Ann. UP, Série Sci. Nat. Agron. Juin 2023, Vol.13 (No.1) : 43-52

ANNALES DE L'UNIVERSITÉ DE PARAKOU
Série « Sciences Naturelles et Agronomie »
(AUP-SNA)

ISSN : 1840-8494
eISSN : 1840-8508
Parakou, Bénin

ARTICLE DE RECHERCHE

https://doi.org/10.56109/aup-sna.v13i1.25

https://sna.fa-up.bj

Farmer's perception of agrochemical use on honeybees and honey production in Benin: Implication for organic honey production

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Recieved on January 3, 2022 - Acceped on February 20, 2023 - Published on June 30, 2023

Abstract : Beekeeping faces numerous challenges, including the use of agrochemicals. Honeybee colonies are lost because of chemical pesticides use in agriculture to control pests and diseases, which affects detoxifying mechanisms and immune responses, making them more vulnerable to parasites. The purpose of this study was to investigate people's perception of the impact of agricultural pesticide use on the honeybee community and honey production in northern Benin. A survey was conducted using a questionnaire among 100 beekeepers. Individual interviews were used to gather information on treated crops, the distance between beehives and these cultivated fields, the effect of pesticides and herbicides, alternative methods to pesticide use and honey production. Chemical pesticides such as Callifor G, Kalach, Atrazila 80 WP, Herbextra, Atraforce, Adwumawura (480 SL), Cottonex, Thalis, Cotonix and Cypercal P 330 EC were used in agricultural fields, and beehives were typically found near treated fields. The majority of beekeepers (79%) are aware of the risks associated with pesticides and employ non-pesticide alternatives such as biopesticides to minimize them. In general, beekeepers reported a reduction in the big breed of bees and a 40% decrease in the little breed. When the beehives were placed far away from the treated areas, the honey yield was higher. Alternative pest management strategies to farmers' pesticide use would result in long-term increases in honey production and would constitute the main step of the conversion to organic apiculture in northern Benin.

Keywords: Beekeeping, Agrochemicals, Honeybees, Honey production, Benin.

Perception des agriculteurs sur l'impact des produits agrochimiques sur les abeilles et la production de miel au Bénin : Implications pour la production de miel biologique

Résumé : L'apiculture est confrontée à de nombreuses contraintes, notamment l'utilisation de produits chimiques en agriculture près des systèmes apicoles. Les colonies d'abeilles diminuent à cause de l'utilisation des pesticides chimiques, qui affectent les mécanismes de détoxification et les réponses immunitaires, les rendant plus vulnérables aux parasites. Cette étude vise à examiner la perception des agriculteurs quant à l'impact de l'utilisation de pesticides agricoles sur la communauté des abeilles mellifères et la production de miel dans le nord du Bénin. Une enquête a été menée auprès de 100 apiculteurs au moyen d'un questionnaire. Des entretiens individuels ont été réalisés pour recueillir des informations sur les cultures traitées, la distance entre les ruches et ces cultures, l'effet des pesticides et des herbicides, les méthodes alternatives à l'utilisation des pesticides et la production de miel. Des pesticides chimiques tels que Callifor G, Kalach, Atrazila 80 WP, Herbextra, Atraforce, Adwumawura (480 SL), Cottonex, Thalis, Cotonix et Cypercal P 330 EC ont été utilisés dans les champs agricoles, et les ruches étaient généralement situées à proximité des champs traités. La majorité des apiculteurs (79 %) sont conscients des risques associés aux pesticides et utilisent des alternatives sans pesticides, telles que les biopesticides, pour les minimiser. En général, les apiculteurs ont signalé une réduction de la grande race d'abeilles (60% des apiculteurs) et une diminution de la petite race (40 % des apiculteurs). Lorsque les ruches étaient placées loin des zones traitées, le rendement en miel était plus élevé. Des stratégies alternatives de lutte contre les ravageurs, en remplacement de l'utilisation de pesticides par les agriculteurs, permettraient d'augmenter à long terme la production de miel et constitueraient une étape majeure dans la conversion vers l'apiculture biologique au nord Bénin.

