Vol. 16(7), pp. 275-285, July 2022
DOI: 10.5897/AJEST2022.3111
Article Number: 861413669423
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

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African Journal of Environmental Science and Technology

Full Length Research Paper

Environmental implications of pesticide use and application practice on beekeeping: Evidence from Gudeya Bila Woreda of East Wollega Zone in Oromia Regional State, Ethiopia

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Received 23 March, 2022; Accepted 14 June, 2022

The existence of honeybees within the ecosystem is crucial in worldwide agricultural production. Exposure of these insects to residues of many contaminants or poisonous materials like plant protection products (pesticides) causes death or reduces their activity. This study aims to assess the status of pesticide application, its use and possible impacts on bee communities in East Wollega Zone of Oromia Regional State, Ethiopia. A simple structure questionnaire and key informant interviews were conducted to generate qualitative and quantitative data. A pre-developed model called Pesticide Risks In the Tropics for Man, Environment and Trade (PRIMET) was used to determine risks to bees when beehives are in the in-crop and off-crop situations. Results of the analysis indicated that pesticides, particularly carbaryl, malathion, diazinon, fipronil, chlorpyrifos and profonefos are highly risky to bees when used in the in-crop situations (ETRs 3254-120000); while they are possibly risky when used in the off-crop scenario (ETRs 91-335). The result also revealed that farmers are not aware of how to protect bees while applying pesticides. Developing proper risk communication strategies (selecting time of application when honey bees are inactive, covering hives during application, notifying beekeepers before pesticide application) and awareness creation are recommended to avert damage.

Key words: Pesticides, risk assessment, PRIMET, bees, Ethiopia.

INTRODUCTION

Pesticide use definitely helps to improve crop productivity and quality if the right type is used at the right time with the correct dose (Khan et al., 2010). Farmers in Africa have long adapted to climatic and other risks by diversifying their farming activities (Ebi et al., 2011).

The uncontrolled use of pesticides has become one in

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every of the foremost alarming challenges when pursuing sustainable development. Although pesticides are directly applied in soils and plants, just few amount of pesticide sprayed is delivered to the intended target. An accidental release of pesticides due to leaking pipes, spills, waste dumps, underground storage tanks, and groundwater may lead to their persistence within the environment for a protracted time (due to long half-lives). For proper management of pesticides, one should accurately assess the status of their contamination in soil, water, and air (Knapton et al., 2006). Multiclass environmental endocrine disruptor compounds (EDCs), like organochlorine pesticides (OCPs), phthalate esters (PAEs), and polybrominated diphenyl ethers (PBDEs) may coexist in soils and accumulate in crops and human bodies through food chains, posing risks to human health and thus the ecosystem (Net et al., 2015).

Insecticides may kill not only the target species but also other invertebrates on which birds rely on for their food. Additionally, herbicides are designed to manage weed species which also kill many other plant species in fields, including the essentially beneficial species, which give both shelter and food for the members of wildlife. Amphibians are now considered as the foremost threatened and rapidly decreasing species on earth (Brühl et al., 2013).

In Ethiopia, due to the intensification of agricultural activities, inputs like pesticides and fertilizers use are increasing at an alarming rate (Mengistie 2016; Amera and Abate, 2008). The influence of pesticides on the environment consists of the harmful and toxic effects of pesticides to non-target plants and animals. Residues of pesticides may contaminate all the environmental compartments including soil, air and surface or ground water (Gupta et al., 2003; Konstantinou et al., 2006). Thus, the global use of pesticides may have contributed to environmental degradation and depletion of biodiversity negatively impacting the wellbeing of the global flora and fauna (Al-Shaalan et al., 2019; Naik and Wanganeo, 2014; Zhang et al., 2011; Ali and Jain, 1998).

Among the widely impacted non-target animals by pesticide application, bees are the main concern. There are 20,000 species of bees on earth, pollinating 90% of the 107 main crops in the world. Bee numbers have declined dramatically in recent years (Sheridan, 2017). It is estimated that 75% of the world's honeybees have been found to have traces of bee-damaging insecticides, particularly to neonicotinoids, such as *acetamiprid, clothianidin, imidacloprid, thiacloprid*, and *thiamethoxam* (Sheridan, 2017).

Ethiopia is known for its immense variety of agro-climate and biodiversity conditions that favored the life of diversified honeybee flora and large numbers of colonies of honeybees (Nuru, 2007). Thus, beekeeping may be a long-standing tradition in Ethiopia's rural communities (Yirga and Teferi, 2010). Being an export commodity, it has significant contribution for household wealth and poverty reduction as well as the economy of the country. Central Statistical Agency (2011) report shows that Ethiopia is among the four largest beeswax producing countries. For example, the honey export in 2010/2011 production year was estimated to be 620,101 kg from which the country on average generated 420 million Ethiopian Birr on annual basis from the sale of honey. It is estimated that the overall honeybee colonies population in the country is estimated to be10 million, of which 7.5 million are tamed, while the remaining are from wild colonies found in forests (Kenesa, 2018).

However, with the introduction of pesticides in Ethiopia, the poisoning effect of the agro-chemical on honeybees has been increasing over time, where some beekeepers have even lost all their colonies (Kerealem et al., 2009). In connection to this, Melaku et al. (2008) attributed colonial death and absconding with insecticides and herbicides. Chauzat et al. (2006) also showed that improper use of insecticides results in the demise of honeybee. Study conducted by Fikadu (2020) attributed the declining of honeybees’ pollinators with unwise use and practices of pesticides to lack of knowledge of pest, and predators’ management causes the misuse of pesticide.

Pesticides are harmful compounds with a common mode of action, which means that they are primarily engineered to regulate a target group of species by interacting with certain biochemical pathways. Pesticide effect on species can be categorized based on the lethal dose (LD50) values which determine the dose that kills 50% of the exposed animal after a given time of exposure. The sub-lethal effect induced by the chemical to the exposed organisms can also cause other irregularities in their behavioural and physiological activities including stress paralysis or irregular habits without killing them like exposure to neurotoxic insecticides. This effect works for bees as it does for any other organism (Chakrabarti et al., 2015; Zaluski et al., 2015; De Grandi-Hoffman et al., 2013).

