Farmer knowledge and perceptions of agrochemicals use on honeybee community and honey production in Benin

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Abstract

Background

Apiculture faces many constraints including the use of agrochemicals. Chronic exposure to chemical pesticide use results in the loss of honeybee colonies and alters detoxification mechanisms and immune responses, driving them more susceptible to parasites. This study aims at investigating the impact of agrochemical use on honeybee community and honey production in northern Benin.

Methods

For this purpose, 100 beekeepers were surveyed using a survey questionnaire. Information on treated crops, the distance of beehives from these crops, the effect of insecticides and herbicides, adaptation patterns and honey production were collected through individual interviews. Socio-demographic data and farmer's knowledge on agrochemical uses and their impacts on honeybee communities were determined. Information were also collected on alternative methods to agrochemicals, beehive types and honey taste.

Results

Apicultural investigations have shown that chemical pesticides were applied in fields of crops and that beehives were mostly located near treated fields. The most used chemical pesticides were Kalach (glyphosate), Callifor G (glyphosate, fluometuron, prometyrn), Atrazila 80 wp (atrazin), Herbextra (glyphosate) and Cotonix (deltamethrin and chlorpyrifos). The majority of beekeepers (79%) recognize the effect of pesticides and use alternatives to pesticides to reduce the risk. In general, 49% of beekeepers found the decrease in the big breed of bees and 40% that of the small breed. The honey production was higher when the beehives were installed far from the treated fields.

Conclusion and implications:

This study allowed to knowing the direct and indirect effects of the agrochemical use on beekeeping. Alternative pest management methods to the pesticide use practiced by farmers would lead to sustainable improvements of honey production in Benin.

Background

Achieving high yields in agriculture requires the use of pesticides for the weed control and plant health management. The sharp increase in the use of chemical pesticides in recent years endangers plant and animal biodiversity [1; 2]. The increased use of chemical pesticides coupled with the agricultural boom is raising the vulnerability of natural resources, plant and animal biodiversity [3]. Many pesticides are toxic to beneficial insects, birds, mammals, amphibians or fishes [4, 5]. The poisoning of non-target species

depends on the toxicity of a pesticide and its other properties, the amount applied, frequency, timing and method of spraying, climate, vegetation structure and type of soil. Insecticides, rodenticides, fungicides and herbicides threaten the animal species that is exposed to them [6]. During these last years, the use of very toxic carbamates and organophosphates has increased significantly. In Africa, organochlorines such as endosulfan, which are highly environmentally persistent, moderately persistent in soil systems and not in aqueous systems are still widely used [7, 8, 9]. Like habitat change, pesticide poisoning can cause major decline of a population that threaten non-target species.

Pesticides are a major factor affecting biodiversity [10] and especially beneficial insects. Several studies have reported unusual bee colony decay and mortality in several countries around the world [11]. Broad spectrum insecticides including carbamates, organophosphates and pyrethroids can cause population decline of beneficial arthropods such as bees, spiders and beetles. Many of these species play an important role in the food web or as natural pests' enemies. Bees provide essential pollination. Honeybees are also under pressure from parasitic mites, viral diseases, habitat loss and pesticides [12, 13]. Intensive farming practices, habitat loss and agrochemicals are considered to be among the main environmental threats to honeybees and wild bees. The relative low number of detoxification genes in bees suggests greater sensitivity to pesticides compared to other insects [14]. It has been frequently reported that exposure to pesticides can have a direct effect on certain compounds of the immune system, even on physical defenses or behaviors preventing contamination in insects, particularly bees [15]. Thus, pesticides can have an effect on the humoral immune responses of insects [16]. They can also impact cellular responses. Thus, beekeeping professionals estimate that there was a loss of global honey production of 20 to 30% between the years 1997 and 2009 [17].

