BILINGUAL PUBLISHING GROUP

Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

ARTICLE

Evaluation of Pesticide Effects on Honeybee Health and Colony Collapse: Findings from a Beekeeper Survey in the Beni Mellal-Khenifra Region, Morocco

Amina Brhich [1*] **, *Tarik Hachimi*** [2] **, *Hicham Chatoui*** [1,3,4] **, *Malika Ait Sidi Brahim*** [5] **, *Rachid Hnini*** [1] **, *Redouane Chatoui*** [1] **, *Hasna Merzouki*** [1] **, *Mohamed Merzouki*** [1]

[1] *Biological Engineering Laboratory, Faculty of Sciences and Techniques, Sultan Moulay Slimane University, Beni Mellal 23000, Morocco*

[2] *Water, Biodiversity and Climate Change Laboratory, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakech 40000, Morocco*

[3] *Higher Institute of Nursing Professions and Health Techniques (ISPITS-M), Ministry of Health, Marrakech 40000, Morocco*

[4] *Anthropogenetics, Biotechnologies and Health Laboratory, Nutritional Physiopathologies, Neurosciences and Toxicology Team, Faculty of Sciences, Chouaib Doukkali University, El Jadida 24000, Morocco*

[5] *Laboratory of Agri-Food, Biotechnology, and Valorization of Plant Resources; Phytochemistry and Pharmacology of Medicinal Plants Unit, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakech 40000, Morocco*

ABSTRACT

Since it first appeared in 2022, the phenomenon referred to as Colony Collapse Disorder (CCD) has affected several regions of Morocco to varying degrees. In order to assess the possible impact of pesticides on the appearance of this syndrome, we conducted a study aimed at evaluating the impact of pesticide use on the emergence of this syndrome through a year-long survey involving 160 beekeepers in the Beni Mellal–Khenifra Region (BKR) who also experienced

*CORRESPONDING AUTHOR:

Amina Brhich, Biological Engineering Laboratory, Faculty of Sciences and Techniques, Sultan Moulay Slimane University, Beni Mellal 23000, Morocco; Email: amina.brhich@usms.ac.ma

ARTICLE INFO

Received: 11 November 2024 | Revised: 24 November 2024 | Accepted: 29 November 2024 | Published Online: 23 January 2025
DOI: https://doi.org/10.30564/jees.v7i2.7645

CITATION

Brhich, A., Hachimi, T., Chatoui, H., et al., 2025. Evaluation of Pesticide Effects on Honeybee Health and Colony Collapse: Findings from a Beekeeper Survey in the Beni Mellal-Khenifra Region, Morocco. Journal of Environmental & Earth Sciences. 7(2): 89–100.
DOI: https://doi.org/10.30564/jees.v7i2.7645

an unprecedented desertion of hives during the same period. The majority of surveyed beekeepers practice mixed (45%) or migratory beekeeping (42%) and provide supplementary feeding (83.75%) to support their bees. Nearly 37.5% of the hives are located near crops treated with pesticides, exposing the bees to these chemicals. The results showed that the majority of beekeepers reported a cessation of queen laying (74.38%), high mortality rates among worker bees (81.25%), drones (65.63%), and queens (61.88%). Abnormal behaviors such as immobility with trembling (42.50%), reduced flights (47.50%), and disoriented navigation (28.75%) were also observed. Correlation analyses indicate that proximity to treated crops significantly increases the risk of queen laying cessation (Odds Ratio 6.0) and a reduction in waggle dances (Odds Ratio 2.41). Extended foraging flights show a borderline statistical significance (Odds Ratio 2.33), suggesting a disruption of natural food sources. These results highlight the potential impact of pesticides on colony health and bee behavior, pointing out the need to adapt beekeeping practices and implement protective measures against pesticides.

Keywords: Beekeeping; Honeybees; Colony Collapse Disorder; Pesticides; Beni Mellal-Khenifra; Morocco

1. Introduction

Through their pollinating activity, honeybees (*Apis mellifera*) and wild bees contribute to the world's food supply and ecosystems' durability. Beekeeping, being a crucial element of global food production, fully participates in sustainable development while protecting the environment as well as fighting against hunger and poverty[1].

In Morocco, beekeeping is present in the different regions of the kingdom due to its important floristic, faunistic, and landscape diversity[2]. The sector plays a significant socio-economic role, with more than 54,000 beekeepers deriving their income wholly or in part from this activity[3]. Between modern and traditional methods, the estimated annual production of honey is about 2,500 to 3,500 tons[4].

Due to the Green Morocco Plan launched in 2008 by the Department of Agriculture of the Moroccan Ministry of Agriculture, Fisheries, Rural Development, Water, and Forests, the number of modern hives has increased from 110,000 in 2009 to 640,000 hives in 2019[5]. However, the sector has recently been going through a rather restrictive situation. Indeed, a total or partial colony collapse has been noticed in several regions[6], leading to the disappearance of a considerable number of all kinds of bees. Some hypotheses have been put forward suggesting an accumulation of years of mismanagement including poor nutrition and inappropriate use of pesticides.

