

Report

Cry1Ab susceptibility in European origins of *Ostrinia nubilalis* (ECB)

- Results for 2019-2020 -

Date

04/09/2020

Testing Facility

BTL Bio-Test Labor GmbH Sagerheide
Thünenplatz 1
D-18190 Sanitz OT Groß Lüsewitz
Germany

Sponsor

Bayer Agriculture BV
Avenue de Tervuren 270-272
B-1150 Brussels
Belgium

**Statement of Compliance with the Principles of
Good Experimental Practice**

The study described in this report was conducted in compliance with the most recent edition of:

- The Principles of Good Experimental Practice (GEP), (Plant Protection Products Ordinance, paragraph (5) of Article 1c, Germany).

Head of testing facility

Date / Signature: 04. September 2020 *M. Hoffmann*

Study director

Date / Signature: 04. September 2020 *TL TL*

Contents

1. Introduction.....	5
2. Materials and Methods	6
2.1 Insect collection	6
2.2 Insect culture	6
2.3 Bioassays	8
2.3.1 Susceptibility to Cry1Ab	8
2.3.2 Exposure to MON 810 tissue (confirmatory experiment)	9
2.3.3 Exposure to maize tissue not expressing <i>Bt</i> protein (negative control)	10
2.3.4 Exposure to maize tissue expressing <i>Bt</i> protein (positive control)	10
2.3.5 Susceptibility of the reference strains G.04 and ES.ref to Cry1A	10
2.4 Statistical analysis	10
3. Results and Discussion	11
3.1 Collection of ECB.....	11
3.2 Susceptibility to Cry1Ab in the 2019-2020 campaign	13
3.3 Exposure to MON 810 tissue (confirmatory experiment)	14
3.4 Exposure to maize tissue not expressing <i>Bt</i> protein (negative control).....	14
3.5 Exposure to maize expressing <i>Bt</i> protein (positive control)	15
3.6 Historical susceptibility of corn borers to Cry1Ab	15
3.7 Susceptibility of the reference strains G.04 and ES.ref to Cry1Ab.....	15
4. Conclusions.....	16
5. Acknowledgement	17
6. References	17
Annex I	20
Annex II	21

Tables and Figures

Table 1.	<i>O. nubilalis</i> diet recipe	9
Table 2.	<i>O. nubilalis</i> collection details for the 2019-2020 season.	12
Table 3.	Development of <i>O. nubilalis</i> collected in Spain for the 2019-2020 season.....	13
Table 4.	Response of <i>O. nubilalis</i> larvae from in the 2019-2020 season	14
Table 5.	Susceptibility of <i>O. nubilalis</i> neonates exposed to Cry1Ab as measured by the MIC or response to DC (RDC) for areas tested.	15
Table 6.	Results from Probit analysis for the ECB reference strains tested in the season 2019-2020.....	16
Figure 1.	Dissected maize stalk with larvae.....	7
Figure 2.	Corrugated cardboard with pupae	7
Figure 3.	Growth chamber with plastic boxes containing diapausing ECB larvae.	7
Figure 4.	Oviposition cages for adult ECB.....	7
Figure 5.	IDs of Bio-Ba-128 trays (tray number, field letter, well number; i.e.: 1.A.13)	9
Figure 6.	Fitted curves of susceptibility as percentage moult inhibition after seven days of feeding by ECB (Es.ref) when exposed to treated diet from the batches 2b (blue) and 2c (red) of protein Cry1Ab (PoloPlus, LeOra Software 2002-2009).....	13
Figure 7.	Fitted curves of susceptibility as percentage moult inhibition after seven days feeding on treated diet of ECB reference strains to the batch 2c of protein Cry1Ab (PoloPlus, LeOra Software 2002-2009)	16
Figure A1	Area where ECB were sampled in 2019 (Iberia Northeast).....	20
Figure A2	PCR analyses for checking if the reference strains of G.04 (Germany) and ECB (ES.ref (Spain)) are infected with <i>Nosema</i> (according to SA EGLITZ, 2004).....	21

1 Introduction

Maize containing event MON 810 is genetically modified maize expressing the Cry1Ab protein derived from *Bacillus thuringiensis* subsp. *kurstaki*, and conferring protection against certain lepidopteran insect pests such as *Ostrinia nubilalis* and *Sesamia nonagrioides*. Resistance development in targeted lepidopteran pests is a potential concern arising from the widespread cultivation of MON 810 maize varieties. In order to maintain the benefits obtained from growing MON 810 maize varieties, Bayer established an insect resistance monitoring program across Europe and in particular in areas where commercial activity of MON 810 is occurring or planned, *i.e.*, areas where the European target pests *O. nubilalis* and *S. nonagrioides* are prevalent. This monitoring program follows directions described in the plan of the industry working group on Insect Resistance Management (IRM) proposed to the Member State Competent Authorities and the European Commission (available since 2003 but published in 2007; ALCALDE et al., 2007 and subsequently updated as the EuropaBio harmonised IRM plan in 2012, 2017 and 2019) as well as EFSA recommendations (EFSA 2017, 2018). The current report focuses on the susceptibility monitoring of *O. nubilalis*.

The European corn borer (ECB), *O. nubilalis*, is native to southern Europe (BECK, 1987) and is believed to have been introduced into North America between 1909 and 1914 (VINAL, 1917), where multiple introductions have probably occurred (SHOWERS, 1993). Since then, *O. nubilalis* has rapidly spread across North America (CAFFREY & WORTHLEY, 1927; ROELOFS et al., 1985; HUDON & LEROUX, 1986). Apart from maize, more than 200 weeds and cultivated plants are known to serve as host plants for *O. nubilalis* (HODGSON, 1928; PONSARD et al., 2004). Before *Bt* maize was commercially available, *O. nubilalis* was one of the most damaging pests of maize in North America and Europe and was therefore a major target pest for control with genetically modified maize expressing *Bacillus thuringiensis* (*Bt*) proteins.

In accordance with the EuropaBio Harmonised IRM plan of 2019 the baseline susceptibility of *O. nubilalis* to the Cry1Ab protein needs to be established after which subsequent routine monitoring for changes in susceptibility should be carried out. The objective is to detect in a timely manner shifts relative to baseline susceptibility that could result in inadequate protection of MON 810 maize varieties expressing Cry1Ab against the target species. This program will enable early detection of potential development of resistance in *O. nubilalis* if it occurs, and this will allow the proposal and implementation of additional risk mitigation measures.

Previous baseline susceptibility to the Cry1Ab protein has been established for *O. nubilalis* populations collected in different maize growing areas in Spain (GONZALEZ-NUNEZ et al., 2000, FARINÓS et al., 2004), Germany (SAEGLITZ et al., 2006) and the United States of America (USA) (MARÇON et al., 1999a, b and 2000). The European Union (EU) baseline results have been generated in areas where the MON 810 maize adoption by farmers was expected to be significant given the local abundance of the pests.