In Benin, pesticides are used in agriculture with the installation of beehives not far from fields treated with agrochemicals. These farming practices could also have adverse effects on the dynamics of the bee population and the honey production [18]. Chemicals are used to treat seeds of agricultural products. When a treated seed grows, chemicals can integrate in the environment to poison the bees [19]. Chemicals residues in pollen from crop plants from treated seed may pose a high risk to bees [20]. Sub-lethal doses of chemicals may lead to reduced learning ability in bees [21]. These toxic molecules (neurotoxicants) were found in plant pollens [22, 23] and their effects associated to the declining bee health remains to be determined. Indeed, the Northern Benin is an area of strong agricultural and apicultural production characterized by two breeds of bees, the first race with small, yellow bees, more aggressive and producing more honey and the second race with larger, black, bees, less aggressive and producing less honey. Since these two income generating activities are carried out in the same agro-ecological zones and with the same farmers, they must be done sustainably. Agricultural activities must not pollute honey produced by beekeepers for consumption. These areas of agricultural production are polluted by agrochemicals. Crops are treated with chemical pesticides the most treated being cotton. The increase in the number of organic cotton producers would contribute to reduce the pollution by chemical pesticides. Farmers continue to use agricultural practices based on biopesticides based on extracts of plants as *Azadirachta indica* for example [24, 25]. They also use compost and animal droppings to

fertilize the soils. These agroecological practices used by some farmers would reduce the risk of contamination of beekeeping systems closer to organic beekeeping.

This work aims to determine the influence of the use of chemical pesticides in agriculture on the honey bee abundance and their potential for honey production in Benin. Specifically, this involves: (1) listing all the chemical products (insecticides, nematocides, herbicides, fungicides) used in agriculture in the study area, (2) collecting the folk perception on the effects of chemical use in agriculture on honeybee communities and honey production in the study area and finally (3) determining the influence of the distance of beehives from cultivated fields on the honey production.

Methods

Study site

Four districts investigated in the study were Banikoara, Gogounou, Kandi and Segbana. These districts were located in Alibori region and characterized by agricultural and beekeeping production with a wide range of chemical pesticides used. Alibori is located between 11°19' north latitude and 2°55' east longitude. It is bordered to the north by the Republic of Niger, to the north-west by the Republic of Burkina Faso, to the south by the Borgou Department, to the east by the Federal Republic of Nigeria, and to the west by the Department of Atakora. Its area is 26242 km² (23% of the national territory). The far-north zone and the cotton zone of north Benin are the two agro-ecological zones. It has only one rainy season which lasts between 5 to 6 months with annual precipitation ranging between 700 mm and 1200 mm. The vegetation is a mosaic of dense dry forests, clear forests, wooded savannas and shrubby savannas [26]. The most dominant crops are sorghum, rice, maize and cotton.

Selection of respondents

An exploratory survey was made to select districts for investigation. Choice of those districts was based on following criteria: i) agricultural production and beekeeping and (ii) pesticide use in agriculture. In each district, 25 beekeeper farmers were chosen randomly, making a total of one hundred (100) farmers in the study area. Then, data were collected about the socio-demographic characteristics of the farmers. Structured questionnaire was administered to 100 beekeepers selected using a multistage sampling procedure in villages of the four districts. Individual and group surveys were conducted among beekeepers.

Data collection of agrochemicals use on bee communities and honey production

First, we have inventoried all crops produced that require the use of agrochemicals in the study area and also made an inventory of the agrochemicals used with their active ingredients. Secondly, we sought to understand the period during which farmers were heavily using chemicals and that of an intense beekeeping activity. Data were collected on whether these agrochemicals have contaminated bees and honey during the same year that both these two activities were conducted using farmer's perception.

Farmers were asked to list all the agroecological practices they use as an alternative to the use of chemicals. Third, we determined farmers' perceptions of the possible effects of using agrochemicals on bees and honey produced. In this part, the farmers gave their perception of the increase or decrease of each of the two breeds of bees in the study area. Then, the farmers provided information on the average abundance of the two breeds of bees per hive for the study area. Finally, the relationship between the distance between the beehives and the fields treated on the honey production were determined. For that, all the beehives placed between 100 and 500 m from the treated fields and the quantity of honey produced per beehive were identified.

Data collection on beehive systems types and the honey taste

Information has been collected on the types of beehive systems. Three categories of beehives (modern type, wood type, sheet metal type) have been identified in the study area [27]. The amount of honey produced by these three types of beehives has been determined. The taste of the honey produced by these beehives types was determined using scores (0.20: very poor taste; 0.40: poor taste; 0.60: good taste; 0.80: very good taste; 1: better taste).