Mots cléfs : Apiculture, produits chimiques, abeilles, production du miel, Bénin.

1. Introduction

Pesticides have been used for weed control and plant health management, especially to achieve high yields in agriculture. In recent years, the excessive use of chemical pesticides has posed a significant threat to both plants and animals (Sutherland et al., 2018; Tubbs and McDonough, 2018). For instance, the widespread use of chemical pesticides, combined with the expansion of farming, has heightened the vulnerability of natural resources, and the biodiversity of plants and animals (Gentilcore, 1960). Animal species exposed to pesticides, such as insecticides, rodenticides, fungicides, and herbicides, are at risk of harm (Colborn et al., 1993). Many pesticides are toxic not only to pests but also to beneficial insects, mammals, birds, amphibians, and fish (Aktar et al., 2009; Robbins and Sharp 2003).

The toxicity of a pesticide and its other properties depend on the amount of application, frequency, time and method of spraying, climate, vegetation structure, soil type and the non-target species (Resende et al., 2016). Organochlorines such as endosulfan are still commonly used in Africa and are highly environmentally sustainable and moderately persistent in soil systems rather than aqueous systems (Iloba and Ekrakene 2008; Pazou et al., 2006; Darko et al., 2017). The improper use of pesticides and habitat changes can lead to significant declines in non-target species populations.

Pesticides are an important factor in biodiversity (Isenring, 2010) and particularly beneficial insect declines. In several countries around the world, several studies have shown unusual colony declines and mortality (Fairbrother et al., 2014). With a big spectrum of actions, these pesticides including carbamates, organophosphates and pyrethrenoids, can lead to decreases in the population of beneficial arthropods such as bees, spiders and beetles (Bakker et al., 2022). Many of these beneficial arthropods play a major role in the food web or as natural enemies of pests. Bees, in particular, are notable pollinators and have been experiencing pressure from a combination of factors, including parasite mites, viral diseases, habitat loss, and intensive pesticide use (Hapke 2008; Cresswell 2011). The main environmental threats to honeybees and wild bees are intensive farming practices, habitat loss and agrochemicals. The relatively small number of detoxifying genes in bees suggests that they are more susceptible to pesticides than other insects (Claudianos et al., 2006). It has often been reported that pesticide exposure can have a direct impact on certain immune system compounds, even on physical defenses or behaviors preventing insect contamination, especially bees (Berenbaum and Johnson, 2015). Pesticides can therefore influence insect humoral immune responses (James and Xu, 2012). They can also influence cellular reactions. For this reason, beekeeping professionals have reported a global loss of 20-30% in honey production between 1997 and 2009 (Genersch et al., 2010).

In Benin, pesticides are frequently used in agriculture, and beehives are often located near agrochemical fields. These farming practices can have a negative effect on bee population dynamics and honey production (Paraïso et al., 2012). Chemicals used to treat agricultural seeds can contaminate bees when the treated seeds germinate (Bogdanov, 2006). The residues of chemicals from treated seed crops in pollen may pose a high risk to bees (Thompson 2003). Sublethal doses of chemicals can lead to a reduction in bees' learning ability9 (Girard et al., 1998). These toxic molecules (neurotoxicants) have been found in plant pollens (Mullin et al., 2010; Cresswell, 2016) and their effects on bee health have been well-documented. Notably, the northern region of Benin is characterized by intensive agriculture and beekeeping, involving two distinct bee races: a small, yellow, aggressive breed that produces highly sweet honey, and a larger, black, less aggressive breed that produces honey with less sweetness. As these two income-generating activities are carried out in the same agroecological areas and with the same farmers, they must be carried out sustainably to ensure that agricultural practices do not contaminate the honey produced by beekeepers. Agrochemicals contribute to pollution in these agricultural production areas. Crops are mostly treated with cotton with chemical pesticides. An increase in the number of producers of organic cotton would help reduce chemical pesticide pollution. Certain farmers have already adopted agroecological practices, such as using plant extracts like *Azadirachta indica* (Togbé et al., 2015; Lernoud et al., 2019) and fertilizing the soil with compost and animal droppings. These agroecological practices used by certain farmers can significantly reduce the risk of contamination in beekeeping systems, promoting a transition toward organic beekeeping principles.