Various tools are used to determine risks of agrochemicals to non-target organisms. Among them is an already developed pesticide risk assessment tool for an Ethiopian situation known as Pesticide Risks In the Tropics for Man, Environment and Trade (PRIMET). This tool was developed in collaboration with Wageningen University of the Netherlands, considering specific scenarios in Ethiopia and can be taken as a pioneer in Africa. It can estimate risks of pesticides currently registered or to be registered in Ethiopia for non-target organisms including bees. The software calculates the Exposure Toxicity Ratio (ETR) for each chemical pesticide for both off-crop and in-crop scenarios (Wipfler et al., 2014).

The impact of harmful pesticides on bees and assessment of risks need to be studied in Ethiopia. Even

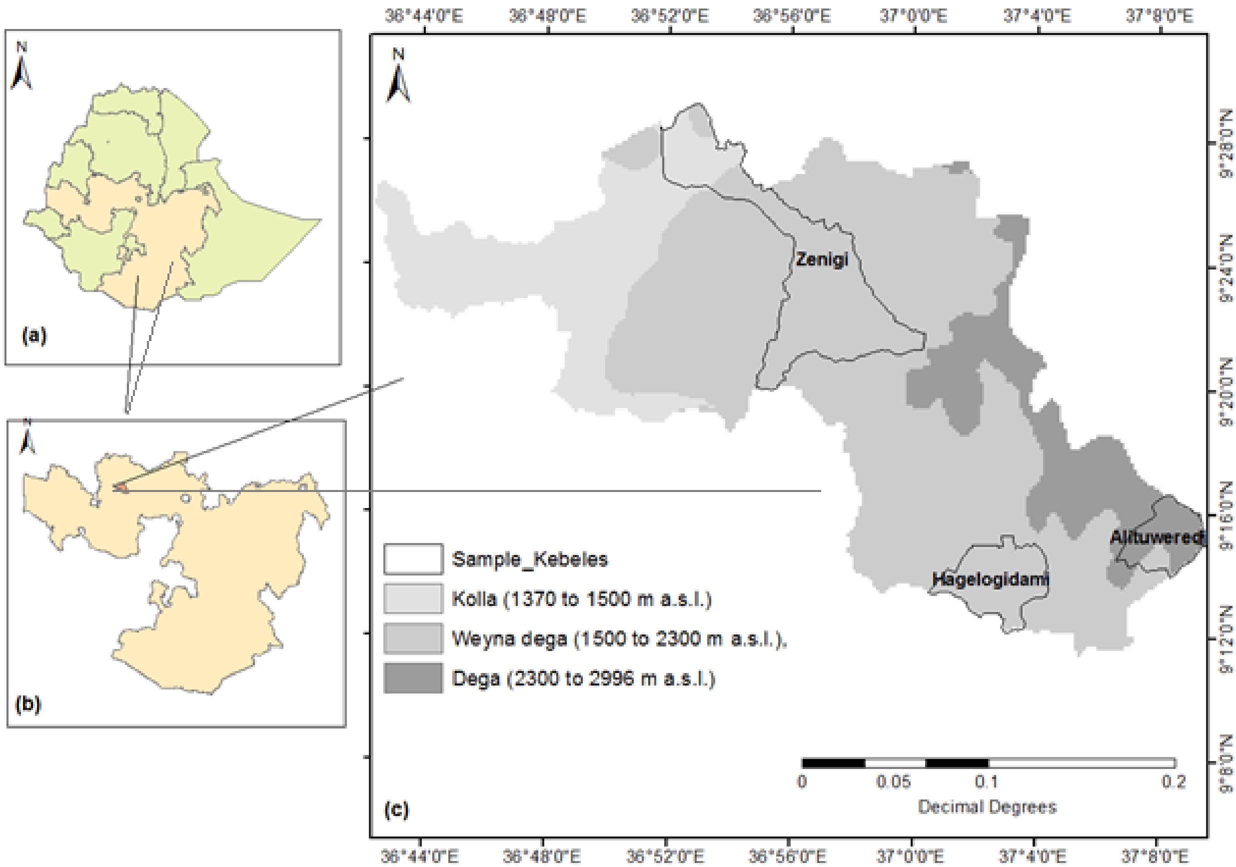

Figure 1. Location and agro-ecological map of Gudeya Bila: (a) Oromia region in Ethiopia, (b) Gudeya Bila wereda in Oromia region and (c) agro-ecology of Gudeya Bila wereda
Source: Authors

though there are some studies that tried to show the impact of pesticides on bees in Ethiopia, they cannot objectively quantify the level of risks to bees via application of pesticides for the control of other pest incidences. For example, Fikadu (2020) studies pesticides use, practice and its effect on Ethiopian honeybee; nevertheless, the study was based on secondary data and thus the finding was more general. The objective of this study is to assess pesticide application, use and its implications on honey bees.

MATERIALS AND METHODS

The study was conducted in Gudeya Bila wereda/district, which is among the weredas in the East Wollega zone in Oromiya Region, Ethiopia (Figure 1). The wereda has 13 rural *kebeles (*lowest administration structure below district/wereda in Ethiopia) and 2 local councils (Bila and Jare). Geographically, the wereda is located between 9°11'00'' - 9°30'00'' North latitude and 36°42'00'' to 37°10'30'' East longitude (Figure 1). The elevation of the wereda ranges from 1370 to 2996 m a.s.l. Thus, according to local classification (Hurni, 1998), the wereda has three agro-ecological zones, that is, *dega* (cool, humid highlands, 2300 to 2996 m a.s.l.), *weyna dega* (mild, sub-humid highlands, 1500 to 2300 m a.s.l.), and *kolla* (warm, semi-arid, lowlands, 1370 to 1500 m a.s.l.) that cover about 13.5, 67 and 19.5%, respectively (Figure 1). Gudeya Bila wereda has two rainy seasons, where the main rainy season occurs between June and September while the second occurs between October and May, with an average annual rainfall of 1100 to 1950 mm. The temperature of the district varies between 11 and 23°C, respectively. Major crops grown in the wereda include maize (*Zea mays*), teff (*Eragrostis tef*), beans (*Phaseolus vulgaris*) and some kinds of fruit and vegetables.