Colony Collapse Disorder (CCD) is an atypical phenomenon that emerged in the early 2000s[7], characterized by the sudden disappearance of honeybees. Bee mortality is linked to a variety of factors, including genetic strains, the Varroa destructor mite, habitat degradation, the Asian hornet and viruses[8]. In recent years, pesticides are considered a possible cause of pollinator decline and honeybee colony losses experienced in several countries[9]. The phenomenon of Colony Collapse Disorder (CCD) has been recorded before in several African, American and European countries. Among the international research conducted to study the responsible factors, Frazier et al.[10] carried out a study to determine pesticide levels in pollen, bee bread, and wax. The reported levels in the 108 analyzed samples were of concern regarding pesticide interactions, sublethal impacts, and interactions with other stressors. Moreover, it has been shown that cholinergic and octopaminergic neuronal signaling in foraging bees can be impaired by chronic exposure to pesticides; this biogenic amine-mediated anomaly impacts olfactory learning and memory, leading to disruption of the forager's ability to return to the hive, resulting in CCD[11]. Pesticide exposure was also among the CCD causal theories reported by the United States Department of Agriculture in July 2007[12].

At the national scale, the number of Moroccan scientific studies previously conducted on this issue remains limited. Thus, in this research, we targeted the Beni Mellal-Khenifra Region (BKR)given its position as a center of the beekeeping areas in Morocco, its intensive cultivation, and the reputation of its local honey. The massive disappearance of honeybees, leading to the loss of around 100,000 hives in this region, has been observed by local beekeepers, though the cause of this phenomenon remains unknown[13]. The purpose of this study is to assess the impact of pesticide use in agricultural fields on honeybee mortality, queen fertility, and bee

behavior.

2. Materials and Methods

2.1. Study Area

Located in the center of Morocco, the BKR has important natural wealth likely to strengthen its economic position, including the beekeeping sector which plays a significant socio-economic role (**Figure 1**). In fact, over 5,390 farmers in the BKR derive all or part of their income from this activity[14]. According to the Haut-Commissariat au Plan, the region ranks third nationally in terms of honey production, recording an annual production of 274 tonnes in 2017[15].

Regarding the melliferous resources, the BKR is characterized by great floristic diversity distributed in several strata: tree, shrub and herbaceous. Euphorbia is one of the region's specific plants, located exclusively between El Ksiba and Demnate. It is a wild plant that grows spontaneously, covering an area exceeding 8,000 ha[16]. This particularity has allowed the growth of a very important beekeeping activity that is nationally renowned. In fact, this region's floral and melliferous richness ensures a quality honey widely appreciated locally and nationwide for its peppery taste as well as its medicinal and cosmetic values.

Figure 1. Map of the study region with the most representative beekeeping sites circled.

2.2. Survey

The survey spanned from 2022 to 2023. Beekeepers throughout the BKR were invited to fill out an online questionnaire with individualized access. Before setting up the questionnaire, a pilot study was performed on a sample of two respondents specialized in beekeeping to assess its clarity and remove the elements that do not significantly impact the study.

The questionnaire used is composed of 4 closed-ended multiple-choice questions, 4 semi-open questions with an "Other" option, and 3 open-ended questions, designed to gather both specific and detailed responses. Two sections have been designed: the first relating to the beekeeper and his beekeeping practice, the second to apiary health status. The collected data were then exported and entered into a database intended for statistical analysis.

2.3. Statistical Analysis

To analyze the relationships between the different variables, we used the chi-squared (Khi-2) test. This test allowed us to determine the statistical associations between beekeeping practices, pesticide exposure, and various indicators of bee health and behavior. Additionally, odds ratios were calculated to evaluate the strength of the observed associations. Differences were considered significant at the $p = 0.05$ threshold.

3. Results

Participants' ages ranged from 23 to 67 years, with an average of 43 years. Most of the respondents were trained in beekeeping. The group was heterogeneous in terms of experience, including beekeepers who have been operating for more than 20 years and others who have started the activity for less than five years. The number of owned hives ranged from less than 50 to more than 250. Beekeepers in the region are commonly raising two races of honeybees: Apis mellifera sahariensis (yellow bee) and Apis mellifera mellifera (black bee).

3.1. General Features of Livestock

The various aspects of beekeeping among 160 beekeepers in the Beni Mellal-Khenifra region are shown in **Table 1**.

Table 1. General features of beekeeping stock.

Features	Number (n)	Percentage
Type of beekeeping		
Stationary	21	13.13
Stationary and migratory	72	45.00
Migratory	67	41.88
Not Identified (NI)	0	0.00
Total	160	100
Supplementary feeding		
Yes	134	83.75
No	25	15.63
NI	1	0.63
Total	160	100
Apiary near crops treated with pesticides		
Yes	60	37.50
No	98	61.25
NI	2	1.25
Total	160	100
Bees health		
Very good	17	10.63
Good	42	26.25
Average	90	56.25
Fair	5	3.13
Very bad	5	3.13
NI	1	0.63
Total	160	100

About the types of beekeeping practiced, 21 beekeepers, or 13.13%, practice stationary beekeeping where the hives are not moved. The majority of beekeepers, that is 72 of them (45%), combine stationary and migratory beekeeping, which involves seasonal movement of the hives to exploit various flowering periods. Nearly 42% of respondents, or 67 beekeepers, practice exclusively migratory beekeeping, optimizing production by following flowering cycles.

The vast majority of beekeepers (83.75%) provide supplementary feeding for their bees, which is essential, especially in periods when natural resources are insufficient. Only 25 beekeepers, or 15.63%, do not feed their bees. Only one beekeeper did not answer this question.

Regarding the proximity of apiaries to crops treated with plant protection products, 60 beekeepers, or 37.5%, have their hives near such crops. This may pose risks of pesticide contamination. The majority, 61.25% or 98 beekeepers, have their hives away from this type of crop, thus reducing the risk of bees being exposed to chemicals.

