Beekeeper's perception of risks affecting colony mortality: a pilot survey

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Abstract

Understanding hobby beekeepers' perception of risks affecting bee health and mortality is essential to analyse the reasons for adopting or rejecting good management practices. A perception survey on how beekeepers perceive and manage risks related to climate change, Varroa infestation, management practices, and pesticide exposure was designed and launched online. This unprecedented sociological survey involved 355 beekeepers spread all over Belgium. A two-sample t-test with unequal variances comparing beekeepers with colony mortality rates below or exceeding the acceptable level, i.e. <10% and [?]10%, indicates that beekeepers (N=213), with colony mortality rates <10% generally have greater levels of perceived risk and the benefits of action that lead to increased motivation to act in better ways. The results of this survey highlight the importance of taking socio-economic determinants into account in any risk mitigation strategy associated with bee mortality when dealing with hobby beekeepers.

Introduction

While wild bees are acknowledged to be extremely important pollinators for many plant species, honey bees (*Apis mellifera* spp.) remain the most economically and easily managed pollinator of the main crop monocultures worldwide (Klein et al., 2007). In recent years, the decline in pollinators, both wild and managed, has gained much attention (Samson-Robert et al., 2017), prompting a considerable amount of research (Lundin et al., 2015). In light of these studies, a suite of numerous, and interacting factors have been highlighted as possible risk factors having an impact on bee decline and mortality. These risks include the loss of foraging resources due to habitat loss and its homogenization (Kennedy et al., 2013), the introduction of invasive species (Monceau et al., 2014), climate change (Dennis and Kemp, 2016; Murcia Morales et al., 2020; Neumann & Carreck, 2015; Switanek et al., 2017), parasites (Goulson et al., 2015; Muli et al., 2014), pathogens (Doublet et al., 2015; Mondet et al., 2014), loss of genetic diversity (Oldroyd, 2007), exposure to pesticides (Cresswell et al., 2012; James and Xu, 2012; Johnson et al., 2010; Nazzi et al., 2012) and beekeeping management practices (Giacobino et al., 2017; Steinhauer, 2017; vanEngelsdorp et al., 2012).

Honey bees are managed pollinators, their survival relies thus on the competence and experience of the beekeeper (Steinhauer et al., 2018). Nevertheless, the impacts of beekeepers 'knowledge and management practices have often been overlooked (Jacques et al., 2017). When facing (e.g.) high pest pressure, beekeepers can reduce hazards through physical or chemical interventions (Giacobino et al., 2014). While good management can alleviate stress, poor management can accentuate it. Good management practices or good risk management must be developed with proper education and experience (Steinhauer et al., 2018).

The Belgian beekeeping context is particular as the majority of beekeepers are hobbyists (not professional/commercial). Honey bees are largely kept in stationary apiaries, for honey production, by amateur beekeepers with relatively small operations and often, with empirical, local, and heterogeneous bee management practices. Beekeepers' main occupation and source of income lay outside beekeeping; they keep bees because of the activity satisfaction they derive and the intrinsic values attached to beekeeping.

Before applying adequate risk management, beekeepers need to perceive the impact of risks on the colony, as well as the benefits of the actions to undertake. Understanding beekeepers' perception of risks affecting honeybee health and mortality is essential to analyse the reasons for adopting or rejecting some beekeeping management practices. Identifying and preventing risks associated with beekeeping management may help avoid exacerbating colony mortality rate (Giacobino et al., 2014).

In this study, a grounded theory from health psychology was used to build a framework adapted to the beekeepers: the Health Belief Model (HBM) (Janz and Becker, 1984; Rosenstock, 1974) (**Figure 1**). The HBM was specifically developed for the understanding of health-related behaviour (Vande Velde et al., 2015). It has four key concepts: (i) perceived susceptibility is an individual's belief that a risk can occur. The relationship of perceived susceptibility to taking a risk management action is modified by (ii) perceived severity of the risk, (iii) the perceived benefits of risk management to mitigate the risk and its consequences, and the (iv) perceived barriers to taking action. Beyond these, actions or intentions, health responsibility, and influences can also modify the relationship of perceived susceptibility to action. Actions (or intentions) include recognized clinical signs, knowledge, and education. It is expected that greater levels of perceived risk combined with strong perceptions of the benefits of action will lead to increased motivation to act in better ways. Other intangible elements of risk perception and other motivations for strategy adoption within animal health risk management often remain unidentified though research on these issues is beginning to emerge (Ellis-Iversen et al., 2010; Jansen et al., 2009; Valeeva et al., 2007). This may be one of the reasons why the adoption of risk management strategies is hard to predict and influence (Valeeva et al., 2011).

This cross-sectional survey aimed to estimate the current state of perception of risks related to bee health and mortality at the level of hobbyist beekeepers in Belgium and to assess a possible association between colony mortality, the four key concepts as well as the demography, the actions or intentions, the health responsibility, and the influences.

Conventional production economics suggests that producers' decisions are essentially economic ones, driven by the desire to maximize household welfare, net income, or profit (Garforth, 2015). As the majority of Belgian beekeepers are hobbyists, we need to look beyond economic drivers in the search for an understanding of beekeeper's decisions and behaviour.