The objective of this research is to evaluate the impact and potential of chemical pesticides use in farming on honey production in northern Benin. Specifically, the study aims to (1) identify the agricultural chemical compounds commonly used in the region, including insecticides, nematicides, herbicides, and fungicides; (2) analyze local perceptions of the use of agricultural chemicals on honeybee communities and honey production; and 3) determine the relationship between beehive placement, the type of beehive, and honey quantity and sweetness.

2. Material and Methods

2.1. Study sites

The study was performed in four communes: Banikoara, Gogounou, Kandi, and Segbana. These communes were selected due to their agricultural and beekeeping culture, as well as their widespread use of chemical pesticides. Alibori lies between latitude 11°19' north and longitude 2°55' east. It is bounded by Niger and the Republic of Burkina Faso in the north, Borgou in the south, the Federal Republic of Nigeria in the east and Atacora in the west. It covers an area of 26 242 km^2, which accounts for 23% of the national territory. The region comprises two agroecological zones: the far northern area and the cotton zone in northern Benin. It experiences a single rainy season, with annual precipitation ranging from 700-1200 mm. The vegetation consists of a mosaic of dense, dry and sparkling forests, clear forests and wooded savannas (Adomou, 2011). Sorghum, rice, maize and cotton are the most prevalent crops cultivated in the region.

2.2. Selection of respondents

An exploratory survey was conducted to select the target districts for the study. The selection was based on the following criteria: i) agricultural and beekeeping production and (ii) the use of pesticides in agriculture. A total of 25 beekeepers were randomly selected from each commune, making a total of one hundred (100) farmers in the study area, using the snowball method. Data regarding farmers' socio-demographic characteristics were collected as part of the survey. Individual surveys were conducted using a structured questionnaire in the villages of the four communes, involving 100 selected beekeepers. Both individual and group surveys were carried out among beekeepers.

2.3. Data collection on agrochemical effects on honeybees and honey production

Firstly, an inventory was conducted to document the crops produced and the specific agrochemicals used, including their active ingredients. Secondly, we sought to understand the period during which farmers heavily used chemicals and when beekeeping activities were intense. Data were collected to examine farmer's perceptions of the contamination of honeybees and honey, as agriculture and beekeeping were concurrently carried out by the same individuals. Farmers were asked to provide a list of all agroecological practices they employed for the management of chemicals. Thirdly, we sought to determine farmers' perceptions of the potential effects of agrochemicals on bees and honey production. Specifically, we assessed farmers' perception of the population dynamic of the two bee races in the study areas. We also collected information on the average density of the two races of bees per hive in the study areas. Additionally, farmers assisted in counting the number of dead honeybees around the beehives in order to establish any relationship with the use of agrochemicals. Lastly, we determined the relationship between the distance between the beehives and the honey production fields. For this purpose, we identified all the beehives located between 100 and 500 m from the treated fields and recorded the quantity of honey produced per beehive.

2.4. Data collection on the type and taste of beehive systems

Information was gathered on three categories of beehive systems: modern type, wood type, sheet metal type (Dassou et al., 2019). Moreover, we determined the honey production of each type of beehive. The taste of the produced honey was assessed using the following indicators: 0.20 for very poor taste, 0.40 for poor taste, 0.60 for good taste, 0.80 for very good taste, and 1 for better taste.