Health status varies among beekeepers. A total of 59 beekeepers, or 36.88%, report a good health state for their bees, while 56.25% or 90 beekeepers rate the state of health as average. Only 10 beekeepers, or 6.25%, reported poor health. One beekeeper did not answer to this question.

3.2. Queen Laying and Bee Mortality

Table 2 gives an in-depth view of queen laying and the different mortality rates in bee colonies in the BKR.

Table 2. Queen laying patterns and mortality rates in different bee castes.

Features	Number (n)	Percentage
Cessation of queen laying		
Yes	119	74.38
No	36	22.50
NI	5	3.13
Total	160	100
Worker mortality		
Yes	130	81.25
No	23	14.38
NI	7	4.38
Total	160	100
Drone mortality		
Yes	105	65.63
No	44	27.50
NI	11	6.88
Total	160	100
Queen mortality		
Yes	99	61.88
No	53	33.13
NI	8	5.00
Total	160	100

The survey revealed that a vast majority of beekeepers (119 or 74.38%) reported cessation of queen laying. This may indicate the occurrence of various environmental or health problems within the colony; the major reasons for this could be stress, disease, or other factors such as pesticides leading to exposure to toxic substances. In contrast, only 36 beekeepers (22.50%) observe normal queen laying which may imply more stable living conditions specifically in these hives. Five beekeepers did not answer this question, accounting for 3.13%, leaving uncertainty surrounding their colonies' status.

The mortality rate of worker bees is quite high. It was observed by 130 beekeepers, which accounts for 81.25%. This high mortality could be due to different factors such as disease, unfavorable management practices, pesticide exposure, and other harmful chemicals. In contrast, there were 23 beekeepers (14.38%) who did not report any significant mortality, which might suggest better management practices or lower exposure to risk factors among their bees. Data on worker mortality was not provided by 7 beekeepers (4.38%).

Figures for drone mortality are not promising either: it is reported that 105 beekeepers (65.63%) face this issue.

The death of drone bees can have a large impact on hive reproductive dynamics. It should be noted that 44 beekeepers (27.50%) did not report high drone mortality, and 11 beekeepers (6.88%) did not specify their observations regarding this aspect in the survey.

99 beekeepers (61.88%) reported queen mortality. The loss of a queen is particularly important as it directly impacts the long-term stability and viability of the colony. 53 beekeepers (33.13%) reported no queen mortality, which may indicate more favorable conditions or adapted management practices. 8 missing responses (5%) completed this section.

3.3. Behavioral Troubles

Table 3 illustrates the behavior of the honeybee population, highlighting several behavioral aspects that may indicate disturbances or stress suffered by the colonies.

Table 3. Behavioral aspects in bee colonies.

Features	Number (n)	Percentage
Immobility with trembling		
Yes	68	42.50
No	76	47.50
NI	16	10.00
Total	160	100
Reduced flight behavior		
Yes	76	47.50
No	66	41.25
NI	18	11.25
Total	160	100
Disturbed orientation		
Yes	46	28.75
No	97	60.63
NI	17	10.63
Total	160	100
Longer foraging flights		
Yes	60	37.50
No	79	49.38
NI	21	13.13
Total	160	100
Decrease in wiggle dances		
Yes	43	26.88
No	99	61.88
NI	18	11.25
Total	160	100
Disrupted food exchange		
Yes	37	23.13
No	103	64.38
NI	20	12.50
Total	160	100

Of the beekeepers surveyed, 68 (42.50%) observed bees showing immobility with tremors, a potential sign of toxicity or neurological disease. On the other hand, 76 beekeepers (47.50%) did not notice this behavior, indicating variation in exposure or reaction to potential stressors. 16 beekeepers (10%) did not provide a response, which may introduce some uncertainty into the overall interpretation of this symptom.

A reduced number of flights was reported by 76 beekeepers (47.50%), which could reflect a general weakness in colonies or unfavorable weather conditions. On the other hand, 66 beekeepers (41.25%) reported no significant reduction in the number of flights. 18 beekeepers (11.25%) did not respond, adding to the complexity of deducing a clear trend in this behavior.

46 beekeepers (28.75%) observed disturbed orientation in their honeybees, a behavior that could be induced by environmental interferences such as pesticides or magnetic disruptors. However, a majority of 97 beekeepers (60.63%) did not detect any significant disturbance in orientation, suggesting that this problem could be localized or specific to certain farming practices. 17 (10.63%) gave no information on this subject.

60 beekeepers (37.50%) reported that foraging flights had become longer, which could indicate a scarcity of local food sources or the effects of toxic substances affecting the bees' ability to feed effectively. 79 (49.38%) did not observe this change, and 21 (13.13%) did not respond.

According to 43 beekeepers (26.88%), wriggling dances, which are essential for communicating the location of food, have decreased. This could be linked to a disturbance in the bees' sensory or cognitive abilities. However, 99 beekeepers (61.88%) did not report any reduction, and 18 (11.25%) failed to reply.

37 beekeepers (23.13%) noted a disturbed exchange of food (trophallaxis) among the bees, a behavior that could be influenced by stress factors or toxins in the environment. A majority, 103 beekeepers (64.38%), reported no disturbance in this exchange, while 20 (12.50%) left this question unanswered.

3.4. Correlation Analysis

Correlation analysis indicates that proximity to treated crops significantly increases the risk of queen laying cessation (Odds Ratio 6.0) (**Tables 4** and **5**) and a reduction in waggle dances (Odds Ratio 2.41) (**Table 6**). Extended foraging flights show a borderline statistical significance (Odds Ratio 2.33) (**Table 7**), suggesting a disruption of natural food sources.

