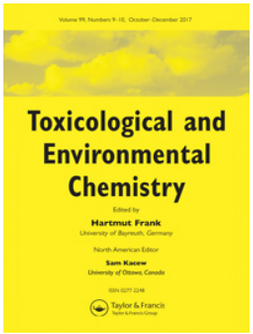

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Human dietary intake and hazard characterization for residues of neonicotinoides and organophosphorus pesticides in Egyptian honey

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ABSTRACT

In two recently published reports, hazards posed by dietary exposure to organophosphate and neonicotinoid plant protection products on the European honey bee (*Apis mellifera* L.) in Egypt were investigated. Using concentrations reported in those studies, an assessment of hazards posed by these two classes of insecticides to humans due to consumption of Egyptian honey from the Nile Delta during both spring and summer was performed. Twenty-eight compounds including metabolites were assessed for exposure of adult Egyptians based on the best- and worst-case scenarios. Even for the worst-case scenario, exposure to these two classes of pesticides in honey was 15-fold less than hazard index value of 1.0 for adverse effects on humans. Based upon this analysis, people exposed to these insecticides through consumption of honey products would be unlikely to exhibit adverse health outcomes.

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Pesticides; honey; hazard index; mixture risk assessment

1. Introduction

Honey is widely used for both nutritional and therapeutic purposes and has been used as a sterile medium to dress wounds (Molan 1999). Egypt has some of the oldest records of managed hives and honey that has been a key feature of Egyptian diet for thousands of years. Over the past few years, however, concern over food security has led to investigations over potential contamination of honey and other bee products (Tsipi, Triantafyllou, and Hiskia 1999; Shalaby, Abdou, and Sallam 2012). Residues of potentially toxic compounds in honey predominantly from agricultural and veterinary use have been measured (Totti et al. 2006; Calatayud-Vernich et al. 2016). Food alerts due to the presence of antibiotics, pesticides or metals in honey have caused some jurisdictions to restrict imports of bee products from some countries, which have damaged the reputation of

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honey (Juan-Borrás et al. 2015). For example, in the European Union (EU), the maximum-allowable concentration of chloramphenicol, an antibiotic, in honey is 0.3 μg kg^{-1} wet mass (wm). In 2002, honey from China exceeded this concentration leading to a ban on all Chinese honey (Huang et al. 2014).

Several classes of pesticides including organochlorines (OCs), organophosphorus (OPs), carbamates, ureas, anilides, and pyrethroids are used in Egypt (Badawy 1998). In 1995, >80% of pesticides in use were OPs (Mansour 2004), but resistance of *Benisia tabaci* and other pests to OPs has led to an increased use of neonicotinoids (NIs) (Kady and Devine 2003). Though there is limited information on mass of pesticides used in Egypt, it was estimated that >30% of insecticide treatments have NIs as the active ingredient (Malhat et al. 2014). In a study of contamination of humans in Egypt, blood was tested for the Nis, thiamethoxam, and acetamiprid, used by 29% and 26% of Egyptian farmers, respectively, but no exposure of people through occupational use was observed (Shalaby, Abdou, and Sallam 2012). However, that study investigated the parent compound and not the metabolite. In the case of acetamiprid, the metabolite N-desmethyl-acetamiprid has been found in patients exposed to this insecticide (Taira et al. 2013). For people without occupational exposure, dietary exposure is considered a primary vector for pesticides. Due to their global application, contamination of food with OPs and NIs has led to concern that concentrations may reach levels that could affect human health (Torres, Picó, and Manes 1996).

With increased awareness of contamination of foodstuffs, a risk/benefit approach to some products can be considered (Mozaffarian and Rimm 2006). In recent years, decline in bee populations has led to a focus upon contaminant residues in honey and other products produced by bees. For human consumption, awareness that residues might diminish beneficial properties of honey and if present in sufficient concentrations pose a significant threat to human health has increased (Aliferis et al. 2010). Measuring concentrations of pesticides residues in honey allows assessment of dietary hazards and risks while also giving information on pesticide treatments that have been used in field crops surrounding the hives (Fernández, Picó, and Manes 2002).