Materials and methods

Development of the perception survey

The survey was developed to assess the perception of four key concepts: the susceptibility and severity of the risk, as well as the benefits, and barriers linked to mitigating the risk. The perceived susceptibility is an individual's belief that risk can occur. The perceived severity is the outcome of the risk. The perceived benefits are the expected effectiveness of the practices to modify the consequences. The barriers are the perceived obstacles to take action (Janz and Becker, 1984) or to obtain benefits from these actions. Four major risks having an impact on honey bee were assessed, i.e., climate change, *Varroa destructor*infestation, pesticide exposure, and management practices. In addition to the close-ended questions assessing the perceived susceptibility, severity, benefits and barriers, questions related to demography (e.g. age, years of experience, and the number of hives), psychological characteristics (risk aversion), bee mortality rates, health responsibility, actions, and influences have been asked. Beekeepers' attitude to risk was derived by measuring their degree of risk aversion using four statements on general issues (i.e. to read the medicine prescription instructions before using them, to carry a first aid kit, to take financial risks in order to invest and increase financial opportunities, to consult various people before taking a decision) (**Appendix S1**). The variable 'relative risk aversion' was obtained as an average score of the stated values. To ensure consistency, the questions were formulated in such a way that "yes" implied a higher value and respondents could rate their agreement with the statement on a hundred-point scale (0: not at all in agreement, 100: completely in agreement) using a visual scale. To check the respondents' rationality and internal consistency, some of the above variables were assessed by multiple questions and consolidated in an average (see**Appendix S2**). The questionnaire was pretested individually on two experts in beekeeping and four beekeepers. It was then launched online via the platform LimeSurvey.

Data collection

An information letter on the survey, containing a short description of the survey, the duration of the questionnaire and the assurance that responses would be anonymous and confidential was spread in 2 national languages (French and Dutch) through the University of Liège, the University of Gent, and the Beekeeping Research and Information Center (CARI) networks. Due to the absence of a complete sampling frame of beekeepers, the recruitment email directed participants to an online survey and asked respondents to forward the survey invitation and the link to fellow beekeepers. Requests to distribute the survey were also sent to beekeeping unions, and regional beekeeping schools. We used the snowball sampling strategy, so respondents are the subset of the target population who learned about the survey and were willing to participate (Lupo et al., 2016; Thoms et al., 2018). The online survey was open from 22 December 2017 until 06 February 2018. The survey was edited for processing and entered into a database. Filters were developed to exclude from the analysis responses such as questionnaires with incomplete answers, irrational (e.g. age=3 years), or those that were obviously duplicate answers. Only beekeepers older than 18 years, with at least a year of experience and a minimum of 1 hive were considered for the survey.

Statistical analysis

The database was examined for potential outliers concerning questions related to demography variables to exclude invalid questionnaires. Some of the variables were assessed by multiple questions than consolidated in an average (e.g. risk aversion score is the average of questions related to psychological (P) characteristics P1 to P5, health responsibility (R) score is the average of questions R1 to R5) (**Appendix 2**). The representativeness of the participants and completion rate compared to the number of registered beekeepers in the Federal Agency for the Safety of the Food Chain (FASFC) database was evaluated with a chi-squared test ($\alpha = 0.05$; df=1). A two-sample*t* -test with unequal variances (Welch-test) was performed to compare the means of each variable regarding the colony mortality rate; i.e. under the 10% colonies mortality threshold and above or equal the 10% (Morgenthaler, 1968). The cut-off level of 0.05 was considered as the *p* -value for significance.

Results

Study population

The survey recorded 627 responses all over Belgium, from which 355 were considered complete and valid (i.e. 213 and 142 beekeepers with colony mortality rate <10% and [?]10%, respectively). These valid answers represent 6.7% of the registered beekeepers' number (N = 5852) in Belgium in 2017 suggesting the survey captured a reasonably representative sample. The proportion of beekeepers in Flanders and Wallonia who participated in the survey is representative of the Belgian beekeepers' repartition in each part of the country (**Table 1**). Indeed, the participation rate for the entire Belgian territory was 10.71% and was statistically representative of the sample of registered beekeepers on the FASFC database (Chi-squared test $_{(1\delta\varphi \cdot\ \alpha = 0.05)}$ = 0.0007; *p* -value = 0.98). The completion rate (fully completed surveys) was 56.6%; the number of respondents was also statistically representative of the number of participants to the survey (Chi-squared test $_{(1\delta\varphi \cdot\ \alpha = 0.05)}$ = 0.14; *p*- value = 0.70) (**Table 1**). In total, the respondents managed 5,781 living colonies on 1 April 2017 with an average of 16.3 (standard deviation, std=20.3) hives per beekeeper. Nationwide, beekeeper's average experience was of 16.9 (std = 15.6) years and the average mortality rate for 2017 was

14.5% (std = 22.4). The average score (scale from 0 to 100) given by the beekeepers to their risk aversion was 60.4 with std 13.8 (**Table 2**).

Table 1. Participation and completion rates to the survey among Belgian beekeepers in 2017

Region	No. FASCA Beekeepers 2017	Proportion beekeepers per region (%)	no. Total Participants
Wallonia	1935	33.1%	207
Male			*193*
Female			*14*
Flanders	3917	66.9%	420
Male			387
Female			*33*
Belgium	5852	100.0%	627
Male			*580*
Female			*47*

Legend: Participants are the beekeepers that participated in the survey with or without completing all the survey questions.