In accordance with the EuropaBio harmonized IRM plan, changes in the susceptibility of the target pests, which eventually could lead to resistance, have been reported in the previous years on a biennial basis in areas where MON 810 is grown. As the diagnostic dose method has been established for *O. nubilalis* populations collected in different maize growing areas in Europa (THIEME et al., 2017) this method was applied for the season reported here. Samples were taken in Northeast Iberia, the area where adoption of MON 810 was greater than 60%.

The objectives of the current report on the 2019 maize growing season are:

- 1) To determine the susceptibility of *O. nubilalis* in maize growing areas in Northeast Iberia to the Cry1Ab protein using the diagnostic dose method. This method was established to be the most efficient method and as effective as and providing increased sensitivity compared to the dose-response method to detect changes in susceptibility to Cry proteins (SIMS et al., 1996).
- 2) As requested by EFSA a “negative control” using leaf segments of maize was applied.
- 3) As requested by EFSA a “positive control” using leaf segments of maize expressing *Bt* protein was applied.

2 Materials and Methods

2.1 Insect collection

The three areas identified in the entire EU where adoption of MON 810 in 2015 was expected to be greater than 20% are the Ebro valley (defined in earlier reports as Northeast Iberia), Central Iberia (particularly the province of Albacete) and the Southwest Iberia area. For these areas data on the susceptibility of *O. nubilalis* to Cry1Ab have been collected since 2007. But since 2016, the monitoring efforts have been concentrated in Northeast Iberia based on EFSA opinion as there is high adoption rate of MON 810 in this region (> 60%) and so, here is resistance more likely to develop. Thus, in 2019, it was the aim to collect samples from three sites that were separated by at least 50 km in Northeast Iberia. *O. nubilalis* samples were collected as larvae in naturally infested fields or refuges to MON 810 maize varieties fields following the Standard Operating Procedures (SOPs) as attached to the EuropaBio harmonized IRM plan. Collections were made by dissecting maize stalks in the field before harvest or in spring after diapause. If more than one larva per stalk was found, only one was taken to avoid collecting siblings (Figure 1). The aim was to collect 350 healthy larvae from each sampling site.

2.2 Insect culture

Two reference strains are kept in culture. G.04, originally collected in Niedernberg, Germany, and kept in culture since 2005; ES.ref collected in fields located in Galicia, Northwest Spain (near Barrantes (n=4 larvae), Pontevedra (n=135 larvae) and Ponte Caldelas (n=6 larvae), Spain in 2015).

Larvae and adults of these animals are maintained in a climate cabinet at 25°C, a humidity of 90% RH and a photoperiod of 20:4 h (L:D). Egg masses to incubate were first heat-treated at 43°C for 40 min to reduce *Nosema* infections (SHOWERS et al., 2001) and then placed in an incubator at 25 ± 2°C until all larvae hatched.

O. nubilalis larvae from different sampling sites in Northeast Iberia separated by at least 50 km were analysed. During diapause collected insects from different sites within the area tested were kept isolated as bioassays were to be conducted separately for each sampling site and to avoid cross contamination with *Beauveria* sp. or *Nosema* sp.

These field-collected larvae were placed in plastic boxes containing corrugated cardboard and artificial agar-based diet (Figure 2 and 3, Table 1) and maintained in a growth chamber at 20°C, 70% RH and a photoperiod of 20:4h (L:D) for 5 days. Temperature then was decreased to 15°C for 12 days at a photoperiod of 12:12h (L:D). Afterwards the larvae were transferred to another climatic chamber and maintained at 8 ± 2°C, 70 ± 5% RH, and a photoperiod of 0:24h (L:D) until the time for collective emergence of adults in May.

Larvae surviving the diapause period were transferred to fresh containers and placed in a climate chamber where temperature was raised gradually from 15 to 25°C at a humidity of 90% RH and a photoperiod of 20:4h (L:D) over a period of 10 days and kept at 25°C, a humidity of 90% RH and a photoperiod of 20:4h (L:D) thereafter. Emerging adults (details see tab. 2) were transferred to oviposition cages (Figure 4) and fed 15% honey water to increase fecundity (LEAHY & ANDOW, 1994). The insides of the cages were covered with filter paper (oviposition medium) that was exchanged daily. Egg masses were cut off and transferred to petri dishes with moistened filter paper. If necessary, egg masses were stored for up to seven days at $8 \pm 2^\circ\text{C}$. Incubating egg masses were first heat-treated at 43°C for 40 min to reduce *Nosema* infections (SHOWERS et al., 2001) and then placed in an incubator at $25 \pm 2^\circ\text{C}$ until all larvae hatched.



Figure 1. Dissected maize stalk with larvae



Figure 3. Growth chamber with plastic boxes containing diapausing ECB larvae



Figure 2. Corrugated cardboard with pupae



Figure 4. Oviposition cages for adult ECB

2.3 Bioassays

2.3.1 Susceptibility to Cry1Ab

Two batches of Cry1Ab protein have been used since the start of the MON 810 monitoring plan. The batch 2 (that was used for the campaign 2012-2013) was provided by Monsanto¹ and was stored at -80°C until used (NBR: 11247229, 31/01/2012; concentration 1.64 mg/ml in 50 mM bicarbonate buffer, pH 10.25). To prepare the test concentrations, a bicarbonate buffer (50 mmol/l) with pH 10.25 was used. This batch had reached the expiry date specified by the manufacturer, therefore a new batch (2a) was provided by Monsanto. The batch 2a (NBR: 11247229, 31/01/2015; concentration 1.64 mg/ml in 50 mM bicarbonate buffer, pH 10.25) was also stored at -80°C until being used. As this batch had also reached the date of expiry specified by the manufacturer a new batch (2b) was re-supplied by Monsanto. The batch 2b (NBR: 11247229, 31/01/2020; concentration 1.64 mg/ml in 50 mM bicarbonate buffer, pH 10.25) was also stored at -80°C until being used. As this batch had also reached the date of expiry specified by the manufacturer a new batch (2c) was re-supplied by Bayer. The batch 2c (NBR: 11247229-381, 31/01/2023; concentration 1.64 mg/ml in 50 mM bicarbonate buffer, pH 10.25) was also stored at -80°C until being used. What has been used as batch 2 (2, 2a, 2b, 2c) are different “batches” of a protein but all from the same original production i.e., they are all sub-samples from the same protein source. As they were stored and delivered at different times (with different expiry dates specified by the manufacturer), experiments were done demonstrating equivalence in biological activity of the protein batches 2b and 2c.

