NEONICOTINOIDS

A worldwide survey of neonicotinoids in honey

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Growing evidence for global pollinator decline is causing concern for biodiversity conservation and ecosystem services maintenance. Neonicotinoid pesticides have been identified or suspected as a key factor responsible for this decline. We assessed the global exposure of pollinators to neonicotinoids by analyzing 198 honey samples from across the world. We found at least one of five tested compounds (acetamiprid, clothianidin, imidacloprid, thiacloprid, and thiamethoxam) in 75% of all samples, 45% of samples contained two or more of these compounds, and 10% contained four or five. Our results confirm the exposure of bees to neonicotinoids in their food throughout the world. The coexistence of neonicotinoids and other pesticides may increase harm to pollinators. However, the concentrations detected are below the maximum residue level authorized for human consumption (average ± standard error for positive samples: 1.8 ± 0.56 nanograms per gram).

Neonicotinoids are currently the most widely used class of insecticides worldwide (*1*). These pesticides are increasingly prevalent in terrestrial and aquatic environments (*2*, *3*). Neonicotinoids are taken up by plants and transported to all organs, including flowers, thus contaminating pollen and nectar as well as any fluid produced by the plant (*3*). There are increasing concerns about the impact of these systemic pesticides, not only on nontarget organisms—especially pollinators such as honey bees (*4*–*6*) and wild bees (*7*, *8*), as well as in other terrestrial and aquatic invertebrates (*9*, *10*)—but also on vertebrates (*11*–*14*), including humans (*15*, *16*). Impacts on such a broad range of organisms ultimately also affect ecosystem functioning (*17*). As a result, the pertinence of use of these pesticides is currently being questioned in many countries (*18*), with a ban now implemented in France, and alternatives proposed (*19*). However, despite increasing research efforts to understand the patterns of neonicotinoid uses and their effects on living organisms, we lack a global view of the worldwide distribution of neonicotinoid contamination in the environment (*18*) to evaluate the risk posed to living organisms. To build such a map, we measured neonicotinoid concentrations in 198 honey samples from different regions of the world.

Bees rely on nectar and pollen sources for their survival. Nectar is transformed into honey and stored in the hive for daily adult consumption and is essential for winter survival. A mature colony can be populated by up to 60,000 adult bees and therefore needs vast amounts of food. Individuals harvest nectar and pollen less than 4 km from the hive, on average, but may travel up to 12.5 km away (*20*, *21*), which makes bees distinctive sentinels of environment quality. Indeed, the residue level of pesticides in honey from a hive is a measure of the contamination in the surrounding landscape (*22*). Honey samples are easy to obtain from a very broad range of geographical localities, thus enabling a worldwide analysis. Analytical protocols have been developed to analyze neonicotinoid concentrations in honey (*23*), and several studies have quantified the concentration of neonicotinoids in honey (*24*–*26*). However, the amount of data is limited, quantification thresholds vary among studies, and a global picture of neonicotinoid contamination in honey is lacking.

Here we present a global survey of neonicotinoid contamination in honey samples from all continents (except Antarctica), as well as numerous isolated islands. We measured the concentrations of five commonly used neonicotinoids—acetamiprid, clothianidin, imidacloprid, thiacloprid, and thiamethoxam—in 198 samples (tables S1 to S3) collected through a citizen science project (described in details in the supplementary materials). Overall, 75% of all honey samples contained quantifiable amounts of at least one neonicotinoid. This proportion varied considerably among regions, being highest in North American (86%), Asian (80%), and European (79%) samples and lowest in South American samples (57%) (Fig. 1, figs. S1 and S2, and tables S1 and S4). Thirty percent of all samples contained a single neonicotinoid, 45% contained between two and five, and 10% contained four or five. Multiple contaminations were most frequent in North America, Asia, and Europe and least frequent in South America and Oceania (table S4 and Fig. 1). Frequency of occurrence was highest for imidacloprid (51% of samples) and lowest for clothianidin (16%). Maximum and average concentrations among positive samples were highest for acetamiprid and thiacloprid (table S5).

The frequency of occurrence of individual neonicotinoid in honey samples and their relative contribution to the overall neonicotinoid concentration varied among the regions (Fig. 1). Imidacloprid dominated overall concentrations in Africa and South America, thiacloprid in Europe, acetamiprid in Asia, and thiamethoxam in Oceania and North America (Fig. 1), reflecting regional differences in usage of specific pesticide types. In all regions, at least one neonicotinoid was recorded in at least 25% of samples, and three neonicotinoids (thiamethoxam, imidacloprid, and clothianidin) were recorded in at least 50% of samples in North America (table S6).

The total concentration of the five measured neonicotinoids was, on average, 1.8 ng/g in positive (i.e., contaminated) samples and reached a maximum of 56 ng/g over all positive samples (table S4). This average concentration lies within the bioactive range (*27*, *28*), causing deficits in learning (*29*, *30*), behavior (*31*), and colony performances (*8*, *32*) in honey bees (table S8). As for the percentage of positive samples, maximum, median, and average concentrations were highest in European, North American, and Asian samples (figs. S3 to S8 and table S4). Maximum residue levels (MRLs) authorized in food and feed products in the European Union (EU MRLs: 50 ng/g for acetamiprid, imidacloprid, and thiacloprid and 10 ng/g for clothianidin and thiamethoxam) were not reached for any tested neonicotinoid. The sum of percentages of EU MRLs for the five neonicotinoids reached 3.6%, on average, for all positive samples, exceeded 10% in eight samples, and surpassed 100% in two European samples (table S1).

Our global survey showed that 75% of all analyzed honey samples contained at least one neonicotinoid in quantifiable amounts and that these pesticides are found in honey samples from all continents and regions. Previous studies conducted at smaller scales (regional to national) reported a broad range of frequency of occurrence and concentrations of neonicotinoids in honey, depending on the compound, distance to neonicotinoid-treated agricultural field, and limits of detection. The percentage of positive samples is, to some extent, correlated with the detection limits (table S7). For example, in a British study (*26*), 16 out of 22 samples were positive for clothianidin, but for all of these samples the measured concentrations (>0.02 to 0.82 ng/g) were below the detection limit of a Serbian study (1.0 ng/g) in which no sample tested positive (*33*). With the improvement of analytical methods, we can therefore expect that the proportion of positive samples will increase. Differences in methods and especially in limits of quantification (LOQ) render comparisons among studies of little relevance. Thus, to some extent, our results illustrate that the ever-increasing analytical sensitivity allows detecting traces of pesticides where they previously were not detectable. But given the increasing use of neonicotinoid pesticides in the different regions of the world, despite partial bans such as the one implemented in the EU, it is also reasonable to expect contamination to have increased over time. Total bans, such as the one soon to be implemented in France, may reverse this trend in the future.

Although 75% of samples tested positive for at least one neonicotinoid, concentrations were, in all cases, below the admissible limits for human consumption according to current EU and U.S. regulations (i.e., MRLs). On the basis of our current knowledge, consumption of honey is therefore not thought to harm human health. However, recent evidence for impacts of neonicotinoids on vertebrates (*12*, *13*), including humans (*15*, *16*, *34*), and especially evidence for up-regulation of nicotinic a4b2 AChRs receptors in the mammal brain during chronic exposure and for higher affinity of metabolites versus the parent neonicotinoid (imidacloprid) (*14*), could lead to reevaluating MRLs. Although the impact of the measured concentrations of neonicotinoids in honey on vertebrates, including humans, is considered negligible, a significant detrimental effect on bees is likely for a substantial proportion of the analyzed samples, as adult bees rely on honey for food, including during periods of overwintering or seasons without blossoming flowers. The increasingly documented sublethal effects of neonicotinoid pesticides at environmentally relevant concentrations on bees and other nontarget organisms include growth disorders, reduced efficiency of the immune system, neurological and cognitive disorders, respiratory and reproductive function, queen survival, foraging efficiency, and homing capacity at concentrations as low as 0.10 ng/g (table S8).

One of the challenges of assessing the risks associated with the use of pesticides is to evaluate their impact at field-realistic exposure concentrations. A total concentration of 0.10 ng/g, corresponding to the lowest concentration at which marked detrimental effects were observed on nontarget insects (*27*) (table S8), was exceeded in 48% of our honey samples (table S1). Therefore, our results, combined with the growing body of evidence for detrimental effects on bees and other nontarget invertebrates, suggest that a substantial proportion of world pollinators are probably affected by several neonicotinoids. Another challenge is to evaluate the influence of chronic exposure to some neonicotinoids on nontarget insects' sensitivity to other neonicotinoids. Recent studies showed an increased

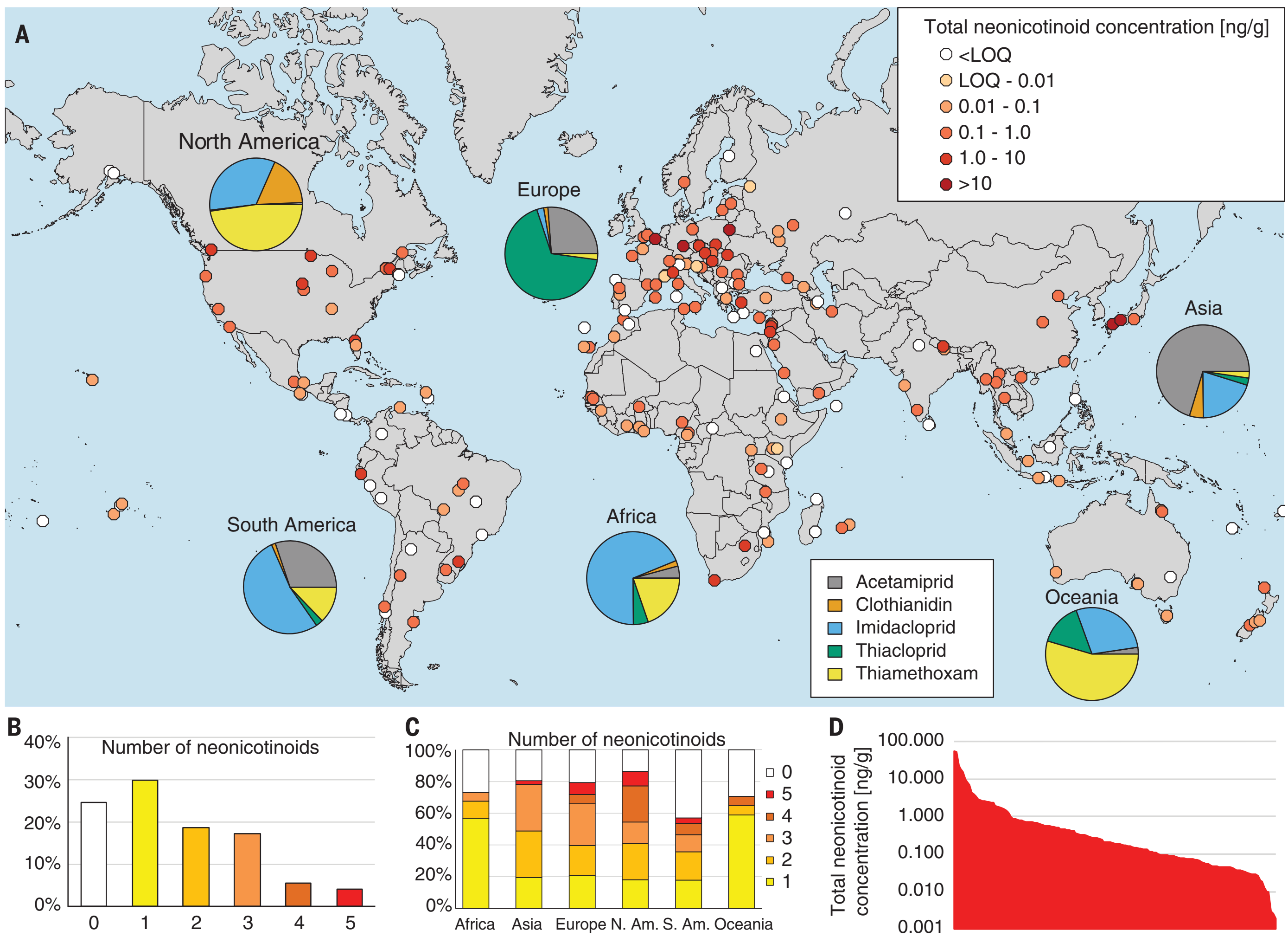

Fig. 1. Worldwide contamination of honey by neonicotinoids. (**A**) Worldwide distribution of honey contamination by neonicotinoids. White symbols, concentration below quantification levels (<LOQ) for all tested neonicotinoids; colored symbols, >LOQ for at least one neonicotinoid; shading indicates the total neonicotinoid concentration (nanograms per gram). Pie chart insets: Relative proportion of overall concentration of each neonicotinoid by continent (legend in bottom inset). (**B**) Overall percentage of samples with quantifiable amounts of 0, 1, or a cocktail of 2, 3, 4, or 5 individual neonicotinoids. (**C**) Proportion of samples with 0, 1, 2, 3, 4, and 5 individual neonicotinoids in each continent. (**D**) Rank-concentration distribution of total neonicotinoids in all of the 149 samples in which quantifiable amounts of neonicotinoids were measured.

sensitivity to neonicotinoids after frequent or long-term exposure (*27*, *32*).

Defining the thresholds below which neonicotinoids would not even have a sublethal effect under chronic exposure is much more difficult than assessing levels corresponding to short-term acute toxicity. Therefore, the proportion of samples that may affect bees cannot be ascertained based on current knowledge, but this study shows that pollinators are globally exposed to neonicotinoids, partly at concentrations shown to be harmful to bees. The fact that 45% of our samples showed multiple contaminations is worrying and indicates that bee populations throughout the world are exposed to a cocktail of neonicotinoids. The effects of exposure to multiple pesticides, which have only recently started to be explored (*35*), are suspected to be stronger than the sum of individual effects (*18*). This worldwide description of the situation should be useful for decision-makers to reconsider the risks and benefits of using neonicotinoids and provides scientists an inventory of the most frequent combinations of neonicotinoids found in honey (table S9). We urge national agriculture authorities to make the quantities of neonicotinoids and other pesticides used on their territories publicly available and also professionally available to epidemiologists at a much higher geographical resolution to enable correlative studies between local events and pesticide load.