Data analysis

Data collected was summarized using descriptive statistics (mean, standard deviation, frequency and percentage). Correspondence Analyses (CA) were carried out using the 'FactoMinor' package to determine the relationship between the honey production districts and i) types of herbicides used by farmers, ii) types of insecticides used by farmers. Correspondence Analyses (CA) were also carried out to show the relationships between the crops and the herbicides and insecticides used by farmers. GLMs were used to determine the relationship between pesticide use and abundances of small and large breeds of bees. A linear model (lm) was used to understand the relationship between the distance from the treated fields and the amount of honey collected per hive. This model was simulated using the PermTest function of the 'pgirmess' package. A probabilistic function was used to estimate the quantity of honey due to fluctuations in the distances from the treated fields [28]. Consequently, a stochastic Monte Carlo model was used to generate the honey quantity per beehive based on a random outputs model with a normal distribution function [29] with a 10,000 iteration model. GLMs have also been used to show the relationship between types of hives and the quantity and taste of honeys. The TukeyHSD test was used to show the significant difference between the honey tastes produced from modern beehives, beehives made from woods and beehives made from sheet metal. All statistical analyzes were performed with R version 3.2.2 [30] at the significance level of 5%.

Results

Socio-demographic characteristics of surveyed farmers

Beekeeping is an activity mainly performed by men (97%). Women were among the surveyed farmers and represented 3%. Of surveyed farmers, 76% of farmers had no formal education and others farmers had

primary (12%), secondary (9%) and university (3%) levels. The surveyed beekeepers had a mean age of 37.58 ± 1.48 (SD) years. The age group of 20–35 years had the largest number, with 45% of the farmers. Then, others farmers aged 36–50 (37%) and 51–68 (18%). The average number of years of experience was 9.194 ± 0.778 (SD) years with beekeepers with seniority, between 16–20 corresponding to 7% and 4% for more than 20 years of experience.

Inventory of the main treated crops and their requirements for agrochemical treatments in Northern Benin

Whatever the crop, farmers necessarily applied some agrochemical to control weeds or pests of crops. The most popular crop combinations were cotton and maize, cultivated by all the beekeepers, followed by sorghum, soya, cowpeas, yam and millet. Among these crops, cotton (100% of farmers), maize (100% of farmers), sorghum (60% of farmers), soy (45% of farmers), cowpeas (20% of farmers), yam (3% of farmers) and millet (2% of farmers) needed agrochemical treatment (Fig. 1).

Correspondence Analysis (CA) realized to show the relationship between honey production areas and herbicide types revealed that the first factor plane formed by axes 1 and 2 explained 87.78% of the total variability. The first axis contributed for 61.18% and the second 26.60%. The projection of the honey production areas in the factorial plan defined by 1 and 2 revealed that the beekeepers from Segbana and Banikoara used the herbicides Atrforce, Callifor and Atrazila in their fields. The beekeepers from Gogounou used the herbicides Cottonex, Herbextra, Adwuma, Kabasate, Butaforce, Malik, Grasskiller and Glyphader. The beekeepers from Kandi used Kalach and Butaplus (Fig. 2). Correspondence analysis (CA) performed to show the association between honey production areas and insecticide types revealed that the first factor plane formed by axes 1 and 2 explained 99.34% of the total variability. The first axis contributed for 94.76% and the second 4.58%. The projection of the honey production areas in the factorial plan defined by 1 and 2 revealed that the beekeepers from Segbana and Banikoara used the insecticides Thalix and LambdaSuper. The beekeepers from Gogounou used the insecticides Emacot and Cypercal. The beekeepers from Kandi used Cotonix (Fig. 3). Correspondence analysis (CA) performed to show the relationship between the treated crops and used herbicides types revealed that the first factor plane formed by axes 1 and 2 explained 68.45% of the total variability. The first axis contributed for 45.54% and the second 22.91%. The herbicides Kabasate, Adwuma and Grasskiller were used in the fields of soy and millet. The herbicides Callifor, Butaforce and Kalach were used in the fields of cowpea, yam and sorghum. Malik, Herbextra, Atrforce, Butaplus were used in the fields of maize. Cottonex and Glyphader were used in the field of cotton. Paraeforce was used in the all fields (Fig. 4). Correspondence Analysis (CA) performed to show the relationship between the treated crops and used insecticides types revealed that the first factor plane formed by axes 1 and 2 explained 89.41% of the total variability. The first axis contributed for 66.17% and the second 23.24%. The insecticides LambdaSuper and Cypercal were used in the fields of soy cowpea and millet. The insecticides Cotonix and Thalix were used in the fields of cotton. Emacot was used in the fields of maize and sorghum. No product was used in the field of yam (Fig. 5).