2.5. Statistical analysis

The data were summarized using descriptive statistics (mean, standard deviation, frequency, and percentage). The relationship between pesticide use and the abundance of small and large bee species was determined using Generalized Linear Models (GLMs). A linear model (lm) was used to explore the relation between the distance from the treated fields and the amount of honey collected per hive. This model was simulated using the 'pgirmess' package function of PermTest. The honey quantity was estimated by a probabilistic function due to fluctuations in the distances from the treatment fields (Hacura et al., 2001). A stochastic model from Monte Carlo was therefore used to generate the honey quantity per beehive based on a model with the normally distributed random outputs (Platon and Constantinescu, 2014) and performing 10 000 iterations. GLMs were also used to investigate the relationship between the hive type and the quantity and taste of the honey sweetness. The Tukey HSD test was used to determine significant differences in in the taste of honey produced in modern beehives, wood-based beehive and sheet metal beehives. All statistical analyses were conducted at a significance level of 5% using R version 3.2.2 (R Core Team, 2012).

3. Results

3.1. Socio-demographic characteristics of surveyed farmers

Beekeeping was primarily carried out by male farmers (97%) with a smaller representation of female farmers (3%). Approximately 76% of the farmers had no formal education and other farmers had primary (12%), secondary (9%) and university (3%) education level. The age group of 20-35 years was the most dominant accounting for 45% of the farmers, followed by 36-50 years (37%) and 51-68 years (18%). The average years of experience was 9.194 ± 0.778 (SD) years for senior beekeepers, with 7% of beepeekers having 16-20 years of experience and 4% with more than 20 years of experience.

3.2. Inventory of the main treated crops and their needs for agrochemical treatments in Northern Benin

Whatever the crop grown, farmers necessitated the application of some agrochemicals to control weeds or pests. The most popular crop combinations included cotton and maize, which were cultivated by all beekeepers, followed by sorghum, soybean, cowpeas, yam and millet. Among these crops, cotton (100% of the farmers), maize (100% of the farmers), sorghum (60% of the farmers), soybean (45% of the farmers), cowpeas (20% of the farmers), yam (3% of the farmers) and millet (2% of the farmers) required agrochemical treatments (Figure 1).

3.3. Major pesticides used by farmers in the study area

A total of 19 agrochemicals were used in the study areas, 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%), Adwumawura (480 SL) (9%) and Cottonex (8%). Insecticides such as Thalis (48%), Cotonix (36%) and Cypercal P 330 EC (10%) were predominantly used compared to other types (Table 1). The effect of the agrochemicals on bees varied depending on the agrochemicals categories: herbicides indirectly affected honeybees by eliminating small flowering plants and rendering the bees' food resources unavailable, while insecticides directly affected honeybees (Table 2).

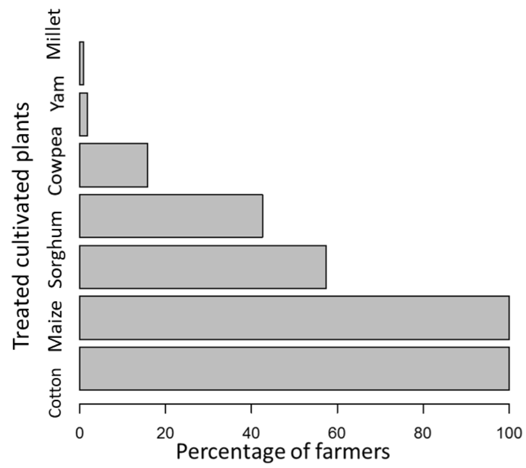

Figure 1. Main crops cultivated and treated with agrochemicals in Northern Benin / Plantes cultivées traitées avec les pesticides chimiques au Nord du Bénin

Table 1. Main pesticides used (% respondents) and their active ingredients / Principaux pesticides utilisés (% répondants) et leurs matières actives

Pesticides	Active ingredients	Pesticide use (% of farmers)
Herbicides		
Callifor G	Prometryn + Fluometuron (250g/kg)	15
Kalach	Glyphosate (Glycine) (700g/kg)	12
Atrazila 80WP	Atrazine (800g/kg)	10
Herbextra 720SL	Amino salt (720g/L)	10
Atraforce	Atrazine 50%SC + 80%WP	10
Adwuma wura (480 SL)	Glyphosate (480g/L)	9
Cottonex PG 560 SC	Fluometuron (250g/L) + Prometryn (250g/L + Glyphosate (60g/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 680g/kg	4
Malik	Haloxyfos 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) + Chlorpyriphos-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 (%respondents) of the consequences of the agrochemical use on bee communities / Perception paysanne (% répondants) des conséquences d'utilisation des pesticides chimiques sur les communautés d'abeilles

