RR-Ls ranged from 0.7 to 6.0, and RR-Ps ranged from 0.4 to 3.7. The Isle sur la Sorgue population had RR values of 17.1 when compared to the most susceptible population, 11.5 when compared to the laboratory colony and of 7.1 when compared to the pooled LC₅₀ (Table 3).

Discussion

Only small variations in emamectin benzoate susceptibility were observed between populations of codling moth collected across a wide geographic range in Europe, indicating no selection of resistance to this active ingredient. These results are in agreement with the findings of the only other study on emamectin benzoate against codling moth in Spain (Bosch et al. 2018b). Earlier studies conducted either by surface-treated diet (Wu et al. 2015) or leaf/fruit-dip bioassays (Ioriatti et al. 2009) recorded LC₅₀ values ranging between 0.016 mg/L and 0.026 mg/L. Lethal concentrations in our bioassays were three to five folds lower in comparison with the values reported by other authors. The differences were likely due to our use of a diet-incorporated bioassay, which involves continuous exposure of larvae to insecticides in the diet, which may have led to lower LC values than surface assays for all active ingredients.

Emamectin benzoate was registered nearly 20 years ago, but little evidence of resistance has been recorded to date on lepidopteran pests. A six fold decrease in susceptibility to emamectin benzoate compared to a laboratory susceptible strain originally obtained from an isolated abandoned apple orchard was found in *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) collected in apple and cherry orchards in USA (Hafez et al. 2018). Contrasting results have been reported for noctuid moths. In major cropping regions of eastern Australia, no resistant population was detected for *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), a pest species which is considered prone to the selection of insecticide resistance (Bird et al. 2017), whereas high levels of resistance were reported for *S. exigua* (Hübner) (Lepidoptera: Noctuidae) in

1 Pakistan (Ahmad et al. 2018). A European survey on emamectin benzoate resistance in *Tuta*
2 *absoluta* (Lepidoptera: Gelechiidae) reported resistance factors ranging from susceptibility levels
3 (twofold and fourfold) to low resistance levels (15- to 16-fold) (Roditakis et al. 2018).

4 In this study, a wider range of responses was detected for lambda-cyhalothrin than for emamectin
5 benzoate in codling moth populations across Europe. Three out of four French populations were
6 considered tolerant, including L'Isle sur la Sorgue, which was also above the arbitrary limit to be
7 ranked as resistant (i.e. with an LC₅₀ nearly 11-fold higher than the susceptible population).

8 Codling moth populations resistant to lambda-cyhalothrin have been detected in Spain since 2011
9 (Rodríguez et al. 2011, Bosch et al. 2018b). High levels of lambda-cyhalothrin resistance were also
10 found in codling moth larvae collected in the US (Mota-Sanchez et al. 2008) and more recently in
11 apple and pear orchards throughout Argentina (Soleño et al. 2019) and China (Wei et al. 2020).

12 Because of the long term and widespread use of lambda cyhalothrin and the chances of cross
13 resistance with other widely used pyrethroids, the detection of codling moth populations resistant
14 to lambda cyhalothrin was expected, but only two population from south France showed a RR L
15 similar to resistant populations collected in North America, which had six- and tenfold resistance
16 to lambda-cyhalothrin (Mota-Sanchez et al. 2008). Although most codling moth populations
17 remained susceptible to lambda cyhalothrin in this study, in contrast with resistance already
18 documented in Spain, Argentina, and China (Rodríguez et al. 2011, Soleño et al. 2019, Wei et al.
19 2020), the decrease of susceptibility in codling moth collected in southern France is concerning.

20 Therefore, proactive resistance monitoring in codling moth field populations in Europe is
21 important to help to implement insecticide resistance management strategies for this key pest.

22 The determination of diagnostic (or discriminant) concentrations to separate resistant from
23 susceptible individuals of a given insecticide is highly valuable because it can speed up resistance
24 monitoring without the need to establish concentration-response curves for each field population.

1 The appropriateness of a laboratory-susceptible strains as reference point for determining
2 changes in susceptibility in field populations over time has been questioned (Roush et al. 1990), as
3 susceptible colonies isolated and reared for a long time in the laboratory may not resemble
4 susceptible strains actually occurring in the fields (ffrench-Constant et al. 1990). The susceptibility
5 of a range of geographically diverse field populations can also be used to set diagnostic
6 concentrations rather than a poorly representative response of an inbred laboratory-susceptible
7 strain (Sawicki et al. 1987). Therefore, using our estimates of the pooled LC₉₅, we propose the use
8 of 0.021 mg a.i./kg and 0.59 mg a.i./kg of diet for emamectin benzoate and lambda cyhalothrin,
9 respectively, to discriminate between resistant and susceptible individuals.