Descriptive analysis

Perception of climate change

Beekeepers' opinions were divided on climate change impact on bee health (susceptibility) (average 65.3 and std 31.2), its severity (average 59.8 and std 32.1), and perceived benefits of acting to mitigate these risks (average 60.3 and std 24.7). Important disparities appeared in the answer scores with std values that were high compared to their respective average values. The perception of barriers to mitigate climate change (average 72.2 and std 29.9) appeared though more homogenous (**Table 2**).

Table 2. Average results and standard deviation (std) for measures of demography, risk aversion, health responsibility, perception of climate change, *Varroa* infestation, management practices, and exposure to pesticides), actions or intentions, and influences

Variables	Item	Average	Standard deviation	Variables	Item	Average	Standard deviation
Demographic variables	Beekeeping experience (years)	16.90	15.6	**Health responsibility**	Bee health/environment	80.1	25.7
	Flanders	17.3	15.7		Honey quality (for human consumption)	90.9	19.7
	Wallonia	16.1	15.6		Colony loss is more than a material loss	91.7	16.6
	Gender				A colony replaceability	43.8	31.9

Variables	**Item**	**Average**	**Standard deviation**	**Variables**	**Item**	**Average**	**Standard deviation**
	Male %	91			Honey production is as important as bee health	80	26.6
	Female %	76.1		**Intention and actions**	Avoid bringing into winter too weak colonies	73.1	33
	No. colonies September 1, 2016	11	14.8				
	No. splits /increases/buy between September 1, 2016 and April 1, 2017	5.2	7		Avoid bringing into winter too strong colonies	14.8	23.5
	No. colonies sold/given away between September 1, 2016 and April 1, 2017	1.7	3.4		Equalizing colony strength by gathering two weak ones	54.6	37.5
	No. living colonies on April 1, 2017	16.3	20.3		Resilience to environmental changes	73.2	28.7
	Average losses (%) 2017	14.5	22.4		Equipment hygiene before reusing equipment	78.1	29.5
	Dutch-speaking	13.7	22.4		Treatment combination (Varroa control)	73.1	34.1
	French-speaking	16.2	22.5				

Variables	Item	Average	Standard deviation	Variables	Item	Average	Standard deviation
Relative risk aversion	Psychological characteristics	60.4	13.8		Regularly monitor for Varroa infestation levels	77.9	27.8
Climate changes	Susceptibility	65.2	31.3		Treatment only if affected by moderate to high infestations of Varroa	39.5	36.2
	Severity	59.7	32.2				
	Benefits	60.3	24.7		Use varroacides more sensibly (delay resistance development)	65.5	38
	Barriers	72.2	29.9				
Varroa infestation	Susceptibility	85.2	24.1		Waxes replacement every 4 years	83.3	25.9
	Severity	65.8	22.3		Avoid wild swarms introduction without quarantine/treatment	70.9	35.9
	Benefits	64.8	20				
	Barriers	63.1	25.3	**Influences**	Colonies mortality	76.8	28.8
Exposure to pesticides	Susceptibility veterinary pesticides	19.5	25.4		Unions/federations	56.8	31.2
	Susceptibility agricultural pesticides	37.4	31		Research and information centre	65.4	29.4
	Severity	69.0	21.6		Universities	55.0	33.2
	Benefits	58.9	22.3		Newspapers, journals, magazines, internet	54.6	30.2

Variables	Item	Average	Standard deviation	Variables	Item	Average	Standard deviation
	Barriers to veterinary pesticides	39.2	36.2		Federal Agency for the Safety of the Food Chain recommendations	53.7	32
	Barriers agricultural pesticides	65.0	31.1				
Management practices	Susceptibility	87.9	20.3		Own health	77.6	29.3
	Severity	86.4	20		Environment protection	83	23.2
	Benefits	67.4	16		Honey production	52.4	30.9
	Barriers	72.6	16.4		Packages/queen production	54	35

Perception of *Varroa* infestation

For *Varroa* perception, the parasite susceptibility scored high (average 85.2 and std 24.1). Nevertheless, the perception of the severity of *Varroa* was less important (average 65.8 and std 22.3) (**Table 2**). The benefits of mitigating *Varroa* risk were positive and homogenous (average 64.8 and std 20) and the barriers to reduce the *Varroa* risk did not seem challenging (average 63.1 and std 25.3).

Perception of pesticide exposure

For susceptibility and barriers, the distinction between pesticides coming out of agriculture and veterinary drugs was made. The susceptibility of high exposure to veterinary drugs scored low (average 19.5 and std 25.4), while susceptibility of agricultural pesticides scored higher (average 37.4 and std 31). The scores concerning the severity of veterinary drug/agricultural pesticide (average 69 and std 21.6) and their benefits on colonies (average 58.9 and std 22.3) (agriculture and veterinary jointly) scored respectively high and moderately high; the answers to the questions were quite homogenous as sdt were low. The barriers to reduce the use of veterinary drugs (average 39.2 and std 36.2) scored low, similarly to the barriers for reducing agricultural pesticides (average 34.5 and std 31.1).