Pesticide effects on bees	Farmer's perception (% respondents)
Herbicides	
Kill growing herbs, destroy seeds and prevent regrowth of herbs, reduce 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

3.4. Negative effects of pesticide use on honeybee communities

During our field visits, we observed dead honeybees in the vicinity of the beehives, with the number of dead honeybees varying across districts ($P < 0.00001$; $Df = 3$). Beekeepers reported a gradual decrease in honeybees regardless of the breed, with approximately 49% of farmers observing a decrease in the population of the larger breed and 40% in the smaller breed across the study areas. However, some beekeepers mentioned an increase in the population dynamics of bees, with 6% observing an increase in the smaller breed and 5% in the larger breed. Statistical analysis indicated a negative effect of pesticides use (insecticide and herbicide) on the abundance of both the larger honeybee breed (Estimate = - 2.45; P = 0.0042) and the smaller honeybee breed (Estimate = - 0.29; P = 0.001). Farmers collected honey in May through November, which coincided with the period of agrochemical use (Figure 2). Given the gradual pollution of this honey production environment, some farmers adopted agroecological practices such as placing beehives away from pesticide-treated fields, practicing crop association, utilizing biopesticides, and embracing ecological beekeeping to ensure sustainable honey production (Figure 3).

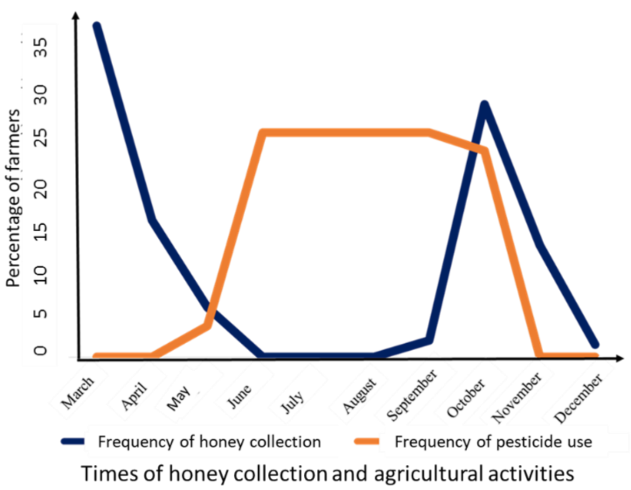

Figure 2. Periods of honey collection and pesticide uses / Périodes de collecte du miel et d'utilisation des pesticides dans les champs

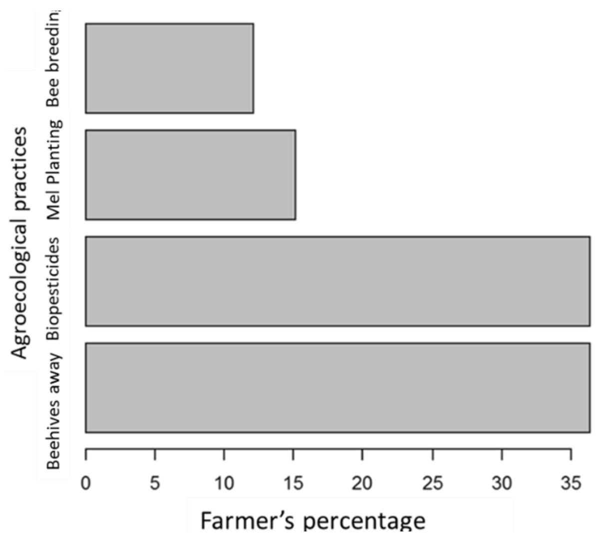

Figure 3. Agroecological practices adopted by some farmers for sustainable honey production as an alternative solution to reducing pesticide effects / Pratiques agroécologiques adoptées par quelques paysans pour une production du miel durable comme solution alternative pour réduire les effets des pesticides

Notes: Beehives away = Beehives placed away / Ruches placées loin ; Mel planting = Crop association / Association de cultures ; Bee breeding = Bee breeding in natural areas / Élevage d'abeilles dans des zones naturelles.