Major Pesticides Used By Farmers In The Study Area

A total of 19 agrochemicals were used by farmers, including 14 herbicides (73.68%) and 5 insecticides (26.32%). The most used herbicides were Callifor G (15%), Kalach (12%), Atrazila 80 WP (10%), Herbextra (10%), Atraforce (10%), Adwuma wura (480 SL) (9%) and Cottonex (8%). Concerning insecticides, Thalix (48%), Cotonix (36%) and Cypercal P 330 EC (10%) were more used (Table 1). According to the farmers, the effect of the agrochemicals on bees depended on their categories. Herbicides have an indirect effect on honeybees by killing small flowering plants and making the bees' food resources unavailable, while insecticides act directly on them (Table 2).

Table 1
Main pesticides used with their active ingredients

Pesticides	Active ingredients	Percentage of use
Herbicides		
Callifor G	Prometryn + Fluometuron (250 g/kg)	15
Kalach	Glyphosate (Glycine) (700 g/kg)	12
Atrazila 80WP	Atrazine (800 g/kg)	10
Herbextra 720SL	Amino salt (720 g/L)	10
Atraforce	Atrazine 50%SC + 80%WP	10
Adwuma wura (480 SL)	Glyphosate (480 g/L)	9
Cottonex PG 560 SC	Fluometuron (250 g/L) + Prometryn (250 g/L + Glyphosate (60 g/L)	8
Kabasate	Glyphosate 480 g/l SL	5
Buta force EC	Butachlor 50% EC	5
Grass Killer	Cinnamon bark 0.95%	4
Glyphader 75SG	Glyphosate 680 g/kg	4
Malik	Haloxifos R-methyl	3
Parae force	Dichlorure de Paraquat 276 g/l SL	3
Buta Plus	Lambda cyhalothrin	2
Insecticides		
Thalis	Emamectine benzoate 48 g/l-acetamipride 64 g/l. 0.25	48
Cotonix	Deltamethrin (12 g/L) + Chlorpyrifos-ethyl (300 g/L) + Acetamipride (160 g/L)	36
Cypercal P 330 EC	Cypermethrin (30 g/L) + Profenos (300 g/L)	10
Emacot	Emamectin benzoate	4
Lambda Super 25 EC	Lambda cyhalothrin (25 g/L)	2

Table 2

Farmer's perception of the consequences of the agrochemical use on bee communities

Pesticide effects on bees	Farmer's percentage
Herbicides	
Kill growing herbs, destroy seeds and prevent regrowth of herbs, reducing the availability of bee foods	60
Cause the death of bees	30
Decrease the production capacity of honey	10
Insecticides	
Repel bees	35
Kill bees	30
Poison the flowers	12
Pollute the air surrounding bees	10
Weaken worker bees and diminish the production capacity of honey	8
Decolonize beehives	5

Farmer's perception on negative effects of pesticide use on bee communities

A gradual decrease in bees has been observed by beekeepers regardless of breed. By taking the study area in general, 49% of the farmers found the decrease in the big breed and 40% that of the small breed. In the same area, some beekeepers mentioned an increase in the population dynamics of bees; 6% for the small breed and 5% for the big breed (Fig. 6). Statistical analyses showed negative effects of pesticide use (insecticide and herbicide) on big honeybee abundances (Estimate = - 2.45; $P = 0.0042$) and small honeybee abundances (Estimate = - 0.29; $P = 0.001$). Farmers collected honey (May - November) during a period of the year following the use of agrochemicals (Fig. 7). Given the gradual pollution of this honey production environment, some farmers adopted agroecological practices such as the installation of hives away from fields treated with pesticides, association of crops, biopesticide use and ecological beekeeping for sustainable production of honey (Fig. 8).