To prepare the test concentration, a bicarbonate buffer (50 mmol/l) with pH 10.25 was used. The bioassays were performed in 128 well trays (BAW128, Frontier Agricultural Sciences). In each cell 1 ml of artificial diet was dispensed (see Table 1 for recipe). After the diet solidified, 100 µl of protein solution were applied to the surface and allowed to dry overnight at room temperature. To avoid contamination the trays were covered with a sheet of filter paper. Egg masses of each sampling site (offspring of field-collected larvae) were incubated and neonate larvae, within 12 h after hatching, were transferred to the cells. A single neonate was placed in each cell and confined with a cover (BACV16, Frontier Agricultural Sciences) (Figure 5). A single discriminating concentration (28.22 ng Cry1Ab/cm²) and a control (bicarbonate buffer) were tested for each population. For the calculation of the diagnostic dose the data for all experiments with ECB from 2005-2012 were used. These include ECB collection in fields from Czech Republic, France, Germany, Italy, Panonia, Poland, Portugal, Romania and Spain representing the responses of 11,502 larvae. Using the average of the moulting inhibition concentrations (MIC) for 99% (MIC₉₉) the diagnostic dose for ECB larvae from Europe was calculated to be 28.22 ngCry1Ab/cm² (see report 2013). Data from bioassays with more than 20% response at the control after exposure to buffer have been neglected. To determine the susceptibility of the field collections as well as the reference strains to Cry1Ab, larval mortality and larval moult inhibition data at the discriminating concentration of Cry1Ab tested were studied. In total 1,488 larvae from north-Iberian collection sites were exposed to the discriminating concentration. In the control (50 mM bicarbonate buffer, pH 10.25) 432 larvae were tested.

Field collected insects used in bioassays came from samples of healthy insects collected in different fields within an area. All assays were conducted at 25°C, 70% RH and a photoperiod of 0:24h (L:D). After seven days, larval mortality and developmental stage were recorded. Larvae that had not grown beyond first instar would not survive under field conditions (e.g. SIEGFRIED et

¹ **Disclaimer:** Monsanto has become the member of the Bayer group as of 21 August 2018. The owner of this report is Bayer Agriculture BV.

al., 2000). As a result, the criterion for moulting inhibition used in this study accounts for both death and complete moulting (or growth) inhibition.

Cry1Ab bioassays as well as control and negative control bioassays ran in parallel. All those larvae not used for these bioassays were exposed to maize plants expressing *Bt* protein as positive control as described in section 2.3.4.

Table 1. *O. nubilalis* diet recipe

Component	Amount	Provided
Distilled H2O	680 ml	
Benzoic acid	1 g	Carl Roth GmbH & Co. KG
Sorbic Acid	1 g	BioServ
Nipagin (methyl-paraben)	1 g	BioServ
Agar	16 g	Carl Roth GmbH & Co. KG
Maize powder	112 g	Gut & Gerne, BZ Bio-Zentrale GmbH
Wheatgerm	28 g	Frießinger Mühle GmbH
Brewer's yeast	30 g	Biolabor GmbH & Co.KG
Ascorbic acid	3 g	BioServ
Vanderzant vitamin mix	2 g	BioServ

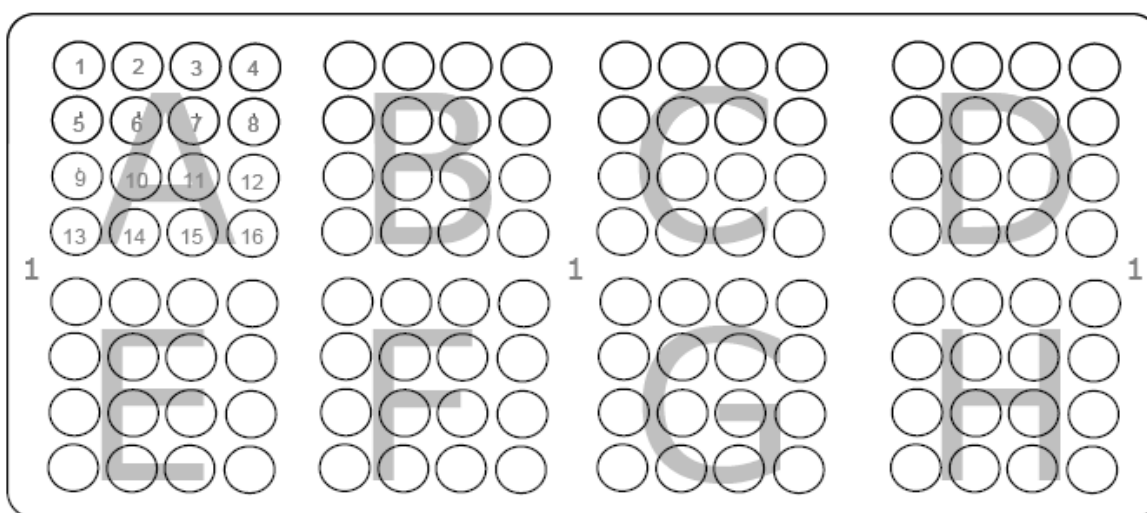


Figure 5. IDs of BAW128 trays (tray number, field letter, well number; e.g.: 1.A.13)

2.3.2 Exposure to MON 810 tissue (confirmatory experiment)

For larvae developing beyond first larval stage at the diagnostic dose (28.22 ng/cm²) a confirmatory experiment is planned. Therefore these larvae should be fed *ad libitum* with MON 810 leaves. The exposure to MON 810 is to be performed in 128 well trays (BAW128, Frontier Agricultural Sciences) for up to seven days. 1 ml of an agar solution (2.0 %) containing sorbic acid, benzoic acid and methyl paraben (each 0.1 %) to prevent leaf degradation and microbial contamination is dispensed in each cell. After solidification a detached disc of maize leave (MON 810) without central nerve and 13 mm in diameter and a larva that grew beyond first larval stage will be added to each cell which then will be closed with a lid (BACV16, Frontier Agricultural Sciences). The trays were kept in a climate cabinet at 25°C.

2.3.3 Exposure to non-GM maize tissue (negative control)

As requested by EFSA (2018) a negative control was performed in 128 well trays (BAW128, Frontier Agricultural Sciences). 1 ml of an agar solution (2.0 %) containing sorbic acid, benzoic acid and methyl paraben (each 0.1 %) to prevent leaf degradation and microbial contamination was dispensed in each cell. After solidification a detached disc of maize leave (variety Golden Bantam) without central nerve and 13 mm in diameter and a neonate larva (from IbNE, the population that was also used for analysing the susceptibility to Cry1Ab) not older than 12 hours was added to each cell which then was closed with a lid (BACV16, Frontier Agricultural Sciences). The trays were kept in a climate cabinet at 25°C. After seven days mortality and developmental stage of the larvae were recorded. Cry1Ab bioassays and negative control bioassays ran in parallel.

2.3.4 Exposure to maize tissue expressing *Bt* protein (positive control)

As requested by EFSA (2018) a positive control was performed with MON 810 leaves. The exposure to MON 810 is to be performed in plastic boxes with a diameter of 12 cm for up to seven days. 30 ml of an agar solution (2.0 %) containing sorbic acid, benzoic acid and methyl paraben (each 0.1 %) to prevent leaf degradation and microbial contamination is dispensed in each box. After solidification 3 detached leaves of maize (MON 810) without central nerve and a maximum of 300 freshly hatched larvae not older than 12 hours were added to each box. The boxes were kept in a climate cabinet at 25°C.