Perception of management practices

Management practices stood out with the highest scores and with the most homogenous opinions in terms of susceptibility (average 87.9 and std 20.3), severity (average 86.4 and std 20), and barriers (average 72.6 and std 16.4) compared to all other variables (**Table 2**). These concepts were well understood by the beekeepers. Nevertheless, they were not unanimous on the influence of the hive type on colony health, this lowered the benefits average score (average 67.4 and std 16) (**Appendix S1**).

Health responsibility

For health responsibility, beekeepers cared the most about the quality of the honey they produce (average 90.9 and std 19.7). Nevertheless, bee health was as important as the honey production (average 80 and sdt 26.6) as well as bee health and environment protection (average 80.1 and sdt 25.7). For the beekeepers, a colony loss represented more than only an economical loss (average 91.7 and std 16.7) (**Appendix S1**).

Intentions or implemented actions

The intentions or actions already implemented to mitigate the risks, scored generally high: for the equipment hygiene (average 78 and std 29.6), for the diagnosis and regular monitoring of *Varroa*infestations (average 77.6 and std 27.9), for beekeeper's adaptation to environmental changes inside their management practices (average 72.9 and std 28.8), and for the complete replacement of old comb wax in the hive body every 4 years (average 83.1 and std 26.1). Combining *Varroa* treatments scored high (average 73.3 and std 34.1) but treating only the colonies affected by moderate to high infestations of *Varroa* was more controversial (average 39.3 and std 36.1). The use of varroacide more sensibly to delay resistance development scored relatively high (average 65.8 and std 37.9). Avoiding to bring too weak colonies into winter scored high (average 73.1 and std 33), but the same act with too strong colonies scored low (average 14.8 and std 23.5). The score awarded by the beekeepers to the use of partition in the winter was moderate (average 54.6 and std 37.5) (**Appendix S1**).

Influences

Beekeepers expressed mostly being guided in their risk management choices by the protection of the environment (average 83 and std 23.3), the protection of their health (average 77.5 and std 29.4) as well as the mortality of their colonies (average 76.5 and std 28.9). Research and information centres (average 64.9 and std 29.4) seemed to have more influence on their risk management than beekeeping federations and unions (average 56.8 and std 31.2), and universities (average 55 and std 33.2). Honey production seemed of secondary importance (average 54 and std 35) in their risk management choices.

Statistical analysis

The Welch test was performed to compare two means of mortality values; under the 10% mortality threshold (considered as acceptable) and above or equal the 10% for the same variable. Results indicate that beekeepers with mortality rates lower than 10% had a higher average number of hives (average 12.67 and std 17.25; p -value < 0.0001) and a significantly higher ability to renewing their colonies (average 6.31 and std 8.17; p -value < 0.0001). Their score in perceiving varroosis occurrence was significantly higher (average 71.38 and std 22.85; p -value = 0.002) and they were more aware of management practices impact (average 90.15 and std 16.95;p -value = 0.008) and severity (average 88.31 and std 18.34;p -value = 0,014) on their colonies. Nevertheless, they scored significantly lower in the perception of climate change severity (average 55.45 and std 33.12; p -value = 0.009) and the perception of varroosis severity (average 63.8 and std 21.56; p -value = 0.02). The benefit of management practices was also better perceived by beekeepers with mortality rates < 10% (average 68.96 and std 15.11; p -value = 0.015). Beekeepers with < 10% mortality rates scored higher at all questions related to the actions/intentions. Significant results of the two-sample t -test with unequal variances are depicted in **Table 3** .

Table 3. Welch test's significant variables (p-value <0.05) for mortality rates above and under 10%

Variable	Item	<10% mortality (N=213)	<10% mortality (N=213)	[?] 10% mortality (N=142)	[?] 10% mortality (N=142)	Welch test
		Average	**Standard deviation**	**Average**	**Standard deviation**	
Demographic variables	No. colonies September 1, 2016	12.67	17.25	8.58	9.41	<0.0001

Variable	Item	<10% mortality (N=213)	<10% mortality (N=213)	[?] 10% mortality (N=142)	[?] 10% mortality (N=142)	Welch test
	No. splited/increased/bought between September 1, 2016 and April 1, 2017	6.31	8.17	3.65	4.25	<0.0001
	No. lost colonies September 1, 2017	0.38	0.83	3.74	4.65	<0.0001
	No. living colonies on April 1, 2017	18.98	23.59	12.23	12.85	0.0003
Health responsibility	Bee health/environment awareness	78.26	27.25	82.83	22.95	0.04
	Colony replacement, without much effort	49.29	33.51	35.49	27.46	<0.0001
Susceptibility	Varroa infestation	71.38	22.85	63.75	25.26	0.002
	Management practices	90.15	16.95	84.52	24.16	0.008
	Exposure to pesticide	34.46	29.52	41.69	32.63	0.02
Severity	Climate change	55.45	33.12	66.12	29.87	0.009
	Varroa infestation	63.80	21.56	68.90	23.16	0.02
	Management practices	88.31	18.34	83.40	21.90	0.014
Benefits	Management practices	68.96	15.11	65.10	17.12	0.015
Intentions or actions	Avoid bringing into winter too weak colonies	77.04	30.97	67.30	35.22	0.004
	Equiment disinfection before reuse	80.78	27.53	74.14	31.83	0.02
	Complete wax replacement every 4 years	85.28	25.01	80.33	27.04	0.04