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/358/6359/109/suppl/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S8
Tables S1 to S9
References (*36*–*79*)

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Nomenclature

To avoid potential confusions between the use of the terms bees, honeybees and pollinators we refer to bees when honeybees (*Apis mellifera mellifera* and *A. cerana*) are concerned and to pollinators in all other cases.

Materials and Methods

Honey sample collection through citizen science

We obtained a worldwide collection of honey samples through a citizen science effort led by the botanical garden of Neuchâtel between November 2012 and February 2016. Over one hundred colleagues, friends and relatives provided honey from various regions of the world. We asked people to bring back local honey from a local producer, ideally with indication of the type of honey and address of the producer. We constructed a database with all the available data: GPS coordinates, country, province, region, locality, description of the honey as stated on the label, the name of the beekeeper (only available for about 7% of the samples), and the name of the donor.

Each sample was given a number and a searchable database code (JBN.Miel.xxxx). The database can be consulted by sending an email to the Botanical Garden of Neuchâtel (jardin.botanique@unine.ch). In addition, aliquots of honey samples may be requested from the curator of this collection (BM) within the limit of available stocks.

To protect the business and the reputation of the producers and as advised by the legal service of the University of Neuchâtel, we chose to keep the name of the producers (when available) confidential. Upon arrival, each honey sample was split in two lots; one was stored at the Botanical Garden of Neuchâtel at room temperature and the other at the University of Neuchâtel at -80°C in total obscurity. Storage conditions prior to their arrival at Neuchâtel are unknown.

Of the >300 samples we received, we selected 198, aiming for 1) a balanced geographical coverage (Africa: 37, Asia: 41, Europe: 53, North America: 22, South & Central America & Caribbean: 28, Oceania, Zealandia & Pacific Islands: 17) and 2) the broadest representation of the planet biomes and geographical characteristics (e.g. including isolated islands, mountain ranges, urban to natural habitats). We did not analyze all samples received for two main reasons: 1) for some samples, some essential information such as the type of honey or precise location was lacking, and 2), samples from Europe were largely overrepresented. To avoid an overrepresentation of European honeys in our dataset, many samples were not analyzed.

In addition to being easily accessible it should be noted that honey provides a conservative measurement of pesticide exposure by honeybees and other pollinators in comparison to nectar, pollen and beewax. Indeed, in a French study, honey was shown to have the lowest frequency of pesticide occurrence in comparison to pollen or beeswax (*36*) while an Australian and Japanese study showed that neonicotinoids were more frequent in honey than in pollen and beewax even if pollen samples showed higher concentrations (*37*).

Chemicals

Solvents for the preparation of standard solutions and samples were milli-Q water, HPLC grade acetonitrile (ACN) and methanol (MeOH) from VWR. For UHPLC-MS/MS analyses, water, acetonitrile, formic acid (FA) and ammonium formate (NH_4FA) of ULC/MS grade were obtained from Biosolve. All salts used for QuEChERS were obtained from Sigma. Isolute PSA bulk phase was purchased at Biotage. Thiamethoxam, clothianidin, imidacloprid, acetamiprid and thiacloprid were all obtained from Sigma. Isotopically labelled standards (thiamethoxam-D3, clothianidin-D3, imidacloprid-D4, acetamiprid-D3 and thiacloprid-D4) were obtained from CDN Isotopes.

Sample preparation

Honey samples were prepared using a QuEChERS protocol adapted from Paradis and colleagues (*38*). Specifically, 2.5 g of honey was weighed in a 15 ml polypropylene tube (Sartsed) to which 9 mL of H_2O: ACN (50:50, v/v) and 20 µl of a 500 ng/ml internal standard (IS) methanolic solution containing the 5 labelled neonicotinoids were added. The honey was dissolved by manual agitation and ultrasonication for 5 min and the resulting solution was transferred into a 15 ml tube containing the extraction salts (2 g $MgSO_4$, 0.5 g NaCl, 0.5 g sodium citrate dihydrate and 0.25 g sodium citrate sesquihydrate). One ml of H_2O: ACN (50:50, v/v) was added to the first tube and after a brief agitation period the remaining solution was also transferred to the extraction salts tube. The mixture was vigorously shaken by hand for approximately 2 min and centrifuged at 4000 g for 10 min. The upper phase (4.5-4.8 ml) was collected in a second 15 ml tube containing the purification salts (0.15 g $MgSO_4$ and 0.1 g PSA). After vigorous shaking for approximately 1 min, the tube was centrifuged (4000 g, 10 min) and the supernatant (4.0-4.5 ml) recovered into a 13x100 mm glass tube. The solution was evaporated until dry in a CentriVap centrifugal evaporator (Labconco) thermostated at 40°C and the dried residue that remained was re-suspended in 0.5 ml of MeOH 25%. The tubes were vortexed, ultrasonicated for 1 min, and filtered through 20 mm PTFE hydrophilic syringe filters (BGB Analytik) into HPLC vials containing 250 µl conical inserts. The final concentration of the IS was 20 ng/ml.

UHPLC-MS/MS analysis

The analysis of neonicotinoids was performed on a Dionex Ultimate 3000 RSLC (Thermo Scientific) coupled to a 4000 QTRAP mass spectrometer (AB Sciex). The separation of the 5 neonicotinoids was achieved on an Acquity UPLC BEH column (50x2.1mm i.d., 1.7 um particle size, Waters) using a temperature of 25°C and a flow rate of 0.4 ml/min. Mobile phase A was H_2O+0.05% FA+5mM NH_4FA and mobile phase B was ACN+0.05% FA. The following gradient program was used: 10-45% B in 8.0 min, 45-100% B in 0.1 min, holding at 100% B for 2 min and returning to initial conditions at 10% B for 5.0 min. The injection volume was 5 µl. The flow was deviated from the mass spectrometer from 0.0-2.0 min and from 6.5-15.0 min using a 6 port Valco valve (Vici). MS detection was performed in positive electrospray mode using the following parameters: capillary voltage +5500 V, desolvation temperature 550 °C, nebulizing gas flow (GS1) 60 psi, drying gas flow (GS2) 40 psi, curtain gas flow 10 psi. The analysis was carried out in the multiple reaction monitoring (MRM) mode using optimized precursor-to-fragment transitions for each compound and their corresponding labelled forms (Table S2). Under the conditions used, chromatographic peak width was approximately 10 s, enabling the acquisition of 10-15 data points across the peaks. Analyst 1.5.1 (AB Sciex) was employed to process the data.

Quantification and validation

Neonicotinoids were quantified by internal calibration using calibration solutions prepared in MeOH 25% at 0.1, 0.5, 2, 10, 50 and 200 ng/ml, each containing internal standards at a concentration of 20 ng/ml. Linear or quadratic regressions weighted by 1/x were applied. A validation assay was performed using blank honey samples (n=6) spiked with the IS solution as well as a 20 ng/mL neonicotinoid solution using an experimental protocol based on Thevenet et al. (*39*). The validation parameters evaluated were linearity, lowest limits of detection (LLOD) and quantification (LLOQ), intra-day precision, accuracy, recovery and matrix effects. The assay validation results are presented in Table S3. Specificity was assessed on blank samples and for all honey samples individually.

Identification of relevant neonicotinoid concentrations for sub-lethal effects

In Table S8 we compiled data from 47 studies on the impact of neonicotinoids on honeybees, other bees and pollinators and other non-target terrestrial insects (*6*, *8*, *27-32*, *40-77*).

The aim was not to produce a complete list but rather to show a range of studies focusing on the responses of these organisms to exposure to low neonicotinoid concentrations.

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Caveats

The use of bees as environmental samplers to assess the level of neonicotinoid contamination of the environment is bound to be limited by a number of caveats, which we discuss here:

From a beekeeping point of view, collecting honey samples with the aid of citizens does not allow us to control the following factors which may influence our results: the bee subspecies name, the precise environment in which bee hives were placed and in particular the nectar and pollen availability, and the crops grown in the vicinity of the hives. The exact number of colonies contributing to the honey we obtained and the strength of the colonies were also unknown, both of which may influence the actual chemical load of our samples. However, it should be noted that highest concentrations of pesticides should be found in honey from a single hive from a short period of time if an extreme amount of pesticide is used in a given place and time. When several hives are sampled and/or the honey from an extensive period is pooled the impact of such an event will be diluted. Being able to obtain data on the concentration of neonicotinoids along a beekeeping season would enable us to evaluate acute and chronic exposure of the bees to these molecules.

From an agricultural point of view, a crucial piece of information is the pesticide use in the vicinity of the hives or even in the countries concerned by our study. This information is lacking. In particular, the percentage contribution of neonicotinoids to the total pesticide use is simply not available as this information remains confidential, in most countries (*18*). While this assessment is based on a growing body of published evidence, some knowledge gaps remain. These compounds have been subject to regulatory safety tests in a number of countries. However, several potential risks associated with the present global scale of use are still poorly understood. For most countries, there are few or no publicly available data sources on the quantities of systemic pesticides being applied, nor on the locations where these are being applied. Reliable data on the amounts used are a necessary condition for realistic assessments of ecological impacts and risks (*18*).

From a bee biology point of view, the relative frequency and/or abundance of neonicotinoid pesticides found in our samples may not correspond to a true environmental contamination because of behavioral or physiological features of the bees. For example, imidacloprid was shown to be addictive to bumble bees to the point that they actively forage more on plant treated with this molecule (*78*).

From a methodological point of view, we had to work with samples collected through a citizen science project, for which we have no information on the honey storage conditions prior to their arrival at our laboratory. In particular, we do not know if our samples were exposed to sunlight and if yes, for how long. This is important as neonicotinoids might degrade when exposed to sunlight. However, this alteration might only diminish the concentration of neonicotinoids in our samples.

Future perspective for risk assessment of neonicotinoids

Table S9 describes the combination of neonicotinoids we found in the environment with information of the most prevalent combinations. We argue that this information should serve as a basis to prioritize and to test possible interactions between or among neonicotinoids, such as cross-sensitization (*27, 32*), cross-preferences in foraging (*78*) or even cross-resistances in pest species (*79*).

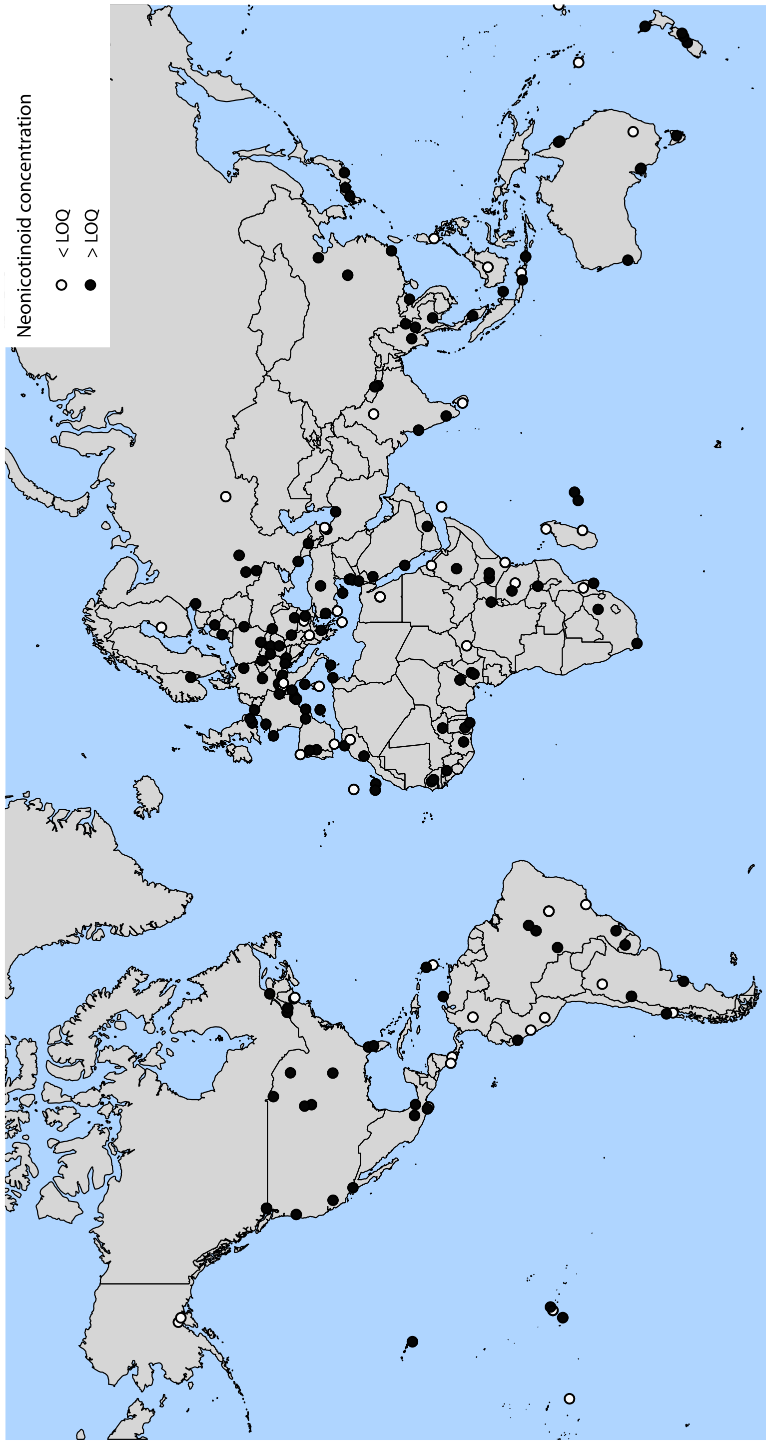

Fig. S1.