2.3.5 Susceptibility of the reference strains G.04 and ES.ref to Cry1Ab

To prepare the test concentration, a bicarbonate buffer (50 mmol/l) with pH 10.25 was used. The bioassays were performed in 128 well trays (BAW128, Frontier Agricultural Sciences). In each cell 1 ml of artificial diet was dispensed (see above for recipe). After the diet solidified, 100 µl of protein solution were applied to the surface and allowed to dry overnight at room temperature. To avoid contamination the trays were covered with a sheet of filter paper. Egg masses of each reference strain were incubated and neonate larvae, within 12 h after hatching, were transferred to the cells. A single neonate was placed in each cell and confined with a cover (BACV16, Frontier Agricultural Sciences).

Each strain was tested with nine concentrations (0.2–28.22 ng Cry1Ab/cm²) and a control (bicarbonate buffer). Per concentration 32 larvae were tested (64 for controls). Then MIC-values obtained for the reference strains were compared with that of the field populations.

All assays were conducted at 25°C, 70% RH and a photoperiod of 0:24h (L:D). After seven days, larval mortality and developmental stage were recorded. Larvae that had not grown beyond first instar would not survive under field conditions (e.g. SIEGFRIED et al., 2000). As a result, the criterion for mortality used in this study accounts for both death and complete moulting (or growth) inhibition.

2.4 Statistical analysis

All statistical analyses were done using the computer program SYSTAT, Version 11.0, except for dose-response analysis where PoloPlus 1.0 was used (LeOra Software Company). The results obtained for growth inhibition at different concentrations of Cry1Ab were adjusted by probit weighted regression lines, and moulting inhibition concentrations (MICs) for 50% (MIC₅₀) and 90% (MIC₉₀) of each origin tested were estimated together with their 95% confidence limits using the POLOPC programme (LeOra Software, 1987). Mortality of the control must be below 20% for *O. nubilalis*, in order to use the bioassay for statistical analysis.

The measure of how well the data (response of *O. nubilalis* to different concentrations of protein) fit the assumptions of the Probit model is goodness-of-fit. To test goodness-of-fit, responses

predicted by the Probit model were compared with responses actually observed in the bioassay (χ^2 test).

Hypothesis tests are essential for the interpretation of bioassay results. Three possible outcomes of comparing Probit regression lines are that lines are parallel but not equal (*i.e.*, different intercepts), lines are parallel and equal, or lines are neither parallel nor equal. When lines are parallel but not equal, their slopes are not significantly different. This means that changes in activity per unit change in rate are the same. If regression lines are equal, they do not differ in either intercept or slope, meaning the populations being compared are equally affected. The significance of differences in the susceptibility of the reference strains was tested by determining the 95% confidence limits (CL) of the MIC ratios (MICR) (ROBERTSON *et al.*, 2007). Concentrations are significantly different ($P < 0.05$) if the MICR 95% confidence limits do not include 1.

3 Results and Discussion

3.1 Collection of ECB

The sample sites where ECB larvae were collected in 2019 are shown in Table 2, and the area is displayed on a map in Annex I. In total 79 oviposition cages were used. Of the 1,110 larvae of ECB collected in the Ebro valley Spain, 526 specimens survived the diapause period, reached the adult stage and mated, meaning that 47.6 % of the field collected larvae were represented in the bioassay. Therefore, the detection limit for resistance allele frequency in 2019 was 4.36 % calculated based on the model developed by ANDOW & IVES (2002).

Table 2. *O. nubilalis* collection details in Spain for the 2019-2020 season.

Area	ID	Collection site ^a	Collected	Surface (ha) ^d	Distance to the nearest MON810 field (m) ^e	No of larvae collected	GPS coordinates
refG ^b	G.04	German reference	2005				
refES ^c	ES.ref	Spanish reference	12.2015				
IbNE	Zone 1						
	ES.13_2019	ES-22250 Lanaja 2 (HU)	16.-19.09.2019	1.2	1000	79	41.8082313, -0.3409892
	ES.13_2019	ES-22250 Lanaja 4 (HU)	16.-19.09.2019	5.5	1000	66	41.7964717, -0.3471771
	ES.13_2019	ES-22251 Cantalobos (HU)	16.-19.09.2019	8.8	10	223	41.8259518, -0.3639382
		Total				368	
	Zone 2						
	ES.05_2019	ES-22591 Candasnos 1 (HU)	30.09.-03.10.2019	7.8	250	247	41.4940033, 0.0840373
	ES.05_2019	ES-22592 Candasnos 6 (HU)	30.09.-03.10.2019	15.5	1290	102	41.4930061, 0.0600671
	ES.05_2019	ES-22591 Candasnos 9 (HU)	30.09.-03.10.2019	50.2	1160	72	41.4834362, 0.08352237
	ES.05_2019	ES-22591 Candasnos 10 (HU)	30.09.-03.10.2019	16.2	590	126	41.4774098, 0.0685274
		Total				547	
	Zone 3						
	ES.14_2019	ES-31150 Mendigorria 2 (NA)	14.-17.10.2019	7.1	1000	6	42.5998230, -1.8732130
	ES.14_2019	ES-31150 Mendigorria 3 (NA)	14.-17.10.2019	14.0	1000	1	42.5900260, -1.8810820
	ES.14_2019	ES-31150 Mendigorria 5 (NA)	14.-17.10.2019	1.4	0	1	42.6236733, -1.8180972
	ES.14_2019	ES-31150 Mendigorria 6 (NA)	14.-17.10.2019	5.2	0	2	42.6013450, -1.8441150
	ES.14_2019	ES-31150 Mendigorria 8 (NA)	14.-17.10.2019	11.1	20	182	42.6051366, -1.8339554
	ES.14_2019	ES-31150 Mendigorria 9 (NA)	14.-17.10.2019	6.1	0	2	42.6057530, -1.8354648
	ES.14_2019	ES-31150 Mendigorria 10 (NA)	14.-17.10.2019	2.4	0	1	42.6105290, -1.8322840
		Total				195	
		GRAND TOTAL				1110	

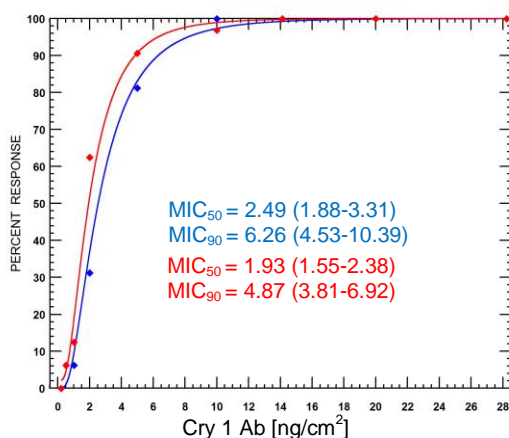
^a Spanish provinces: HU = Huesca, NA = Navarra; ^b reference strain Germany; ^c reference strain Spain; ^d The area of the whole field, even though larvae were collected on the refuge area of the field. Data are approximate; ^e there could be other nearer fields that are not known by the technician and/or the farmer, "0" means that it is adjacent to a MON 810 field, ^e larvae sent to Germany after removing those that were damaged or seemed to have some pathogens

Table 3. Development of *O. nubilalis* collected in Spain for the 2019-2020 season.