Human exposure to pesticides is mainly via the diet, especially through fruits, vegetables, and other commodities including honey. It is estimated that diet, for non-occupational exposed individuals, contributes on average five times more pesticides to the body burden than all other routes of exposure, such as air and drinking water (Claeys et al. 2011). A major challenge in the assessment of contaminant exposure is to determine total exposure, via all relevant pathways, in different population groups for relevant periods, while considering timing and sequence of exposure. There is a general lack of information regarding exposure in particular for chemical mixtures. Development of validated deterministic and probabilistic models to predict exposures during long-term and short-term periods and for various exposure scenarios is needed (Fryer et al. 2006).

To protect human health, hazards posed by pesticides must be controlled to minimize their entering the food chain (Blasco et al. 2011; Bargańska, Ślebioda, and Namieśnik 2013). Assessment of dietary exposures to pesticides and other chemical agents is typically done on a chemical-by-chemical basis. However, consumers are exposed to multiple residues, including mixtures of pesticides and their transformation products through diet. Most farm-produced vegetables and fruit are treated with more than one plant protection product; therefore, multiple residues may be identified. People also consume

combinations of foods where a variety of residues may be present. In assessments of mixtures, if compounds have the same toxicological mechanism of action, the usual method of assessing risks posed by exposure to pesticides individually can result in an underestimation of overall hazard or risk (Gallagher et al. 2015; Judge et al. 2016). Therefore, to address hazards posed by exposure to multiple compounds, assessment of individual compounds would not be sufficiently protective (Boobis et al. 2008; Kortenkamp, Backhaus, and Faust 2009).

Results of previous studies have documented the presence of pesticide residues of various classes: OCs, OPs, pyrethroids, organonitrogen, and carbamates in honey collected from Egypt (Eissa, El-Sawi, and Zidan 2014, Eissa, Hassan, and El Rahman 2014). However, these studies were localized to a specific governorate or area in Egypt and none of them investigated NIs in honey. Therefore, the objective of this study was to assess hazards to humans posed by consumption of honey contaminated with residues of OP (Al Nagger et al. 2015a) and NI insecticides (Codling et al. 2017, in press) in honey collected during spring and summer 2013 from the middle delta region of Egypt.

2. Materials and methods

2.1. Study areas

The primary region of agriculture in Egypt is the Nile River Valley, more specifically the Nile Delta. During spring and summer 2013, samples of honey were collected from 15 locations (3 apiaries per location) in 5 agricultural governorates in the Nile Delta: Kafr El-Sheikh (31°18′N 30°56′E), AlGharbiya (30°52′52″N 31°03′36″E), Al-Menofiya (30°31′N 30°59′E), Al-Beheira 30°37′N 30°26′ E), and Al-Dakahlia (31°03′N 31°23′E) (Figure 1). European honeybees forage largely on clover from mid-April until the first week of June, after which cotton, maize, vegetables, and pumpkins represent the predominant sources of nectar and pollen during summer (Abou-Shaara 2015). Samples were collected at the end of clover and cotton growing seasons of 2013. A third season, citrus season, in early April was not investigated, because the mass of honey produced during that period is typically small and it is not always collected by beekeepers.

2.2. Experimental

Hives were selected randomly in each apiary. Fresh honey was collected directly off an open comb into 50-mL polyethylene falcon tubes (Al-Naggar et al. 2013). Samples were initially stored at Tanta University, Egypt, at −20 °C before transport in a cool box with ice packs to the Toxicology Center of the Saskatchewan University, Canada, where they were again stored at −20 °C until extraction.

2.3. Extraction, cleanup, and quantification of NIs and OPs

Both methodologies for the determination of NIs and OPs have been reported previously (NIs in Codling et al. [2016, Forthcoming] and OPs in Al Nagger et al. [2015a, 2015b]). In brief, both methods used modified QuEChRs methods for the extraction and cleanup of samples as illustrated in Figure 2. For OPs, the method was modified from Lehotay, Maštovská,