Worldwide distribution of honey contaminated by at least one of five tested neonicotinoids (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam). Black circles: >LOQ for at least one neonicotinoid, white circles: <LOQ for all tested neonicotinoids.

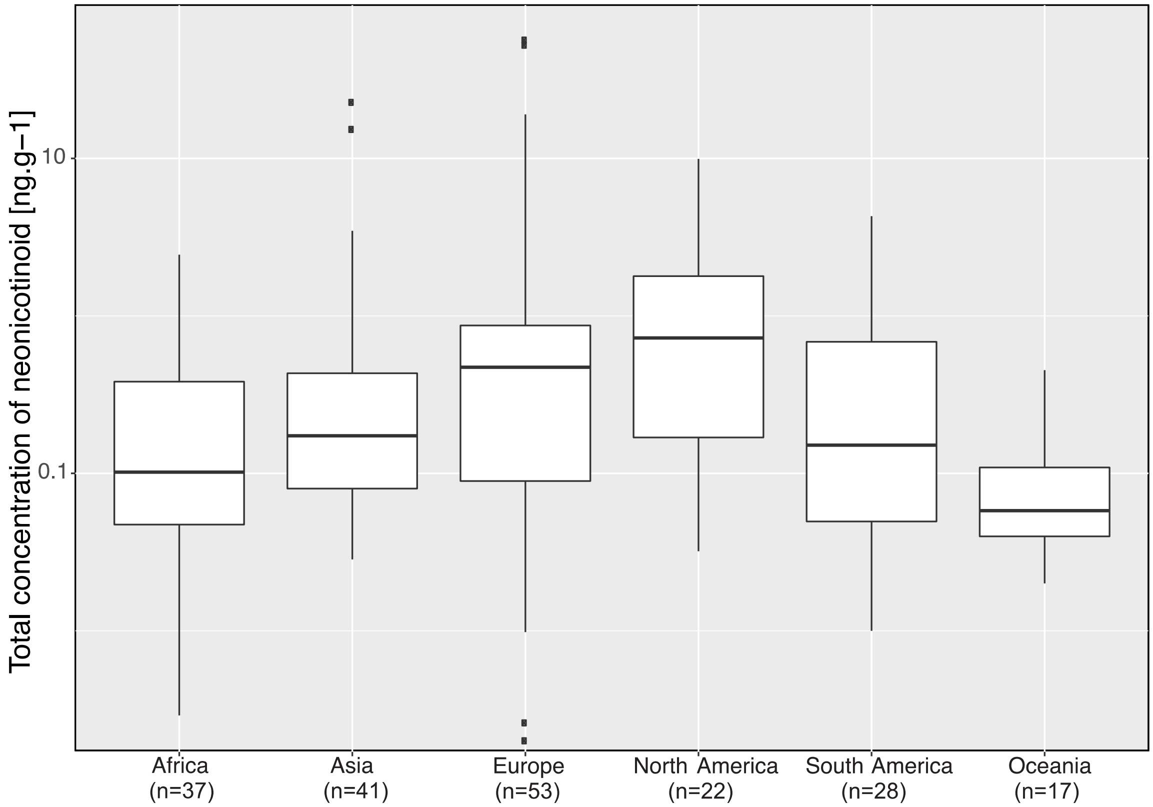

Fig. S2

Median and range of total concentrations for the five analysed neonicotinoids (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam) in honey samples that tested positive for pesticide contamination in each continent.

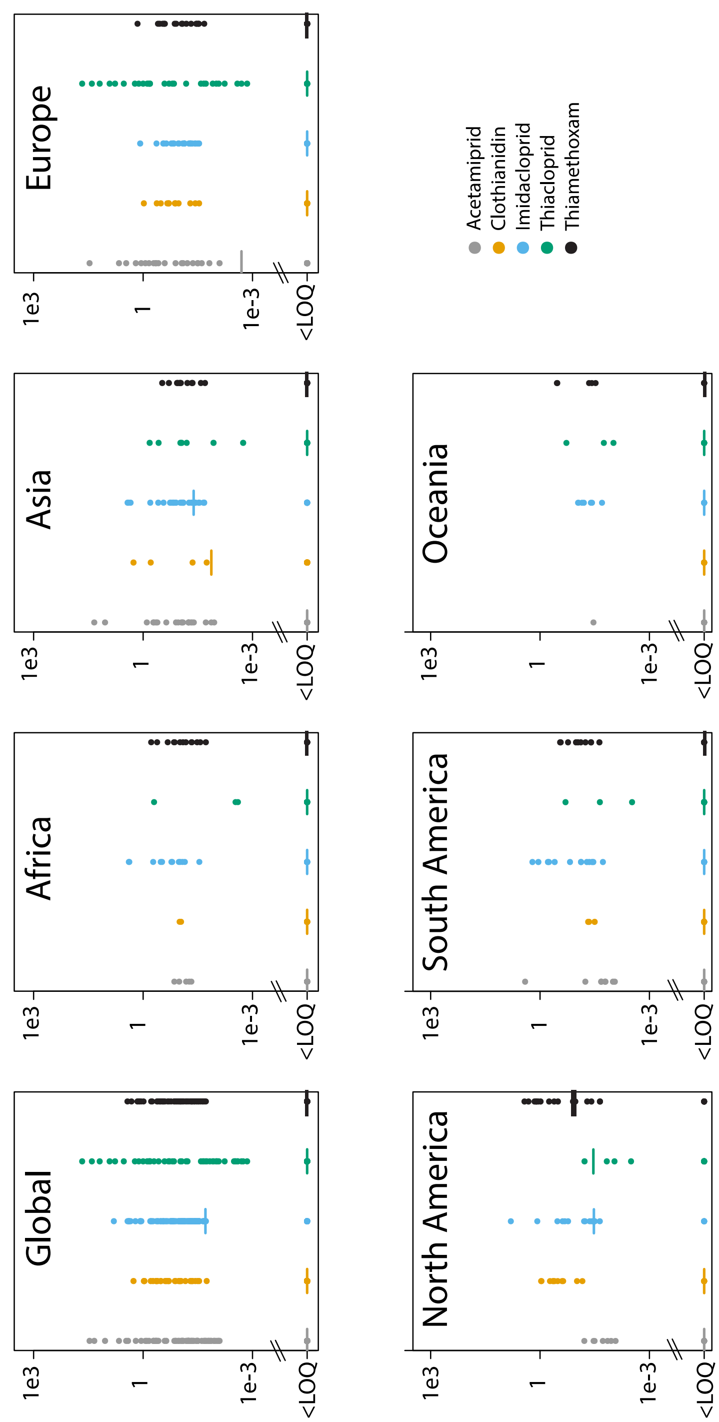

Fig. S3

Median and range of concentrations for the five analysed neonicotinoids (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam) in honey samples globally and in each continent. Plain lines indicate median values. The position of the minimal values is arbitrary and indicates concentrations <LOQ.

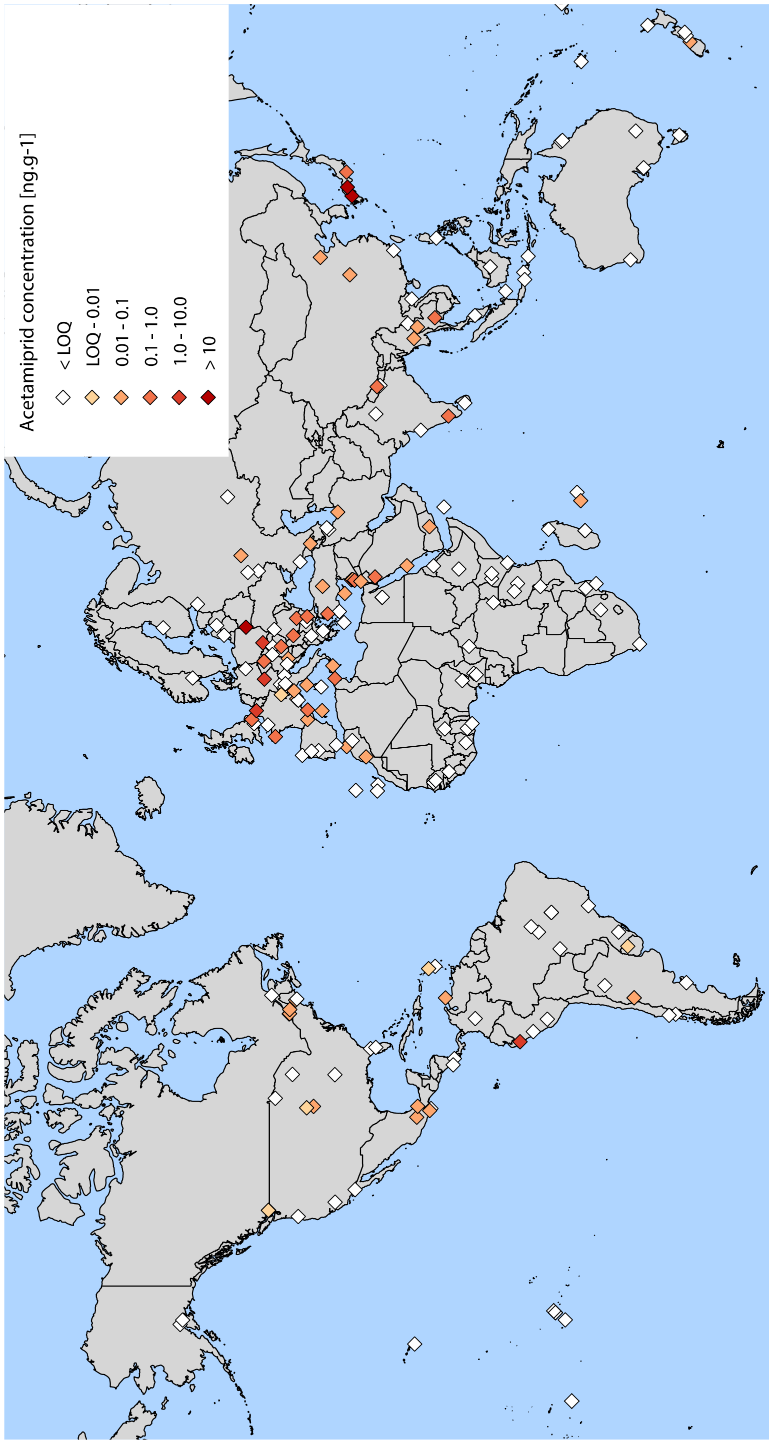

Fig. S4
Worldwide distribution of acetamiprid concentrations in honey samples.

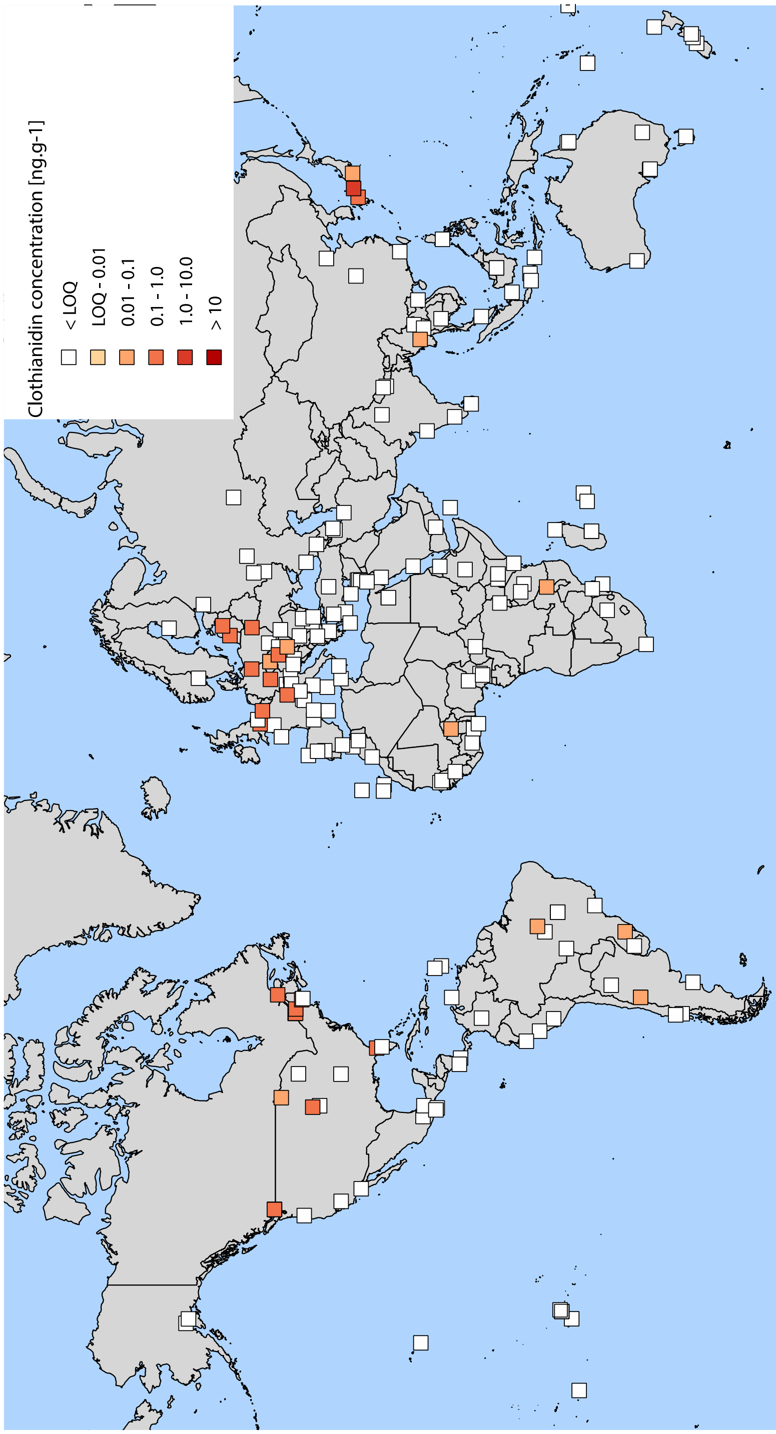

Fig. S5
Worldwide distribution of clothianidin concentrations in honey samples.