Area	ID	No of larvae that reached the adult stage				Parasitized	
		male	female	total	%	n	%
IbNE	Zone 1						
	ES.13_2019	17	14	31	39.2	34	43.0
	ES.13_2019	15	20	35	53.0	11	16.7
	ES.13_2019	53	50	103	46.2	55	24.7
	Total	85	84	169	45.9	100	27.2
	Zone 2						
	ES.05_2019	49	80	129	52.2	23	9.3
	ES.05_2019	23	38	61	59.8	18	17.6
	ES.05_2019	29	22	51	70.8	9	12.5
	ES.05_2019	7	13	20	15.9	2	1.6
Total	108	153	261	47.7	52	9.5	
Zone 3							
ES.14_2019	all Mendigorria sites were pooled						
ES.14_2019							
ES.14_2019							
ES.14_2019							
ES.14_2019							
ES.14_2019							
Total	41	55	96	49.2	80	41.0	
GRAND TOTAL				526	47.6	232	25.9

3.2 Susceptibility to Cry1Ab in the 2019-2020 campaign

To analyze if the Cry1Ab protein batches 2b and 2c differed in efficacy a bridging experiment was done with larvae of strain Es.ref, applying the same method as for the bioassays with the reference strains. The proteins of both batches did not significantly differ in their efficacy (Figure 6).



	MIC ratios	
	(MICR ₅₀)	Conf. limits
Batch 2b vs. 2c	1.290	(0.912-1.824)
	(MICR ₉₀)	
Batch 2b vs. 2c	1.284	(0.787-2.095)

Figure 6. Fitted curves of susceptibility as percentage moult inhibition after seven days of feeding by ECB (Es.ref) when exposed to treated diet from the batches 2b (blue) and 2c (red) of protein Cry1Ab (PoloPlus, LeOra Software 2002-2009). According to the statistical analyses both curves have equal slopes and equal intercepts ($P > 0.05$; χ^2 : 2.21, d.f.: 2; tail probability: 0.332)

To determine the susceptibility of the field collections as well as the reference strains to Cry1Ab, larval mortality and larval moult inhibition data at the discriminating concentration of Cry1Ab tested (determined to be 28.22 ng/cm²) were studied (Table 4).

Table 4. Response of *O. nubilalis* larvae in the 2019-2020 season.

Coll. Site	Test*	Larvae used (n)	Dead	L1	L2	L3	L4	MORT [%]	MI [%]
Zone 1	Cry1Ab	496	42	451	3	0	0	8.47	99.40
	Control	144	0	0	49	91	4	0.00	0.00
	non-GM maize leaves	224	6	1	11	206	0	2.68	3.13
	MON 810 leaves	3765	3765	0	0	0	0	100.00	100.00
Zone 2	Cry1Ab	704	39	664	1	0	0	5.54	99.86
	Control	224	1	0	2	213	8	0.45	0.45
	non-GM maize leaves	256	4	0	10	242	0	1.56	1.56
	MON 810 leaves	7300	7300	0	0	0	0	100.00	100.00
Zone 3	Cry1Ab	288	17	270	1	0	0	5.90	99.65
	Control	64	0	0	1	61	2	0.00	0.00
	non-GM maize leaves	64	1	0	1	62	0	1.56	1.56
	MON 810 leaves	1350	1350	0	0	0	0	100.00	100.00
Total	Cry1Ab	1488	98	1385	5	0	0	6.59	99.74
	Control	432	1	0	52	365	14	0.23	0.23
	non-GM maize leaves	544	11	1	22	510	0	2.02	2.21
	MON 810 leaves	12415	12415	0	0	0	0	100.00	100.00

* Bioassays: "Cry1Ab" = 28.22 ng/cm² Cry1Ab protein, "Control" = 50 mM bicarbonate buffer (pH 10.25). Total number of larvae tested: 14,879. Test duration: 7 days

Of the 1,488 larvae exposed to the discriminating concentration 98 larvae died, 1,385 survived but did not reach the 2nd larval stage, and 5 reached the second larval stage and were used for a confirmatory experiment (Table 4). The resulting moulting inhibition was 99.74 %.

Of 432 larvae exposed to the control only a single larva died, all other larvae developed beyond first larval stage (L2 n=52 (12.04%), L3 n=365 (84.49%), L4 n=14 (3.24%)). Any moulting inhibition was not observed.

3.3 Exposure to MON 810 tissue (confirmatory experiment)

All *O. nubilalis* larvae from field collections that survived the bioassay at the diagnostic dose were subject to a confirmatory experiment (Table 4). For the season reported here, 5 larvae developed to the second larval stage after 7 days of exposure to a dosage representing the diagnostic dose (28.22 ng/cm²). The confirmatory experiment conducted showed that each of these larvae died after feeding on *Bt* maize within 7 days.

3.4 Exposure to maize tissue not expressing *Bt* protein (negative control)

544 freshly hatched neonate larvae of *O. nubilalis* from the same population as tested in Cry1Ab bioassays and in MON810 leaf bioassays were fed with maize cv. Golden Bantam for seven days. Eleven of the larvae died (2.02 %), 1 remained in the first larval stage (0.18 %), 22 reached the second larval stage (4.04 %) and 510 (93.75 %) developed to the third larval stage (Table 4). Since the feeding activity of the larvae was very high and additional leaf material was not added, some larvae remained in the 2nd larval stage.

3.5 Exposure to maize expressing *Bt* protein (positive control)

12,415 freshly hatched neonate larvae of *O. nubilalis* not used for the bioassays mentioned above were transferred to MON810 for seven days. Each of the larvae died (100 %) in the first larval stage (Table 4).

3.6 Historical susceptibility of corn borers to Cry1Ab

During 2008–2018, 63 samples of ECB from different areas were analyzed. Their susceptibility to Cry1Ab is shown in Table 5.

Table 5. Susceptibility of *O. nubilalis* neonates exposed to Cry1Ab as measured by the MIC or response to DC (RDC) for areas tested.