Variable	**Item**	**<10% mortality (N=213)**	**<10% mortality (N=213)**	**[?] 10% mortality (N=142)**	**[?] 10% mortality (N=142)**	**Welch test**
	Avoid introducing swarms from unknown origin without quarantine/treatment	75.13	34.47	64.57	37.10	0.004
Influences	Colony mortality	74.69	31.04	79.94	24.97	0.04
	Packages/queen production	57.34	34.59	48.85	35.22	0.013

Discussion

This first nationwide cross-sectional survey focused on how beekeepers perceive and manage risks (climate change, *Varroa* mite, management practices, and exposure to pesticides). Understanding beekeeper's perception of risks affecting their colony health and mortality is crucial to better understand beekeepers' attitudes toward risks and potentially, to adopt new management practices.

Population representativeness was achieved through a snowball sampling strategy compared to the number of voluntarily registered beekeepers on the FASFC database. Representativeness was confirmed by a Chi-squared test and the respondents were the subset of the target population. Nevertheless, the real number of beekeepers in Belgium and per region was difficult to obtain, as most beekeepers are hobbyists and reluctant to register themselves.

Beekeepers' general attitude towards risk was derived by measuring their degree of risk aversion using four statements on general issues. Beekeepers seemed to have a common understanding of general risk. Nevertheless, for most questions, beekeepers' perception seemed divergent, as important disparities appeared with std values that were high compared to their respective average values. This might be due to the lack of heterogeneity in beekeeping education and/or in a cultural difference in the perception of risk; Belgium being made up of the three linguistically and culturally different regions.

Climate change is not uniformly perceived as a concern compared to management or *Varroa* infestation, though it has been pointed out as one of the causes of the colony mortality by scientific research (Dennis and Kemp, 2016; Flores et al., 2019). Overcoming the barriers to mitigate climate change appeared though to be achievable for most beekeepers.

For *Varroa* perception, the parasite susceptibility was well perceived unlike the severity of the parasite. The benefits of mitigating *Varroa* risk were positive and the answers were homogenous without being really high. Nevertheless, the barriers to reducing *Varroa* risk did not seem challenging. When we looked at the detail of the questions dealing with the barriers, beekeepers did not seem to be much affected by the economic impact of colony losses and did not consider the investment in time for *Varroa* diagnosis as a barrier with divergences in these opinions. To our knowledge, *Varroa* diagnosis is not a widely used practice among hobby beekeepers, because it is time-consuming (Thoms et al., 2018; Underwood et al., 2019).

Pesticide risk perception differed for beekeepers whether it was for agriculture or apicultural use. To them, the susceptibility of high exposure to veterinary drugs was lower than to agriculture pesticides. Moreover, both scored quite low. The susceptibility of pesticide exposure was expected to be higher. The severity of pesticide exposure (agriculture and apiculture jointly) was perceived as important but not alarming and their benefits were positive. Reducing the use of veterinary drugs and agricultural pesticides were perceived as difficult to reach. The answers to the question dealing with reducing the use of veterinary drugs appeared with large disparities and a high std value. These disparities could be explained by three observed tendencies that seemed to coexist in the Belgian beekeeping community: the first tendency implies the use of drug-based treatments yearly, without monitoring *Varroa* infestations. The second tendency applies monitoring of *Varroa* infestations and the use of acids (oxalic) to decrease *Varroa* pressure on honey bees colonies when required. The third tendency is not to treat infested colonies and to start relying on the selection of *Varroa* -resistant honeybees. These three distinctive tendencies could explain partly the average score of the susceptibility of veterinary drugs as well as the high std values.

Out of the three previously assessed risks, the respondents seemed to perceive the importance of management practices more uniformly than any of the 3 other risks. This was of utmost importance for the health and survival of honey bee colonies, as management practices were crucial to compensate the effects made worse by the *Varroa* infestations, changes in climate, and many other interacting stress factors for honey bees. Nevertheless, some questions (e.g. the hive type) kept on being reversed.

Beekeepers felt the most responsible for the quality of the honey they produce and were mostly influenced by their own health and environment protection as well as by the colony mortality. These elements could be considered as a lever for adopting better management practices.

Through the results of this survey, std values fluctuated quite a lot, sometimes exceeding variable average values. The questions with the highest std values, meaning the most controversial ones, were related to the questions regarding varroosis perception, and more specifically the systematic use of chemical treatments (e.g. apistan, apivar) to control *Varroa* and avoid colony mortality, the adoption of more selective use of varroacides to delay the development of resistance, as well as the role played by untreated neighbouring colonies on *Varroa*re-infestation in own apiaries. The biggest disparity in answers appeared with the question related to whether the responsibility of *Varroa* control lay with the authorities, or at the individual beekeeper's level. This issue has always been a sensitive subject for Belgian beekeepers as the authorised treatment substances are limited to products which some do not consider effective.