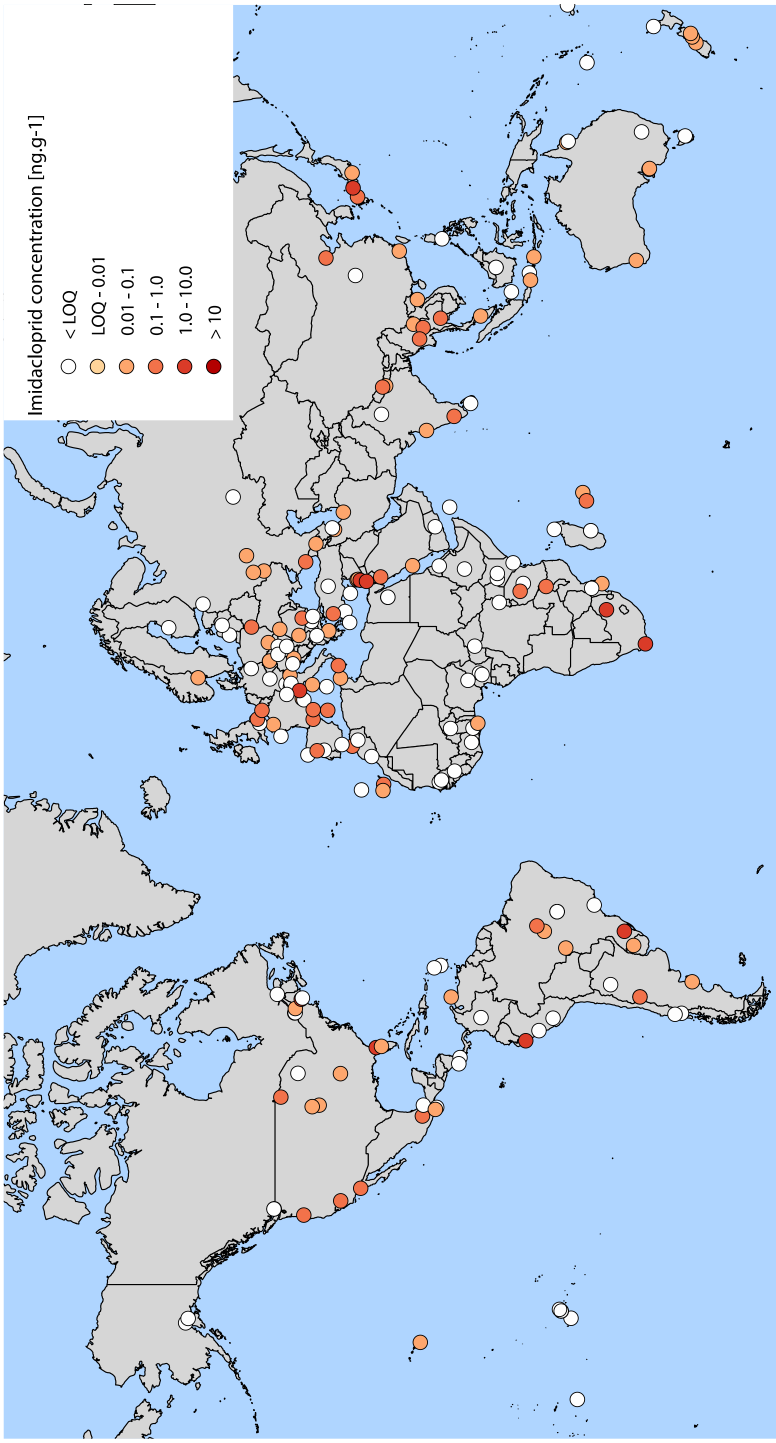

Fig. S6

Worldwide distribution of imidacloprid concentrations in honey samples.

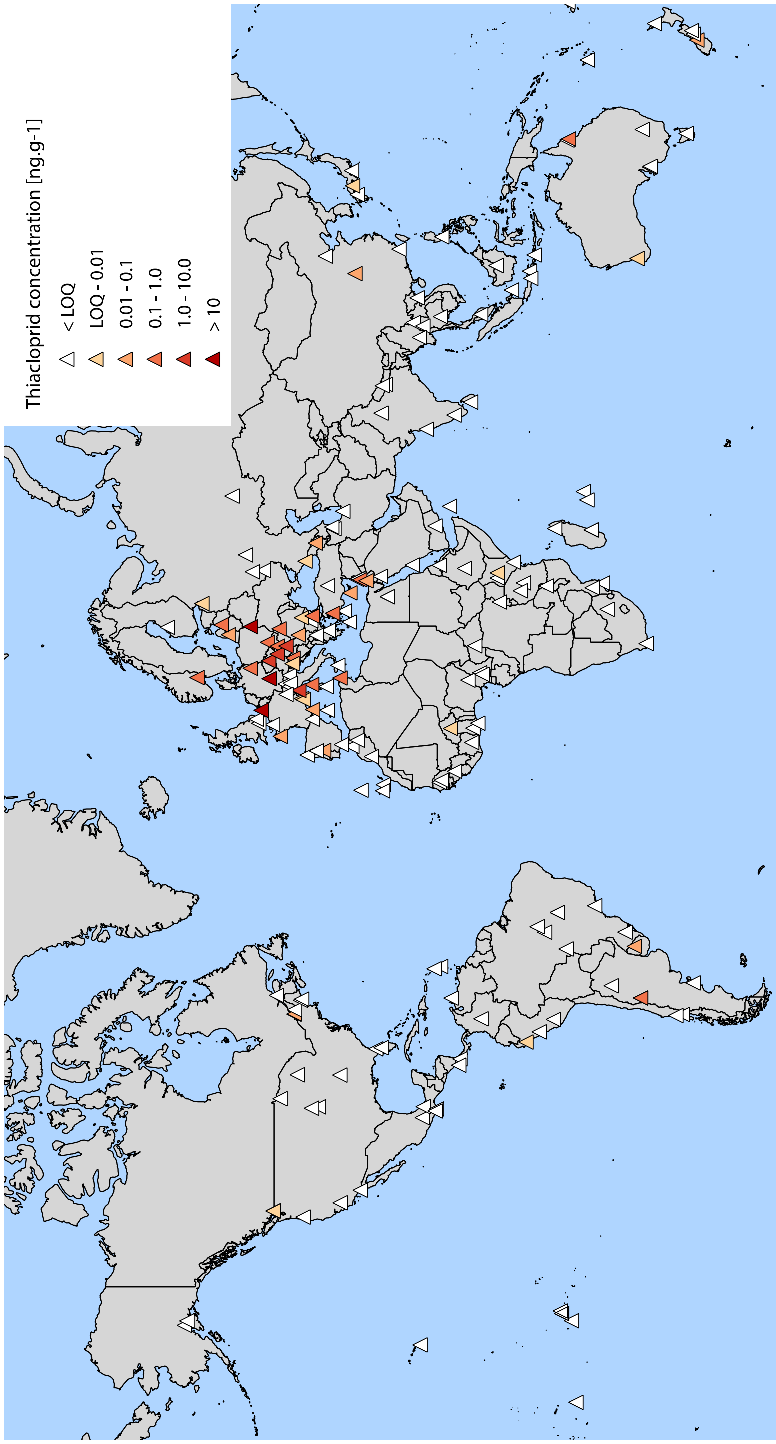

Fig. S7
Worldwide distribution of thiacloprid concentrations in honey samples.

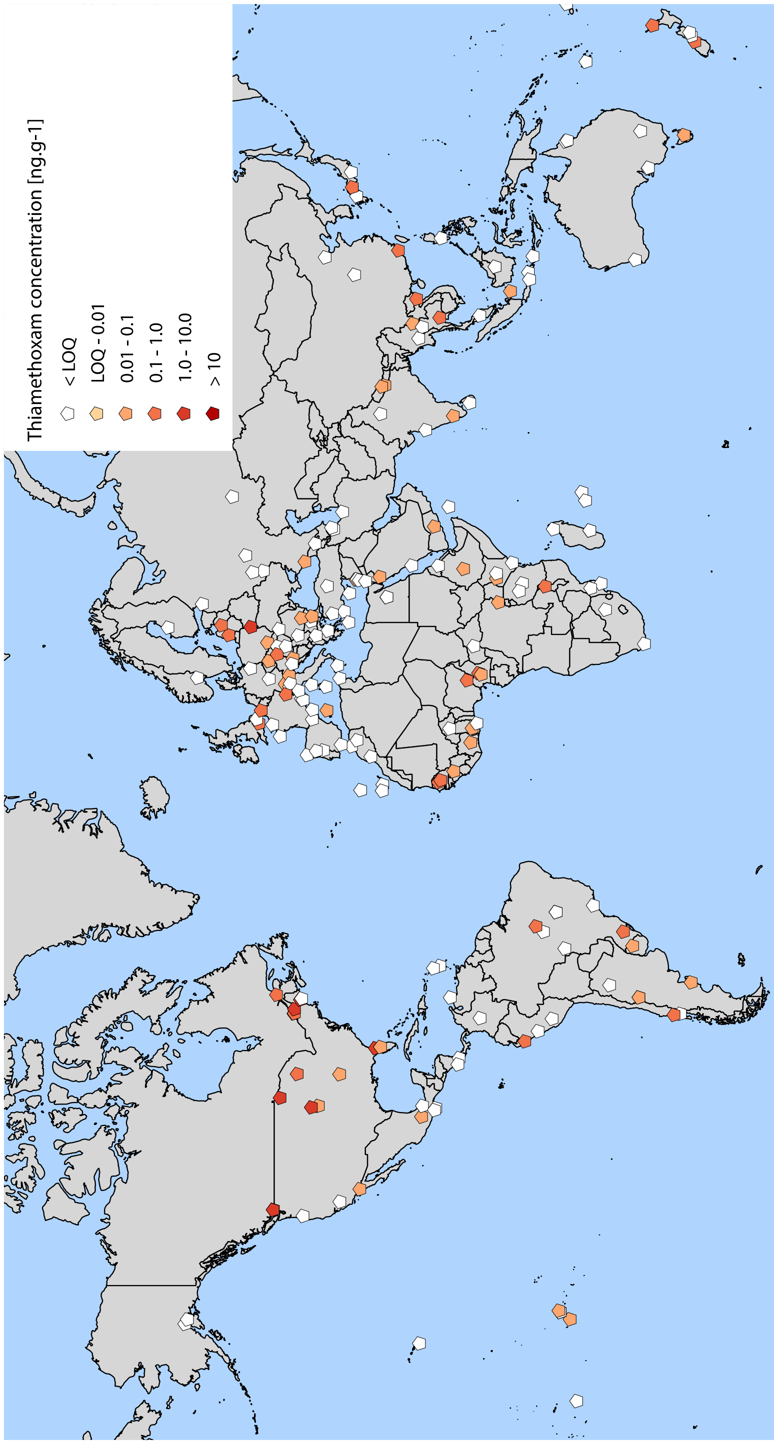

Fig. S8
Worldwide distribution of thiamethoxam concentrations in honey samples.

References and Notes

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Table S1. Coordinates of honey samples, measured concentrations of five neonicotinoids [acetamiprid (ACE) clothianidin (CLO) imidacloprid (IMI) thiacloprid (THP) thiamethoxam (THM)] and corresponding percentage of Maximum Residue Level (MRL) authorised in the EU.