Table 4. Correlation analysis between proximity to crops treated with agrochemicals and queen laying patterns and mortality rates in different bee castes.

	Proximity to Crops Treated with Agrochemicals					
	Yes	**No**	**χ^2**	**Odds Ratio**	**Confidence Interval 95% CI**	**p**
Cessation of queen laying						
Yes	53 (34.4%)	65 (42.2%)	9.89	6.0	(1.93, 18.63)	0.00166
No	5 (3.5%)	31 (20.1%)				
Worker mortality						
Yes	52 (34.0%)	78 (51.0%)	0.78	1.90	0.63, 5.79	0.37764
No	6 (3.9%)	17 (11.1%)				
Drone mortality						
Yes	44 (29.5%)	61 (40.9%)	2.53	2.22	0.92, 5.35	0.11142
No	12 (8.1%)	32 (21.5%)				
Queen mortality						
Yes	40 (26.5%)	58 (38.4%)	0.85	1.561.56	0.71, 3.42	0.35580
No	18 (11.9%)	35 (23.2%)				

Table 5. Correlation analysis between distance from crops treated with pesticides and queen-laying patterns and mortality rates in different bee castes.

	Distance from Crops Treated with Pesticides					
	Close (≤ 10 km)	**Far (>10 km)**	**χ^2**	**Odds Ratio**	**Confidence Interval 95% CI**	**p**
Cessation of queen laying						
Yes	47 (38.2%)	48 (39.0%)	9.63	5.875	1.89, 18.23	0.00191
No	4 (3.3%)	24 (19.5%)				
Worker mortality						
Yes	47 (38.8%)	57 (47.1%)	1.99	2.68	0.82, 8.77	0.15794
No	4 (3.3%)	13 (10.7%)				
Drone mortality						
Yes	47 (38.8%)	57 (47.1%)	0.56	1.51	0.65, 3.52	0.45241
No	4 (3.3%)	13 (10.7%)				
Queen mortality						
Yes	47 (38.8%)	57 (47.1%)	0.75	1.53	0.70, 3.34	0.38509
No	4 (3.3%)	13 (10.7%)				

Table 6. Correlation analysis between proximity to crops treated with agrochemicals and behavioral aspects in bee colonies.

	Proximity to Crops Treated with Agrochemicals					
	Yes	**No**	**χ^2**	**Odds Ratio**	**Confidence Interval (95% CI)**	**p**
Immobility with trembling						
Yes	26 (18.3%)	40 (28.2%)	0.09	1.18	0.60, 2.32	0.763
No	27 (19.0%)	49 (34.5%)				
Reduced number of flights						
Yes	24 (16.9%)	52 (36.6%)	1.81	0.59	0.30, 1.16	0.179
No	29 (20.4%)	37 (26.1%)				
Disturbed orientation						
Yes	21 (14.7%)	25 (17.5%)	1.07	1.56	0.76, 3.17	0.302
No	34 (23.8%)	63 (44.1%)				
Longer foraging flights						
Yes	28 (14.5%)	32 (16.6%)	2.17	0.141	0.89, 3.55	0.141
No	26 (13.5%)	53 (27.5%)				
Decrease in wriggling dances						
Yes	16 (11.2%)	21 (14.7%)	4.80	2.41	1.16, 5.00	0.028
No	37 (25.9%)	66 (46.2%)				

Table 6. *Cont.*

	Proximity to Crops Treated with Agrochemicals					
	Yes	**No**	**χ^2**	**Odds Ratio**	**Confidence Interval (95% CI)**	**p**
Disrupted food exchange						
Yes	16 (11.2%)	21 (14.7%)	0.35	1.36	0.63, 2.91	0.555
No	37 (25.9%)	66 (46.2%)				

Table 7. Correlation analysis between distance from crops treated with pesticides and behavioral aspects in bee colonies.

	Distance from Crops Treated with Pesticides					
	Close (≤ 10 km)	**Far (>10 km)**	**χ^2**	**Odds Ratio**	**Confidence Interval (95% CI)**	**P**
Immobility with trembling						
Yes	26 (22.8%)	29 (25.4%)	0.79	1.51	0.71, 3.18	0.374
No	22 (19.3%)	37 (32.5%)				
Reduced number of flights						
Yes	21 (18.6%)	34 (30.1%)	0.28	0.76	0.36, 1.61	0.599
No	26 (23.0%)	32 (28.3%)				
Disturbed orientation						
Yes	20 (17.5%)	22 (19.3%)	0.51	1.43	0.66, 3.08	0.475
No	28 (24.6%)	44 (38.6%)				
Longer foraging flights						
Yes	25 (22.5%)	22 (19.8%)	3.84	2.33	1.07, 5.05	0.0500
No	21 (18.9%)	43 (38.7%)				
Decrease in wriggling dances						
Yes	17 (14.9%)	19 (16.7%)	0.30	1.36	0.61, 3.01	0.584
No	31 (27.2%)	47 (41.2%)				
Disrupted food exchange						
Yes	14 (12.5%)	18 (16.1%)	0.08	1.23	0.54, 2.82	0.784
No	31 (27.7%)	49 (43.8%)				

4. Discussion

Data analysis collected from 160 beekeepers in the BKR provides an in-depth look at beekeeping practices, colony health, and bee behavior, highlighting the possible effects of plant protection products.