The study followed a quantitative and qualitative approach. Questionnaire focusing on socio-demographic, beekeeping status, pesticide use and application practice, implications of pesticides to beekeeping and other various data collection methods such as household surveys, focus group discussions (FGDs), and key informants interviews (KIIs) and field observations were used to observe seasons of pesticide application, topographies of study area, and beekeeping status, circumstance or community like actions, opinions, skills, values, and expertise. The use data of most frequently applied pesticide by farmers through the survey were analysed for risks to bees using software PRIMET (Pesticide Risks In the Tropics for Man, Environment and Trade). It was done to have a more refined estimation of risks pose d to bees from the application of these pesticides based on the conceptual

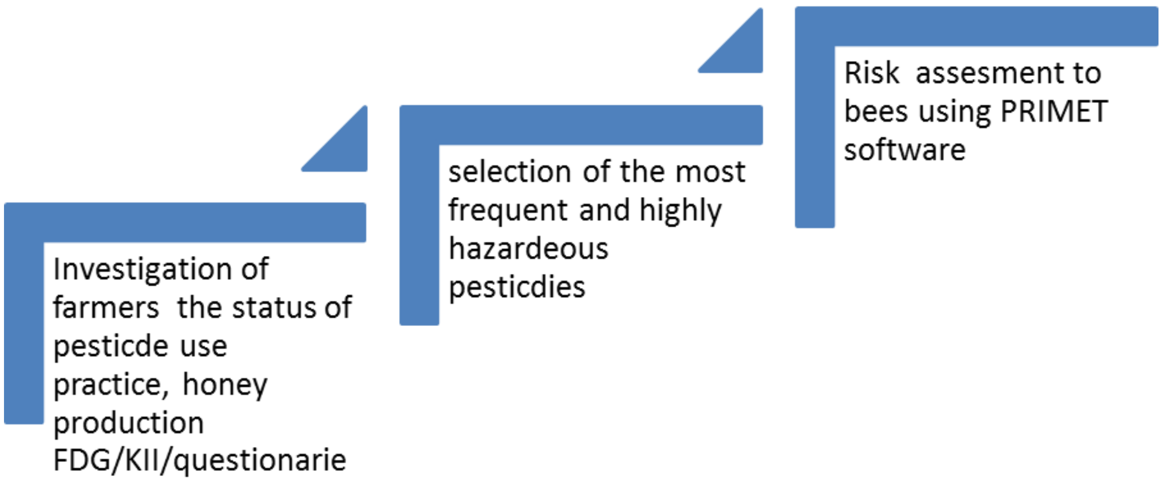

Figure 2. A conceptual framework of the study.
Source: Authors

framework indicated in Figure 2.

Target population, sampling design and sample size

The sampling frame for this particular study was rural farmers found in Gudeya Bila *wereda*. Multi- stage sampling technique was used to select the representative samples. The study area was selected purposefully and carefully so as to represent the *wereda* in terms of economic, socio-cultural, and physical factors like agro-ecology, and familiarity of the researcher to the study area. Therefore, at the first stage, the rural *kebeles* of the wereda were stratified by agro-ecology as *dega*, *weyna dega* and *kolla* and then the sample rural *kebeles* were selected randomly to represent the agro-ecological zones (Figure 1) by lottery method. Households or respondents were selected randomly from the sample *kebeles* agriculture office lists of farmers engaged in beekeeping. In addition to this, pesticide retailers were included in the sampling for FGD and KII to get information on pesticides selection and use status. Hence, it was appropriate to have a deep understanding of the pesticides use practice, application practice and beekeeping status of the study area.

The sample size of the study was determined or calculated using Taro Yamane sample size determination formulas with household number of sample *kebeles*, as given in Equation 1.

$$n = \frac{N}{1+N(e)2} \quad (1)$$

$$n = \frac{1439}{1+1439(0.005)2} = 312$$

n = 312 sample sizes used for this study

where n-sample size, N-is number of households of sample *kebeles*, and e-the precision or sampling error which is 0.005.

As the proportion of respondents/households that is food secure is not known, 0.5 was used as p-value to obtain the sample size (312).

Out of the total respondents involved in the questionnaire survey: respondents were pesticide traders from whom data on pesticides were obtained and 304 respondents were farmer households who were interviewed in relation to pesticide use.

Data analysis

Qualitative and quantitative techniques were used to analyse the study data. Information obtained from key informant interview, focus group discussion and personal observation was analysed qualitatively. The SPSS software version 20 was used to analyse the quantitative data obtained from household survey.

For the risk assessment of in crop and off crop, an oral LD50 and a contact LD50 were available and taken from Pesticide Properties Data Base (PPBD) from which the lowest value was determined. Moreover, pesticide application rate was obtained from Ministry of Agriculture (Ethiopian) Plant Health Regulatory Directorate database (Equations 2 and 3) (Wipfler et al., 2014). The European Union (EU) trigger value of 50 was used, which was established based on empirical research. An assessment of observed bee killings (colony sound effects) for various pesticides and different application rates showed that for sprays a factor of the Exposure Toxicity Ratio (ETR) below 50 is always safe as no field incidents at ETR < 50. While a trigger value of above 400 for the ETR is considered highly risky for bees. This value is taken as the upper limit of the risk classification as shown for in-crop and off-crop situations of beehives from the pesticide application spots (Wipfler et al., 2014).

$$ETR_{in\text{-}crop} = \text{dose rate} / LD50 \quad (2)$$

$$ETR_{off\text{-}crop} = (\text{dose rate} \times \text{drift factor}) / LD50 \quad (3)$$

where Low risk: if ETR in-/off-crop situation is < 50, possible risk: if ETR in-/off-crop situation is between 50 and 400, gigh risk: if ETR in-/off-crop situation > 400.

Thus, risks of some frequently used pesticides were assessed using PRIMET software version 1.1.1.1 (Wipfler et al., 2014) and the household survey data as an input.

Depending on the ETR values, decision was made regarding the pesticide application using PRIMET software to determine the risk

Table 1. Type of beehives and income farmers obtained per production season.

Type of beehive survey households owning	Households reported		Households income from honey production		
	Frequency	%	Income (US dollars/season)	Households reported	
				Frequency	%
Traditional only	207	66.4	50 to 75	42	13.5
Transition only	71	22.7	76 to 100	16	5.1
Tradition, modern and transition	26	8.33	101 to 125	32	10.3
System Missing	8	2.6	>126	214	68.5
Total	312	100	System Missing	8	2.6
			Total	312	100.