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

The beekeepers were grouped into two categories based on the proximity of their beehives to treated crops. The average honey production per beehive in the first category was 8.08 liters, while the second category produced 9.75 liters per harvest. The Monte Carlo method showed a significant positive relationship between the distance of beehives from fields and the quantity of honey production ($F = 116.7$; $Df = 98$; $P = 0.00001$; Figure 4).

3.6. Relationships between beehive type and honey taste and quantity

The effect of beehive type on the quantity of honey produced was not significant ($P = 0.32$; $Df = 2$). However, there was a significant effect of beehive type on the taste of honey ($P < 0.00001$; $Df = 2$). Tukey's test revealed a highly significant difference in the taste of honey produced between beehives made with metal sheet and those made with therapeutic plant woods (Figure 5; Table 3; $P < 0.00001$). Beehives made with therapeutic woods yielded honey with a very appreciable taste. The difference in taste was moderately significant between honey produced from beehives made with therapeutic woods and modern beehives. In addition, there was a minor difference between the honey produced from modern beehives and those made from metal sheet (Figure 5; Table 3).

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

Beehive systems	diff	lwr	upr	p adj
Metal sheet -modern	-0.2928	-0.3969	-0.1888	P < 0.00001
Wood-modern	0.1041	0.0236	0.1846	0.0075877
Wood- metal sheet	0.3969	0.2903	0.5035	P < 0.00001

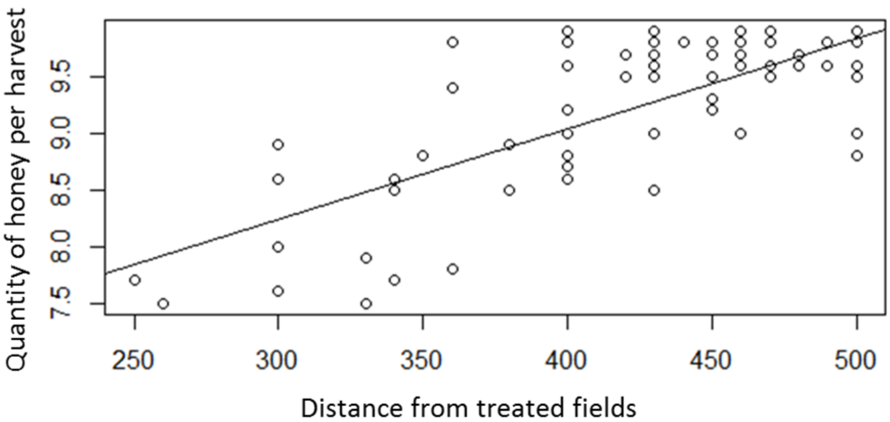

Figure 4. Relationships between quantity of honey and distance from beehives to treated fields / Relation entre la quantité de miel et la distance entre ruches et champs traités avec des pesticides chimiques