Area	Year	RDC (%)	MIC ₅₀ (95% CI) ^a	MIC ₉₀ (95% CI) ^a
Iberia Central	2009 ¹		3.09 (2.03-4.33)	11.98 (8.12-22.31)
	2011 ²		1.56 (1.27-1.91)	4.04 (3.12-5.91)
	2013 ³		2.40 (2.04-2.83)	6.38 (5.18-8.34)
	2015 ³		1.88 (1.68-2.11)	3.38 (2.91-4.21)
Iberia Northeast	2008 ¹		7.03 (4.89-10.03)	23.91 (15.76-46.84)
	2009 ¹		6.40 (5.32-7.75)	13.68 (10.77-20.02)
	2011 ²		1.79 (1.54-2.07)	4.19 (3.45-5.48)
	2013 ³		2.48 (2.03-3.02)	5.41 (4.27-7.61)
	2015 ³		2.12 (1.75-2.55)	5.43 (4.36-7.29)
	2016 ⁴	99.23		
	2017 ⁴	99.19		
	2018 ⁴	99.83		
Iberia Southwest	2019 ⁵	99.74		
	2008 ¹		3.39 (2.94-3.89)	6.90 (5.79-8.89)
	2010 ¹		5.76 (4.38-7.84)	11.85 (8.53-23.52)
	2012 ²		4.08 (2.99-5.50)	8.69 (6.30-15.56)
	2014 ³		1.32 (0.94-1.74)	3.80 (2.78-6.21)

MIC moulting inhibition concentrations, CI confidence interval, ^a ng Cry1Ab/cm²; ¹ batch 1 of Cry1Ab, ² batch 2 of Cry1Ab, ³ batch 2a of Cry1Ab, ⁴ batch 2b of Cry1Ab, ⁵ batch 2c of Cry1Ab

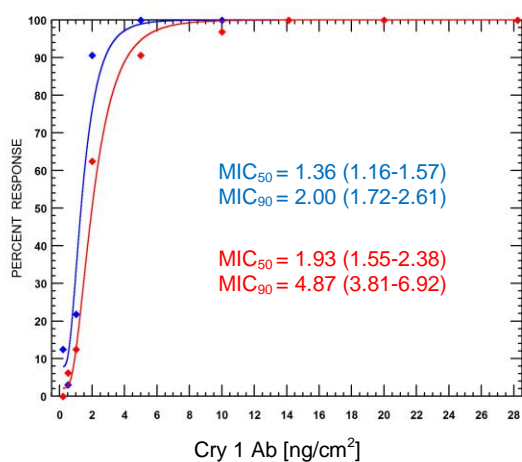
3.7 Susceptibility of the reference strains G.04 and ES.ref to Cry1Ab

The reference strain G.04 was kept in the laboratory in sub-strains since 2011 and checked regularly for performance (size of adults, size of egg masses, and development of larvae). In 2011, by performing a PCR based method (SAEGLITZ, 2004), infection with *Nosema* was identified for some individuals in one sub-strain, which have been eliminated. One sub-strain was used for the subsequent years until now. This sub-strain is producing good-quality egg masses and normal-sized adults. The last PCR analysis (done in June 2020) showed that the reference strain G.04 is not infected with microsporidia or with *Nosema* (Figure A2).

The strain ES.ref was established as a second reference strain with ECB collected in December 2015 in the Northwest region of Spain where *Bt* maize has not been cultivated. This strain has also been checked for infection with *Nosema*. Applying the PCR based method (SAEGLITZ, 2004) there were no individuals identified as being infected with microsporidia or with *Nosema*. (Figure A2).

Fitted curves of susceptibility to the Cry1Ab protein of laboratory reference strains of *O. nubilalis* were generated taking into account the moulting inhibition concentration of neonate larvae after seven days feeding on treated diet (Figure 7). As a dose-response relationship was not found for the mortality of any ECB origin this character will not be used for further discussions. Moulting inhibition concentrations at 50% (MIC₅₀) and 90% (MIC₉₀) for *O. nubilalis* kept as

reference strains are provided in Table 5. The results for both strains appear to continue to be well within the historical range for the populations tested.



	MIC ratios	
	(MICR ₅₀)	Conf. limits
G.04 vs. ES.ref	0.705	(0.546-0.912)
	(MICR ₉₀)	
G.04 vs. ES.ref	0.411	(0.291-0.581)

Figure 7. Fitted curves of susceptibility as percentage moult inhibition after seven days feeding on treated diet of ECB reference strains to the batch 2c of protein Cry1Ab (PoloPlus, LeOra Software 2002-2009). (Reference strain G.04: blue; reference strain ES.ref: red)

A dose-response relationship was calculated for the moulting inhibition of the reference strains ES.ref and G.04. The significance of differences in susceptibility between the reference strains (G.04, originally collected in Niedernberg, Germany, and kept in culture since 2005; ES.ref collected in fields located in Galicia, Northwest Spain) was tested by determining the 95% confidence limits of MIC ratios (MICR) (ROBERTSON et al., 2007). The MIC₅₀ and MIC₉₀ values for the reference strains of ECB from Germany (G04) and Spain (ES.ref) differed significantly in their susceptibility to Cry1Ab/cm² (Figure 6) as indicated by the exclusion of 1 in their MICR 95% confidence limits.

Table 6. Results from Probit analysis for the ECB reference strains tested in the season 2019-2020.

Area	n	Slope ± SE	χ^2	D.f.	MIC ₅₀ (95% CI) ^a	MIC ₉₀ (95% CI) ^a
refG	352	7.666 ± 1.518	1.963	7	1.36 (1.16-1.57)	2.00 (1.72-2.61)
refES	351	3.191 ± 0.406	4.692	7	1.93 (1.55-2.38)*	4.87 (3.81-6.92)*

^a 50% and 90% moulting inhibition concentrations (MIC₅₀ and MIC₉₀) and their 95% confidence intervals (95%CI) are expressed in ng Cry1Ab/cm². * Moulting inhibition concentration is significantly different (P < 0.05) to the reference strain G.04.

4 Conclusions

In 2019, ECB larvae from one area with three sample sites of ECB were analyzed. Thus far, susceptibility to Cry1Ab has been assessed for two reference strains and ECB collected in maize fields in Northeast Iberia. ECB larvae were exposed to artificial diet treated with the discriminating concentration, and mortality and growth inhibition were evaluated after 7 days. Of

the 1,488 larvae exposed to the discriminating concentration 98 larvae died, 1,385 survived but did not reach the 2nd larval stage, and 5 reached the 2nd larval stage and were used for a confirmatory experiment. The resulting effect of Cry1Ab on moulting inhibition (this criterion used accounts for both death and complete moulting (or growth) inhibition) was 99.74 %. In the confirmatory experiment, all of these larvae died after feeding on *Bt* maize within seven days. Therefore, no decrease in Cry1Ab susceptibility of ECB has been observed during the monitoring duration.

5 Acknowledgement

This report presents the results of research only and would not be possible without the kind help of all those who supplied insects: the Spanish group around Félix Ortego and Gema P Farinós (CSIC, Madrid, ES).