Source: Author

level of a given chemical (pesticide) to honeybee. Hence, quantitative household survey data were analysed in Statistical Package for Social Sciences (SPSS) and the outputs of SPSS such as frequency of application, time interval for application, and methods of applications were subjected to PRIMET test. Among most frequently used pesticides, insecticides and herbicides were widely used. Insecticides are the more damaging types of pesticides to honeybees (Leska et al., 2021). Therefore, six types of insecticides which are most frequently used in the study area and anywhere in Ethiopia were selected and their risks were analyzed using PRIMET Version 1.1.1. Following Wipfler et al. (2014) method, LD_{50} name of pesticide chemical, name of the target crop, number of application, application methods, time interval of the application, scenarios of exposure (in-crop or off-crop), category of risk (as chronic or acute risk), pesticide drift factors, rate (that is, concentration of active ingredient per hectare) and target organism were entered into PRIMET software for risk assessment.

RESULTS AND DISCUSSION

Beekeeping status and income of survey households from beekeeping

The study area communities have been using different type of beehives, where most of the survey households (66.4%) have traditional hives (Table 1). As per FGD and KII, there were two forms of traditional beekeeping in the study area, which are forest and backyard based beekeeping. The communities have been practicing forest beekeeping by hanging traditional beehives on trees. This production method is marked by terribly low honey production. Commonly, the average amount of crude honey obtained from conventional (traditional) beehives is about 8 to 15kg/beehive/year (Beyene and David, 2007). Traditional husbandry is practiced with many fixed comb beehives, particularly in remote areas. The traditional beekeeping is carried out with minimum expense and labor input, thus farmers consider it as beneficial particularly for individuals leading a marginal life (Tessega, 2009). The second most widely used hives in the study area is transitional hive as reported by 22.8% households. A transitional framework type beehive is an intermediate form, which is characterized between conventional and modern beehive type. Kenyan Top-Bar (KTB) is a well- known and commonly used hive in the study area. Nearly 8.3% have three types of hives, while the rest 2.6% respondents did not engage in the beekeeping; they were pesticide retailers.

Honey bee could be produced two times in a year. As shown in Table 1, the survey revealed that the households obtain some income from beekeeping by selling the produced honey. Considerably larger proportion (68.6%) of respondents reported that they earn over 5,000 birr (125 USD) in one production season, while the remaining earn below this amount; that is, 13.5, 5.1 and 10.3% respondents reported that they earn 50 to 75 USD, 3001-4000 birr (76 to 100 USD) and 4000 – 5000 birr (101 to 125 USD) in each production season, respectively. This is in line with Ajebush (2018)'s finding who studied economic and ecological importance of beekeeping in Ethiopia.

Pesticides use and application practices

The two important activities for smallholder farmers in relation to pesticides are pesticide use (handling) and procurement (buying and selecting) practices (Mengistie et al., 2015). Concerning pesticides use all survey respondents (100%) reported that they use chemical pesticides in the regular agricultural activities purchasing from local dealers. Among the respondents very few (10.6%) know legality status of the suppliers and purchase from the legal source; while the remaining (89.4%) do not know even what illegal pesticide suppliers means (Table 2). Those who reported that they knew the illegal pesticides they have wrong perception on how to identify the illegal pesticides. As they do not know how to identify illegal pesticides by identifying registration number, lists of registered and label pesticides have to be written in English and their local language (Amharic).

The other important issue in pesticide management and use is reading application instructions written on the

Table 2. Survey household perception on inclusion of pesticide use in agricultural extension.

Questions	Responses	Frequency	Percent
Status of respondents on buying pesticides with and without labels	With label	106	34.0
	Without label	198	63.5
	Missing (system)	8	2.5
	Total	312	100
Do you read the instruction/label on the container during purchasing?	Yes	75	24
	No	237	76
	Total	312	100
Where do you mix pesticides?	Near water sources (river, canal, other sources)	226	72.3
	In the field	86	27.7
	Total	312	100
Fate of pesticide containers	Reuse	257	82.3
	Dispose in the field	55	17.7
	Total	312	100
What material do you use to mix the pesticide?	Knapsack	67	10.6
	open headed plastic containers	245	89.4
	Total	312	100
Are pesticide uses included in extension service package?	Yes	37	11.9
	No	275	88.1
	Total	312	100.0
Do you have sufficient and appropriate information on how to use pesticides	Yes	50	16
	No	262	84
	Total	312	100
Have you seen punished pesticide dealer for selling illegal pesticides by inspectors?	Yes	0	0
	No	8	2.6
	Don't know	304	97.4
	Total	312	100
Do pesticide inspectors visit pesticide shops and you in the field while applying pesticides?	Yes	0	0
	No	312	100
	Total	312	100
Do you consider appropriate timing to apply pesticides in relation to beekeeping?	Yes	130	41.7
	No	174	55.7
	Missing (System)	8	2.6
	Total	312	100

Source: Author

pesticide containers. In this regard most of the respondents (76%) indicated that they never read the label during purchasing and do not strictly follow the instruction on the package while applying the pesticides; about 24% respondents read the label while purchasing. In addition, about 63.5% of the respondents purchase unlabeled pesticides. This means majority of the study area smallholder farmers purchase pesticides without any instruction or information. In converse, the Ethiopian Government Pesticide Registration and Control Proclamation Number 674/2010 part four (b) emphasized that pesticide importers or dealers have to prominently display a legible label approved by concerned body both in Amharic and English languages that cannot easily be detached (Negarit, 2010). Therefore, this indicates the legally registered pesticides always have labels in both Amharic and English and are approved by Ministry of Agriculture (regulatory body). This survey result on the reading and use of pesticide labels is much lower than the study conducted by Gesesew et al. (2016) in Southwest Ethiopia, which reported that 63.2% of smallholder farmers usually follow the instructions/labels written on pesticide containers.

The FGD participants indicated that some retailers sell pesticides with material having safety sheet but most retailers (62.5%) sell pesticides by pouring from the original containers into other container based on the customer request. This is illegal action according to pesticide registration and control proclamation number 674/2010.

The Agricultural Office has given little emphasis in incorporating pesticide use in agricultural extension services. As shown in Table 2, only 11.9% of the respondents know that pesticides use has been included in agricultural extension package. Therefore, very few (16%) survey respondents had sufficient and appropriate information on how to use pesticides.

Based on the FGD and KII, there are eight pesticide retailers in the study area but only five of them had certificate of competency and other legal requirements. All pesticide dealers replied that they began pesticide market in the last two years. All of them have agricultural education background, but all do not have information and knowledge about pesticide registration and they do not have list of registered pesticides in Ethiopia.