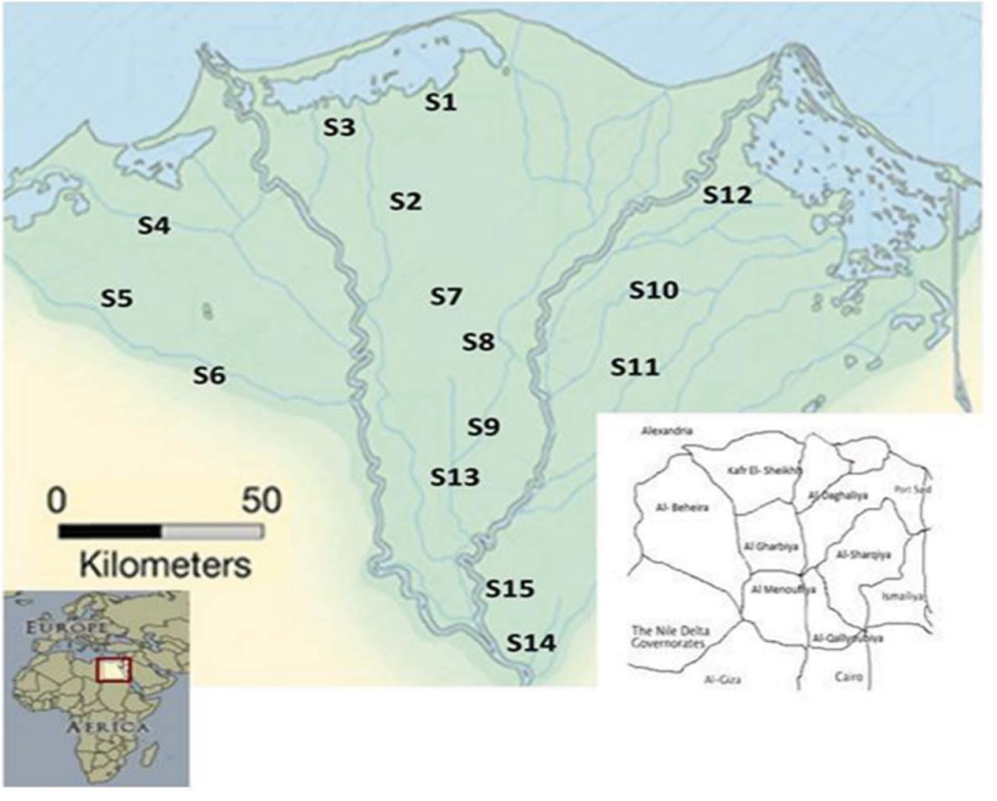

Figure 1. Sampling locations within the Nile River Delta Region of Egypt.

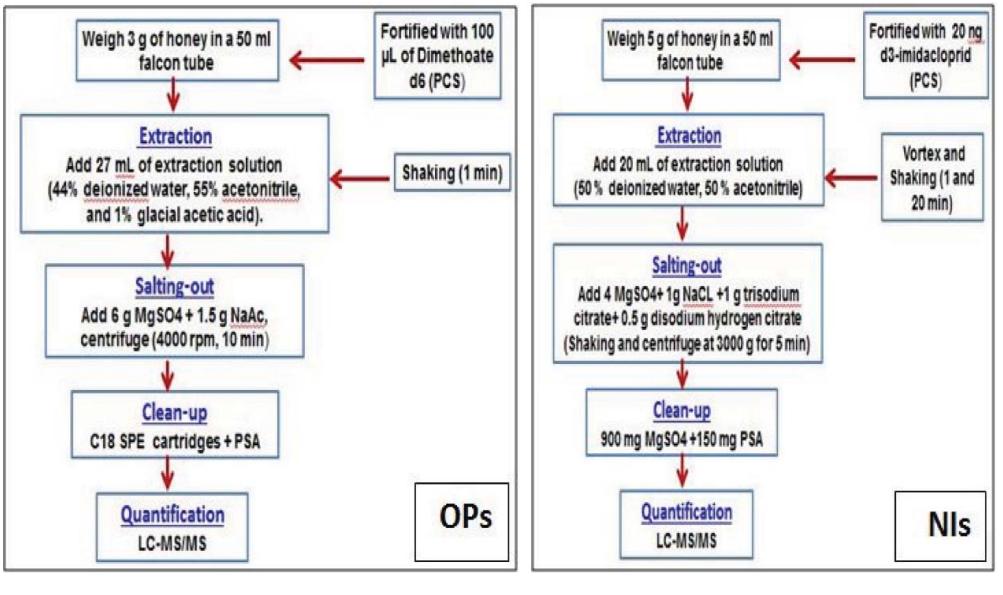

Figure 2. A flow diagram of the procedures of OP and NI detection in honey samples by HPLC-MS/MS.