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.252	Argentina	33°03 S	68°52 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.264	Argentina	26°41 S	65°49 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.084	Argentina	43°18 S	65°06 W	1	< LOQ	< LOQ	0,075	< LOQ	0,040			0,15%		0,08%	0,23%
JBN.Miel.253	Argentina	33°03 S	68°52 W	1	0,016	0,032	0,398	0,200	0,077	0,03%	0,06%	0,80%	0,40%	0,15%	1,45%
JBN.Miel.104	Australia	42°00 S	147°00 E	2	< LOQ	< LOQ	< LOQ	< LOQ	0,045					0,09%	0,09%
JBN.Miel.109	Australia	34°55 S	138°38 E	1	< LOQ	< LOQ	0,091	< LOQ	< LOQ			0,18%			0,18%
JBN.Miel.116	Australia	16°27 S	145°22 E	1	< LOQ	< LOQ	0,088	< LOQ	< LOQ			0,18%			0,18%
JBN.Miel.117	Australia	33°23 S	148°00 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.110	Australia	35°01 S	138°49 E	1	< LOQ	< LOQ	0,040	< LOQ	< LOQ			0,08%			0,08%
JBN.Miel.112	Australia	16°49 S	145°38 E	1	< LOQ	< LOQ	< LOQ	0,190	< LOQ				0,38%		0,38%
JBN.Miel.278	Australia	32°17 S	115°46 E	1	< LOQ	< LOQ	0,038	0,010	< LOQ			0,08%	0,02%		0,09%
JBN.Miel.269	Azerbaijan	38°40 N	48°44 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.145	Belgium	51°05 N	2°58 E	1	2,898	0,134	0,280	15,458	0,266	5,80%	0,27%	0,56%	30,92%	0,53%	**38,07%**
JBN.Miel.155	Brazil	22°57 S	45°51 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.212	Brazil	29°43 S	52°26 W	1	< LOQ	0,048	1,114	< LOQ	0,282		0,10%	2,23%		0,56%	2,89%
JBN.Miel.309	Brazil	11°01 S	52°26 W	1	< LOQ	< LOQ	0,045	< LOQ	< LOQ			0,09%			0,09%
JBN.Miel.310	Brazil	14°09 S	47°30 W	2	< LOQ	< LOQ	0,019	< LOQ	0,024			0,04%		0,05%	0,09%
JBN.Miel.311	Brazil	14°08 S	47°32 W	2	< LOQ	< LOQ	0,151	< LOQ	0,057			0,30%		0,11%	0,42%
JBN.Miel.312	Brazil	9°11 S	51°05 W	3	< LOQ	0,045	0,572	< LOQ	0,171		0,09%	1,14%		0,34%	1,58%
JBN.Miel.313	Brazil	14°09 S	47°31 W	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.315	Brazil	16°15 S	56°38 W	2	< LOQ	< LOQ	0,038	< LOQ	< LOQ			0,08%			0,08%
JBN.Miel.205	Bulgaria	42°38 N	25°17 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.129	Bulgaria	42°23 N	26°31 E	2	0,128	< LOQ	< LOQ	0,259	0,033	0,26%			0,52%	0,07%	0,84%
JBN.Miel.079	Burkina Faso	12°18 N	1°35 W	3	< LOQ	0,099	< LOQ	0,003	< LOQ		0,20%		0,01%		0,20%
JBN.Miel.259	Burma	21°10 N	99°48 E	1	< LOQ	< LOQ	0,021	< LOQ	0,092			0,04%		0,18%	0,23%
JBN.Miel.307	Burma	19°44 N	96°05 E	2	0,084	0,044	0,135	< LOQ	< LOQ	0,17%	0,09%	0,27%			0,53%
JBN.Miel.181	Cameroon	5°07 N	12°19 E	3	< LOQ	< LOQ	< LOQ	< LOQ	0,598					1,20%	1,20%
JBN.Miel.288	Cameroon	4°30 N	11°57 E	3	< LOQ	< LOQ	< LOQ	< LOQ	0,067					0,13%	0,13%
JBN.Miel.203	Canada	45°39 N	72°54 W	1	< LOQ	0,069	< LOQ	< LOQ	0,125		0,14%			0,25%	0,39%
JBN.Miel.276	Canada	48°37 N	68°14 W	1	< LOQ	0,400	< LOQ	< LOQ	0,323		0,80%			0,65%	1,45%
JBN.Miel.100	Canada	45°34 N	72°51 W	1	0,061	0,233	< LOQ	0,060	0,410	0,12%	0,47%		0,12%	0,82%	1,53%
JBN.Miel.213	Canada	45°32 N	71°48 W	1	0,019	0,533	0,023	< LOQ	1,280	0,04%	1,07%	0,05%		2,56%	3,71%
JBN.Miel.343	Canada	49°08 N	122°02 W	1	0,032	0,248	0,035	0,015	0,566	0,06%	0,50%	0,07%	0,03%	1,13%	1,79%
JBN.Miel.344	Canada	49°09 N	122°03 W	1	0,011	0,932	0,043	0,009	0,970	0,02%	1,86%	0,09%	0,02%	1,94%	3,93%
JBN.Miel.345	Canada	49°10 N	122°04 W	1	0,009	0,444	< LOQ	0,003	1,262	0,02%	0,89%		0,01%	2,52%	3,44%
JBN.Miel.162	Central African Republic	6°19 N	19°04 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.228	Chile	41°19 S	72°59 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.103	Chile	40°05 S	73°15 W	2	< LOQ	< LOQ	< LOQ	< LOQ	0,271					0,54%	0,54%

* Geographical precision is as follows 1: minute; 2: centre of the region/state; 3: centre of the country

Table S1 (continued)

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.282	China	24°27 N	118°07 E	2	< LOQ	< LOQ	0,022	< LOQ	0,298			0,04%		0,60%	0,64%
JBN.Miel.024	China	39°54 N	116°23 E	1	0,057	< LOQ	0,151	< LOQ	< LOQ	0,11%		0,30%			0,42%
JBN.Miel.080	China	34°01 N	112°01 E	3	0,089	< LOQ	< LOQ	0,094	< LOQ	0,18%			0,19%		0,37%
JBN.Miel.296	Colombia	4°46 N	74°04 W	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.062	Costa Rica	9°57 N	84°05 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.284	Costa Rica	10°16 N	85°39 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.006	Croatia	45°48 N	16°00 E	1	0,015	< LOQ	0,075	0,194	0,030	0,03%		0,15%	0,39%	0,06%	0,63%
JBN.Miel.340	Curaçao	12°09 N	68°54 W	1	0,016	< LOQ	0,035	< LOQ	< LOQ	0,03%		0,07%			0,10%
JBN.Miel.076	Cyprus	35°03 N	32°17 E	2	0,056	< LOQ	< LOQ	0,087	< LOQ	0,11%			0,17%		0,29%
JBN.Miel.196	Czech Republic	49°53 N	15°20 E	3	1,126	0,037	0,055	1,307	0,252	2,25%	0,07%	0,11%	2,61%	0,50%	5,55%
JBN.Miel.197	Czech Republic	49°52 N	15°19 E	3	0,864	0,029	0,054	5,874	0,083	1,73%	0,06%	0,11%	11,75%	0,17%	**13,81%**
JBN.Miel.031	Egypt	27°03 N	31°19 E	3	0,102	< LOQ	0,159	< LOQ	< LOQ	0,20%		0,32%			0,52%
JBN.Miel.095	Egypt	27°01 N	31°20 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.220	England	51°27 N	0°17 W	1	< LOQ	0,216	< LOQ	< LOQ	0,350		0,43%			0,70%	1,13%
JBN.Miel.101	England	51°48 N	0°45 E	1	0,512	< LOQ	0,168	< LOQ	< LOQ	1,02%		0,34%			1,36%
JBN.Miel.149	Eritrea	15°03 N	39°11 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.265	Ethiopia	8°51 N	38°24 E	3	< LOQ	< LOQ	< LOQ	< LOQ	0,046					0,09%	0,09%
JBN.Miel.334	Fiji	16°40 S	179°50 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.167	Finland	63°33 N	23°42 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.190	France	20°18 S	57°35 E	1	< LOQ	< LOQ	0,055	< LOQ	< LOQ			0,11%			0,11%
JBN.Miel.200	France	49°15 N	0°36 W	1	< LOQ	< LOQ	0,045	< LOQ	< LOQ			0,09%			0,09%
JBN.Miel.233	France	42°28 N	9°24 E	1	0,061	< LOQ	0,038	0,770	< LOQ	0,12%		0,08%	1,54%		1,74%
JBN.Miel.238	France	17°31 S	149°27 W	1	< LOQ	< LOQ	< LOQ	< LOQ	0,038					0,08%	0,08%
JBN.Miel.239	France	15°08 S	147°39 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.240	France	15°09 S	147°39 W	1	< LOQ	< LOQ	< LOQ	< LOQ	0,030					0,06%	0,06%
JBN.Miel.003	France	44°18 N	5°54 E	1	0,031	< LOQ	0,050	0,008	< LOQ	0,06%		0,10%	0,02%		0,18%
JBN.Miel.047	France	44°01 N	5°37 E	1	< LOQ	< LOQ	< LOQ	0,002	< LOQ				0,00%		0,00%
JBN.Miel.049	France	14°40 N	61°00 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.083	France	48°00 N	3°32 W	1	0,445	< LOQ	< LOQ	0,022	< LOQ	0,89%			0,04%		0,93%
JBN.Miel.107	France	21°09 S	55°30 E	1	0,054	< LOQ	0,301	< LOQ	< LOQ	0,11%		0,60%			0,71%
JBN.Miel.136	France	16°15 N	61°35 O	1	0,010	< LOQ	< LOQ	< LOQ	< LOQ	0,02%					0,02%
JBN.Miel.271	France (New Caledonia)	21°16 S	165°22 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.341	Georgia	41°48 N	44°43 E	1	0,013	< LOQ	0,021	0,012	< LOQ	0,03%		0,04%	0,02%		0,09%
JBN.Miel.085	Germany	52°45 N	13°27 E	1	< LOQ	0,197	< LOQ	0,647	< LOQ		0,39%		1,29%		1,69%
JBN.Miel.120	Germany	49°49 N	10°51 E	1	4,579	0,951	< LOQ	46,767	< LOQ	9,16%	1,90%		93,53%		**104,59%**
JBN.Miel.289	Ghana	6°45 N	1°30 O	1	< LOQ	< LOQ	< LOQ	< LOQ	0,027					0,05%	0,05%
JBN.Miel.352	Ghana	5°33 N	0°15 O	2	< LOQ	< LOQ	0,029	< LOQ	< LOQ			0,06%			0,06%
JBN.Miel.178	Greece	36°09 N	27°46 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.236	Greece	39°22 N	22°56 E	1	< LOQ	< LOQ	0,029	< LOQ	< LOQ			0,06%			0,06%
JBN.Miel.020	Greece	35°12 N	25°00 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #

* Geographical precision is as follows 1: minute; 2: centre of the region/state; 3: centre of the country

Table S1 (continued)

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.089	Hungary	47°01 N	19°01 E	3	0,688	0,051	< LOQ	3,378	< LOQ	1,38%	0,10%		6,76%		8,23%
JBN.Miel.164	India	18°06 N	73°09 E	1	< LOQ	< LOQ	0,079	< LOQ	< LOQ			0,16%			0,16%
JBN.Miel.165	India	11°25 N	76°41 E	2	0,109	< LOQ	0,171	< LOQ	0,044	0,22%		0,34%		0,09%	0,65%
JBN.Miel.308	India	28°27 N	77°11 E	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.182	Indonesia	1°01 N	114°01 E	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.183	Indonesia	1°01 N	114°02 E	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.184	Indonesia	7°20 S	112°38 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.185	Indonesia	7°36 S	110°50 E	1	< LOQ	< LOQ	0,037	< LOQ	< LOQ			0,07%			0,07%
JBN.Miel.186	Indonesia	2°50 S	107°55 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,046					0,09%	0,09%
JBN.Miel.327	Indonesia	8°27 S	116°40 E	2	< LOQ	< LOQ	0,028	< LOQ	< LOQ			0,06%			0,06%
JBN.Miel.187	Iran	36°29 N	52°40 E	2	0,057	< LOQ	0,081	< LOQ	< LOQ	0,11%		0,16%			0,28%
JBN.Miel.188	Iran	38°15 N	48°18 E	1	< LOQ	< LOQ	0,089	< LOQ	< LOQ			0,18%			0,18%
JBN.Miel.051	Israel	33°01 N	35°35 E	2	0,443	< LOQ	2,652	0,375	< LOQ	0,89%		5,30%	0,75%		6,94%
JBN.Miel.147	Israel	31°42 N	35°18 E	1	0,011	< LOQ	2,516	0,064	< LOQ	0,02%		5,03%	0,13%		5,18%
JBN.Miel.202	Italy	39°45 N	8°54 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.071	Italy	46°27 N	11°42 E	1	< LOQ	< LOQ	0,049	< LOQ	0,021			0,10%		0,04%	0,14%
JBN.Miel.055	Italy	44°47 N	7°56 E	1	0,080	< LOQ	1,199	1,677	ND	0,16%		2,40%	3,35%		5,91%
JBN.Miel.132	Italy	37°29 N	14°12 E	2	0,043	< LOQ	0,428	< LOQ	< LOQ	0,09%		0,86%			0,94%
JBN.Miel.267	Ivory Coast	7°5 N	5°3 O	1	< LOQ	< LOQ	< LOQ	< LOQ	0,097					0,19%	0,19%
JBN.Miel.208	Japan	34°43 N	137°44 E	1	0,125	0,018	0,030	< LOQ	< LOQ	0,25%	0,04%	0,06%			0,35%
JBN.Miel.025	Japan	33°34 N	131°44 E	1	21,786	0,617	0,274	< LOQ	< LOQ	43,57%	1,23%	0,55%			**45,35%**
JBN.Miel.210	Japan	34°30 N	133°57 E	1	11,038	1,829	2,198	0,002	0,195	22,08%	3,66%	4,40%	0,00%	0,39%	**30,52%**
JBN.Miel.261	Kenya	0°40 N	36°00 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,080					0,16%	0,16%
JBN.Miel.028	Kenya	0°40 N	36°00 E	1	< LOQ	< LOQ	< LOQ	0,003	< LOQ				0,01%		0,01%
JBN.Miel.342	Kenya	3°18 S	39°57 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.059	Latvia	56°56 N	24°17 E	1	< LOQ	0,421	< LOQ	0,142	0,136		0,84%		0,28%	0,27%	1,40%
JBN.Miel.225	Lebanon	33°41 N	35°42 E	1	0,231	< LOQ	0,037	< LOQ	0,020	0,46%		0,07%		0,04%	0,58%
JBN.Miel.231	Lebanon	33°26 N	35°49 E	1	0,019	< LOQ	0,041	< LOQ	< LOQ	0,04%		0,08%			0,12%
JBN.Miel.158	Liechstenstein	47°09 N	9°33 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,035					0,07%	0,07%
JBN.Miel.153	Lithuania	55°55 N	21°51 E	1	< LOQ	0,197	< LOQ	0,019	0,291		0,39%		0,04%	0,58%	1,01%
JBN.Miel.002	Madagascar	22°09 S	48°00 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,033					0,07%	0,07%
JBN.Miel.001	Madagascar	22°10 S	48°01 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.106	Madagascar	13°28 S	48°21 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.088	Malaysia	4°50 N	101°50 E	1	< LOQ	< LOQ	0,095	< LOQ	< LOQ			0,19%			0,19%
JBN.Miel.124	Mexico	19°04 N	98°45 O	1	0,021	< LOQ	0,610	< LOQ	0,040	0,04%		1,22%		0,08%	1,34%
JBN.Miel.125	Mexico	18°51 N	96°01 O	2	0,057	< LOQ	< LOQ	< LOQ	< LOQ	0,11%					0,11%
JBN.Miel.354	Mexico	15°40 N	96°35 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.355	Mexico	15°59 N	97°05 O	1	0,021	< LOQ	0,052	< LOQ	< LOQ	0,04%		0,10%			0,15%
JBN.Miel.026	Morocco	34°39 N	6°01 O	2	0,066	< LOQ	0,104	< LOQ	< LOQ	0,13%		0,21%			0,34%
JBN.Miel.105	Morocco	30°34 N	8°36 O	2	0,048	< LOQ	< LOQ	< LOQ	< LOQ	0,10%					0,10%