The result of household survey and qualitative research also revealed that there were no pesticide inspectors from Agricultural Office to control illegal pesticides and mode of their application. In relation to this, all respondents indicated that they never seen any inspectors and no pesticide dealer has been punished for selling illegal pesticides. Moreover, 56.3% the respondents reported that they apply agro-chemicals (pesticide, insecticide or herbicide) whenever their farm gets infested with weed, insect or disease without due consideration to the natural honeybee production calendar. This means they spray the chemicals even at blooming or flowering stage of the crop although this stage is very acute time for bee to make honey. The other pertinent activity that might affect beekeeping and other environmental factor is the pace and materials to prepare agro-chemical for application. In this regard, most of the farmers (72.7%) mix pesticides near water sources (mainly rivers, canal or other community water source) which are used by bees and local residents for drinking and cooking; while the rest 27.3% mix pesticides in the field where they spray the chemicals by fetching water used for missing the pesticides. This show there might be contamination of water from the containers used to mix pesticides and during the mixing process. This finding is in line with the research conducted by Belay and Alemayehu (2016) in the Central Rift Valley of Ethiopia on agro-chemical management and application practice. Majority (89.4%) of the survey households replied that they mix the pesticide in a knapsack and the rest mix in locally available open headed plastic containers. The other environmental and human health concern is the feat of the container, where 82.3% of the respondents indicated that they reuse the pesticide and other agro-chemical containers without enough rinsing methods. The rest respondents dispose the container in the field without considering where and how to dispose it. The practice of the community in managing pesticide container in the environment including beekeeping is worst compared to Belay and Alemayehu (2016)'s finding, who reported about 48% of the farmers reuse the container without enough rinsing methods. This finding supports the idea forwarded by Fikadu (2020) in the review on pesticide use practice and its effects on honey bee in Ethiopia. The author indicated that majority of Ethiopian beekeepers do not use any control measures for poisoning honey bees with chemicals.

Implications of pesticide use on beekeeping

The household survey and qualitative research (FGD and KIIs) revealed that the use of agro-chemicals including pesticide creates problem in beekeeping. Accordingly, 31.7% of the household survey respondents said they have seen bees die during or after application of pesticides and the bees also show different behaviour (Table 3). For example, the survey respondents (52.9 and 15.4%) indicated that the bees show aggressiveness symptoms and anomalous behaviour besides the observed deaths after and/or during the chemicals spray on crops. The survey result also showed that beekeepers and farmers think that bee colonies have been declining overtime due to their exposure after or during pesticides application. This is evidenced in the observed deaths, aggressiveness, and anomalous behavior of worker bees.

Different findings have also documented that the use of different pesticides could lead to a significant reduction of foraging activity of honeybees (Marinelli et al., 2004; Henry et al., 2012). In this regard, Henry et al. (2012) underlined that droplets and dust from the agro-chemical applications will fall directly on the bees traveling through or around the treated fields and wind will bring the small droplets and soil particles several meters away from the

Table 3. Implication of pesticide use on beekeeping.

Questions	Responses	Frequency	Percent
Which of the following will be observed after pesticides application around hives?	Aggressiveness	165	52.9
	Deaths	99	31.7
	Anomalous behaviour of worker bees as rolling	48	15.4
	Total	312	100.0
Do you displace your hives when applying pesticides nearby hive?	No	304	97.4
	Missing (System)	8	2.6
	Total	312	100.0

Source: Author

flower. Similarly, Marinelli et al. (2004) verified that one insecticide droplet of agro-chemicals could destroy a bee since the spray solutions contain concentrated doses of pollutant compounds, which could be the most commoncause behind the bee outbreaks.

The current study showed that almost all farmers (97.4%) did not move their hives to safe place during pesticide application (Table 3). This implies that honeybees are exposed to the damage of agro-chemicals related with application methods and safety measures. This result is supported by Fikadu (2020)'s finding who indicated that majority of Ethiopian beekeepers do not use any control measures for poisoning honey bees with chemical. Likewise, Sánchez-Bayo and Goka (2016) indicated that most of the time, bees are exposed to pollutants by the ingestion of pollen and nectar residues from infected seeds, whether from crops or from weeds across the fields. It is important to note that bees eat chemicals wherever they go and search for the most fitting flowers that provide ample pollen and nectar. Such crops are also more attractive than others; for example, canola (rape seed oil) yellow flowers, sunflowers, and many of the weeds that grow in and around the crops are more attractive to bees than potato plant flowers (Dötterl and Vereecken, 2010). In converse, farmers apply chemicals to these crops to control pest, insect, disease and weed. The forager bees take pesticide residues in pollen and nectar to their colonies and live inside the beebread and honey for quite some time (Orantes-Bermejo et al., 2010). These residues are then fed to the larvae and the queen as well, that are influenced by the forager bees in comparable ways. Bees also consume water in addition to sugar, to control their temperature (Schmaranzer, 2000). Pesticide compounds in the soil gradually get into the water and emerge in and above the lakes, creeks and rivers in rural areas; they are polluted with a combination of agrochemicals that can eventually be consumed by bees (Belden et al., 2007; Sánchez-Bayo and Goka, 2016; Zhu et al., 2014). Additionally, water pollution from spray applications, particularly from insecticides can impact honey bees. This is very critical for bumblebees and wild bees that prefer to drink from puddles, drainage ditches, rivers and lakes, and they are often eaten by forager bees if these waters are polluted with pesticide residues (Woodrow et al., 1989). Thus, these exposures of honey bees to pesticides cause the collapse of bee colonies.

Risk assessment results of selected pesticides using PRIMET software

According to FGDs and KII, carbaryl, chlorpyrifos, diazinon, fipronil, malathion and profenofos are among the most frequently used insecticide in the study area. Other similar works also confirmed the frequent use of these pesticides in Ethiopia (Teklu et al., 2021). Of these investigated pesticides that are risky to bees, carbaryl and chlorpyrifos are mostly used for the treatment of maize stalk borer. The risk assessment of carbaryl and chlorpyrifos using PRIMET software in this study area revealed 9107 and 3254 Exposure Toxicity Ratio (ETR) value respectively for carbaryl and chlorpyrifos in-crop scenario (Table 4). This showed that both insecticides are highly risky to honey bees. Similarly, assessment in United Kingdom by Mineau et al. (2008) revealed 50% probability of bee mortality at a trigger value of 400 for the ETR for numerous pesticides at different application rates.