and Lightfield (2005) and for NIs, Tanner and Czerwenka (2011). Both methods were adjusted for variants in sample mass. Identification was via LC-MS/MS operating in MRM with multiple paired ions used for quantification (Agilent HPLC and AB SCIEX 3000 MS^2). Quality controls consisted of trials of extraction efficiency using fortified honey at a range of concentrations, and during sample extraction mass labeled recovery standards, fortified honey, matrix blanks, and solvent blanks had been used. Recovery efficiency was on average 68% for d_3-imidacloprid and 86%–106% for a range of OPs.

2.4. Human dietary intake assessment and hazard characterization

Estimated daily intake (EDI) was compared with acceptable daily intake (ADIs) established by the World Health Organization (Lu 1995), Codex Alimentarius Commission on Pesticide (Eissa, El Sawi, Zidan 2014), Australian Government Office of Chemical Safety (2016), and Harada et al. (2016). By comparison of the EDI and ADI, the daily dosage over the entire lifetime of exposure can be estimated for where there is no appreciable risk based upon current information. Estimations of hazard to health were based on integration of pesticide residue data and dietary intake, which aims to represent the actual residue concentrations in food consumed by people in Egypt, which is based upon an average body mass of 60 kg (Gad Alla, Ayoub, and Salama 2012; Eissa, El Sawi, and Zidan 2014).

Uncertainty was assessed by calculating the maximum possible exposure ('worst case') and least possible exposure ('best case') scenarios based on ranges of honey consumption and concentrations of target compounds observed in honey, because concentrations of some OPs and NIs were < limit of quantification (LOQ). Based on positive detections of OPs and NIs residues in honey, median and 95th percentile were used for EDI for the best and worst cases, respectively. Hazard quotients (HQs) were calculated based on EDI of OPs and NIs in honey for which surrogate values for samples for which concentrations were less than the limit of detection was set to the limit of detection (LOD). In the best case scenario, concentrations of OPs and NIs less than the LOD were set to zero (0.0). The average Egyptian adult consumes between 0.5 and 2 kg of honey per year (http://pcela.rs/Egyptian_Beekeeping_2.htm). Therefore, for adults in Egypt, a minimum mass (0.5 kg) and a maximum mass (2 kg) were used for the best- and worst-case consumption (exposure) scenarios. Another uncertainty was that in the initial study no authentic standards were used for quantification of metabolites of imidacloprid and dinotefuran, so the LOD, LOQ, and ADI values of the parent pesticides were set and used for their metabolites as previously explained by Codling et al. (2016, Forthcoming). The choice for the inclusion of these compounds in the HQ estimation was to identify maximum possible exposure.

2.5. Estimated daily intake (EDI)

EDI, expressed as $\mu g\ kg^{-1}\ d^{-1}$, was calculated (Juan-Borrás et al. 2015) as follows:

$$\mathrm{EDI} = \frac{C * \mathrm{Con}}{\mathrm{BM}} \tag{1}$$

where C (μg kg^{-1}) is the average concentration of a given pesticide in honey; Con (kg person^{-1} d^{-1}) is the daily mean consumption of honey by people in Egypt; body mass (BM) (kg person^{-1}) represents body mass.

2.6. Hazard quotient (HQ)

The HQ was calculated for each pesticide by dividing the EDI by the ADI (μg kg^{-1} d^{-1}) for each pesticide:

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{ADI}} \tag{2}$$

2.7. Evaluation of hazard index

Based on the EDI for each pesticide, HQs were calculated individually, then the sum of the HQs ($\sum$HQs) were calculated for the hazard index (HI), which is a measure of the potential for adverse health effects from a mixture of chemical constituents (Zheng et al. 2007; Evans, Scholze, and Kortenkamp 2015). The HI, used in the most assessments of hazard or risk of mixtures, was calculated as the sum of the HQ of each individual chemical:

$$\mathrm{HI} = \sum_{n=1}^{\mathrm{I}} \mathrm{HQ}n \tag{3}$$

A value of HI $<$ 1 indicates that the total exposure ($\sum_{\mathrm{Exp}}$) does not exceed the level considered to be 'acceptable,' and people exposed are unlikely to suffer adverse health outcomes. If HI $>$ 1, there is a possibility of deleterious effects (Evans, Scholze, and Kortenkamp 2015; Yu et al. 2016). The margin of exposure (MOE) is the inverse of the HQ. An HQ of 0.1 would have an MOE of 10. That is, concentrations would need to be 10-fold greater than the ADI to cause 50% of the population to suffer a specified negative effect. This 'margin' is essentially the established 'safety buffer' between the effective dose and the predicted exposure dose. Other MOE values might be lesser or greater than 10-fold depending on the buffer of acceptability for effects.