6 References

- ANDOW, D.A. & IVES, A.R. 2002. Monitoring and adaptive resistance management. *Ecol Appl* **12**: 1378–1390.
- BECK, S.D. 1987. Developmental and seasonal biology of *Ostrinia nubilalis*. *Agric Zool Rev* **2**: 59-96.
- CAFFREY, D.J. & WORTHLEY, L.H., 1927. A progress report on the investigations of the European corn borer. *USDA Bull.* 1476.
- EFSA Panel on Genetically Modified Organisms, 2012. Scientific Opinion on the annual Post-Market Environmental Monitoring (PMEM) report from Monsanto Europe S.A. on the cultivation of genetically modified maize MON 810 in 2010. *EFSA Journal* 2012: **10**(3):2610, 35 pp. doi:10.2903/j.efsa.2012.2610
- EFSA 2017. Scientific Opinion on the annual post-market environmental monitoring (PMEM) report on the cultivation of genetically modified maize MON 810 in 2015 from Monsanto Europe S.A. *EFSA Journal* 2017;15(5):4805, 27 pp. <https://doi.org/10.2903/j.efsa.2017.4805>
- EFSA Statement, 2018. Annual post-market environmental monitoring report on the cultivation of genetically modified maize MON 810 in 2016. *EFSA Journal* 2018: **16**(5):5287, 34 pp. doi/epdf/10.2903/j.efsa.2018.5287
- FARINÓS, G.P., DE LA POZA, M., HERNANDEZ-CRESPO, P., ORTEGO, F. & CASTAÑERA, P., 2004. Resistance monitoring of field populations of the corn borers *Sesamia nonagrioides* and *Ostrinia nubilalis* after 5 years of *Bt* maize cultivation in Spain. *Ent. Experimentalis et Applicata* **110**: 23-30.
- GUTHRIE, W.D., ROBBINS, J.C. & JARVIS, J.L., 1985. *Ostrinia nubilalis*. In: Handbook of insect rearing. Volume 1. SINGH, P. & R.F. MOORE (eds.) Elsevier, Amsterdam, Oxford, New York, Tokyo, pp. i-viii; 488.
- HODGSON, 1928. The host plants of the European corn borer in New England. *USDA Tech Bull* **77**: 1-63.
- HUDON, M. & LEROUX, E.J., 1986. Biology and population dynamics of the European corn borer (*Ostrinia nubilalis*) with special reference to sweet corn in Quebec, Canada. I. Systematics, morphology, geographical distribution, host range, economic importance. *Phytoprotection* **67**: 39-54.

- LEAHY, T.C. & ANDOW, D.A., 1994. Egg weight, fecundity, and longevity are increased by adult feeding in *Ostrinia nubilalis* (Lepidoptera, Pyralidae). *Annals of the Entomological Society of America* **87**: 342-349.
- LEORA SOFTWARE, 1987. POLO-PC. A user's guide to probit and logist analysis. LeOra Software, Berkley, CA.S
- MARÇON, P.C.R.G., TAYLOR, D.B., MASON, C.E., HELLMICH, R.L., & SIEGFRIED, B.D., 1999a. Genetic similarity among pheromone and voltinism races of *Ostrinia nubilalis* Hübner (Lepidoptera: Crambidae): *Insect Molecular Biology*, **8** (2): 213-221.
- MARÇON, P.C.R.G., YOUNG, L.J., STEFFEY, K.L. & SIEGFRIED, B.D., 1999b. Baseline susceptibility of European corn borer (Lepidoptera: Crambidae) to *Bacillus thuringiensis* toxins. *Journal of Economic Entomology* **92**: 279-285.
- MARÇON, P.C.R.G., SIEGFRIED, B.D., SPENCER, T. & HUTCHISON, W.D. 2000. Development of Diagnostic Concentrations for Monitoring *Bacillus thuringiensis* Resistance in European Corn Borer. (Lepidoptera: Crambidae). *Journal of Economic Entomology* **93**: 925-930.
- PONSARD, S., BETHENOD, M.-T., BONTEMPS, A., PELOZUELO, L., SOUQUAL, M.-C. & BOURGUET, D., 2004. Carbon stable isotopes: a tool for studying the mating, oviposition, and spatial distribution of races of European corn borer, *Ostrinia nubilalis*, among host plants in field. *Can J Zool* **82**: 1177-1185.
- ROBERTSON, J.L., RUSSELL, R.M., PREISLER, H.K. & SAVIN, N.E., 2007. Pesticide bioassays with arthropods, 2nd ed. CRC Press, Boca Raton, FL.
- ROELOFS, W.L., DU, J.-W., TANG, X.-H., ROBBINS, P.S., & ECKENRODE, C.J., 1985. Three European corn borer populations in New York based on sex pheromones and voltinism. *J. Chem. Ecol.* **11**: 829-836.
- SAEGLITZ, C., 2004. Untersuchungen der genetischen Diversität von Maiszünsler-Populationen (*Ostrinia nubilalis*, Hbn.) und ihrer Suszeptibilität gegenüber dem *Bacillus thuringiensis* (Bt)-Toxin als Grundlage für ein Resistenzmanagement in Bt-Maiskulturen. *Journal of Economic Entomology* **99**: 1768-1773.
- SAEGLITZ, C., BARTSCH, D., EBER, S., GATHMANN, A., PRIESNITZ, K.U. & SCHUPHAN, I., 2006. Monitoring the Cry1Ab susceptibility of European corn borer in Germany. PhD thesis RWTH Aachen (unpublished): 166 pp.
- SHOWERS, W.B., 1993. Diversity and variation of European corn borer populations. In: *Evolution of Insect Pests*, KIM, K.C. & B.A. MCPHERON (eds.) (John Wiley and Sons) New York, pp. 287-309.
- SHOWERS, W.B., Hellmich, R.L., Derrick-Robinson, M.E. & Hendrix, W.H., 2001. Aggregation and dispersal behavior of marked and released European corn borer (Lepidoptera: Crambidae) adults. *Environ. Entomol.* **30**: 700-710.
- SIEGFRIED, B.D., SPENCER, T. & NEARMAN, J., 2000. Baseline Susceptibility of the Corn Earworm (Lepidoptera: Noctuidae) to the Cry1Ab Toxin from *Bacillus thuringiensis*. *Journal of Economic Entomology* **93**: 1265-1268.
- SIMS, S.B., GREENPLATE, J.T., STONE, T.B., CAPRIO, M.A. & GOULD, F., 1996. Monitoring strategies for early detection of Lepidoptera resistance to *Bacillus thuringiensis* insecticidal proteins. In: *Molecular Genetics and Evolution of Pesticide Resistance*, BROWN, T.M. (ed.). ACS Symposium Series No. 645, Washington, DC, pp. 229-242.

- THIEME, T., BUUK, C., GLOYNA, K., ORTEGO, F. & FARINÓS, G.F., 2017. Ten years of MON 810 resistance monitoring of field populations of *Ostrinia nubilalis* in Europe. J Appl Entomol. 1–9. DOI: 10.1111/jen.12420.
- VINAL, S.C., 1917. The European corn borer, *Pyrausta nubilalis* Hübner, a recent established pest in Massachusetts. Massachusetts Agric Exp Stn Bull **178**: 147-152.