Indeed, our survey revealed that most beekeepers (56.25%) are unsatisfied with the health status of their hives, as they consider it to be average. Regarding apiarian breeding, our investigation revealed the importance of transhumance (41.88%) compared to stationary beekeeping (13.13%), with a percentage of 45% among the two combined practices. As a result, the bees will have only one source of food, as transhumance is performed to pollinate a particular crop. In addition, these transhumances lead to increased bee abundance in the same area, which also contributes to disease spread. According to the beekeepers, transhumance takes place during the four seasons and within different beekeeping areas of the BKR and even outside the region. Indeed, these areas are overflowing with melliferous plants attractive to honeybees and much sought after by beekeepers. However, our survey revealed the proximity of some beekeeping operations to crops using phytosanitary treatments. 37.50% raise their hives nearby intensive agriculture sites using phytosanitary products and whose application method is unknown among them. Of the various factors suggested, pesticides are one of the most relevant and in-depth investigated causes of colony losses[17–19]. Usually, pesticides are applied in liquid form to plants and/or soil. Indeed, only a partial amount of the pesticide applied reaches the intended target. Thus, given their non-discriminatory nature, pesticides necessarily have effects on non-target organisms and ecosystems. Among these chemicals, neonicotinoids are a class of commonly used pesticides that have devastating effects on bees and other pollinating insects. Specifically, imidacloprid and clothianidin have been known to cause symptoms in these insects such as memory loss[20], navigational disruption[21], paralysis[22], and death[23]. When the honeybees are not

killed or paralyzed, they are unable to find their way back to their hives, resulting in colony collapse [24, 25]. This phenomenon, known on a national and international scale, is currently pushing beekeepers to avoid placing their hives near industrial plantations and to favor wild places [26].

Honeybees can be exposed to a wide spectrum of phytosanitary products exposing all individuals, from larvae to queen at any time of the year [27]. In fact, a cessation of queen laying was noted by 74.38% of respondents. Wu-Smart and Spivak [28] demonstrated that neonicotinoids, particularly imidacloprid, impact the behavior and egg-laying activity of queens. Pesticides have also been shown to impact queens by affecting their survival, disrupting their physiology (immunity, antioxidant defenses, chemical communication…), inducing ovarian degeneration or altering sperm quality stored in the spermatheca [29–36]. Furthermore, it is suspected that a shortage of healthful drones producing quality seed results in poorly mated queens also resulting in queen dysfunction [29, 37]. Moreover, Kairo et al. [38] have demonstrated that drone exposure to the systemic insecticide fipronil indirectly impairs queen reproductive potential.

Colony health reveals significant challenges, with high mortality rates among workers, drones, and queens, with respective rates of 81.25%, 65.63%, and 61.88%. Studies have shown that exposure of honeybee drones to neonicotinoids induces reduced survival [39], increased drifting behavior to non-maternal colonies [40], and reduced sperm quantity and viability [41]. Wu, Anelli and Sheppard [42] demonstrated that worker bees exposed to high levels of pesticide residues have a lower survival rate than bees reared in relatively uncontaminated comb. In honeybee queens, exposure to neonicotinoids reduces reproductive performance, leading to an increase in supersedure [36, 43]. Indeed, the compromised physiology and life of queens can seriously threaten the colony's survival under the pressure of stress factors [36]. In a statewide survey of annual colony losses, beekeepers reported the primary reason for colony collapse to be queen failure [44].

The observed abnormal bee behaviors such as immobility with trembling, fewer flights, disturbed orientation, longer foraging flights, fewer wriggling dances and disturbed food exchange could be symptoms of exposure to toxic substances or other environmental stress factors affecting the bees' ability to function normally. Fischer et al. [45] revealed that neonicotinoids weaken bees' ability to use bearings and return to their nests when flying freely. Many studies have reported that ingestion of imidacloprid-containing pollen by honeybees affected their ability to discriminate colors in a T-maze [46]. Furthermore, Eiri and Nieh [47] found that bees exposed to pesticides were less likely to dance. Foraging bees perform wriggling dances to show the rest of their congeners where to find good food. Once a new source of pollen and/or nectar has been identified by the worker bee, she returns to the hive to alert all the other bees. She communicates this information in a meticulously choreographed figure-of-eight dance. The bees are informed of the location of the food by the length and orientation of the undulating part of the dance. Likewise, contamination with imidacloprid leads to a reduction in the bees' dancing performance by 4 to 10 times. Some bees even stopped dancing. In fact, reduced dancing has a negative impact on the bees' ability to feed on new sources.

Our survey also revealed that feeding is applied by 83.75% of participating beekeepers; however, this artificial feeding does not offer a varied diet. This technique is therefore questioned since it might result in weakened immune defenses making the bees more vulnerable to external pathogens and contaminants [48].

Regarding agricultural practices, Morocco's new agricultural strategy aims to rehabilitate agriculture through the Green Morocco Plan, which involves the coexistence of traditional production and intensive agriculture favoring monoculture; the latter however hinders biodiversity and prevents insects from alternating their food sources in a balanced diet. Moreover, when these plants are poor in pollen and nectar, they do not interest bees either [49].