Likewise, for off-crop scenario, the ETR value was 255 for carbaryl and 91.12 for chlorpyrifos sprayed on maize. This implies that there is possible risk if expected from both insecticides (Table 4). Pesticide exposure can have a sizable impact on the nutritional composition of royal jelly produced by honey bees and as a result can influence queen development. Oral exposure to pesticides in adult workers has been shown to influence nurse bee glandular physiology and could therefore impact royal jelly production (Böhme et al., 2018). As shown in Tables 2 and 3, the study area farmers do not

Table 4. Summary of risk assessment to bees in an in crop and off crop situation.

Pesticide	Crop	Application rate (kg/ha)	LD50 Oral/contact (µg/bee)	PNEC (g/ha)	PEC in crop	PEC of crop	In-crop ETR=PEC/ PNEC	off-crop ETR=PEC/PNEC
Carbaryl	Maize	1.275	0.14	0.14	1275	35.7	9107	255
Chlorpyrifos	Maize	0.192	0.059	0.059	192	5.376	3254	91.12
Diazinon	Maize	0.6	0.09	0.09	600	16.8	6667	186.7
Fipronil	Cabbage	0.05	0.00417	0.00417	50	1.4	120000	335.7
Malathion	Potato	0.75	0.16	0.16	750	21	4688	131.3
Profonefos	Faba bean	0.72	0.095	0.095	720	20.16	7579	212.2

ETR < 50 = low risk, 50<ETR < 400 , medium Risk, ETR >400 = high risk.
Source: Author

displace (move) beehives and select appropriate time during pesticide applicant. These practices would expose honey bees to pesticide poisoning. Both pesticides are used foliar in controlling crop pest and have a relatively high toxicity to bees compared to other pesticides (Johnson et al. 2010). Worker honey bees can forage in range up to 12 km around hive and, therefore, are frequently exposed to a dispersal of pesticide residues present in water, nectar and pollen (Mullin et al., 2010).

Diazinon is an insecticide registered to treat maize and sorghum stalk borers and armyworm in Ethiopia. In the study area, it was mainly used to treat maize and sorghum stalk borer. The ETR value of diazinon for in-crop scenario was 6667 and this value shows that diazinon is highly risky to honey bees (Table 4). For off-crop scenario the value of ETR was 186.7 and this value indicated diazinon can be classified in possible risk category. As a matter of fact, diazinon was known to be highly toxic to terrestrial invertebrates, bees and other beneficial insects following acute contact exposure, where acute LD50 for bees was 0.22 µg/one bee as per University of Hertfordshire (2013). In general, the toxicity of insecticides to honey bees increased with increase in the exposure time.

Fipronil is among the insecticides used mainly to treat termites in rice and aphids on cabbage. Fipronil ETR is 12×E4 or 120,000 and this value indicates fipronil was highly risky to honey bees for in-crop scenario (Table 4). For off-crop scenario, the ETR value of fipronil is 335.5 which can be classified under possible risk for honey bee. According to Narahashi et al. (2010), fipronil has an antagonistic action on gamma amino butanoic acid (GABA) neurotransmitters and glutamate-activated chloride channels (GluCls). Therefore, this pesticide/ insecticide can cause interactive changes in bees that embrace agitation, spasms, tremors, and paralysis (Zaluski et al., 2015). Fipronil is more noxious in sublethal doses, spoiling the motor activity of bees. Experimental exposure to dietary fipronil caused dose-dependent reductions in the longevity (days of exposure survived) of adult honey bees and fipronil can be lethal to honey bees in dietary exposures to the trace residues that typify those in nectar and pollen from treated crops (Mullin et al., 2010). Including fipronil, all insecticides assessed as indicator by PRIMET software were risky to honey bee. Therefore, protection measures must be taken to keep honey bees from pesticides poisoning during or after application.

Malathion is one of the most frequently used pesticides and is formulated locally by Adamitulu Pesticide processing company of Ethiopia in addition to imported ones. According to FGDs and KIIs, Malathion, in form of 50% EC formulation type, was mostly used in the study area to treat maize and sorghum stalk borer. For the in-crop scenario, the ETR value of malathion was 4688 which can be categorized as highly risky to honey bee (Table 4). Concerning off-crop scenario, the ETR of malathion was 131.3 that can be classified under possible risk to honey bee. As indicated earlier, bees eat chemicals including malathion wherever they go and search for the most fitting flowers that provide ample pollen and nectar.

Profenofos is another pesticide categorized under organophosphate chemical group. As shown in Table 4, the ETR values of profenofos for in-crop and off-crop scenario were 7579 and 212.2 respectively and thus categorized under high and possible risk to honey bees in the respective order. From the above PRIMET output as an ETR value showed that all (six) pesticides types namely: carbaryl, chlorpyrifos, diazinon, malathion, fipronil and profonefos are highly and possibly risky to honey bees for in-crop and off-crop scenarios considering each chemical (Table 4).

Other exposure routes of bees to pesticides come from water pollution due to drift from spray applications, particularly from insecticides (Woods et al., 2003). Honey bees, bumblebees and wild bees prefer to drink from puddles, drainage ditches, rivers and lakes, and they are often eaten by forager bees if the waters are polluted with pesticide residues. These facts indicate that when bees are exposed to pesticides their colonies are under risk of damage by pesticides poisoning. Wild bees (*Osmia bicornis*) exposed to thiamethoxam and clothianidin sub lethal levels had their reproductive performance reduced by 50% (Sandrock et al., 2014a), while honey bee queens experienced exceptionally high supersede rates (60%) (Sandrock et al., 2014b); colonies of bumble bees (*Bombus terrestris*) exposed to thiamethoxam sub lethal levels did not perform and produced 85% (Whitehorn et al., 2012). In forager bees, sub lethal doses of neonicotinoid insecticides often induce disorientation in the state of mind (Decourtye and Devillers, 2009). Recent global decline on pollinators including honey bees has been reported owing to several factors and unwise use and practices of pesticides honey bee productivity is affected by the indiscriminate use of agrochemicals, lack of knowledge, pest and predators (Fikadu, 2020).