* Geographical precision is as follows 1: minute; 2: centre of the region/state; 3: centre of the country

Table S1 (continued)

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.150	Morocco	33°30 N	4°30 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.163	Mozambique	24°43 S	34°45 E	1	< LOQ	< LOQ	0,096	< LOQ	< LOQ			0,19%			0,19%
JBN.Miel.093	Mozambique	22°21 S	33°34 E	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.229	Nepal	27°30 N	84°20 E	1	< LOQ	< LOQ	0,047	< LOQ	0,026			0,09%		0,05%	0,15%
JBN.Miel.146	Nepal	28°11 N	84°01 E	3	0,524	< LOQ	0,635	< LOQ	0,095	1,05%		1,27%		0,19%	2,51%
JBN.Miel.273	New Zealand	35°52 S	174°26 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,344					0,69%	0,69%
JBN.Miel.007	New Zealand	43°58 S	170°20 E	3	0,034	< LOQ	0,063	0,018	0,337	0,07%		0,13%	0,04%	0,67%	0,90%
JBN.Miel.358	New Zealand	43°18 S	171°49 E	2	< LOQ	< LOQ	0,020	< LOQ	< LOQ			0,04%			0,04%
JBN.Miel.359	New Zealand	43°19 S	171°50 E	2	< LOQ	< LOQ	0,071	< LOQ	< LOQ			0,14%			0,14%
JBN.Miel.218	Nigeria	8°00 N	10°30 E	1	< LOQ	< LOQ	< LOQ	< LOQ	0,211					0,42%	0,42%
JBN.Miel.335	Niue	19°04 S	169°52 W	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.039	Norway	60°04 N	11°08 E	1	< LOQ	< LOQ	0,074	0,647	< LOQ			0,15%	1,29%		1,44%
JBN.Miel.290	Peru	13°10 S	74°14 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.291	Peru	9°43 S	77°20 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.292	Peru	6°26 S	79°52 O	1	2,573	< LOQ	1,618	0,003	0,103	5,15%		3,24%	0,01%	0,21%	8,60%
JBN.Miel.222	Philippines	14°23 N	121°12 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.160	Poland	50°04 N	19°57 E	1	1,583	< LOQ	0,050	0,704	0,087	3,17%		0,10%	1,41%	0,17%	4,85%
JBN.Miel.241	Poland	52°42 N	23°51 E	1	29,312	0,128	0,153	25,340	1,420	58,62%	0,26%	0,31%	50,68%	2,84%	**112,71%**
JBN.Miel.042	Portugal	40°14 N	7°02 O	1	< LOQ	< LOQ	< LOQ	0,012	< LOQ				0,02%		0,02%
JBN.Miel.142	Portugal	41°35 N	7°10 O	1	< LOQ	< LOQ	0,149	< LOQ	ND			0,30%			0,30%
JBN.Miel.297	Portugal	32°45 N	16°59 O	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.207	Republic of Guinea	11°18 N	12°16 O	2	< LOQ	< LOQ	< LOQ	< LOQ	0,019					0,04%	0,04%
JBN.Miel.280	Republic of Macedonia	41°37 N	21°42 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.206	Republic of Malawi	11°27 S	34°01 E	1	< LOQ	0,091	0,328	< LOQ	0,142		0,18%	0,66%		0,28%	1,12%
JBN.Miel.011	Romania	44°54 N	21°45 E	1	0,380	< LOQ	0,081	0,066	< LOQ	0,76%		0,16%	0,13%		1,05%
JBN.Miel.061	Romania	44°20 N	26°05 E	1	0,442	< LOQ	0,104	0,001	0,030	0,88%		0,21%	0,00%	0,06%	1,15%
JBN.Miel.299	Russia	53°27 N	41°46 E	1	0,087	< LOQ	0,031	< LOQ	< LOQ	0,17%		0,06%			0,24%
JBN.Miel.300	Russia	59°28 N	29°37 E	1	< LOQ	< LOQ	< LOQ	0,003	< LOQ				0,01%		0,01%
JBN.Miel.301	Russia	55°24 N	56°28 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.302	Russia	43°41 N	40°13 E	1	< LOQ	< LOQ	0,108	0,006	0,048			0,22%	0,01%	0,10%	0,32%
JBN.Miel.303	Russia	50°46 N	37°54 E	1	< LOQ	< LOQ	0,073	< LOQ	< LOQ			0,15%			0,15%
JBN.Miel.304	Russia	52°25 N	37°34 E	1	< LOQ	< LOQ	0,075	< LOQ	< LOQ			0,15%			0,15%
JBN.Miel.223	Saudi Arabia	28°37 N	36°25 E	2	0,405	< LOQ	0,148	< LOQ	0,061	0,81%		0,30%		0,12%	1,23%
JBN.Miel.075	Saudi Arabia	21°23 N	39°14 E	2	0,045	< LOQ	0,086	< LOQ	< LOQ	0,09%		0,17%			0,26%
JBN.Miel.169	Senegal	15°01 N	15°01 O	3	< LOQ	< LOQ	< LOQ	< LOQ	0,136					0,27%	0,27%
JBN.Miel.170	Senegal	14°30 N	14°30 O	3	< LOQ	< LOQ	< LOQ	< LOQ	0,411					0,82%	0,82%

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.216	Slovakia	48°27 N	18°59 E	1	< LOQ	< LOQ	< LOQ	0,157	< LOQ				0,31%		0,31%
JBN.Miel.217	Slovakia	48°30 N	17°00 E	1	< LOQ	0,106	< LOQ	8,263	0,390		0,21%		16,53%	0,78%	**17,52%**
JBN.Miel.096	Slovenia	45°59 N	14°37 E	1	< LOQ	< LOQ	< LOQ	0,010	< LOQ				0,02%		0,02%
JBN.Miel.029	South Africa	25°45 S	28°11 E	1	< LOQ	< LOQ	2,388	< LOQ	< LOQ			4,78%			4,78%

* Geographical precision is as follows 1: minute; 2: centre of the region/state; 3: centre of the country

Table S1 (continued)

Catalogue nr.	Country	Geographical coordinates			Concentration [ng/g honey]					% of EU MRL (in brackets below: MRL in ng/g)					
				Precision*	ACE	CLO	IMI	THP	THM	ACE (50)	CLO (10)	IMI (50)	THP (50)	THM (10)	Sum of % EU MRL #
JBN.Miel.041	South Africa	34°11 S	19°38 E	2	< LOQ	< LOQ	2,445	< LOQ	< LOQ			4,89%			4,89%
JBN.Miel.152	Spain	27°58 N	15°36 O	1	< LOQ	< LOQ	0,529	< LOQ	< LOQ			1,06%			1,06%
JBN.Miel.171	Spain	36°46 N	5°36 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.274	Spain	39°34 N	2°59 E	1	0,032	< LOQ	0,142	< LOQ	0,065	0,06%		0,28%		0,13%	0,48%
JBN.Miel.050	Spain	28°06 N	17°08 O	1	< LOQ	< LOQ	0,083	< LOQ	< LOQ			0,17%			0,17%
JBN.Miel.060	Spain	43°17 N	8°13 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.090	Spain	42°19 N	0°44 E	2	0,025	< LOQ	0,271	< LOQ	< LOQ	0,05%		0,54%			0,59%
JBN.Miel.141	Spain	42°19 N	3°09 E	1	0,255	< LOQ	0,229	0,026	ND	0,51%		0,46%	0,05%		1,02%
JBN.Miel.179	Sri Lanka	7°21 N	79°56 E	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.022	Switzerland	46°23 N	8°55 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.044	Switzerland	46°18 N	9°42 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.336	Switzerland	47°01 N	6°58 E	1	0,008	0,327	< LOQ	< LOQ	0,123	0,02%	0,65%			0,25%	0,92%
JBN.Miel.069	Tanzania	5°49 S	34°47 E	3	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.137	Tanzania	5°02 S	32°49 E	1	< LOQ	< LOQ	0,166	< LOQ	< LOQ			0,33%			0,33%
JBN.Miel.248	Thailand	14°44 N	101°17 E	3	0,501	< LOQ	0,182	< LOQ	0,117	1,00%		0,36%		0,23%	1,60%
JBN.Miel.285	Thailand	18°54 N	98°57 E	1	0,049	< LOQ	0,383	< LOQ	< LOQ	0,10%		0,77%			0,86%
JBN.Miel.018	Tunisia	37°03 N	11°02 E	1	0,139	< LOQ	0,072	0,500	< LOQ	0,28%		0,14%	1,00%		1,42%
JBN.Miel.194	Turkey	38°29 N	27°11 E	2	0,788	< LOQ	0,124	0,660	< LOQ	1,58%		0,25%	1,32%		3,14%
JBN.Miel.078	Turkey	39°29 N	34°05 E	3	0,080	< LOQ	< LOQ	< LOQ	< LOQ	0,16%					0,16%
JBN.Miel.227	Uganda	0°12 N	30°01 E	2	< LOQ	< LOQ	< LOQ	< LOQ	0,047					0,09%	0,09%
JBN.Miel.177	Ukraine	48°11 N	23°18 E	1	< LOQ	< LOQ	0,036	0,997	< LOQ			0,07%	1,99%		2,07%
JBN.Miel.221	United States	44°02 N	123°35 O	1	< LOQ	< LOQ	0,210	< LOQ	< LOQ			0,42%			0,42%
JBN.Miel.243	United States	45°04 N	88°03 O	1	< LOQ	< LOQ	< LOQ	< LOQ	0,108					0,22%	0,22%
JBN.Miel.287	United States	41°12 N	96°02 O	1	0,034	< LOQ	0,062	< LOQ	0,051	0,07%		0,12%		0,10%	0,29%
JBN.Miel.072	United States	19°34 N	155°30 O	1	< LOQ	< LOQ	0,032	< LOQ	< LOQ			0,06%			0,06%
JBN.Miel.017	United States	37°01 N	120°01 O	2	< LOQ	< LOQ	0,335	< LOQ	< LOQ			0,67%			0,67%
JBN.Miel.098	United States	42°30 N	96°24 O	1	0,002	0,429	0,038	< LOQ	2,080	0,00%	0,86%	0,08%		4,16%	5,10%
JBN.Miel.214	United States	37°04 N	88°07 O	1	< LOQ	< LOQ	0,058	< LOQ	0,039			0,12%		0,08%	0,19%
JBN.Miel.215	United States	48°01 N	94°01 O	2	< LOQ	0,097	0,170	< LOQ	1,415		0,19%	0,34%		2,83%	3,36%
JBN.Miel.337	United States	44°30 N	69°27 O	1	0,014	0,328	1,189	< LOQ	1,130	0,03%	0,66%	2,38%		2,26%	5,32%
JBN.Miel.338	United States	44°17 N	69°10 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.346	United States	61°36 N	150°36 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.347	United States	61°18 N	149°30 O	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.348	United States	29°36 N	81°35 O	1	< LOQ	0,917	6,325	< LOQ	2,674		1,83%	12,65%		5,35%	**19,83%**
JBN.Miel.349	United States	28°27 N	81°17 O	2	< LOQ	< LOQ	0,032	< LOQ	0,023			0,06%		0,05%	0,11%
JBN.Miel.350	United States	32°55 N	116°52 O	2	< LOQ	< LOQ	0,241	< LOQ	0,023			0,48%		0,05%	0,53%
JBN.Miel.126	Uruguay	31°42 S	55°59 O	1	0,009	< LOQ	0,076	0,023	0,091	0,02%		0,15%	0,05%	0,18%	0,40%
JBN.Miel.211	Vietnam	20°15 N	105°58 E	1	< LOQ	< LOQ	0,079	< LOQ	0,111			0,16%		0,22%	0,38%
JBN.Miel.043	Yemen	12°31 N	53°55 E	1	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ						
JBN.Miel.074	Yemen	16°02 N	49°00 E	2	0,041	< LOQ	< LOQ	< LOQ	0,099	0,08%				0,20%	0,28%

* Geographical precision is as follows 1: second; 2: minute; 3: centre of the region/state; 4: centre of the country

Table S2. Compound specific UHPLC-MS/MS parameters for the five neonicotinoids analysed in a worldwide collection of honey.

Analytes	Period	RT	Transitions	DP	CE	CXP	Dwell time	Total cycle time
		[min]	[m/z]	[V]	[V]	[V]	[ms]	[s]
Acetamiprid (Q)	3	4,66	223/126	56	37	8	80	0,68
Acetamiprid (q)	3		223/73	51	77	12	80	0,68
Acetamiprid-D3(Q)	3	4,68	226/126	56	30	10	80	0,68
Acetamiprid-D3 (q)	3		226/73	61	85	12	80	0,68
Clothianidin (Q)	2	3,56	250/169	46	20	12	100	0,84
Clothianidin (q)	2		250/132	46	19	10	100	0,84
Clothianidin-D3(Q)	2	3,58	253/172	45	20	12	100	0,84
Clothianidin-D3(q)	2		253/132	45	20	10	100	0,84
Imidacloprid (Q)	2	3,95	256/209	56	19	16	100	0,84
Imidacloprid (q)	2		256/175	51	25	14	100	0,84
Imidacloprid-D4 (Q)	2	3,95	260/213	61	20	12	100	0,84
Imidacloprid-D4(q)	2		260/179	55	25	12	100	0,84
Thiacloprid (Q)	3	5,81	253/126	61	29	10	80	0,68
Thiacloprid (q)	3		253/90	56	55	6	80	0,68
Thiacloprid-D4 (Q)	3	5,82	257/126	66	30	8	80	0,68
Thiacloprid-D4 (q)	3		257/90	66	53	6	80	0,68
Thiamethoxam (Q)	1	2,48	292/211	46	17	16	200	0,82
Thiamethoxam (q)	1		292/181	46	31	14	200	0,82
Thiamethoxam-D3 (Q)	1	2,51	295/214	46	17	16	200	0,82
Thiamethoxam-D3 (q)	1		295/184	46	33	16	200	0,82

RT, retention time, DP, declustering potential, CE, collision energy, CXP, collision cell exit potential, Q, quantifier transition, q, qualifier transition.