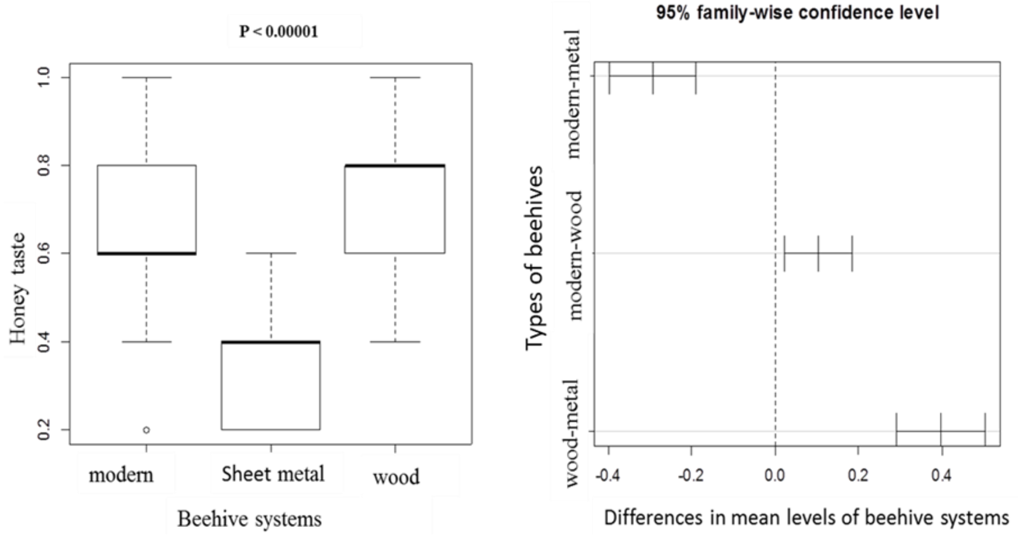

Figure 5. Relationship between beehive types and honey taste / Relation entre les types de ruche et le goût du miel

4. Discussion

The present study reveals that beekeeping is an activity mainly practiced by men (97%) and by individuals with limited formal education. These findings are consistent with Paraïso et al. (2012), who observed that honey production in the study area was predominantly carried out by male beekeepers with a low level of education. The average age of the surveyed beekeepers was 37.58 ± 1.48 years and beekeepers with years of experience ranging from 1 to 5 are the most numerous, indicating a higher involvement of young people in beekeeping. The interest of young individuals in beekeeping is an important asset for the modernization and intensification of honey production. By attracting and engaging the younger generation, beekeeping can experience a rejuvenation, bringing fresh perspectives, innovative ideas, and a renewed energy to the field. This can contribute to the sustainability and growth of beekeeping practices, ensuring their continuity for future generations.

Farmers in Northern Benin heavily rely on chemical pesticides for the cultivation of their crops. Agrochemicals were extensively applied from June to October, coinciding with the period when bees are collecting nectar for honey production. This timing of pesticide use may lead to high mortality rates in the bee community as observed in other studies that have shown the negative effects of neonicotinoids on bee health (Johansen et al., 1983; Cresswell 2011; Doublet et al., 2015). Furthermore, honey harvesting occurs after the pesticide application, potentially resulting in the presence of pesticide residues in the honey. Studies in Uganda have reported significant contamination of honey with insecticides, including neonicotinoids, organophosphates, carbamates, triazines, and diacylhydrazines in contaminated samples (Amulen et al., 2017).

The perception of beekeepers regarding the effects of pesticides on bees reflects their understanding of how different categories of chemicals impact bees. Herbicides were seen to have indirect effects, primarily through trophic interactions, as they reduce species diversity by destroying weeds that serve as food sources for other animals. The use of pesticides in market gardening and other crops has been reported to negatively impact the honeybee species *Apis mellifera* adansonii (Zoclanclounon et al., 2017). Farmers also reported that insecticides increased bee mortality, contributing to the depopulation of beehives and subsequent loss of honey harvest (Panseri et al., 2014). The presence of fungicides in bees, pollen, and honey has been observed in other studies as well (David et al., 2016). Bees can become contaminated by insecticides containing active ingredients such as cypermethrin, deltamethrin, and emamectin, which can have both lethal and sublethal effects on forager worker honeybees (Abdu-Allah and Pittendrigh 2018).