CONCLUSION AND RECOMMENDATIONS

In this study, six pesticides were identified to be used frequently by farmers that are considered to be used frequently and at the same time risky to bees namely, carbaryl, chlorpyrifos, diazinon, malathion, fipronil and profonefos. Farmers' awareness in considering the presence of bees in pesticide applications and caring for bee hives that are present in/off-crop situation is found to be less. Moreover, concern to protect human and environmental health in general is minimal. The dominant type of bee hive present in the study area is traditional followed by transitional one. Thus it is common to see bee hives hanged in trees in the middle of farming areas. Thus, in-crop risks form application of pesticides is found to be high. This is evidenced by farmers reporting to observe serious physical, behavioural and physiological changes of the honey bees after application of pesticides in the area.

Risk assessment for the selected six pesticides revealed that all the six pesticides pose high risk to bees if applied in an in-crop situation. Possible risks are also indicated for bee hives available in an off-crop situation. Therefore, farmers and retailers need to be constantly informed about hazards of theses pesticides so that the current haphazard handling of pesticides is improved. Concerning application practice, there must be legal bindings or directives that obligate pesticide users and farmers to notify beekeepers of the neighbouring areas before application of these pesticides. Protection measures like removing or covering beehives during application, avoiding application of pesticide on time of flowering of either to main or fodder crops, application only after sunsets need to be adopted for honey bees risky pesticides. Pesticide registration and control department of Ministry of Agriculture should notify and regulate the registrants or agents of pesticides traders to indicate on the labels clearly the toxicity status of pesticides. Moreover, it is important to translate labels to languages appropriate to local situation.

CONFLICT OF INTERESTS

The authors declare no financial, commercial and legal conflict of interest directly or indirectly related to this published article.

ACKNOWLEDGEMENTS

The authors thank the Addis Ababa University and the Ministry of Agriculture of Ethiopia for the successful completion of this study.

REFERENCES

Ali I, Jain CK (1998). Groundwater Contamination and Health Hazards by Some of the Most Commonly Used Pesticides. Current Science 7(10):1011-14. Available at: http://www.jstor.org/stable/24101777

Al-Shaalan NH, Ali I, Zeid A, Alothman A, Al-Wahaibi LH, Alabdulmonem H (2019). High performance removal and simulation studies of diuron pesticide in water on MWCNTs. Journal of Molecular Liquids 289:111039.

Amera T, Abate A (2008). An assessment of pestucide use, practice and hazards in the Centeral Rift Valley. Report for the African Stockpiles Program: Institute for Sustainable Development, Ethiopia and PAN UK, London.

Belay FD, Alemayehu OW (2016). The Significance of Honey Production for Livelihood In Ethiopia. Journal of Environment and Earth Science 6(4):46-53.

Belden JB, Gilliom RJ, Martin JD, Lydy MJ (2007).Relative toxicity and occurrence patterns of pesticide mixtures in streams draining agricultural watersheds dominated by corn and soybean production. Integrated Environmental Assessment and Management: An International Journal 3(1):90-100.

Beyene T, Davide P (2007). Ensuring Small Scale Producers in Ethiopia to Achieve Sustainable and Fair Access to Honey Markets. Paper Prepared for International Development Enterprises (IDE)and Ethiopian Society for Appropriate Technology (ESAT).

Böhme F, Bischoff G, Zebitz CPW, Rosenkranz P, Wallner K (2018). From field to food - will pesticide-contaminated pollen diet lead to a contamination of royal jelly? Apidologie 49(1):112-119,

Brühl CA, Schmidt T, Pieper S, Alscher A (2013). Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline? Scientific Reports. 3(1):1-4.

Chakrabarti P, Rana S, Sarkar S, Smith B, Basu P (2015). Pesticide-induced oxidative stress in laboratory and field populations of native honey bees along intensive agricultural landscapes in two Eastern Indian states. Apidologie 46(1):107-129.

Chauzat MP, Faucon JP, Martel AC, Lachaize J, Cougoule N, Aubert M (2006). A survey of pesticide residues in pollen loads collected by honey bees in France. Journal of Economic Entomology 99(2):253-262.

Central Statistical Agency (CSA) (2011). Key Findings of the 2008/2009-2010/11 agricultural sample surveys for all sectors and seasons country summery. Central Statistics Authority. Addis Ababa, Ethiopia.

Decourtye A, Devillers (2009). Ecotoxicity of Neonicotinoid Insecticides to Bees. In: Thany SH, editor. Advances in Experimental Medicine and Biology - Insect Nicotinic Acetyl-choline Receptors. Austin, TX: Landes Bioscience pp. 85-95.

De Grandi-Hoffman G, Chen Y, Simonds R (2013). The effects of pesticides on queen rearing and virus titers in honey bees (*Apis* *mellifera* L.). Insects 4(1):71-89.

Dötterl S, Vereecken NJ (2010). The chemical ecology and evolution of bee–flower interactions: a review and perspectives. Canadian Journal of Zoology 88(7):668-697.

Ebi K, Padgham J, Doumbia M, Kergna A, Smith J, Butt T, McCarl B (2011). Smallholders adaptation to climate change in Mali. Climatic Change 108(3):423-436.

Fikadu Z (2020). Pesticides use, practice and its effect on honeybee in Ethiopia: a review. International Journal of Tropical Insect Sciences 40(3):473-481.

Gesesew HA, Woldemichael K, Massa D, Mwanri L (2016). Farmers Knowledge, Attitudes, Practices and Health Problems Associated with Pesticide Use in Rural Irrigation Villages, Southwest Ethiopia. PLOS ONE 11(9):e0162527.

Gupta VK, Ali I, Aboul-Enein HY (2003).Chirality: A challenge for the Environmental Scientists. Current Science 84(2):152-156.

Henry M, Béguin M, Requier F, Rollin O, Odoux JF, Aupinel P, aptel J, Tchamitchian S, Decourtye A (2012). Common Pesticide Decreases Foraging Success and Survival in Honey Bees. Science 336(6079):348-350.

Hurni H (1998). Agro-ecological belts of Ethiopia: explanatory notes on three maps at a scale of 1:1,000,000. Research report, Soil Conservation Research Program, Addis Ababa

Kenesa T (2018). Status of Beekeeping in Ethiopia- A Review. Dairy and Veterinary Sciences Journal 8(4):555743.

Kerealem E, Tilahun G, Preston TR (2009). Constraints and prospects for apiculture research and development in Amhara region, Ethiopia. Livestock Research and Rural Development 21(10):172.