3. Results and discussion

Median and 95th centile concentrations of OPs and NIs residues (μg kg^{-1} wm) in honey collected from Egypt during spring and summer 2013 are reported (Table 1) based on the results of previous studies (Al Naggar et al. 2015a; Codling et al. Forthcoming). In brief, dimethoate and dichlorvos were the only OPs detected in honey collected during spring, with mean concentrations of 3.4 and 1.9 μg kg^{-1} wm, respectively. In honey collected during summer, OPs detected were diazinon, dicrotophos, profenofos, and chlorpyrifos with mean concentrations of 0.3, 0.34, 0.28, and 3.3 μg kg^{-1} wm, respectively (Al Naggar et al. 2015a). For NIs, parent compounds of acetamiprid, imidacloprid and dinotefuran were detected in honey collected in both spring and summer with no differences in concentrations between the two seasons. Metabolites of imidacloprid and dinotefuran were detected at a

similar frequency and at similar concentrations. For example, imidacloprid-5-hydroxy were detected with a mean concentration of 0.7 during spring and 0.4 μg kg^{-1} wm during summer (Table 1) (Codling et al. Forthcoming). Concentrations of OPs and NIs were comparable to those found in other studies (Tables S1 and S2).

Based on the consumption of honey by adult humans in Egypt, for both best- and worst-case consumption scenarios, the EDI of a mixture of 13 OP pesticides, 6 NIs, and some of its metabolites analyzed in a total of 39 honey samples were calculated (Table 2). HI values ranged from 0.02 to 0.2 during spring and from 0.01 to 0.37 during summer, which were the best- and worst-case exposure scenarios, respectively (Table 2). This means that HI values were significantly less than thresholds for which health effects would be expected to occur. In spring, the MOE for residues of insecticides in honey were 15–54, while during summer, the MOE ranged from 9 to 170 for the worst- and best-case exposures (consumption), respectively.

Few studies have reported HI values for pesticides in other types of food in Egypt or the world. However, the European Food Safety Authority (EFSA) is developing some European food safety databases as are other regions (European Food Safety Authority 2013). Forty-six

Table 1. Concentrations (μg kg^{-1}, wm) of neonicotinoids (NIs) and organophosphorus (OPs) in honey collected from Egypt during spring and summer 2013.