Table S3. Validation parameters for the quantification of neonicotinoids in a worldwide collection of honey.

Analytes	Linearity	LLOD	LLOQ	Precision	Accuracy	RE	ME
	[ng/ml]	[ng/g]	[ng/g]	[% RSD]	[%]	[%]	[%]
Acetamiprid	0.03-200	0,003	0,008	3,2	102	70	66
Clothianidin	0.15-200	0,01	0,03	4,4	89	69	73
Imidacloprid	0.15-200	0,01	0,03	7,6	76	71	82
Thiacloprid	0.01-200	0,001	0,002	2,8	100	73	65
Thiamethoxam	0.1-200	0,01	0,02	4,3	117	73	49

RE, recovery, ME, matrix effects.

Table S4. Summary statistics of neonicotinoids measured in a worldwide collection of honey: Total concentration for acetamiprid, clothianidin, imidacloprid, thiacloprid and thiametoxam and proportion of positive samples.

Region	Total concentration [ng/g]				% of samples with n neonicotinoids > LOQ					
	Maximum	Median *	Average *	SE *	1	2	3	4	5	∑ 1-5
All regions	56,4	0,19	1,78	0,56	30%	19%	17%	6%	4%	75%
Africa (n=27/37)	2,4	0,07	0,26	0,11	57%	11%	5%	0%	0%	73%
Asia (n=33/41)	22,7	0,13	1,27	0,73	20%	29%	29%	0%	2%	80%
Europe (n=42/53)	56,4	0,24	3,15	1,65	21%	19%	26%	6%	8%	79%
N.-America (n=19/22)	9,9	0,30	1,19	0,49	18%	23%	14%	23%	9%	86%
S.-America (n=16/28)	4,3	0,04	0,32	0,21	18%	18%	11%	7%	4%	57%
Oceania (n=12/17)	0,5	0,04	0,09	0,04	59%	6%	0%	6%	0%	71%

* of samples >LOQ; # number of positive samples / total number of samples

Table S5. Summary statistics of neonicotinoids measured in a worldwide collection of honey; detail per compound.

Analytes	LOQ [ng.g-1]	> LOQ	Maximum [ng.g-1]	Median [ng.g-1] *	Average [ng.g-1] *	SE [ng.g-1] *
Acetamiprid (n=198)	0,008	33%	29,3	0,06	1,27	0,57
Clothianidin (n=198)	0,03	16%	1,8	0,20	0,32	0,07
Imidacloprid (n=198)	0,03	51%	6,3	0,08	0,35	0,08
Thiacloprid (n=198)	0,002	24%	46,8	0,08	2,40	1,14
Thiamethoxam (n=195)	0,02	37%	2,7	0,10	0,29	0,06

* of samples >LOQ

Supplementary Table 6. Summary statistics of neonicotinoids measured in a worldwide collection of honey.

Continent	Statistic	Neonicotinoid				
		Acetamiprid	Clothianidin	Imidacloprid	Thiacloprid	Thiamethoxam
Africa	% samples > LOQ	13,5%	5,4%	32,4%	8,1%	35,1%
	Maximum [ng/g]	0,139	0,099	2,445	0,500	0,598
	Median [ng/g]*	0,000	0,000	0,000	0,000	0,000
	Average [ng/g]*	0,011	0,005	0,181	0,014	0,052
	SE [ng/g]*	0,014	0,015	0,160	0,047	0,034
Asia	% samples > LOQ	53,7%	9,8%	68,3%	17,1%	29,3%
	Maximum [ng/g]	21,786	1,829	2,652	0,660	0,298
	Median [ng/g]*	0,013	0,000	0,041	0,000	0,000
	Average [ng/g]*	0,891	0,061	0,254	0,032	0,029
	SE [ng/g]*	0,802	0,149	0,121	0,045	0,018
Europe	% samples > LOQ	41,5%	22,6%	49,1%	52,8%	32,1%
	Maximum [ng/g]	29,312	0,951	1,199	46,767	1,420
	Median [ng/g]*	0,000	0,000	0,000	0,002	0,000
	Average [ng/g]*	0,823	0,053	0,076	2,127	0,069
	SE [ng/g]*	0,866	0,044	0,035	1,423	0,051
North America	% samples > LOQ	36,4%	50,0%	63,6%	18,2%	72,7%
	Maximum [ng/g]	0,061	0,932	6,325	0,060	2,674
	Median [ng/g]*	0,000	0,035	0,033	0,000	0,117
	Average [ng/g]*	0,008	0,210	0,400	0,004	0,567
	SE [ng/g]*	0,006	0,088	0,360	0,007	0,193
South-America	% samples > LOQ	47,1%	17,6%	76,5%	17,6%	58,8%
	Maximum [ng/g]	2,573	0,048	1,618	0,200	0,282
	Median [ng/g]*	0,000	0,000	0,000	0,000	0,000
	Average [ng/g]*	0,097	0,004	0,172	0,008	0,041
	SE [ng/g]*	0,172	0,008	0,106	0,022	0,025
Oceania	% samples > LOQ	3,6%	0,0%	25,0%	10,7%	17,9%
	Maximum [ng/g]	0,034	0,000	0,091	0,190	0,344
	Median [ng/g]*	0,000	0,000	0,000	0,000	0,000
	Average [ng/g]*	0,002	0,000	0,024	0,013	0,047
	SE [ng/g]*	0,008	0,000	0,013	0,026	0,050

* of samples >LOQ

Table S7. Summary statistics for concentrations of neonicotinoids measured in honey samples in different studies and maximum residue level (MRL) authorised in the EU.

Location of study & reference	Statistic	Acetamiprid	Clothianidin	Imidacloprid	Thiacloprid	Thiamethoxam	Dinotefuran	Nitenpyram
	MRL (EU) [ng/g]	50	10	50	50	10	10	10
World collection of honey, from apiaries, local markets and commercial (this study)	LOD [ng/g]	0,003	0,01	0,01	0,001	0,01		
	LOQ [ng/g]	0,008	0,03	0,03	0,002	0,02		
	n	198	198	198	198	195		
	mean of >LOQ; max	1.27; 29.31	0.32; 1.83	0.35; 6.32	2.4; 46.77	0.29; 2.67		
	>LOQ	66	32	100	48	73		
	% >LOQ	33%	16%	51%	24%	37%		
France - 3 yrs study in 5 regions in continental France (Chauzat et al. 2009, 2011)	LOD [ng/g]			0,3				
	LOQ [ng/g]			1				
	n			239				
	Range			0-1.8				
	>LOD			52				
	% >LOD			21,8%				
Republic of Serbia - honey purchased at local market in Novi Sad (Jovanov et al. 2013).	LOD [ng.g] *	0,5	1,0	0,5	0,5	0,7	0,9	0,8
	LOQ [ng.g] *	1,5	2,5	1,5	1,5	1,5	2,5	1,8
	n	15	15	15	15	15	15	15
	>LOD	0	0	0	0	0	0	0
UK - honey from apiaries sampled in spring 2013 (Jones & Turnbull 2016)	LOQ [ng/g]		0,02	0,10		0,01		
	n		22	22		22		
	Range		>0.02-0.82	all <0.1		<0.01-0.79		
	>LOQ		16	0		15		
	> MRL EU		0	0		0		
	% >LOQ		73%	0%		68%		
	% > MRL EU		0%	0%		0%		
Saskatchewan, Canada - 26 samples from 7 apiaries from hives within 30km from Saskatoon (Codling et al. 2016)	LOQ [ng/g]	0,1	0,4	0,6	2	2		2
	n	26	26	26	26	26		26
	>LOQ	0	19	4	1	21		0
	% >LOQ	0	73,1%	15,4%	3,8%	80,8%		0%
Belgium, samples collected during winter 2004-5 in 16 hives spread out in Wallonia (Pirard et al. 2007)	LOD [ng/g]			0.069-0.084				
	LOQ [ng/g]			0				
	n			109				
	Mean ; range			<0.084				
	>LOD			5				
	>LOQ			0				
	> MRL EU			0				
	% >LOD			5%				
Belgium, August- October 2004, 16 apiaries, 3 hives per apiary (Nguyen et al. 2009)	LOD [ng/g]			0,05				
	LOQ [ng/g]			0,5				
	n			48				
	Mean ; range			0.275; >0.05-<0.5				
	>LOD			4				
	>LOQ			0				
	> MRL EU			0				
	% >LOD			8%				
North-west Spain, 73 apiaries (Garcia-Chao et al. 2010)	LOQ [ng/g]			2,33		0,51		
	n			91		91		
	Mean ; range			<2.33		<0.51		
	>LOQ			0		0		
	> MRL EU			0		0		

* Indicated as mg/kg, but assumed to be µg/kg (= ng/g) as otherwise indicated EU values would be 1000 too high. These values are much higher than other studies and thus the lack of detection is not very meaningful.

Table S8. Compilation of statistically significant effects of neonicotinoids on honey
(MRFC) or lower concentrations.

Pesticide	Tested organism	Measured variable
Imidacloprid	*Apis mellifera* (Hymenoptera: Apidae)	Mortality
		Size of hypopharyngeal glands (HPGs)
		Glucose oxidase activity
Imidacloprid		Foraging performance
Thiamethoxam		Homing capacity of foraging bees
Imidacloprid		Olfactory associative behavior of adult bees when larvae were exposed
Imidacloprid		Mushroom body Kenyon cells (KC) neuronal firing and nicotinic response
Clothianidin		
Imidacloprid		Volume of hypopharyngeal gland's lobe
		Bursting pattern of abdominal ventilation movements: inter-burst interval duration
		Mean duration of abdominal ventilation movement
Imidacloprid		Short/mid-term and early long-term memory
Clothianidin		Alteration of motor function behaviour: loss of postural control, increased time spend on the back, (disruption of the righting reflex), increased time spent grooming
Dinotefuran		
Imidacloprid		

Thiamethoxam		grooming

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable
Clothianidin & thiamethoxam	*Apis mellifera* (Hymenoptera: Apidae)	Population size of adult bees
		Brood size
		Queen replacement (supersedure)
		Swarming
Imidacloprid		Home flight capacity (navigation memory)
Clothianidin		
Thiacloprid		
Clothianidin & thiamethoxam		Percent of honey bee queens that oviposited (i.e. laid worker eggs).
		Reproduction success (alive and producing worker offspring)
		Ovaries size (hyperplasia)
		Spermathecal-stored sperm quantity
		Spermathecal-stored sperm quality (living vs. dead)
Acetamiprid		Proboscis extension response (PER) of bees treated 24h before learning session
Deltamethrin		
Acetamiprid		Proboscis extension response (PER) of bees treated 24h during learning session
Deltamethrin		

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable
Clothianidin & thiamethoxam	*Apis mellifera* (Hymenoptera: Apidae)	Varroa infestation
		Number of dead colonies
Clothianidin		Early long-term memory (24h)
Clothianidin, imidacloprid		Gene expression: vitellogenin
Thiamethoxam		
Imidacloprid		Gene expression: cAMP response element binding protein (creb).
Clothianidin		
Clothianidin		Gene expression: cAMP-dependent kinase (pka)
Acetamiprid		Gene expression: cAMP-dependent kinase (pka)
Thiamethoxam		Proboscis extension response (PER) at high sucrose concentration
Clothianidin		Long-term (24h) memory
Clothianidin		Hemocyte density, encapsulation responses & anti-microbial activity
Imidacloprid		
Thiacloprid		

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable

Imidacloprid	*Apis mellifera* (Hymenoptera: Apidae)	Mortality Additive toxicity with other pesticides)
		Mortality (synergetic toxicity with other pesticides)
Imidacloprid		Hygienic behaviour
Clothianidin		Life span
Clothianidin		Likeliness to loose queen
Clothianidin		Worker numbers during oilseed rape flowering period at the UK site
Clothianidin		Egg cells number during OSR flowering period at the German site
Thiamethoxam		
Clothianidin		Number of storage cells during OSR flowering period at the UK site
Thiamethoxam		
Clothianidin		Worker number following the winter period
Clothianidin		Total hemocyte counts in larvae
		Level of granulocytes and oenocytoids in larvae
		Larval mortality
		Total hemocyte hemocyte and differential hemocyte counts in larvae
		Levels of plasmatocytes and granulocytes in larvae

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable
		Flight duration

Thiamethoxam	*Apis mellifera* (Hymenoptera: Apidae)	Flight distance
		Mean flight velocity
		Mean flight velocity
Imidacloprid		Daily mortality
		Body mass
		Vitellogenin level in adult worker
Thiamethoxam	*Apis mellifera scutellata* (Hymenoptera: Apidae)	Thermoregulation in response to cold shock (4°C) or alternating exposure to 33°C and 22°C
Imidacloprid	*Apis mellifera anatoliaca* (Hymenoptera: Apidae)	Percentage of foragers returning to an artificial flower patch
		Total number of foraging trips per bee
Imidacloprid	*Apis cerana* (Hymenoptera: Apidae)	Number of bees returning to food source (foraging reduction)
		Volume of nectar collected per bee
		Avoidance of predator (hornet)