Influence of the distance of beehives from cultivated fields on the honey production and Monte Carlo modeling

The beekeepers were grouped into two groups according to the proximity of the beehives to treated crops. The average honey production per beehive in the first group was 8.08 liters, the second group was 9.75 liters per harvest. The Monte Carlo method showed that the variation in the quantity of honey production with the beehive distance from fields was significant ($F = 116.7$; $Df = 98$; $P = 0.00001$; Fig. 9).

Influence of beehive systems on the quantity and taste of honey

There was no significant effect of the beehive systems types on the quantity of honey produced ($P = 0.32$; $Df = 98$). However, there was a significant effect of beehive systems types on the honey taste ($P < 0.00001$; $Df = 98$). Tukey's test showed a highly significant difference between the tastes of honey produced from beehives made with sheet metal and beehives made with therapeutic plant woods. The beehives made with therapeutic wood contained honey with a very appreciable taste. The difference was moderately significant between honeys produced from beehives made with therapeutic woods and modern beehives. In addition, there was a low difference between the honey produced from modern beehives and those made from sheet metal (Fig. 10; Table 3).

Table 3
Tukey's test on the honey taste according to beehive systems types

Beehive systems	diff	lwr	upr	p adj
Sheet metal-modern	-0.2928105	-0.39685193	-0.1887690	$P < 0.00001$
Wood-modern	0.1040936	0.02357754	0.1846096	0.0075877
Wood-sheet metal	0.3969040	0.29026739	0.5035407	$P < 0.00001$

Discussion

The present study reveals that beekeeping is an activity mainly practiced by men (97%) and by illiterates. These observations were similar to those of [18] who observed that honey production in the study area was predominantly male and had a low level of schooling. The average age of beekeepers surveyed was 37.58 ± 1.48 years. This result showed that this activity was more practiced by young people. The interest of these young people in beekeeping was an important asset for training in modern beekeeping, production and intensification of production. Beekeepers with one year of experience ranging from 1 to 5 are the most numerous, which shows beekeepers were taking over their business by involving more young people in this income-generating activity.

The farmers use chemical pesticides for the most cultivated crops in Northern Benin. Agrochemicals were heavily applied from June to October while the bees were in the process of collecting nectar for the honey production. This could lead to the high mortality in the bee community as shown in others studies [31, 13, 32] in which the negative effects of neonicotinoids on bee health has been shown. The honey harvesting activity occurred after the pesticide application. This could affect the quality of honey that could contain some traces of pesticides. In Uganda, a significant contamination of honey with insecticides including neonicotinoids, organophosphates, carbamates, organophosphorus, triazines and diacylhydrazines has been observed in contaminated samples [33].

The perception of beekeepers on the effect of pesticides on bees reveals that the beekeepers comprehend that chemical pesticides affect bees according to their categories. Herbicides had an indirect effect, while

insecticides act directly on them. Indirect effects, especially trophic effects, are related to the feeding of wildlife. By destroying weeds, herbicides affect the animal species that feed on them, even if they are not toxic to these animals. The use of pesticides in market gardening and probably other crops had a negative impact on the honey bee *Apis mellifera adansonii* [34]. Farmers thought that insecticides increased the bee mortality. These intoxications contribute to the massive depopulation of beehives and a loss of honey harvest [35]. Other studies have shown the presence of fungicides in bees, pollen and honey [36]. Results showed that bees could be contaminated by insecticides containing active ingredients such as cypermethrin, deltamethrin and emamectin. Additionally, these active ingredients had lethal and sublethal effects on forager worker honeybees in experimental conditions [37].