	Conc. (μg kg^{-1}) in spring			Conc. (μg kg^{-1}) in summer			LOD	LOQ
Pesticides	Range	Median	95th centile	Range	Median	95th centile	(ng mL^{-1})	(ng mL^{-1})
Neonicotinoids								
Acetamiprid	2.7–8.7	5.7	8.4	1.7–9.4	3.1	8.4	0.03	0.1
Clothianidin	ND	ND	ND	ND	ND	ND	0.12	0.4
Imidacloprid	0.5	0.5	0.5	0.5–1.7	1.1	1.64	0.18	0.6
Thiacloprid	ND	ND	ND	ND	ND	ND	0.6	2
Thiamethoxam	18.8	18.8	18.8	ND	ND	ND	0.6	2
Imidacloprid metabolites								
Olefin	0.9	0.9	0.9	ND	ND	ND	0.18	0.6
5-hydroxy	0.4–1.1	0.6	1.025	0.4–0.5	0.45	0.49	0.18	0.6
urea	ND	ND	ND	ND	ND	ND	0.18	0.6
desnitro olefin	ND	ND	ND	0.5	0.5	0.5	0.18	0.6
desnitro HCL	ND	ND	ND	ND	ND	ND	0.18	0.6
6-Chloronicotinic acid	0.6	0.6	0.6	ND	ND	ND	0.18	0.6
Dinotefuran	0.3–1.0	0.6	0.91	0.4–0.9	0.5	0.82	0.6	2
Di-Urea	0.2–0.7	0.45	0.67	0.3–0.5	0.4	0.49	0.6	2
Di-DN-Phos	0.7–1.0	0.9	0.98	0.8–1.0	0.8	0.98	0.6	2
Organophosphates								
Diazinon	ND	ND	ND	0.3	0.3	0.3	0.13	0.44
Dicrotophos	ND	ND	ND	0.3	0.3	0.3	7.2	25.9
Ethoprop	ND	ND	ND	ND	ND	ND	0.31	1.7
Malathion	ND	ND	ND	ND	ND	ND	0.43	2.2
Dimethoate	1.4–5.2	3.4	5	ND	ND	ND	3.4	11.4
Coumaphos	ND	ND	ND	ND	ND	ND	0.79	2.9
Phorate	ND	ND	ND	ND	ND	ND	0.05	0.2
Dichlorvos	1.9	1.9	1.9	ND	ND	ND	21.54	56.4
Fenamiphos	ND	ND	ND	ND	ND	ND	0.12	0.8
Profenofos	ND	ND	ND	0.2–0.4	0.3	0.3	0.31	2.3
Chlorpyrifos	ND	ND	ND	3.3	3.3	3.3	0.14	5.4
Ch. methyle	ND	ND	ND	ND	ND	ND	2.8	13.5
Ch. oxon	ND	ND	ND	ND	ND	ND	0.26	1.3
Fenthion	ND	ND	ND	ND	ND	ND	1.46	3.9

LOD: limit of detection, LOQ: limit of quantification, ND: none detected.

Table 2. Estimated daily intake (EDI), calculated hazard quotients (HQ), and overall hazard index (HI) of organophosphorus and neonicotinoids pesticides residues found in honey collected during spring and summer 2013 from middle delta of Egypt to human population in Egypt.

		EDI (mg kg^{-1} d^{-1}) spring		EDI (mg kg^{-1} d^{-1}) summer		HQ spring		HQ summer	
Pesticides	ADI (μg kg^{-1})	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case
Neonicotinoids									
Acetamiprid	71[a]	6E−02	3E−01	3E−02	3E−01	8E−04	4E−03	4E−04	4E−03
Clothianidin	97[a]	0E+00	4E−03	0E+00	4E−03	0E+00	4E−05	0E+00	4E−05
Imidacloprid	57[a]	5E−03	2E−02	1E−02	5E−02	9E−05	3E−04	2E−04	1E−03
Thiacloprid	10[c]	0E+00	2E−02	0E+00	2E−02	0E+00	2E−03	0E+00	2E−03
Thiamethoxam	20[c]	2E−01	0E+00	0E+00	2E−02	9E−03	0E+00	0E+00	1E−03
Imidacloprid metabolites									
olefin	57[a]	9E−03	3E−02	4E−03	2E−02	2E−04	5E−04	8E−05	3E−04
5-hydroxy	57[a]	6E−03	3E−02	0E+00	6E−03	1E−04	6E−04	0E+00	1E−04
urea	57[a]	0E+00	6E−03	0E+00	6E−03	0E+00	1E−04	0E+00	1E−04
desnitro olefin	57[a]	0E+00	6E−03	5E−03	2E−02	0E+00	1E−04	9E−05	3E−04
desnitro HCL	57[a]	0E+00	6E−03	0E+00	6E−03	0E+00	1E−04	0E+00	1E−04
6-Chloronicotinic acid	57[a]	6E−03	2E−02	0E+00	6E−03	1E−04	4E−04	0E+00	1E−04
Dinotefuran	220[a]	6E−03	3E−02	5E−03	3E−02	3E−05	1E−04	2E−05	1E−04
Di-Urea	220[a]	4E−03	2E−02	4E−03	2E−02	2E−05	1E−04	2E−05	7E−05
Di-DN-Phos	220[a]	9E−03	3E−02	8E−03	3E−02	4E−05	1E−04	4E−05	1E−04
Organophosphates									
Diazinon	2[b]	0E+00	4E−03	3E−03	1E−02	0E+00	2E−03	1E−03	5E−03
Dicrotophos	–	0E+00	2E−01	3E−03	3E−03	–	–	–	–
Ethoprop	0.3[b]	0E+00	1E−02	0E+00	1E−02	0E+00	3E−02	0E+00	3E−02
Malathion	20[b]	0E+00	1E−02	0E+00	1E−02	0E+00	7E−04	0E+00	7E−04
Dimethoate	10[b]	3E-02	2E-01	0E+00	1E-01	3E-03	2E-02	0E+00	1E-02
Coumaphos	0.5[b]	0E+00	3E−02	0E+00	3E−02	0E+00	5E−02	0E+00	5E−02
Phorate	0.2[b]	0E+00	2E−03	0E+00	2E−03	0E+00	8E−03	0E+00	8E−03
Dichlorvos	4[b]	2E−02	6E−02	0E+00	7E−01	5E−03	2E−02	0E+00	2E−01
Fenamiphos	5[b]	0E+00	4E-03	0E+00	4E−03	0E+00	8E−04	0E+00	8E−04
Profenofos	10[b]	0E+00	1E−02	3E−03	1E−02	0E+00	1E−03	3E−04	1E−03
Chlorpyrifos	10[b]	0E+00	5E−03	3E−02	1E−01	0E+00	5E−04	3E−03	1E−02
Ch. methyle	10[b]	0E+00	9E−02	0E+00	9E−02	0E+00	9E−03	0E+00	9E−03
Ch. oxon	10[b]	0E+00	9E−03	0E+00	9E−03	0E+00	9E−04	0E+00	9E−04
Fenthion	1[b]	0E+00	5E−02	0E+00	5E−02	0E+00	5E−02	0E+00	5E−02
Hazard Index (HI)						**0.02**	**0.20**	**0.01**	**0.37**
Margin of exposure (MOE)						**53.84**	**14.65**	**170.34**	**9.09**