The results of correlation analysis suggest several significant relationships between proximity to treated crops and bee behavior. Laying cessation, with an odds ratio (OR) of 6.0, indicates that queens are six times more likely to stop laying near treated crops. This may reflect exposure to neonicotinoid pesticides, known for their neurotoxic effects on insects [50]. A reduction in queen laying leads to a reduction in the colony population, compromising its long-term viability. The data also revealed a significant reduction in the bees' waggle dances, a crucial behavior used to communicate the location of food sources. A reduction in this behavior, with an OR of 2.41, suggests that bees exposed to treated crops are less able to communicate effectively. This disruption may be

caused by the effect of pesticides on the bees' nervous system, affecting their ability to navigate and memorize flower locations[45]. Ultimately, the extended foraging flights, with an OR of 2.33, are statistically significant, although borderline. This suggests that bees need to fly further and longer to find suitable food sources. This may be due to the destruction or contamination of natural food sources in the vicinity of treated crops. Honeybees exposed to pesticides may also suffer from orientation disorders, preventing them from locating flowers efficiently[51]. This behavior leads to reduced pollination efficiency, as well as increased bee fatigue and mortality, resulting in CCD.

5. Conclusions

Our study has revealed the issue of pesticide involvement in bee colony collapse, which remains a sensitive and recurrent controversy, and has justified the successive banning of several systemic insecticides since the 1990s in the world. In Morocco, although the use of certain harmful pesticides has been restricted, the regulatory framework for beekeeping and pesticide approval remains insufficient, and there is a growing need for updated legislation to better protect bee populations and ensure sustainable beekeeping practices.

Hence, this work remains preliminary to more analyses that should be carried out by examining further correlations between colony health and the occurrence of pesticide residues in beekeeping matrices. This task would then require more sophisticated statistical models and likely a reexamination of the working data.

Author Contributions

A.B. assured the conceptualization, original draft preparation, and visualization of the results. She contributed to formal analysis, investigation, and the development of the methodology in collaboration with T.H. and H.C. M.M. handled the processing and statistical analysis of the data and provided overall supervision to ensure the study's quality and rigor. R.C. and H.M. provided resources for the project. The writing and editing of the manuscript involved A.B., M.A.S.B. and R.H. All authors have read and approved the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

The authors extend their deepest gratitude to the participating beekeepers for their involvement and time devoted to the survey.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article. The research was conducted independently, and no financial or personal relationships exist that could have influenced the work reported in this study.

References

[1] Nzula, M.C., 2018. Evaluation of apiculture in the context of food security and environmental management in Kathonzweni division, Makueni county, Kenya. Available from: https://ir-library.ku.ac.ke/server/api/core/bitstreams/86224b5d-9639-4037-b448-9e786237453e/content (cited 23 January 2025).

[2] Ministère de l'Environnement, 2017. Etude nationale sur la biodiversité au Maroc. Projet GEF 6105/92.

[3] Moujanni, A., Essamadi, A.K., Terrab, A., 2017. Beekeeping in Morocco: focus on honey production. International Journal of Innovation and Applied Studies. 20(1), 52–78. Available from: https://hal.science/hal-01464924v1 (cited 23 January 2025).

[4] Département de l'Agriculture, Maroc, 2016. Contrats Programmes pour le développement des filières de production marocaine. Available from:

https://www.agriculture.gov.ma/sites/default/files/contrats_programmes_vf.pdf (cited 23 January 2025).

[5] Les Chiffres Clés de La Filière Apiculture—Fellah Trade, 2022. Available from: www.fellah-trade.com (In French) (cited 23 January 2025).

[6] Apiculture: Un effondrement des colonies est constaté dans la plupart des régions. La vie eco, 2022. Available from: https://www.lavieeco.com/affaires/apiculture-un-effondrement-des-colonies-est-constate-dans-la-plupart-des-regions/ (In French) (cited 23 January 2025).

[7] Johnson, R., 2011. Honey bee colony collapse disorder. DIANE Publishing: Darby, PA, USA.

[8] Vanengelsdorp, D., Traynor, K.S., Andree, M., et al., 2017. Colony Collapse Disorder (CCD) and bee age impact honey bee pathophysiology. PLoS One. 12(7), e0179535. DOI: https://doi.org/10.1371/journal.pone.0179535

[9] Grillone, G., Laurino, D., Manino, A., et al., 2017. Toxicity of thiametoxam on in vitro reared honey bee brood. Apidologie. 48, 635–643. Available from: https://hal.science/hal-02973432v1 (cited 23 January 2025).

[10] Frazier, M., Mullin, C., Frazier, J., et al., 2008. What have pesticides got to do with it?. American Bee Journal. 148(6), 521–524. Available from: https://www.researchgate.net/publication/242418397 (cited 23 January 2025).

[11] Farooqui, T., 2013. A potential link among biogenic amines-based pesticides, learning and memory, and colony collapse disorder: A unique hypothesis. Neurochemistry International. 62(1), 122–136. DOI: https://doi.org/10.1016/j.neuint.2012.09.020

[12] CCD Steering Committee Working Group, 2007. Colony collapse disorder action plan. Available from: http://www.ars.usda.gov/is/br/ccd/ccd_actionplan.%20Pdf (cited 23 January 2025).

[13] Pollinisateurs Au Maroc, les abeilles désertent le plus ancien rucher au monde. Liberation, 2022. Available from: https://www.liberation.fr/environnement/biodiversite/au-maroc-les-abeilles-desertent-le-plus-ancien-rucher-au-monde-20220404_SHC3LHW56BADDPTCFHAXVEDJ6U/ (In French) (cited 23 January 2025).