Some beekeepers applied alternatives to try adapt to the risk of bee extinction caused by agricultural pesticides. The forms of adaptation recorded were: keeping the beehives away from the treated fields and reserving a space especially for the bees breeding. These two methods could reduce the disappearance of bees [38]. The major problem is the land availability because of their occupation for the benefit of agriculture. Another method was the biopesticide use. Several plant extracts are used to control crop pests. These plant extracts are also used in combination with biological control methods to control crop pests in Integrated Pest Management (IPM) programs which could enhance the pollinators [39]. The development of agroforestry systems based on melliferous plants species in association with cultivated plants could be a better solution for the ecological and sustainable production of honey. A diversity of agroforestry honey plants exists in the study area [27] and could be an asset for the design of agroforestry systems with crop planting.

The study has also showed the farmer's perception on the decrease in the populations of the two breeds of bees existing in Benin also reported by [40]. About 49% of farmers found the decrease of the big breed (yellow breed) and 40% that of the small breed (black breed). This possible decrease is not only due to the use of pesticides but also the agricultural pressure with the bee biotope destruction [41]. Others factors including pests like *Varroa* which is known most important pest of bees, decline both the bee and the honey production [42, 43]. The influence of the distance of the apiaries from the fields which was evaluated showed that the effect was significant. As a result, beehives set up far from treated fields produce on average the most quantity of honey. Far from the treated fields, bees are less exposed to agrochemicals and can survive for a long time and increase their populations. They have the possibility of looking for nectar on several honey plants without being contaminated. Several factors threaten the honey production such as the lack in maintenance for beehives. Some beekeepers abandon their beehives installed far from the fields for the benefit of agriculture and do not return to beehives until harvest. The quality of the hives could contribute to the taste of honey [44]. In our study area, we have identified 3 categories of beehives that could affect the honey taste according to beekeeping producers. Beehives made of wood provide a good taste to honey compared to hives made of sheet metal and modern hives. The woods have therapeutic properties which could be yielded to honey.

Conclusion

Beekeeping is an activity mainly carried out by cotton farmers in the north of Benin. These farmers use chemical pesticides to treat almost all of the cultivated crops. Herbicides and insecticides are the most widely used pesticides. Chemicals coming mainly from the informal supply networks are more applied during the months when bees collect nectar and pollen. The present study has shown that the pesticides used in the study area can cause a decrease in the two bee breeds encountered in northern Benin. A minority of beekeepers are developing forms of adaptation to the risk of the bees disappearing. It is therefore necessary to reduce the damage of pesticides on bees using biopesticides which are not necessarily less harmful for bees.

Abbreviations

BIORAVE

Biotechnology, Genetic Resources and Plant and Animal Breeding;

CA

Correspondence Analyzes;

GLMs

Generalized linear models.

Declarations

Ethics approval and consent to participate

No ethical approval was needed for this study. Prior to data collection, participants gave oral consent to participate in the study.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data generated during this study are available from the corresponding author.

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Authors' contributions

AGD, CA, SV, SDV, VK, DB, ST and LA participated in the study design; they analyzed and interpreted the data and drafted the manuscript. CA, BD, and AAE carried out the field surveys. AGD, CA, SV, AAE, BD, DB, ST, VK, SDV and LA corrected the manuscript. All authors approved the final manuscript.

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Figures

Figure 1

Main crops cultivated and treated by agrochemicals in Northern Benin

Figure 2

Correspondence analysis (CA) performed to show the relationship between honey production areas and herbicide types

Figure 3

Correspondence analysis (CA) performed to show the relationship between honey production areas and insecticide types

Figure 4

Correspondence analysis (CA) performed to show the relationship between the treated crops and used herbicides types

Figure 5

Correspondence analysis (CA) performed to show the relationship between the treated crops and used insecticides types

Figure 6

Farmer's perception on the evolution of honeybee communities; Big decreased = Big bee breed decreased ; Small = Big bee breed decreased ; Big increased = Big bee breed increased ; Small increased = small bee breed increased.

Figure 7

Periods of honey collecting and pesticide uses

Figure 8

Agroecological practices adopted by some farmers for sustainable honey production as alternatives solutions to reduce pesticide effects, Beehives away = Beehives placed away ; Mel planting = Crop association ; Bee breeding = Bee breeding in natural areas.

Figure 9
Relationship between honey quantity and distance of beehives from treated fields

Figure 10

Supplementary Files

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