10 Although non-chemical control methods are available, codling moth management still relies on
11 insecticides in most of the regions where this pest occur. Therefore, IRM strategies implementing
12 rotation of insecticides with different MoA is paramount. Unfortunately, proper rotation of active
13 ingredients is often hampered by pressures of the food chains in favor of a small number of active
14 ingredients identified in residues. Stringent market requirements in terms of number of active
15 substances and their residue levels in fruits at harvest drove farmers toward the use of broad-
16 spectrum insecticides such as pyrethroids (Bosch 2018b). The severe residue requirements
17 claimed by the commercial market which are stronger than the legal requirements should be
18 reduced, in order to provide growers with active ingredients with different mode of actions, to
19 promote rotation of insecticides and to develop a resistance management strategy in IPM
20 programs (Ju et al. 2021). The susceptibility data for emamectin benzoate lambda-cyhalothrin
21 established in this study can be a useful tool for tracking future changes in the susceptibility of
22 codling moth populations to these widely used active ingredients, thus avoiding a possible decline
23 in effectiveness in controlling *C. pomonella*. Nevertheless, further sampling for proactive
24 resistance management will be required for improving the control of this pest.

1

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4

- 1 **Table 1.** Details of the population tested. Each population was named with the name of the closest
- 2 village on the map.

Country	City	Region	Collection date	Crop	Coordinates	Insecticides tested
France	L'Isle sur la Sorgue	Provence	09/2015	Apple	43°54'07"N 5°03'25"E	Emamectin benzoate Lambda cyhalothrin
France	Meauzac	Occitane	10/2015		44°05'15.0"N 1°14'09.0"E	Emamectin benzoate
France	Grisolles	Occitane	10/2017	Apple	43°48'18.2"N 1°17'12.9"E	Emamectin benzoate Lambda cyhalothrin
France	Le Ponts de Cè	Pays de la Loire	09/2018	Apple	47°26'16.8"N 0°32'24.0"W	Emamectin benzoate Lambda cyhalothrin
France	Vaucluse	Provence	09/2019	Apple	43°54'26.0"N 5°03'26.0"E	Emamectin benzoate Lambda cyhalothrin
Italy	Ghibullo	Emilia Romagna	09/2015		44°20'30.51"N 12°08'48.24"E	Emamectin benzoate Lambda cyhalothrin
Italy	Ravenna	Emilia Romagna	10/2015		44°25'59.6"N 12°11'55.8"E	Emamectin benzoate
Italy	Belfiore	Veneto	10/2016	Apple	45°22'46.2"N 11°13'23.4"E	Emamectin benzoate
Italy	Palù	Veneto	11/2016	Apple	45°19'36.5"N 11°09'45.8"E	Emamectin benzoate
Italy	Pieve di Cento	Emilia Romagna	10/2017	Pear	44°43'40.0"N 11°19'24.5"E	Emamectin benzoate Lambda cyhalothrin
Italy	Baricella	Emilia Romagna	10/2017	Pear	44°38'37.0"N 11°33'00.1"E	Emamectin benzoate Lambda cyhalothrin
Italy	Bovolone	Veneto	11/2017	Apple	45°15'57.6"N 11°08'55.8"E	Emamectin benzoate Lambda cyhalothrin
Poland	Grójec	Mazowieckie	12/2015		51°45'56.1"N 20°46'37.1"E	Emamectin benzoate
Spain	Villanova de Belpuig	Catalunya	09/2016		41°37'06.6"N 0°57'08.7"E	Emamectin benzoate
Belgium	Ciney	Wallonie	11/2017		50° 16' 36"N 5° 09' 57"E	Emamectin benzoate Lambda cyhalothrin

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4

1 **Table 2.** Results of the probit analysis and the RRs of populations tested with emamectin benzoate.