The Welch test was performed to compare the perception of beekeepers with colony mortality lower and higher than 10% assuming that beekeepers with lower mortality rates have better risk management. The empirical threshold of 10% is considered acceptable in Belgium but is open to discussion. Although no reference values exist for the acceptable level of colony losses, various acceptable rates of colony mortality were reported in European countries (Charrière and Neumann, 2010; Genersch et al., 2010) and outside Europe (Steinhauer et al., 2014).

The results indicated that beekeepers with mortality rates lower than 10% had a higher average number of colonies, and were more active in increasing them than the ones with mortality rates higher than 10%. The size of the apiary, the age, and the experience of the beekeeper have already been reported as factors directly linked to the survival of the honey bee colony (Brodschneider et al., 2016; Jacques et al., 2017).

We assumed that these results expressed better capacities in risk management and thus in management practices, and a proactive approach of beekeeping. The scores of the benefits of reducing the risk of colony mortality through better management practices confirmed our assumption. These risks were significantly better perceived by the beekeepers with mortality rates under 10% and had a higher score at all questions related to the actions or intentions of actions. This confirms the hypothesis that greater levels of perceived risk combined with strong perceptions of the benefits of action would lead to increased motivation to act in better ways. Nevertheless, those same beekeepers scored significantly lower in the perception of climate change severity and varroosis severity. We cannot state with certainty if these perceptions were due to the beekeepers' resilience capacity or to the lack of the perception of impact severity, due to good management practices. No other studies that would allow us to compare our results are currently available.

Conclusions

Belgium counts a majority of hobby beekeepers. Understanding their perception of risks affecting colony health and mortality is crucial to analyse the reasons for adopting or rejecting some beekeeping management practices. Beekeepers with a greater level of perceived risk combined with strong perceptions of the benefits of action lead to increased motivation to act in better ways have lower mortality rates. Despite a good general estimate of risks to bee colonies, the agricultural pesticides, and veterinary drug treatment issue appears to be a source of confusion and misunderstanding. Clear and harmonised information should be integrated into risk management recommendations. The lack of feeling of the financial impact that the loss of a colony entails seems to be an obstacle to the implementation of measures to limit the risk. The results of this survey highlight the importance of taking socio-economic determinants into account in any strategy aimed at mitigating the risks associated with bee mortality. To successfully translate recommendations in such a way that the adoption of good management practices will be facilitated, more socio-psychological research is essential.

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Abbreviations

CARI: Beekeeping Research and Information Centre

FASFC: Federal Agency for the Safety of the Food Chain

Std : Standard deviation

Ethical approval

Due to the nature of the survey and the low risk posed to participants, formal approval from an Ethics Committee was not a requirement at the time of the survey.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

The data that support the findings of this survey are available from the corresponding author upon reasonable request.

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References

Brodschneider, R., Gray, A., van der Zee, R., Adjlane, N., Brusbardis, V., Charrière, J.-D., Chlebo, R., Coffey, M.F., Crailsheim, K., Dahle, B., Danihlík, J., Danneels, E., de Graaf, D.C., Dražić, M.M., Fedoriak, M., Forsythe, I., Golubovski, M., Gregorc, A., Grzeda, U., Hubbuck, I., İvgin Tunca, R., Kauko, L., Kilpinen, O., Kretavicius, J., Kristiansen, P., Martikkala, M., Martín-Hernández, R., Mutinelli, F., Peterson, M., Otten, C., Ozkirim, A., Raudmets, A., Simon-Delso, N., Soroker, V., Topolska, G., Vallon, J., Vejsnæs, F., Woehl, S., 2016. Preliminary analysis of loss rates of honey bee colonies during winter 2015/16 from the COLOSS survey. J. Apic. Res. 55, 375–378. doi:10.1080/00218839.2016.1260240

Charrière, J.-D., Neumann, P., 2010. Surveys to estimate winter losses in Switzerland. J. Apic. Res. 49, 132–133. doi:10.3896/IBRA.1.49.1.29

Cresswell, J.E., Desneux, N., vanEngelsdorp, D., 2012. Dietary traces of neonicotinoid pesticides as a cause of population declines in honey bees: an evaluation by Hill's epidemiological criteria. Pest Manag. Sci. 68, 819–827. doi:10.1002/ps.3290

Dennis, B., Kemp, W.P., 2016. How Hives Collapse: Allee Effects, Ecological Resilience, and the Honey Bee. PLoS One 11, e0150055. doi:10.1371/journal.pone.0150055

Doublet, V., Labarussias, M., de Miranda, J.R., Moritz, R.F.A., Paxton, R.J., 2015. Bees under stress: sublethal doses of a neonicotinoid pesticide and pathogens interact to elevate honey bee mortality across the life cycle. Environ. Microbiol. 17, 969–983. doi:10.1111/1462-2920.12426

Ellis-Iversen, J., Cook, A.J.C., Watson, E., Nielen, M., Larkin, L., Wooldridge, M., Hogeveen, H., 2010. Perceptions, circumstances and motivators that influence implementation of zoonotic control programs on cattle farms. Prev. Vet. Med. 93, 276–285. doi:10.1016/j.prevetmed.2009.11.005

Flores, J.M., Gil-Lebrero, S., Gámiz, V., Rodríguez, M.I., Ortiz, M.A., Quiles, F.J., 2019. Effect of the climate change on honey bee colonies in a temperate Mediterranean zone assessed through remote hive weight monitoring system in conjunction with exhaustive colonies assessment. Sci. Total Environ. 653, 1111–1119. doi:10.1016/j.scitotenv.2018.11.004