[14] L'apiculture: Un secteur à fort potentiel dans la région Béni Mellal-Khénifra. La Vérité, 2021. Available from: https://www.laverite.ma/lapiculture-un-secteur-a-fort-potentiel-dans-la-region-beni-mellal-khenifra/#:~:text=B%C3%A9ni%20Mellal%2DKh%C3%A9nifra,L'apiculture%3A%20Un%20secteur%20%C3%A0%20fort%20potentiel%20dans,la%20r%C3%A9gion%20B%C3%A9ni%20Mellal%2DKh%C3%A9nifra&text=En%20raison%20de%20sa%20diversit%C3%A9,cette%20activit%C3%A9%20en%20pleine%20expansion (In French) (cited 23 January 2025).

[15] HCP, 2017. Projections de la population des régions et des provinces 2014-2030. Available from: https://www.hcp.ma/region-drta/PROJECTIONS-DE-LA-POPULATION-DES-REGIONS-ET-DES-PROVINCES-2014-2030_a59.html (In French) (cited 23 January 2025).

[16] Order, M., 2012. Reconnaissance de l'IGP « Miel d'Euphorbe Tadla-Azilal » et homologation du cahier des charges y afférent (NOMACERT sarl). Morr off Bull. 6074, 2542–2525. Available from: https://faolex.fao.org/docs/pdf/mor204633.pdf (In French) (cited 23 January 2025).

[17] Blacquiere, T., Smagghe, G., Van Gestel, C.A., et al., 2012. Neonicotinoids in bees: A review on concentrations, side-effects and risk assessment. Ecotoxicology. 21, 973–992. DOI: https://doi.org/10.1007/s10646-012-0863-x

[18] Van der Sluijs, J.P., Simon-Delso, N., Goulson, D., et al., 2013. Neonicotinoids, bee disorders and the sustainability of pollinator services. Current Opinion in Environmental Sustainability. 5(3–4), 293–305. DOI: https://doi.org/10.1016/j.cosust.2013.05.007

[19] European Academies' Science Advisory Council (EASAC), 2015. Ecosystem services, agriculture and neonicotinoids. Available from: https://easac.eu/fileadmin/PDF_s/reports_statements/Easac_15_ES_web_complete.pdf (cited 23 January 2025).

[20] Siviter H., Koricheva J., Brown M.J., et al., 2018. Quantifying the impact of pesticides on learning and memory in bees. Journal of Applied Ecology. 55(6), 2812–2821. DOI: https://doi.org/10.1111/1365-2664.13193

[21] Palmer, M.J., Moffat, C., Saranzewa, N., et al., 2013. Cholinergic pesticides cause mushroom body neuronal inactivation in honeybees. Nature Communications. 4(1), 1–8. DOI: https://doi.org/10.1038/ncomms2648

[22] Diao, Q., Li B., Zhao H., et al., 2018. Enhancement of chronic bee paralysis virus levels in honeybees acute exposed to imidacloprid: A Chinese case study. Science of the Total Environment. 630, 87–494. DOI: https://doi.org/10.1016/j.scitotenv.2018.02.258

[23] Dai, P., Jack C.J., Mortensen A.N., et al., 2019. Chronic toxicity of clothianidin, imidacloprid, chlorpyrifos, and dimethoate to Apis mellifera L. larvae reared in vitro. Pest Management Science. 75(1), 29–36. DOI: https://doi.org/10.1002/ps.5124

[24] Gupta, D., Chauhan, H., Gupta, S., et al., 2019. Effect of colony collapse disorder on honeybees. Journal of Computational and Theoretical Nanoscience. 16(10), 4149–4152. DOI: https://doi:10.1166/jctn.2019.8494

[25] Magal, P., Webb, G.F., Wu, Y., 2019. An environmental model of honey bee colony collapse due to pesticide contamination. Bulletin of Mathematical Biology. 81, 4908–4931. DOI: https://doi.org/10.1007/s11538-019-00662-5

[26] Buchori, D., Rizali, A., Priawandiputra, W., et al., 2022.

Beekeeping and managed bee diversity in Indonesia: Perspective and preference of beekeepers. Diversity. 14(1), 52. DOI: https://doi.org/10.3390/d14010052

[27] Yordanova, M., Evison, S.E., Gill, R.J., et al., 2022. The threat of pesticide and disease co-exposure to managed and wild bee larvae. International Journal for Parasitology: Parasites and Wildlife. 17, 319. DOI: https://doi.org/10.1016/j.ijppaw.2022.03.001

[28] Wu-Smart, J., Spivak, M., 2016. Sub-lethal effects of dietary neonicotinoid insecticide exposure on honey bee queen fecundity and colony development. Scientific Reports. 6(1), 1–11. Available from: https://www.researchgate.net/publication/307086827 (cited 23 January 2025).

[29] Camazine, S., Cakmak, I., Cramp, K., et al., 1998. How healthy are commercially-produced US honey bee queens?. The American Bee Journal. 138, 677–680. Available from: https://www.researchgate.net/publication/282053963 (cited 23 January 2025).