Khan DA, Shabbir S, Majid M, Naqvi TA, Khan FA (2010). Risk assessment of pesticide exposure on health of Pakistani tobacco farmers. Journal of Exposure Science and Environmental Epidemiology 20(2):196-204.

Knapton D, Burnworth M, Rowan SJ, Weder C (2006). Fluorescent Organometallic Sensors for the Detection of Chemical Warfare Agent Mimics. Angewandte Chemie, 118(35):5957-5961.

Konstantinou JK, Hela DG, Albanis TA (2006). The status of pesticide pollution in surface waters (rivers and lakes) of Greece. Part I. Review on occurrence ad levels. Environmental Pollution 141(3):555-70.

Leska A, Nowak A, Nowak I, Górczyńska A (2021). Effects of insecticides and microbiological contaminants on Apis mellifera health. Molecules 26(16):5080.

Marinelli E, Pulcini P, Margio C, De Pace F, Allegrini F, Persona Oddo L (2004). Oxalic acid by Varrox to Varroa control in Central Italy. Apiacta 39:39-43.

Melaku G, Shifa B, Azage T, Negatu A, Lulseged B (2008). Approaches, methods and processes for innovative apiculture development: Experiences from Ada'a-Liben Woreda, Oromia Regional State, Ethiopia. IPMS of Ethiopian Farmers Project Working Paper 8.

Mengistie BT (2016). Environmental Governance of Pesticides in Ethiopian Vegetable and Cut Flower Production: PhD thesis, Wageningen University and Research.

Mengistie BT, Arthur Mol PJ, Peter O (2015). Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley. Environmental Development and Sustainability 19(1):301-324.

Mineau P, Harding KM, Whiteside M, Fletcher MR, Garthwaite D, Knopper LD (2008). Using reports of bee mortality in the field to calibrate laboratory-derived pesticide risk indices. Environmental Entomology 37(2):546-554.

Mullin CA, Frazier M, Frazier JL, Ashcraft S, Simonds R, Vanengelsdorp D, Pettis JS. (2010). High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health. PLoS One 5(3):e9754.

Naik AA, Wanganeo A (2014). Occurrence of some pesticides in Bhoj wetland Bhopal and their effect on phytoplankton community: An ecological perspective. Journal of Toxicology and Environmental Health Sciences 6(9):170-180.

Negarit G (2010). Pesticide registration and control proclamation. https://chilot.me/knowledge-base/proclamation-no-674-2010 pesticide-registration-control-proclamation/ Accessed on July 6, 2022.

Net S, Delmont A, Sempere R, Paluselli A, Ouddane B (2015) Reliable quantification of phthalates in environmental matrices (air, water, sludge, sediment and soil): A review. Science of the Total Environment 515:162-180.

Nuru A (2007). Atlas of pollen grains of major honeybee flora of Ethiopia. Holetta bee research center. Holeta, Ethiopia.

Sánchez-Bayo F, Goka K (2016). Impacts of pesticides on honeybees. Beekeeping and Bee Conservation - Advances in Research Chapter: 4Publisher: InTech Open Science Editors: Emerson D. Chambo. DOI: 10.5772/62487

Sandrock C, Tanadini LG, Pettis JS, Biesmeijer JC, Potts SG, Neumann P (2014a). Sub lethal neonicotinoid insecticide exposure reduces solitary bee reproductive success. Agricultural Forestry and Entomology 16(2):119-28.

Sandrock C, Tanadini M, Tanadini LG, Fauser-Misslin A, Potts SG, Neumann P (2014b). Impact of chronic neonicotinoid exposure on honeybee colony performance and queen supersedure. Public Library of Science One 9(8):e103592.

Sheridan K (2017). Bee-harming pesticides in 75 percent of honey worldwide: study. https://phys.org/news/2017-10-bee-harming-pesticides-percent-honeyworldwide.html. Accessed on October 8, 2017.

Teklu BM, Hileslassie A, Mekuria W (2021). Pesticides as water pollutants and level of risks to environment and people: an example from Central Rift Valley of Ethiopia. Environment, Development and Sustainability 24(4):5275-5294.

Tessega B (2009). Honeybee Production and Marketing Systems, Constraints and opportunities in Burie District of Amhara Region, Ethiopia. A Thesis Submitted to the Department of Animal Science and Technology, School of Graduate Studies Bahir dar University.

University of Hertfordshire (2013). The Pesticide Properties Data Base (PPDB) developed by the Agriculture & Environment Research Unit (AERU), University of Hertfordshire, UK. http://www.eu-footprint.org/ppdb.html.

Wipfler EL, Adriaanse PI, ter Horst MMS, Vlaming J, van den Brink PJ, Peeters FM, Deneer JW, Boesten JJTI, Groenwold JG (2014). PRIMET_ Registration_Ethiopia_1.1, technical description and manual. In: A Decision Support System for Assessing Pesticide Risk in the Tropics to Man, Environment and Trade, for Pesticide Registration in Ethiopia. Altera report 2573, Wageningen, The Netherlands.

Whitehorn PR, O'Connor S, Wackers FL, Goulson D (2012). Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science 336(6079):351-352.

Woodrow JE, Wong JM, Seiber JN (1989). Pesticide residues in spray aircraft tank rinses and aircraft exterior washes. Bulletin of Environmental Contamination and Toxicology 42(1):22-29.

Yirga G, Teferi M (2010). Participatory Technology and Constraints Assessment to Improve the Livelihood of Beekeepers in Tigray Region, northern Ethiopia, Momona Ethiopian Journal of Science 2(1):76-92.

Zaluski R, Kadri SM, Alonso DP, Martins Ribolla PE, de Oliveira Orsi R (2015). Fipronil promotes motor and behavioral changes in honey bees (*Apis mellifera*) and affects the development of colonies exposed to sub lethal doses. Environmental Toxicology and Chemistry 34(5):1062-1069.

Zhang WJ, Wopke van der Werf, Pang Y (2011). A simulation model for vegetable-insect pest-insect nucleopolyhedrovirus epidemic system. Journal of Environmental Entomology 33(3):283-301.

Zhu W, Schmehl DR, Mullin CA, Frazier JL (2014). Four common pesticides, their mixtures and a formulation solvent in the hive environment have high oral toxicity to honey bee larvae. Public Library of Science One 9(1):e77547.