Garforth, C., 2015. Livestock keepers' reasons for doing and not doing things which governments, vets and scientists would like them to do. Zoonoses Public Health 62, 29–38. doi:10.1111/zph.12189

Genersch, E., Von Der Ohe, W., Kaatz, H., Schroeder, a, Otten, C., BÃ¼chler, R., Berg, S., Ritter, W., MÃ¼hlen, W., Gisder, S., Meixner, M., Liebig, G., Rosenkranz, P., 2010. The German bee monitoring project: A long term study to understand periodically high winter losses of honey bee colonies. Apidologie 41, 332–352. doi:10.1051/apido/2010014

Giacobino, A., Bulacio Cagnolo, N., Merke, J., Orellano, E., Bertozzi, E., Masciangelo, G., Pietronave, H., Salto, C., Signorini, M., Cagnolo, N.B., Merke, J., Orellano, E., Bertozzi, E., Masciangelo, G., Pietronave, H., Salto, C., Signorini, M., 2014. Risk factors associated with the presence of Varroa destructor in honey bee colonies from east-central Argentina. Prev. Vet. Med. 115, 280–7. doi:10.1016/j.prevetmed.2014.04.002

Giacobino, A., Pacini, A., Molineri, A., Cagnolo, N.B., Merke, J., Orellano, E., Bertozzi, E., Masciangelo, G., Pietronave, H., Signorini, M., 2017. Environment or beekeeping management: What explains better the prevalence of honey bee colonies with high levels of Varroa destructor? Res. Vet. Sci. 112, 1–6. doi:10.1016/j.rvsc.2017.01.001

Goulson, D., Nicholls, E., Botías, C., Rotheray, E.L., 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science (80-.). 347.

Jacques, A., Laurent, M., Consortium, E., Ribière-Chabert, M., Saussac, M., Phanie Bougeard, S., Budge, G.E., Hendrikx, P., Chauzat, M.-P., 2017. A pan-European epidemiological study reveals honey bee colony survival depends on beekeeper education and disease control. PLoS One. doi:10.1371/journal.pone.0172591

James, R.R., Xu, J., 2012. Mechanisms by which pesticides affect insect immunity. J. Invertebr. Pathol. 109, 175–182. doi:10.1016/J.JIP.2011.12.005

Jansen, J., van den Borne, B.H.P., Renes, R.J., van Schaik, G., Lam, T.J.G.M., Leeuwis, C., 2009. Explaining mastitis incidence in Dutch dairy farming: The influence of farmers' attitudes and behaviour. Prev. Vet. Med. 92, 210–223. doi:10.1016/J.PREVETMED.2009.08.015

Janz, N.K., Becker, M.H., 1984. The Health Belief Model: A Decade Later. Health Educ. Q. 11, 1–47. doi:10.1177/109019818401100101

Johnson, R.M., Ellis, M.D., Mullin, C.A., Frazier, M., 2010. Pesticides and honey bee toxicity – USA*. Apidologie 41, 312–331. doi:10.1051/apido/2010018

Kennedy, C.M., Lonsdorf, E., Neel, M.C., Williams, N.M., Ricketts, T.H., Winfree, R., Bommarco, R., Brittain, C., Burley, A.L., Cariveau, D., Carvalheiro, L.G., Chacoff, N.P., Cunningham, S.A., Danforth, B.N., Dudenhöffer, J.-H., Elle, E., Gaines, H.R., Garibaldi, L.A., Gratton, C., Holzschuh, A., Isaacs, R., Javorek, S.K., Jha, S., Klein, A.M., Krewenka, K., Mandelik, Y., Mayfield, M.M., Morandin, L., Neame, L.A., Otieno, M., Park, M., Potts, S.G., Rundlöf, M., Saez, A., Steffan-Dewenter, I., Taki, H., Viana, B.F., Westphal, C., Wilson, J.K., Greenleaf, S.S., Kremen, C., 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecol. Lett. 16, 584–599. doi:10.1111/ele.12082

Klein, A.-M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proceedings. Biol. Sci. 274, 303–13. doi:10.1098/rspb.2006.3721

Lundin, O., Rundlöf, M., Smith, H.G., Fries, I., Bommarco, R., 2015. Neonicotinoid Insecticides and Their Impacts on Bees: A Systematic Review of Research Approaches and Identification of Knowledge Gaps. PLoS One 10, e0136928. doi:10.1371/journal.pone.0136928

Lupo, C., Wilmart, O., Van Huffel, X., Dal Pozzo, F., Saegerman, C., 2016. Stakeholders' perceptions, attitudes and practices towards risk prevention in the food chain. Food Control 66, 158–165. doi:10.1016/j.foodcont.2016.02.003

Monceau, K., Bonnard, O., Thiéry, D., 2014. Vespa velutina: A new invasive predator of honeybees in Europe. J. Pest Sci. (2004). 87, 1–16. doi:10.1007/s10340-013-0537-3

Mondet, F., de Miranda, J.R., Kretzschmar, A., Le Conte, Y., Mercer, A.R., 2014. On the front line: quantitative virus dynamics in honeybee (Apis mellifera L.) colonies along a new expansion front of the parasite Varroa destructor. PLoS Pathog. 10, e1004323. doi:10.1371/journal.ppat.1004323

Morgenthaler, O., 1968. Les maladies infectieuses des ouvrières, in: Chauvin, R. (Ed.), Traité de Biologie de l'Abeille. Paris, p. 327.