In response to the risks posed by agricultural pesticides, some beekeepers have adopted alternative practices. These include placing beehives away from treated fields and establishing buffer zones, especially for bee breeding. These methods can reduce the negative impacts on bees. However, land availability remains a major challenge due to agricultural expansion. Another adaptation method is the use of biopesticides, which involve the application of plant extracts to control crop pests. These plant extracts can be combined with biological control methods in Integrated Pest Management (IPM) programs, which can benefit pollinators (Gomes et al., 2011). The development of agroforestry systems incorporating melliferous plant species in association with cultivated plants could also provide a better solution for ecologically and sustainably producing honey (Lee-Mäder et al., 2020). The study area is characterized by a diversity of agroforestry honey plants (Dassou et al., 2019), which could be utilized in designing agroforestry systems integrated with crop cultivation.

The study also highlights the beekeepers' perception of a decline in the populations of the two honeybee breeds in Benin. Approximately 49% of farmers reported a decrease in the population of the larger breed (yellow breed), while 40% observed a decline in the smaller breed (black breed). This possible decrease is not only due to the use of pesticides but also the agricultural pressure responsible for the bee biotope destruction. Other factors including pests like Varroa which is known as most important pest of honeybees decline both honeybee and honey production (Vanhove et al., 2020). The declines observed in the populations of the two honeybee breeds in Benin have important implications, particularly for pollination services and biodiversity. Honeybees play a vital role in pollinating crops (Fikadu, 2019) and maintaining ecosystem balance (Breeze et al., 2011). The decrease in honeybee populations can disrupt pollination dynamics, affecting agricultural productivity and biodiversity conservation (Maderson, 2023). Understanding the broader ecological impacts of these declines is crucial for implementing effective conservation strategies.

The distance between beehives and cultivated fields was found to have a significant influence, with beehives located farther from treated fields producing a higher quantity of honey. Bees located far from treated fields are less exposed to agrochemicals, allowing them to thrive and increase their populations. These bees have access to a variety of honey plants without contamination. However, factors such as the lack of hive maintenance and abandonment of beehives installed far from fields for the benefit of agriculture can also affect honey production. The quality of the hives could also contribute to the taste of honey (Dassou et al., 2019). In this study the type of beehive used was not found to significantly impact honey quantity, but it did have a significant effect on honey taste. Beehives made of therapeutic plant woods were associated with honey of highly appreciable taste, while the taste differences between honey produced in modern beehives and those made of metal sheets were minor.

5. Conclusion

Beekeeping is predominantly carried out in the north of Benin by cotton farmers who extensively use chemical pesticides for their crop cultivation. Herbicides and insecticides, coming largely from informal supply networks, are the most used pesticides. The timing of pesticide application during the period when bees are collecting nectar poses a risk to the bee population, potentially leading to a decline in the two honeybee breeds found in northern Benin. However, a minority of beekeepers have adopted adaptation measures to mitigate the risk of bee population decline. Yet, the harmful effects of biopesticide contamination on bees should be minimized as well.

This study highlights the challenges faced by beekeeping in Benin due to the use of chemical pesticides and the resulting decline in honeybee populations. To promote sustainable beekeeping and honey production, it is essential to engage young beekeepers, foster innovation in beekeeping practices, and raise awareness about the importance of protecting honeybees and their habitats. Implementing alternative pest management strategies, such as agroforestry systems and integrated pest management, can minimize the negative impacts of agrochemicals on bees and support the ecological and sustainable production of honey.

ACKNOWLEDGEMENT

We thank the beekeepers of northern Benin for their active collaboration in this study. This work was funded by Ecological Organic Agriculture (EOA-Phase 1).

AUTHORS CONTRIBUTIONS

Rôles	Names
Study design	AGD, CA, SV, SDV, VK, DB, ST and LA
Data collection	CA, BD, and AAE
Data analysis	AGD, CA, SV, SDV, VK, DB, ST and LA
Funding acquisition	SDV
Methodology	AGD, CA, SV, SDV, VK, DB, ST and LA
Project management	ST and SDV
Supervision	SDV
Writing – original draft	AGD, CA, SV, SDV, VK, DB, ST and LA
Writing – review & editing	AGD, CA, SV, AAE, BD, DB, ST, VK, SDV and LA

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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.

AVAILABILITY OF DATA AND MATERIALS

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

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