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable

Imidacloprid	*Apis cerana* (Hymenoptera: Apidae)	Olfactory learning acquisition of adult bees, when exposed as adults, at short term (0-40 min) and long term (1, 5 & 17h)
		Olfactory learning acquisition of bees, when exposed to pesticide during larval phase, at short term (0-40 min) and long term (1, 5 & 17h)
Imidacloprid		Binding of chemosensory protein (CSP1) to floral scent ß-ionone
Imidacloprid	*Bombus impatiens* (Hymenoptera: apidae)	Queen survival
Clothianidin		
Imidacloprid		Worker movement
Clothianidin		
Imidacloprid		Time and dose dependant expression of antimicrobial peptid genes
Imidacloprid	*Bombus terrestris* (Hymenoptera: Apidae)	Colony survival rate
Imidacloprid		Drone production
		Number of drones
		Nest reproduction
		Worker mortality
Thiamethoxam		Drone production
Thiacloprid		Nest reproduction
		Worker mortality
Imidacloprid		Worker fecundity
Imidacloprid		Queen production

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable
		Brood development (number of larvae and puppae)

Imidacloprid	*Bombus terrestris* (Hymenoptera: Apidae)	Forager recruitment
		Pollen load brought back by forager
		Succesfull pollen collection trips
		Duration of pollen collecting trips
		Number of worker lost while foraging
Imidacloprid		Colony growth
Clothianidin		Reproduction
		Colony growth
		Wild bee density
Imidacloprid		Neuronal sensitivity to Acetylcholine
Imidacloprid		Mitochondrial depolarization in neurons
Imidacloprid		Stimulation of Kenyon cells of the mushroom body
Clothianidin		
Imidacloprid		Bee immobility
Imidacloprid		Number of brood cells
Thiamethoxam		Altered sex-ratio (decreased number of females)
Thiamethoxam		Number of brood cells
Clothianidin		Queen production

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable
		Foraging activity

Clothianidin	*Bombus terrestris* (Hymenoptera: Apidae)	Number of adult workers, drones and gynes
Thiacloprid		Colony failure during experiment
		Colony weight
		Number of reproductive individuals produced per colony (nr females + 0.5 * nr males, both including pupae)
Thiamethoxam		Drone production at UK site
Thiamethoxam		Drone production at Germany site
Clothianidin, imidacloprid & thiamethoxam		Queen production
Imidacloprid	*Melipona quadrifasciata anthidioides* (Hymenoptera: Apidae)	Survival over ca. 45 days
Clothianidin & thiamethoxam	*Osmia bicornis* (Hymenoptera: Megachilidae)	Number of nests completed during a season
		Number of brood cells
		Number of offspring completing larval development
		Number of offspring able to hatch after hibernation
		Total offspring production
		Prportion of females offspring

Supplementary Table 8 (continued)

Pesticide	Tested organism	Measured variable

Clothianidin	*Osmia bicornis* (Hymenoptera: Megachilidae)	Solitary bee nesting
		Wild bee density
Clothianidin, imidacloprid & thiamethoxam		number of reproductive cells
Imidacloprid	Diptera: Syrphidae, Chironomidae, Tephritidae, Tachinidae and Calliphoridae	Number of flying insects captured in pan traps
Imidacloprid	Coleoptera: Nitidulidae, Cantharidae and Scarabaeidae	Number of flying insects captured in pan traps
Acetamiprid	*Eriopis connexa* (Coleoptera: Coccinellidae)	Proportion of malformation in adults

Minimal concentration for which a signifiant effect was observed

/bees, wild bees and other non-target pollinators and terrestrial insects at Maximum Recomme

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	
Significant increase	0,7			Alaux et al. 2010
Significant decrease in combination with *Nosema* infection	7			
-6% to -20%	1-10			Cresswell 2011
-10% to -32%		0,067		Henry et al. 2012
Significant decrease			0,04	Yang et al. 2012
Depolarization of KC & inhibition of Acetylcholine-evoked responses	2,56	2,56		Palmer et al. 2013
	2,50	2,50		
-15% to -16%	2.1 & 2.7			Hatjina et al. 2013
+59%				
-57%				
Significant decrease		0,256		Williamson & Wright 2013
Variable magnitude depending on the response variable and pesticide	2,50	2,50	0,344	Williamson et al. 2014
	2,02	2,02	0,323	
	2,56	2,56	0,401	

	2,92	2,92	0,481	

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	
-28%	7,36			Sandrock et al. 2014a
-13%				
+60%				
-80%				
-68%	75			Fischer et al. 2014
-22%	25			
-55%	112,5			
-38%	5,12			Williams et al. 2015
-34%				
+6.8%				
-20%				
-9%				
Significant decrease 6 & 24h after learning			100	Thany et al. 2015
Significant decrease 24h after learning			10	
Significant decrease 24h after learning			10	
			100	

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	
+ 126%	<LOQ-0.17; <LOQ-0.07			Alburaki et al. 2015; 2017
+86% ; +400%				
Significant decrease	15			Alkassab & Kirchner 2016
Significant increase	3			Christen et al. 2016
	0,1			
Significant decrease	3			
Significant increase	0,3			
Significant decrease	0,3			
Significant decrease	80			
Significant decrease	10			Démares et al. 2016
Significant decrease	15			Alkassab & Kirchner 2016
Significant decreases		50		Brandt et al. 2016
		1,0		
		200		

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	

4 to 10% increase		0,274		Zhu et al. 2017
15 to 26% increase		0,274		
Significant decrease	cf. remarks			Tsvetkov et al. 2017
-23%				
Significant increase				
Significant decrease	cf. remarks			Woodcock et al. 2017
Significant increase				
Significant decrease				
Significant decrease				
Significant increase				
-24%				
Significant increase			32	Hernandez-Lopez et al. 2017
Significant increase				
+18%				
Significant decrease				
Significant decrease				

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	
+78%			1,34	
-54%			1.95/bee/day	

+72%			1,34	Tosi et al. 2017
-56%			1.95/bee/day	
-7%			3.71/bee/day	
-6%			2.90/bee/day	
Significant increase	50			Abbo et al. 2017
Significant decrease	50			
Significant decrease to ca. 1/265 of control (7421/28)	25			
Significant up or down-regulation			0.2-2.0	Tosi et al. 2016
Significant decrease			0.36-7.20	Karahan et al. 2015
Significant decrease			0,36	
-23%		34		Tan et al. 2014
-46 ; -63%		17 ; 34		
ca. -19% (65% vs. 80-85%)		34		

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	

Significant reduction in both short- and long-term			0,10	Tan et al. 2015
Significant reduction in short-term			0,24	
Nearly 50% decrease			0,28	Li et al. 2017
-37%	20			Scholer and Krischik 2014
-56%				
-20%				
-32%				
Significant increase	12			Simmons and Angelini 2017
-10%	6-10			Tasei et al. 2000
-75%	20			Mommaerts et al. 2010
-62%	10			
-100%				
-92%				
-86%	100			
-36%	1200			
+6%	10			
-42%	1			Laycock et al. 2012
-85%	6			Whitehorn et al. 2012

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	
-22%				

Significant increase	10			Gill et al. 2012
-7%				
Significant decrease				
Significant increase				
50%				
Significant decrease	10			Bryden et al. 2013
Significant decrease	in pollen: <LOQ-23	in nectar <LOQ-16		Rundlöf et al. 2015
Significant increase	0,25			Moffat et al. 2015
Significant increase	2,1			
Significant increase	2,5			Moffat et al. 2016
Significant increase				
-46%				
Significant decrease				
-70%				
Significant increase				

Reported effect	**Concentration used**			**Reference**
	[ng/g]	**[ng/ml]**	**[ng/ind.]**	
Significant decrease				

Significant decrease	5			Arce et al. 2016
+124% (14/30 vs. 5/24)	up to 771 in pollen and up to 561 in nectar			Ellis et al. 2017
-10%				
-46%				
Significant decrease	cf. remarks			Woodcock et al. 2017
Significant increase				
Significant negative correlation to peak neonicotinoid residues found in nests	0.53 - ca. 8			
- ca. 40%			5,6	Tomé et al. 2012
-22%	3,32			Sandrock et al. 2014b
-44%				
-15%				
-8,5%				
-48%				
-15%				

Reported effect	Concentration used			Reference
	[ng/g]	[ng/ml]	[ng/ind.]	

Significant decrease	in pollen: <LOQ-23	in nectar <LOQ-16		Rundlöf et al. 2015
Significant negative correlation to median neonicotinoid residues found in nests	0.53 - ca. 6.5			Woodcock et al. 2017
Significant decrease		0,01		Easton and Goulson 2013
Significant decrease		1		Easton and Goulson 2013
+87%			230	Fogel et al. 2016

	0,10	**0,01**
% of our samples above this value	**48%**	**74%**

nded Field Concentration

Remarks
Concentration: Not specified in the paper but information provided orally by 1st author.
1-10 ug/kg
1.34 ng in 20ml sucrose solution.
0.04 ng/lava
Mushroom body placed in a 10nM solution; depolirization due to sustanined activation of Nicotinic acetylcholine receptors.
2.1 ng/g in sugar solution, 2.7 ng/g in pollen pastry.
10nM, 100 nM and 1 µM solutions in 1M surcose solutions.
10nM solution = field-relevant doses determined to be sublethal and willingly consumed by (non-foraging) bees kept in petri dishes. Intake corresponds to 0.45-

corresponds to 0.45 0.54ng/bee.

Remarks
Thiamethoxam 5.31 ng/g + clothianidin 2.05 ng/g mixed together.
75 ppb
25 ppb
112.5 ppb

Remarks
Calculated as (average nr overtime for treated - untreated) / average nr overtime for untreated.
Higher in treated fields: 4 vs. 1 in this study and 28% vs. 15% (+87%) increase over two years.
Enhanced vitellogenin expression may decrease foraging activity.
Downregulation of creb and pka may cause a decrease in long-term memory.

Remarks

Observational study is a commercial farming environment, clothianidin, thiamethoxam, imidacloprid and acetamiprid.
Clothianidin: 11.86 to 18.05 g a.i./ha; thiamethoxam: 10.07-11.14 g a.i./ha. All treatments including controls also received fungicide treatments, and different fungicides were used in the three different countries.
Effect of clothianidin alone.
Combined effects of clothianidin and American Foulbrood (*Paenibacillus larvae*) infection: immune depression and increased mortality.

Remarks
Acute exposure.
Chronic exposure.

Acute exposure.
Chronic exposure.
Chronic exposure.
Chronic exposure.
Viteloggenin participates in honeybee's immunity, stress resistance, hormone dynamics and life span.
Direction of effect differed between low and high dose and with exposure to high or low temperature.
Tested doses 0.36, 0.72, 1.8 ng/ind.
20 and 40 µg/l imidacloprid in 1.25 M sucrose feeder = 17 and 34 ng/ml. No effect observed at 8.5 ng/ml.

Remarks

Inhibition of the molecular mechanism of chemoreceptive system.

Remarks

Field study, seed-coated oilseed rape. Clothianidin in combination with a pyrethroid beta-cyfluthrin. Residues of 4 other neonicotinoids were also detected.
Suggested mechanism: up-regulation in nAChR expression.
2.1ppb, chronic exposure.
2.5ppb

Remarks

Field experiment : bumblebee nests placed on raspberry farms. The concentration range given is what was measued in pollen and nectar in the nests.
Clothianidin: 11.86 to 18.05 g a.i./ha; thiamethoxam: 10.07-11.14 g a.i./ha. All treatments including controls also received fungicide treatments, and different fungicides were used in the three different countries.
2.87 µg/kg of thiamethoxam and 0.45 µg/kg of clothianidin.

Remarks

Field study, seed-coated oilseed rape. Clothianidin in combination with a pyrethroid beta-cyfluthrin. Residues of 4 other neonicotinoids were also detected.
11.86 to 18.05 g a.i./ha. All treatments including controls also received fungicide treatments, and different fungicides were used in the three different countries.
200 mg/l is the MRFCs registered in Argentina.

Table S9. Relative proportion of honey samples from a worldwide survey containing between one and five different neonicotinoids. Percentage of samples containing A) each neonicotinoid alone (1), or in combination with 1, 2,3, or 4 other neonicotinoids (2-5), B) each neonicotinoid in combination with 0 to 4 others (1+), 1-4 others (2+), ..., 4 others (5), and C) each specific combination of two neonicotinoids (with or without more).

A	Percentage of samples containing 1,2,… or 5 neonicotinoids				
	1	2	3	4	5
Acetamiprid	2,0%	9,1%	11,6%	6,6%	4,0%
Clothianidin	0,0%	2,5%	7,1%	2,5%	4,0%
Imidacloprid	13,6%	14,6%	10,1%	5,6%	4,0%
Thiacloprid	3,5%	4,0%	10,1%	5,1%	4,0%
Thiamethoxam	10,1%	8,1%	9,6%	6,6%	4,0%

B	Percentage of samples containing 1-5, 2-5, … ,5 neonicotinoids				
	1+	2+	3+	4+	5
Acetamiprid	33,3%	31,3%	22,2%	10,6%	4,0%
Clothianidin	16,2%	16,2%	13,6%	6,6%	4,0%
Imidacloprid	48,0%	34,3%	19,7%	9,6%	4,0%
Thiacloprid	26,8%	23,2%	19,2%	9,1%	4,0%
Thiamethoxam	38,4%	28,3%	20,2%	10,6%	4,0%

C	Percentage of sample containing each combination of two neonicotinoids *			
	CLO	IMI	THP	THM
ACE	9,6%	22,2%	16,2%	16,2%
CLO		9,6%	8,6%	12,6%
IMI			14,1%	22,7%
THP				11,6%

* These values include samples containing also other neonicotinoids, i.e. corresponds to table B, column 2+; ACE: Acetamiprid, CLO: Clothianidin, IMI: Imidacloprid, THP: Thiacloprid, THM: Thiamethoxam