Muli, E., Patch, H., Frazier, M., Frazier, J., Torto, B., Baumgarten, T., Kilonzo, J., Kimani, J.N., Mumoki, F., Masiga, D., Tumlinson, J., Grozinger, C., 2014. Evaluation of the distribution and impacts of parasites, pathogens, and pesticides on honey bee (Apis mellifera) populations in East Africa. PLoS One 9, e94459. doi:10.1371/journal.pone.0094459

Murcia Morales, M., Gómez Ramos, M.J., Parrilla Vázquez, P., Díaz Galiano, F.J., García Valverde, M., Gámiz López, V., Manuel Flores, J., Fernández-Alba, A.R., 2020. Distribution of chemical residues in the beehive compartments and their transfer to the honeybee brood. Sci. Total Environ. 710, 136288. doi:10.1016/j.scitotenv.2019.136288

Nazzi, F., Brown, S.P., Annoscia, D., Del Piccolo, F., Di Prisco, G., Varricchio, P., Della Vedova, G., Cattonaro, F., Caprio, E., Pennacchio, F., 2012. Synergistic Parasite-Pathogen Interactions Mediated by Host Immunity Can Drive the Collapse of Honeybee Colonies. PLoS Pathog. 8, e1002735. doi:10.1371/journal.ppat.1002735

Neumann & Carreck, 2015. Honey bee colony losses. J. Apic. Res.

Oldroyd, B.P., 2007. What's killing American honey bees? PLoS Biol. 5, e168. doi:10.1371/journal.pbio.0050168

Rosenstock, I.M., 1974. Historical Origins of the Health Belief Model. Health Educ. Monogr. 2, 328–335. doi:10.1177/109019817400200403

Samson-Robert, O., Labrie, G., Chagnon, M., Fournier, V., 2017. Planting of neonicotinoid-coated corn raises honey bee mortality and sets back colony development. PeerJ 5, e3670. doi:10.7717/peerj.3670

Steinhauer, N., 2017. Reducing the risk of honey bee colony loss through beekeeping management practices.

Steinhauer, N., Kulhanek, K., Antúnez, K., Human, H., Chantawannakul, P., Chauzat, M.-P., vanEngelsdorp, D., 2018. Drivers of colony losses. Curr. Opin. Insect Sci. 26, 142–148. doi:10.1016/J.COIS.2018.02.004

Steinhauer, N., Rennich, K., Wilson, M., Caron, D., Lengerich, E., Pettis, J., Vanengelsdorp, D., 2014. A national survey of managed honey bee 2012-2013 annual colony losses in the USA. J. Apic. Res. 53, 1–18. doi:10.3896/IBRA.1.53.1.01

Switanek, M., Crailsheim, K., Truhetz, H., Brodschneider, R., 2017. Modelling seasonal effects of temperature and precipitation on honey bee winter mortality in a temperate climate. Sci. Total Environ. 579, 1581–1587. doi:10.1016/j.scitotenv.2016.11.178

Thoms, C.A., Nelson, K.C., Kubas, A., Steinhauer, N., Wilson, M.E., vanEngelsdorp, D., 2018. Beekeeper stewardship, colony loss, and Varroa destructor management. Ambio 1987. doi:10.1007/s13280-018-1130-z

Underwood, R.M., Traver, B.E., López-Uribe, M.M., 2019. Beekeeping Management Practices Are Associated with Operation Size and Beekeepers' Philosophy towards in-Hive Chemicals. Insects 10, 10. doi:10.3390/insects10010010

Valeeva, N.I., Lam, T.J.G.M., Hogeveen, H., 2007. Motivation of Dairy Farmers to Improve Mastitis Management. J. Dairy Sci. 90, 4466–4477. doi:10.3168/jds.2007-0095

Valeeva, N.I., van Asseldonk, M.A.P.M., Backus, G.B.C., 2011. Perceived risk and strategy efficacy as motivators of risk management strategy adoption to prevent animal diseases in pig farming. Prev. Vet. Med. 102, 284–295. doi:10.1016/J.PREVETMED.2011.08.005

Vande Velde, F., Claerebout, E., Cauberghe, V., Hudders, L., Van Loo, H., Vercruysse, J., Charlier, J., 2015. Diagnosis before treatment: Identifying dairy farmers' determinants for the adoption of sustainable practices in gastrointestinal nematode control. Vet. Parasitol. 212, 308–317. doi:10.1016/j.vetpar.2015.07.013

vanEngelsdorp, D., Caron, D., Hayes, J., Underwood, R., Henson, M., -Lincoln vanEngelsdorp, N., 2012. A national survey of managed honey bee 2010-11 winter colony losses in the USA: results from the Bee Informed Partnership. J. Apic. Res. 51, 115–124.

Figure caption

Fig 1. Basic elements of the health belief model applied for beekeepers in this survey