[a, b, c]ADI ; Acceptable daily intake values obtained from Harada et al. (2016), Lu (1995), and Australian Government Office of Chemical Safety (2016) respectively.

OCs, OPs, pyrethroid, and organonitrogen pesticides were analyzed in honey collected from 18 apiaries located in 9 centers in Kafr El-Sheikh governorate, Egypt, during 2011. Data obtained was then used for estimating potential adverse effects on humans associated with exposure to these pesticides. That evaluation demonstrated a negligible risk associated with exposure via consumption of honey (Eissa, El-Sawi, and Zidan 2014). Thirteen pesticides were analyzed in a total of 22 samples of polyfloral honey that represent almost all of the retail sales in the Spanish market and the HI for adults have been estimated which was less than 0.002 in all cases (Juan-Borrás, Domenech, and Escriche 2016).

Values for HIs obtained during the current assessment of adverse effects posed by mixtures of OPs and NIs in Egyptian honeys were greater than HI values obtained previously (Eissa, El-Sawi, and Zidan 2014; Juan-Borrás, Domenech, and Escriche 2016) even for

best-case exposure scenarios. There could be several reasons for these differences: (1) different pesticides analyzed, (2) differences in the daily consumption of honey and ADIs according to each country, (3) differences in between seasons and times of honey collection, and (4) differences in which HIs were calculated.

The HI for adults due to 11 pesticides in fresh vegetables (n = 214) from Changchun (China) was 0.44 (Yu et al. 2016). This value is less than half of the limit of acceptability; however, it is greater than that estimated for honey during the assessment presented here. This is mainly due to the large quantitative difference in consumption of both types of food. It should be emphasized that dietary intakes of pesticides estimated in this study considered only exposures from honey and did not include other food products such as grains, vegetables, fruits, dairy, fish, and meats. As such, estimates are not considered as total dietary exposure to the pesticides, nor did we consider drinking water, residential, or occupational exposures.