Population	n	Intercept \pm SE	Slope \pm SE	LC ₅₀ (mg/kg)	95%CL	LC ₉₅ (mg/kg)	(95%CL)	χ^2 (df)	p	RR F	RR L	RR P
Baricella IT	989	7.65 \pm 0.65	3.41 \pm 0.30	0.0057	0.0044-0.0070	0.0172	0.0127-0.0311	55.30 (15)	<0.001	3.4	0.8	1.1
Belfiore IT	667	6.47 \pm 0.61	2.74 \pm 0.27	0.0043	0.0035-0.0051	0.0173	0.0139-0.0232	4.68 (9)	0.86	2.5	0.6	0.9
Bovolone IT	669	6.87 \pm 0.60	3.21 \pm 0.29	0.0083	0.0043-0.0149	0.0271	0.0151-0.273	94,38 (9)	<0.001	4.9	1.2	1.7
Ciney BE	665	9.06 \pm 0.97	3.37 \pm 0.43	0.0036	0.0017-0.0050	0.0101	0.0072-0.0264	46.02 (9)	<0.001	2.1	0.5	0.7
Ghibullo IT	663	7.49 \pm 0.79	3.06 \pm 0.34	0.0036	0.0029-0.0042	0.0123	0.0101-0.0164	12.88 (9)	0.17	2.1	0.5	0.7
Grisolles FR	997	6.60 \pm 0.50	2.91 \pm 0.23	0.0054	0.0019-0.0092	0.0198	0.0110-0.2340	256.31 (15)	<0.001	3.2	0.8	1.1
Grójec PL	656	12.25 \pm 1.3	5.37 \pm 0.58	0.0052	0.0047-0.0058	0.0106	0.0092-0.0128	6.28 (9)	0.71	3.1	0.8	1.0
L'Isle Sorgue FR	652	7.91 \pm 0.78	3.63 \pm 0.36	0.0066	0.0058-0.0075	0.0187	0.0154-0.0247	15.61 (9)	0.08	3.9	1.0	1.3
Lab colony	702	6.77 \pm 0.6	3.12 \pm 0.28	0.0068	0.0040-0.0106	0.0228	0.0136-0.0955	73.45 (10)	<0.001	4.0	1.0	1.4
Le Ponts de Cè FR	648	8.32 \pm 0,75	3.10 \pm 0.30	0.0021	0.0011-0.0032	0.0071	0.0047-0.0140	31.20 (9)	<0.001	1.2	0.3	0.4
Meuzac FR	945	5.82 \pm 0.51	2.56 \pm 0.25	0.0056	0.0009-0.0105	0.0244	0.0127-0.4830	180.27 (14)	<0.001	3.3	0.8	1.1
Palù IT	668	9.01 \pm 0.98	4.07 \pm 0.45	0.0061	0.0045-0.0079	0.0186	0.0136-0.0329	29.08 (9)	<0.001	3.6	0.9	1.2
Pieve di Cento IT	333	6.67 \pm 0.91	3.35 \pm 0.46	0.0102	0.0082-0.0124	0.0316	0.0239-0.0491	2.60 (3)	0.46	6.0	1.5	2.0
Ravenna IT	598	6.63 \pm 0.83	2.97 \pm 0.34	0.0059	0.0046-0.0071	0.0210	0.0162-0.0311	9.58 (9)	0.39	3.5	0.9	1.2
Vaucluse FR	651	6,84 \pm 0.87	2.47 \pm 0.40	0.0017	0.0008-0.0026	0.0078	0.0058-0.0109	7.47 (9)	0.59	1.0	0.3	0.3
Villanova de B. ES	666	6.55 \pm 0.71	3.40 \pm 0.40	0.0119	0.0089-0.0145	0.0361	0.0298-0.0479	15.91 (9)	0.07	7.0	1.8	2.4
Pooled	11169	6.00 \pm 0.15	2.61 \pm 0.068	0.0050	0.0043-0.0056	0.0213	0.0181-0.0263					

1 **Table 3.** Results of the probit analysis and the RRs of populations tested with lambda cyhalothrin.