[30] Alaux, C., Folschweiller, M., McDonnell, C., et al., 2011. Pathological effects of the microsporidium Nosema ceranae on honey bee queen physiology (Apis mellifera). Journal of Invertebrate Pathology. 106(3), 380–385. DOI: https://doi.org/10.1016/j.jip.2010.12.005

[31] Gauthier, L., Ravallec, M., Tournaire, M., et al., 2011. Viruses associated with ovarian degeneration in Apis mellifera L. queens. PLOS ONE. 6(1), e16217. DOI: https://doi.org/10.1371/journal.pone.0016217

[32] Collins, A.M., Pettis, J.S., 2013. Correlation of queen size and spermathecal contents and effects of miticide exposure during development. Apidologie. 44, 351–356. DOI: https://hal.science/hal-01201304v1

[33] Sandrock, C., Tanadini, L.G., Pettis, J.S., et al., 2014. Sublethal neonicotinoid insecticide exposure reduces solitary bee reproductive success. Agricultural and Forest Entomology. 16(2), 119–128. DOI: https://doi.org/10.1111/afe.12041

[34] Williams, G.R., Troxler, A., Retschnig, G., et al., 2015. Neonicotinoid pesticides severely affect honey bee queens. Science Reports. 5, 146211. DOI: https://doi:10.1038/srep14621

[35] Chaimanee, V., Evans, J.D., Chen, Y., et al., 2016. Sperm viability and gene expression in honey bee queens (Apis mellifera) following exposure to the neonicotinoid insecticide imidacloprid and the organophosphate acaricide coumaphos. Journal of Insect Physiology. 89, 1–8. DOI: https://doi.org/10.1016/j.jinsphys.2016.03.004

[36] Dussaubat, C., Maisonnasse, A., Crauser, D., et al., 2016. Combined neonicotinoid pesticide and parasite stress alter honeybee queens' physiology and survival. Scientific Reports. 6(1), 1–7. DOI: https://doi.org/10.1038/srep31430

[37] Rhodes, J., Somerville, D., 2003. Introduction and early performance of queen bees: Some factors affecting success: A report for the rural industries research and development corporation. RIRDC Publication No 03/049.

[38] Kairo, G., Provost, B., Tchamitchian, S., et al., 2016. Drone exposure to the systemic insecticide Fipronil indirectly impairs queen reproductive potential. Scientific Reports. 6(1), 1–12. DOI: https://doi.org/10.1038/serp31904

[39] Grassl, J., Holt, S., Cremen, N., et al., 2018. Synergistic effects of pathogen and pesticide exposure on honey bee (Apis mellifera) survival and immunity. Journal of Invertebrate Pathology. 159, 78–86. DOI: https://doi.org/10.1016/j.jip.2018.10.005

[40] Straub, L., Villamar-Bouza, L., Bruckner, S., et al., 2021. Negative effects of neonicotinoids on male honeybee survival, behaviour and physiology in the field. Journal of Applied Ecology. 58(11), 2515–2528. DOI: https://doi.org/10.1111/1365-2664.14000

[41] Strobl, V., Albrecht, M., Villamar-Bouza, L., et al., 2021. The neonicotinoid thiamethoxam impairs male fertility in solitary bees, Osmia cornuta. Environmental Pollution. 284, 117106. DOI: https://doi.org/10.1016/j.envpol.2021.117106

[42] Wu, J.Y., Anelli, C.M., Sheppard, W.S., 2011. Sublethal effects of pesticide residues in brood comb on worker honey bee (Apis mellifera) development and longevity. PlOS ONE, 6(2), e14720. DOI: https://doi.org/10.1371/journal.pone.0014720

[43] Sandrock, C., Tanadini, M., Tanadini, L.G., et al., 2014. Impact of chronic neonicotinoid exposure on honeybee colony performance and queen supersedure. PLOS ONE. 9(8), e103592. DOI: https://doi.org/10.3389/finsc.2022.821145

[44] Seitz, N., Traynor, K.S., Steinhauer, N., et al., 2015. A national survey of managed honey bee 2014–2015 annual colony losses in the USA. Journal of Apicultural Research. 54(4), 292–304. DOI: https://doi.org/10.1080/00218839.2016.1153294

[45] Fischer, J., Müller, T., Spatz, A.K., et al., 2014. Neonicotinoids interfere with specific components of navigation in honeybees. PloS ONE. 9(3), e91364. DOI: https://doi.org/10.1371/journal.pone.009136

[46] Han, P., Niu, C.Y., Lei, C.L., et al., 2010. Use of an innovative T-tube maze assay and the proboscis extension response assay to assess sublethal effects of GM products and pesticides on learning capacity of the honey bee Apis mellifera L. Ecotoxicology. 19, 1612–1619. DOI: https://doi.org/10.1007/s10646-010-0546-4

[47] Eiri, D.M., Nieh, J.C., 2012. A nicotinic acetylcholine receptor agonist affects honey bee sucrose responsiveness and decreases waggle dancing. Journal of Experimental Biology. 215(12), 2022–2029. DOI: https://doi.org/10.1242/jeb.068718

[48] Alaux, C., Ducloz, F., Crauser, D., et al., 2010. Diet effects on honeybee immunocompetence. Biology Let-

ters. 6(4), 562–565. DOI: https://doi.org/10.1098/rsbl.2009.0986

[49] Chiron, J., Hattenberger, A.M., 2008. Mortalités, effondrements et affaiblissements des colonies d'abeilles. Entomology Papers from Other Sources. 3. Available from: https://digitalcommons.unl.edu/entomologyother (In French) (cited 23 January 2025).

[50] Tsvetkov, N., Samson-Robert, O., Sood, K., et al., 2017. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. Science. 356(6345), 1395–1397. DOI: https://doi.org/10.1126/science.aam7470

[51] Gill, R.J., Ramos-Rodriguez, O., Raine, N.E., 2012. Combined pesticide exposure severely affects individual-and colony-level traits in bees. Nature. 491(7422), 105–108. DOI: https://doi.org/10.1038/nature11585