4. Conclusions

A current trend in assessment of human health is the use of the exposome, which involves assessment of all factors that may affect human health. One significant factor observed in negative health outcomes is our dietary intake in respect to anthropogenic chemicals such as pesticides. The present study represents the first of its kind to assess the hazard to humans posed by the consumption of honey contaminated with residues of OP and NI insecticides. These findings can be used towards a more comprehensive understanding of human health from dietary intake. In this study, the HI for the current use of pesticides was not exceeded in adults; the current study did not investigate groups that might be more at risk, such as pregnant women and young children whose ADI values will differ. For example, it is known that compounds that affect neurodevelopment will have more significant impact on the developing brain of a young child than in adults. However, due to scarcity of data regarding the ADI values of both OPs and NIs for children and pregnant women, calculation of their HIs is not reported in the current study. To understand fully the exposome, each facet of exposure must be known and this study provides for Egyptian honey such findings. Further, work to develop dietary exposure models and ADI values for at-risk groups are needed to fully understand the findings of this study in the broader context of human health risks.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Human dietary intake and hazard characterization for residues of neonicotinoides and organophosphorus pesticides in Egyptian honey

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Table S1. Concentrations of untransformed, active ingredient, neonicotinoids (NIs) in honey reported previously in comparison to the present study.

NIs	Mean Concentration (μg kg^{-1}, wm) in honey	References
Acetamiprid	ND	Mullin et al. (2010)
	ND	Codling et al. (2016)
	5.7- 4	(Spring- Summer) present study
Clothanidin	ND	Codling et al. (2016)
	0.9[a]	Cutler and Scott-Dupree (2007)
	ND	present study
Imidacloprid	2[a]	Kamel (2010)
	32.1	Codling et al. (2016)
	(0.5-1.1)	(Spring- Summer) present study
Thicloprid	33[a]	Frazier et al. (2008)
	3.6	Codling et al. 2016)
	ND	present study
Thiamethoxam	ND	Mullin et al. (2010)
	75	Codling et al. (2016)
	18.8-ND	(Spring- Summer) present study
Imidaclopid metabolites		
Olefin	46.4	Codling et al. (2016)
	0.9-ND	(Spring- Summer) present study
5-hydroxy	71.4	Codling et al. (2016)
	0.7-0.4	(Spring- Summer) present study
urea	7.1	Codling et al. (2016)
	ND	present study
desnitro olefin	ND-0.5	(Spring- Summer) present study
desnitro HCL	3.6	Codling et al. (2016)
	ND	present study
6-chlornicotinic acid	ND	Codling et al. (2016)
	0.6-ND	(Spring- Summer) present study
Dinotefuran	0.6-0.6	(Spring- Summer) present study
Di-Urea	0.4-0.45	(Spring- Summer) present study
Di-DN-Phos	0.9-0.9	(Spring- Summer) present study

[a] These are the upper concentrations.

Table S 2. Concentrations of organophosphorus pesticides (OPs) in honey reported previously in comparison to the present study.

Pesticides	Concentration of OPs in Honey (µg kg^{-1} , wm)	References
Diazinon	ND	Rissato et al. (2007)
	35	Johnson et al. (2010)
	14	Wiest et al. (2011)
	67.3	Eissa et al. (2014)
	0.3	Al Naggar et al. (2015b)
	(ND-0.3)	(Spring-Summer) (Present study)
Malathion	0.24	Rissato et al. (2007)
	243	Johnson et al. (2010)
	ND	Chuazat et al. (2011)
	14	Eissa et al. (2014)
	ND	(present study)
Dimethoate	9	Johnson et al. (2010)
	ND	Wiest et al. (2011)
	1.5	Al Naggar et al. (2015b)
	(3.36-ND)	(Spring-Summer) (Present study)
Coumaphos	2020	Mullin et al. (2010)
	29	Wiest et al. (2011)
	934	Chuazat et al. (2011)
	60	Pareja et al. (2011)
	ND	(present study)
Phorate	0.9	Johnson et al. (2010)
	ND	(present study)
Dichlorvos	ND	Rissato et al. (2007)
	8	Johnson et al. (2010)
	ND	Wiest et al. (2011)
	(1.9-ND)	(Spring-Summer)
Profenofos	ND	Rissato et al. (2007)
	166	Eissa et al. (2014)
	(ND-0.23)	(Spring-Summer)
Chlorpyrifos	0.01	Rissato et al. (2007)
	15	Johnson et al. (2010)
	80	Pareja et al. (2011)
	ND	Wiest et al.(2011)
	10	Eissa et al. (2014)
	(ND-3.3	(Spring-Summer)
Ch. Methyl	0.2	Johnson et al. (2010)
	ND	(present study)
Fenthion	ND	(Rissato et al. (2007)
	ND	(present study)