Annex I
Areas of collection activities for ECB in 2019

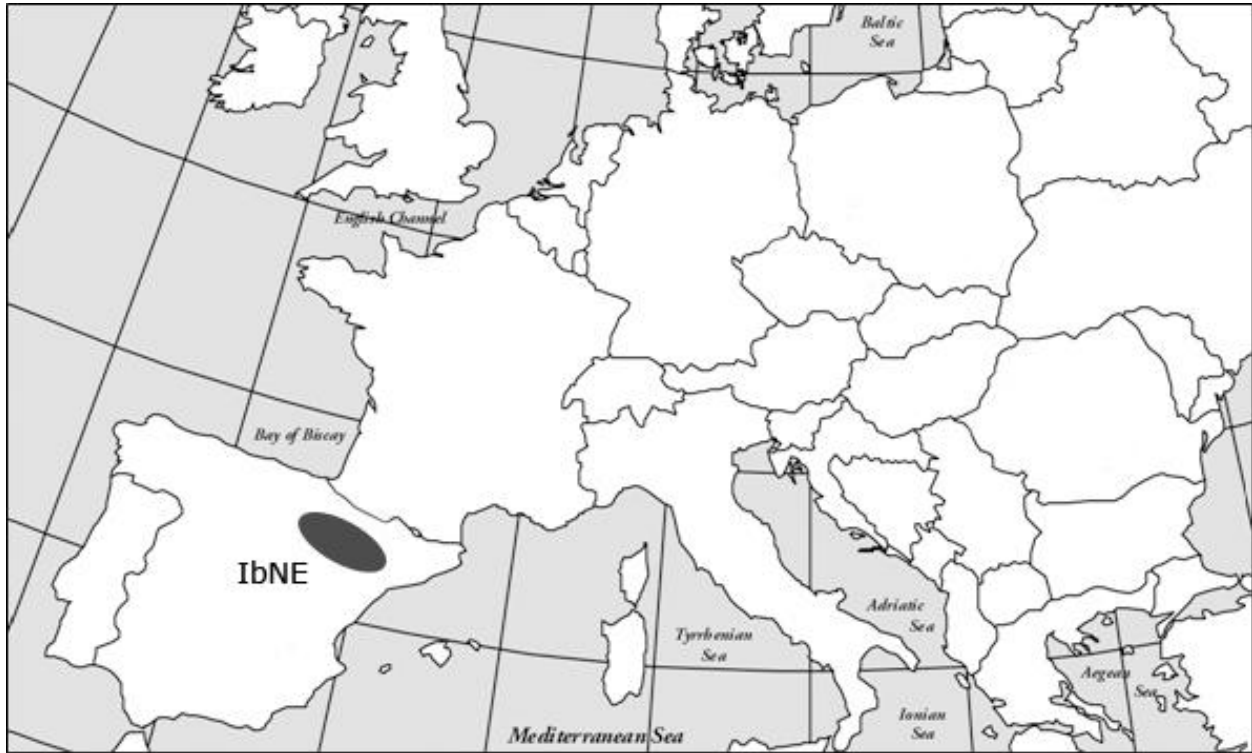


Figure A1. Area where ECB were sampled in 2019 (Iberia Northeast)

Annex II
Proof for stability and quality of the pest insect reference strains

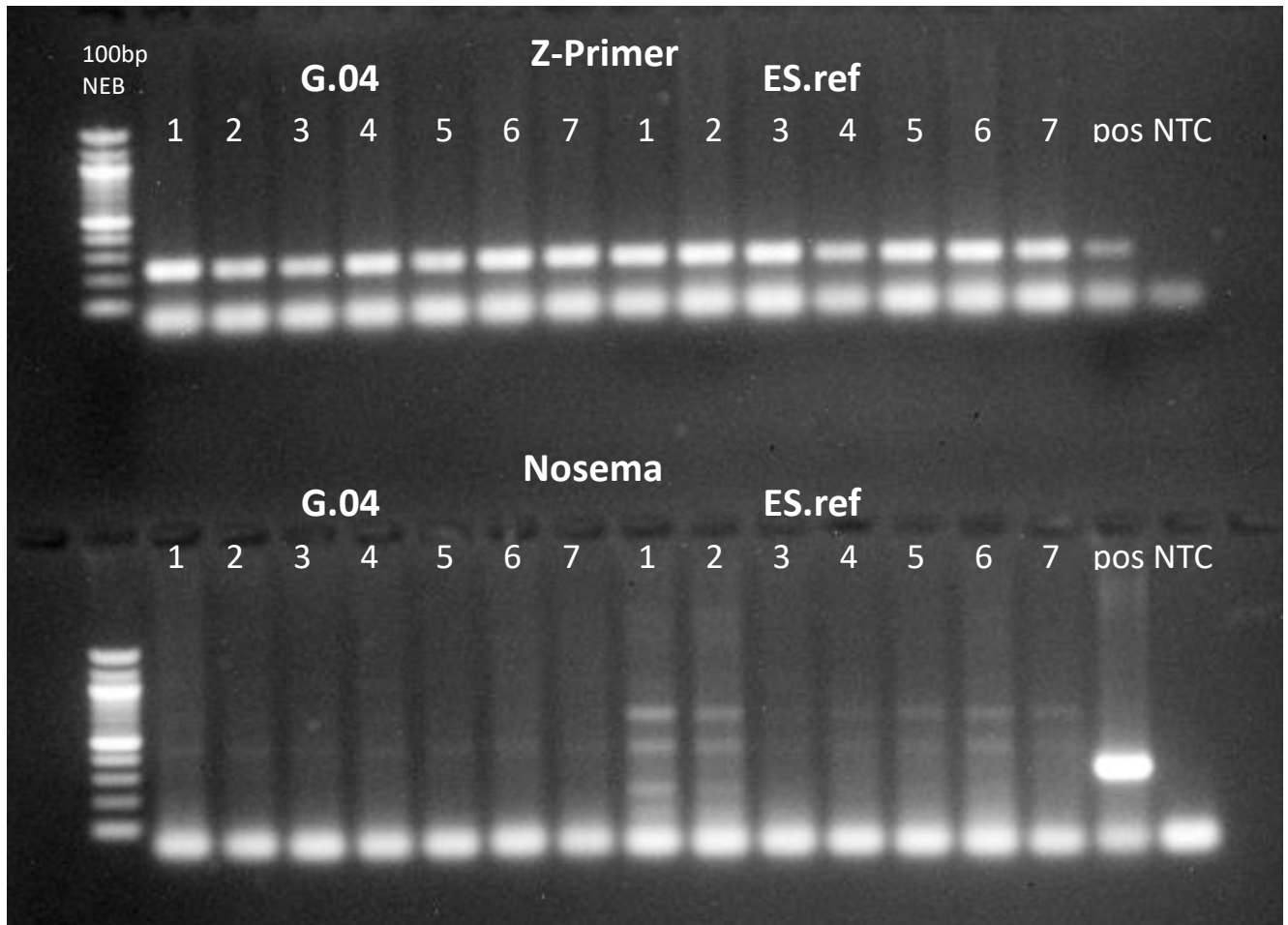


Figure A2. PCR analyses for checking if the reference strains of G.04 (Germany) and ECB (ES.ref (Spain)) are infected with *Nosema* (according to SAEGLITZ, 2004).

(pos: positive control, NTC: no template control; G.04: 1-7 each with 10 larvae (Lv1) pooled; ES.ref: 1-7 each with 10 larvae (Lv1) pooled; Z-Primer was applied to check that the DNA was not destroyed)