Population	n	Intercept (\pm SE)	Slope (\pm SE)	LC ₅₀ (mg/kg)	(95%CL)	LC ₉₅ (mg/kg)	(95%CL)	χ^2 (df)	p	RR F	RR L	RR P
Baricella IT	661	4.30 \pm 0.47	3.22 \pm 0.39	0.046	0.039-0.053	0.150	0.122-0.204	8.76 (9)	0.46	1.4	0.9	0.6
Bovolone IT	664	2.17 \pm 0.24	3.14 \pm 0.35	0.204	0.176-0.234	0.682	0.543-0.953	8.68 (9)	0.47	6.2	4.2	2.6
Ciney BE	710	3.70 \pm 0.35	3.71 \pm 0.37	0.100	0.088-0.113	0.279	0.234-0.335	15.73 (10)	0.11	3.0	2.0	1.3
Ghibullo IT	661	3.94 \pm 0.45	2.93 \pm 0.38	0.045	0.036-0.054	0.166	0.131-0.236	10.14 (9)	0.34	1.4	0.9	0.6
Grisolles FR	661	0.88 \pm 0.09	1.65 \pm 0.22	0.292	0.192-0.391	2.910	2.020-5.160	12.28 (9)	0.33	8.8	6.0	3.7
L'Isle sur la Sorgue FR	1089	0.48 \pm 0.07	1.92 \pm 0.14	0.565	0.411-0.747	4.070	2.650-7.880	50.51 (17)	<0.001	17.1	11.5	7.1
Lab colony	642	6.62 \pm 0.76	5.07 \pm 0.60	0.049	0.044-0.055	0.104	0.089-0.131	1.96 (9)	0.99	1.5	1.0	0.6
Le Ponts de Cè FR	614	2.97 \pm 0.26	2.00 \pm 0.23	0.033	0.005-0.068	0.218	0.111-0.009	39.42 (9)	<0.001	1.0	0.7	0.4
Pieve di Cento IT	665	4.41 \pm 0.54	4.77 \pm 0.63	0.119	0.103-0.133	0.263	0.225-0.335	7.13 (9)	0.62	3.6	2.4	1.5
Vaucluse FR	666	1.45 \pm 0.13	1.91 \pm 0.21	0.174	0.128-0.222	1.260	0.930-1.940	9.20 (9)	0.42	5.3	3.6	2.2
Pooled	5944	2.07 \pm 0.06	1.89 \pm 0.07	0.080	0.058-0.103	0.594	0.443-0.896					

Highlights

The susceptibility to two insecticides was tested in many codling moth populations.

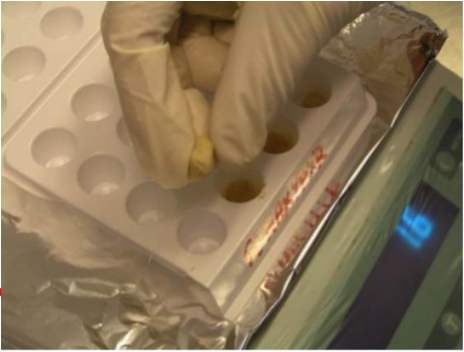
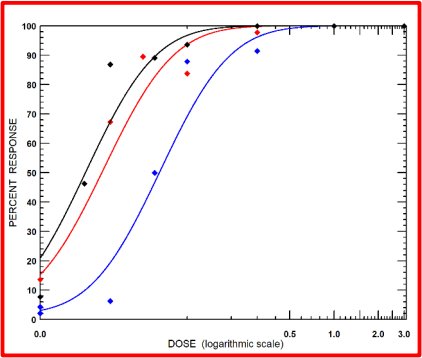
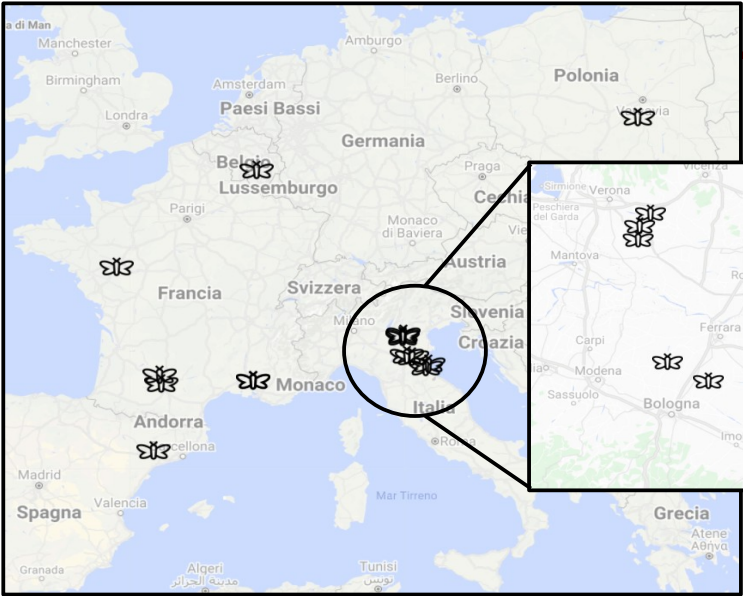
Small range of responses and no resistant strains were found for emamectin benzoate.

A wider variability and a resistant population were detected for lambda cyhalothrin.

0.021 mg a.i./kg is suggested as discriminant concentration for emamectin benzoate.

A discriminant concentration of 0.60 mg a.i./kg is proposed for lambda cyhalothrin.

Graphical Abstract



The susceptibility of wild populations of the codling moth *Cydia pomonella* (L.) to emamectin benzoate and lambda-cyhalothrin, was tested by diet incorporation bioassays.

Results revealed small variations in emamectin benzoate susceptibility between all the populations, while a wider range of responses was detected for lambda cyhalothrin.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: