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A survey of knowledge, attitudes, and practices of veterinary professionals regarding ticks and tick-borne diseases: Insights from Ohio, USA

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ABSTRACT

Globally, ticks are becoming more problematic as agricultural pests and vectors of tick-borne diseases (TBDs), many of which are shared between animals and people. Veterinary professionals, including veterinarians and non-veterinarians, are considered a vulnerable group through occupational exposure. To inform educational interventions at the intrapersonal level, a common approach is to first assess knowledge, attitudes, and practices (KAP) of target populations. Thus, our objective was to assess KAP of veterinary professionals in Ohio, a state faced with expanding and invading ticks of medical and veterinary concern. Using a convenience sample, we surveyed 178 veterinary professionals across Ohio with an electronic questionnaire that covered knowledge, attitudes, practices, exposures, demography, education, and surveillance regarding ticks and TBDs. We found that veterinary professionals had cautionary attitudes towards ticks and TBDs and practiced prevention for themselves and their patients, even when tick exposures were infrequently reported. However, veterinary professionals significantly lacked in knowledge regarding tick biology and local TBD epidemiology. Furthermore, we found that knowledge regarding tick biology and attitudes towards ticks and TBDs did not associate with practices. Instead, we found that veterinarian status and routine tick checks of patients were associated with frequent discussions of tick prevention with clients. Our findings emphasize that most tick exposures of veterinary professionals are occupational, and thus prevention should start at the workplace. Cultivating knowledge of veterinary professionals regarding tick biology and local TBD epidemiology may lead to greater motivation and confidence with identifying ticks and testing for TBDs, which may also increase the diagnostic capacity of veterinary professionals for tick and TBD surveillance. Because veterinary professionals typically interact with both animals and their owners, improving their KAP regarding ticks and TBDs, can in turn promote animal, human, and environmental health within a "One Health" context.

1. Introduction

Ticks and tick-borne diseases (TBDs) have gradually increased across space and time in human and animal populations [1]. In North America, ticks of veterinary and medical importance, such as the Lone star (*Amblyomma americanum*) and blacklegged ticks (*Ixodes scapularis* and *I. pacificus*) have become more problematic in recent years [1–4]. Tick bites can lead to anemia, infectious diseases, and alpha-gal syndrome (in humans), which can have alarming consequences for human, animal, and environmental health. Thus, addressing ticks and TBDs requires an integrated One Health approach [1–4].

Findings from population surveys that target the knowledge, attitudes, and practices (KAP) of participants regarding ticks and TBDs have been used to characterize the assets and needs of high-risk groups, such as agricultural [5], medical [6] and veterinary professionals [7]. In this manner, health practitioners can more effectively design education strategies to improve and sustain health outcomes related to ticks and TBDs. Although KAP surveys primarily target the intrapersonal level (e.g., personal attitudes) of a social ecological model [8], they can diagnose educational, environmental, and behavioral factors [9] to facilitate

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health promotion planning at upstream levels, including community and policy.

Veterinary professionals experience high exposure risk to ticks through their direct work with animals and visits to tick habitats for providing on-site care [10,11]. As tick species spread across North America [2], assessing knowledge, attitudes and practices regarding ticks and TBDs in vulnerable groups becomes essential. In Ohio, there has been a recent increase in the number of ticks with medical and veterinary significance, an alarming pattern also echoed in nearby regions [4,12,13]. Consequently, veterinary professionals are experiencing novel occupational exposures and clinical presentations as the landscape of tick exposure shifts, as recently observed with the invading Asian longhorned tick (*Haemaphysalis longicornis*) and its associated disease, bovine theileriosis [14]. Although the Companion Animal Parasite Council [15] provides support for veterinary professionals regarding ticks and TBDs, the absence of a national surveillance system, akin to public health [16], makes staying updated challenging.

Veterinary professionals are also instrumental in bridging the gap between animal and human health through educating clients about ticks and TBDs and protecting public health by diagnosing infestations and associated zoonoses [17]. For example, cattle producers in Oklahoma, U. S., and companion animal owners in Canada reported veterinarians as their top source for tick information [5,18]. By targeting and improving KAP of professionals towards ticks and TBDs, health educators may more effectively reach animal owners and strengthen the diagnostic capacity of veterinary professionals.

Our objective was to assess the knowledge, attitudes, and practices (KAP) of veterinary professionals in Ohio, U.S., towards ticks and TBDs to inform continuing educational interventions. To accomplish our objective, we conducted a cross-sectional KAP survey of veterinary professionals, including veterinarians and non-veterinarians, across Ohio using a convenience sample. Herein we report descriptive statistics that summarize the demography, knowledge, attitudes, exposures, education, surveillance, and practices of veterinary professionals regarding ticks and TBDs. To guide targeted interventions, we also examine associations between demography, knowledge, attitudes, exposures, and practices using classification trees and report on preferred delivery methods for continuing education regarding ticks and TBDs.

2. Materials and methods

2.1. Survey design and development

We developed an electronic KAP questionnaire (Supplementary Material), self-administered in English using an online survey platform (Qualtrics, Provo, UT, USA). The mobile-friendly survey included 43 questions with a predicted completion time of 10–20 min. The questionnaire consisted of five sections: 1) tick exposure (3 questions), 2) knowledge about tick biology, identification, and TBDs (7 questions), 3) demographic and practice information (12 questions), 4) attitudes towards ticks and TBDs (4 questions), and 5) control and prevention practices (17 questions). The "practices" section also included one question on preferred methods for learning new content. Some questions were conditional on answers from previous questions, so not all questions were displayed to every participant.

The questionnaire went through internal content validation by our research team and external validation by one small and three large animal veterinarians. We provided instructions to these veterinarians for evaluating the questionnaire and incorporated their feedback before the questionnaire became accessible to participants.

2.2. Recruitment of participants and data collection

Participant recruitment occurred via social media and e-mails to small, large, and mixed animal practices listed on the Ohio Veterinary Medical Association website (n = 169), through The Ohio State University's extension veterinarian network, and two Ohio-based large animal commodity groups (cattle and sheep). We actively recruited from September 2021 to January 2022, but the survey remained accessible until July 25, 2022. The eligibility criteria to participate in the survey were to be a veterinary professional (veterinarian, registered veterinary technician, or veterinary assistant) who resided in Ohio and was over 18 years of age. Participants who completed the questionnaire were eligible to receive a financial incentive of five U.S. dollars in the form of a gift card to the business of their choosing within five business days of taking the survey by completing a separate questionnaire. This process ensured that their original responses remained anonymous. The study received Institutional Review Board exemption by The Ohio State University (#2021E0922).

2.3. Statistical analysis

Survey entries deemed fraudulent or duplicates by the online platform's algorithm were discarded. Entries that were <80% completed were also excluded. Analyses were done in RStudio (ver. 2022.07.2) [19] using R (ver. 4.2.2, [20]) and packages "rpart" [21] and "rpart.plot" [22]. We generated descriptive statistics (median and range for continuous variables; frequency and percentages for categorical variables) for all questions and built classification trees to examine relationships among practices, knowledge, attitudes, exposures, and training level. Trees were built separately for small and large or mixed animal professionals because of intrinsic differences that these two groups experience in the workplace.

Classification trees are a machine-learning approach for separating observations into subgroups through recursive partitioning and are powerful in unmasking complex interactions among predictors. The algorithm begins with a "root node" and continues separately for each subgroup until all observations are classified in "terminal nodes" [23,24]. Predictors closer to the root node are considered more important. To develop trees, we used the CART algorithm [21,24] implemented in "rpart" where observations with missing data for the response variable are excluded.

Classification trees were used to identify the variables out of an a priori list (Table S1) that most strongly predicted how frequently veterinary professionals discussed tick prevention with clients (frequently versus infrequently). The number and identity of predictors for small versus large or mixed animal professionals were similar with minor exceptions. We chose questions of knowledge, practices, attitudes, occupation, and exposures as predictors that best and most simply represented each aspect and collapsed categories for most variables to increase sample size and aid in tree interpretation (Table S1).

For small animal professionals, model predictors included: 1) attitudes towards tick risks for themselves and coworkers (major versus minor or none), 2) attitudes towards tick risks for clients (major versus minor or none), 3) knowledge regarding what life stage needs blood (correct versus incorrect response), 4) proficiency in identifying ticks (proficient versus non-proficient), 5) comfort with tick identification (comfortable versus neutral versus uncomfortable), 6) training (veterinarian versus non-veterinarian), 7) tick exposure in clinic (frequent versus infrequent) and 8) if routine tick check was practiced (yes versus no). For large or mixed animal professionals, predictors were identical except that personal tick exposure was assessed on farms, and attitude towards tick risks for animals was added.

3. Results

3.1. Participant demographics

We recorded 1632 entries, of which 1454 were excluded based on 1) fraudulent or duplicate responses (n = 1428, primarily identified by Qualtrics), and 2) <80% completion (n = 26). Unfortunately, hundreds of internet robot (or "bot") responses were recorded after we

disseminated the questionnaire on social media. "Bots" are software that are programmed to complete automated tasks, such as online surveys, and are becoming increasingly problematic for researchers as they can rapidly produce hundreds of fraudulent responses [25]. Because we did not track how participants reached the survey (social media or other), we were not able to exclude responses based on this factor. Notwithstanding, we were confident that 178 veterinary professionals completed at least 80% of the survey after systematic exclusion. We did not calculate a response rate because we did not know who received, but did not take, the survey.

Of those who reported age and years in practice (n = 174, 97.8%), the median age was 33 years (20–70) and 5 years (1–44), respectively. Most identified as male (66.9%) and were veterinarians (50.6%) (Table 1). Out of the professionals that followed a specialization track in veterinary school, most (56.9%) pursued a mixed animal track (Table S2). Most participants described their practice as mixed or small animal (81.4%) (Table 1) and large or mixed animal professionals primarily reported treating dairy (55.8%) and beef cattle (55.8%), horses (53.8%), and poultry (53.8%) (Table S2).

3.2. Knowledge about ticks and TBDs

Most professionals rated their ability to identify ticks as "beginner" or "average" (85.9%), with half (50.0%) feeling somewhat or very comfortable identifying life stages. Most (63.5%) stated that nymphs require blood, with only a small minority (9.6%) correctly reporting that all life stages require blood. Additionally, most participants (60.7%) correctly reported how ticks find their hosts (climbing plants and waiting) but fewer (42.1%) reported this as their sole answer (Table 2).

With the aid of associated pictures, most veterinary professionals felt comfortable identifying the American dog tick (*Dermacentor variabilis,* 72.5%), the blacklegged tick (57.9%), and the brown dog tick (*Rhipicephalus sanguineus,* 52.2%); three species that most (at least >65%) believed were present in Ohio (Fig. 1). This was not the case with the Lone star and ear ticks (*Otobius* spp.) even though most believed they were present in the state (Fig. 1, Table S3). Although many TBDs occur in Ohio [e.g., [26]], Lyme disease was the only TBD thought by most (52.2%) to occur (Table S4).

3.3. Attitudes towards ticks and TBDs

Participants offered similar opinion for whether ticks pose major (45.5%) or minor (47.8%) health risks to themselves and their coworkers, and whether ticks pose major (50.0%) or minor (42.1%) health risks to clients (Table S5). However, a larger (56.6%) portion of professionals in large or mixed animal practice thought that ticks or TBDs severely affected the productivity or performance of their patient populations. Out of the foreign TBDs presented, African swine fever was the disease that most (56.7%) professionals thought presented a serious risk for introduction into the state. Additionally, bovine theileriosis was the disease reported by most (51.1%) as potentially presenting a serious risk (Table S6).

Table 1
Demographic and practice information of Ohio-based veterinary professionals (n = 178) who participated in a self-administered electronic survey regarding ticks and tick-borne diseases.

Question	n (%)
How would you describe yourself?	
Man	119 (66.8%)
Woman	58 (32.6%)
Non-binary	0 (0%)
Prefer to self-describe	0 (0%)
Prefer not to say	0 (0%)
No answer	1 (0.6%)
What best describes your level of veterinary training?	
Veterinarian (DVM, VMD, equivalent)	90 (50.6%)
Registered Veterinary Technician (RVT, CVT, or equivalent)	65 (36.5%)
Veterinary Assistant (trade school or on-the-job training)	17 (9.5%)
No answer	6 (3.4%)
Which category best describes your practice?	
Mixed Animal	74 (41.5%)
Small Animal	71 (39.9%)
Large Animal	32 (18.0%)
No answer	1 (0.6%)

Table 2
Knowledge regarding ticks and tick-borne diseases of veterinary professionals (n = 178) from Ohio who participated in a self-administered electronic survey.

Question	n (%)
How would you rate your ability to identify ticks?	
Novice: I cannot reliably differentiate ticks from other arachnids and insects	12 (6.7%)
Beginner: I can differentiate a tick from other arachnids and insects	75 (42.1%)
Average: I can recognize a few of the most common species in my area	78 (43.8%)
Expert: I can look at ticks under the microscope, apply tick identification keys, and identify any species of tick native to my area	11 (6.2%)
No answer	2 (1.2%)
How comfortable do you feel identifying the different life stages of ticks (larva, nymph, adult)?	
Very comfortable	17 (9.5%)
Somewhat comfortable	72 (40.4%)
Neither comfortable nor uncomfortable	35 (19.7%)
Somewhat uncomfortable	35 (19.7%)
Very uncomfortable	8 (4.5%)
No answer	11 (6.2%)
Which of the following life stages require a blood meal? †*	
Nymph	113 (63.5%)
Adult	83 (46.6%)
Larva	31 (17.4%)
No answer	14 (7.9%)
How do ticks find their hosts? †‡	
Climb up plants and wait for hosts to walk by	108 (60.7%)
Drop from trees	75 (42.1%)
Fly	20 (11.2%)
Not sure	1 (0.6%)
No answer	15 (8.4%)

† Percentages do not add up to 100% because participants could choose more than one answer.
* All life-stages (adult, nymph, larva) require a blood meal.
‡ To find hosts, ticks climb up plants and wait for hosts to walk by.

3.4. Exposures to ticks and TBDs

Most participants (65.7%) reported tick encounters most frequently at work (Table 3). Within the past year, most (71.9%) professionals reported finding a tick on themselves during or after a farm call half of the time (37.6%) or rarely (34.3%). In a clinic setting, most (72.5%) reported finding a tick on themselves every few months (41.0%) or rarely (31.5%). The most diagnosed (69.7%) animal TBD was anaplasmosis (Table S7).

3.5. Practices against ticks and TBDs

Personal prevention strategies used by most large or mixed animal professionals on farms included applying tick repellent (63.2%) and checking for ticks soon after leaving the area (52.8%) (Table 4). Most (70.8%) participants routinely checked patients for ticks. Additionally, most (79.2%) wrote certificates of veterinary inspection, and a majority

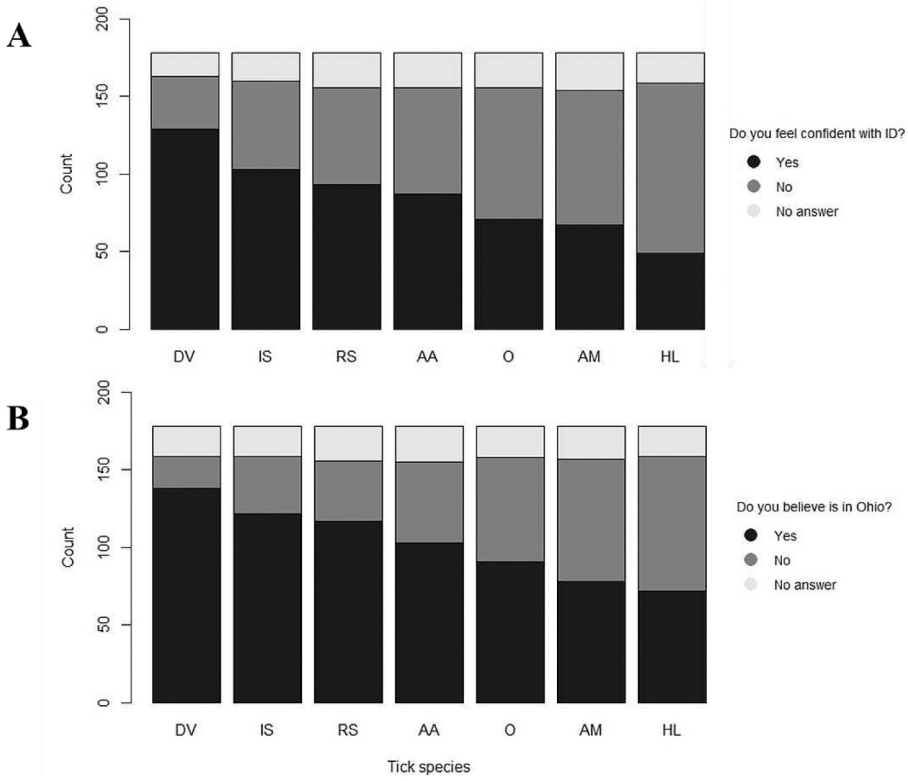

Fig. 1. Knowledge of veterinary professionals (n = 178) that participated in an electronic anonymous survey regarding tick species relevant to the health of animals and people in Ohio. A. Distribution of answers to the question "Do you feel comfortable identifying this species?" B. Distribution of answers to the question "Do you believe that this species is present in Ohio?" AA = *Amblyomma americanum*, AM = *Amblyomma maculatum*, DV = *Dermacentor variabilis*, HM = *Haemaphysalis longicornis*, IS = *Ixodes scapularis*, RS = *Rhipicephalus sanguineus*, O = *Otobius* spp. More details in Table S3. All species listed are present in Ohio.

Table 3
Occupational/personal exposures of Ohio-based veterinary professionals (n = 178), who participated in a self-administered electronic survey, regarding ticks and tick-borne diseases.

Question	n (%)
Where do you encounter ticks most frequently?	
At work	117 (65.7%)
At home	30 (16.9%)
During leisure activities (not at home or work)	30 (16.9%)
Other	0 (0%)
I don't encounter ticks	0 (0%)
No answer	1 (0.5%)
How often in the past year have you found a tick on yourself during or after a farm call?	
Happens at almost every call	16 (9.0%)
Happens at about half my calls	67 (37.6%)
Rarely happens	61 (34.3%)
Never happens	10 (5.6%)
I do not make farm calls	18 (10.1%)
No answer	6 (3.4%)
How often in the past year have you found a tick on yourself after handling a patient in your hospital?	
Happens one or more times a month	26 (14.6%)
Happens every few months	73 (41.0%)
Rarely happens	56 (31.5%)
Never happens	15 (8.4%)
I do not see patients in a hospital/clinic	2 (1.2%)
No answer	6 (3.4%)

Table 4
Practices of Ohio-based veterinary professionals, who participated in a self-administered electronic survey, regarding ticks and tick-borne diseases.

Question	n (%)
Which of the following methods of tick bite prevention strategies do you use when you go on farm calls? † (n = 106)	
Using tick repellent (spray, or repellent-impregnated clothing)	67 (63.2%)
Checking for ticks soon after leaving the area	56 (52.8%)
Wearing long sleeves and long pants	50 (47.2%)
Showering and changing clothes soon after leaving the area	39 (36.8%)
None	2 (1.9%)
No answer	1 (0.9%)
Do you routinely check patients for ticks? (n = 178)	
Yes	126 (70.8%)
No	36 (20.2%)
It depends on the circumstances	3 (1.7%)
No answer	13 (7.3%)
Have you ever submitted a tick to a lab for identification? (n = 178)	
Yes	128 (71.9%)
No	49 (27.5%)
No answer	1 (0.6%)
Do you believe that an animal with ticks can be cleared for sale/transport? (n = 141)	
No	88 (62.4%)
Yes	52 (36.9%)
It depends on where they are going	1 (0.7%)

† Percentages do not add up to 100% because participants could choose more than one answer.

of these (62.4%) believed that infestation precluded transportation (Tables 4, S8).

Most small animal professionals discussed tick prevention with clients at every visit (26.8%) or once a year (23.9%) (Table S8). Large or mixed animal professionals differed to some extent - 20.8% discussed tick prevention at every visit, 20.8% if ticks were found on animals, and 19.8% once a year (Table S8). Oral or injectable preventatives were most recommended by small (81.3%) and large or mixed animal (58.2%) professionals (Table S8). Factors most important to small animal clients when choosing a preventative were ease of application (31.9%) and efficacy (24.2%) whereas for livestock clients, these included cost

(28.1%) and ease of application (25.0%) (Table S8).

3.6. Surveillance and education

Most professionals (71.9%) had submitted a tick for identification during their careers. Out of those who never had, the main reasons were lack of awareness (49.0%) or associated costs (34.7%). Most indicated they would more likely submit ticks for surveillance if they could submit photos (57.3%) (Table S9).

The topic most professionals (57.3%) were interested in learning about was local TBD risks. Most reported learning about ticks and TBDs primarily through school (35.9%) or continuing education (29.8%) (Table S9). Written literature (20.8%, 37 ranked #1) and tick ID charts (21.3%, 38 ranked #2) were selected as the most preferred format for learning new content.

3.7. Classification tree analysis

After missing data were excluded, 58 small animal professionals were included in the analysis. Predictors selected as important were level of training (veterinarian versus non-veterinarian) and routine patient checks for ticks (yes versus no). We found that 48% ($n = 28$) were veterinarians that frequently discussed prevention with clients (Fig. 2a). However, technicians and assistants discussed prevention frequently when they also routinely checked patients for ticks ($n = 14$).

We again excluded missing data, which resulted in a sample size of 71 mixed or large animal professionals. Selected variables were routine tick checks of patients and level of training with the addition of personal tick exposure on farms (frequent versus infrequent). We found 15% ($n = 11$) of participants did not routinely check patients for ticks and discussed tick prevention with clients infrequently (Fig. 2b). Forty-nine percent ($n = 35$) discussed prevention frequently when there was also frequent personal tick exposure after farm calls. If there was infrequent exposure ($n = 25$), level of training was important, where technicians and assistants ($n = 11$) still discussed prevention frequently, unlike veterinarians.

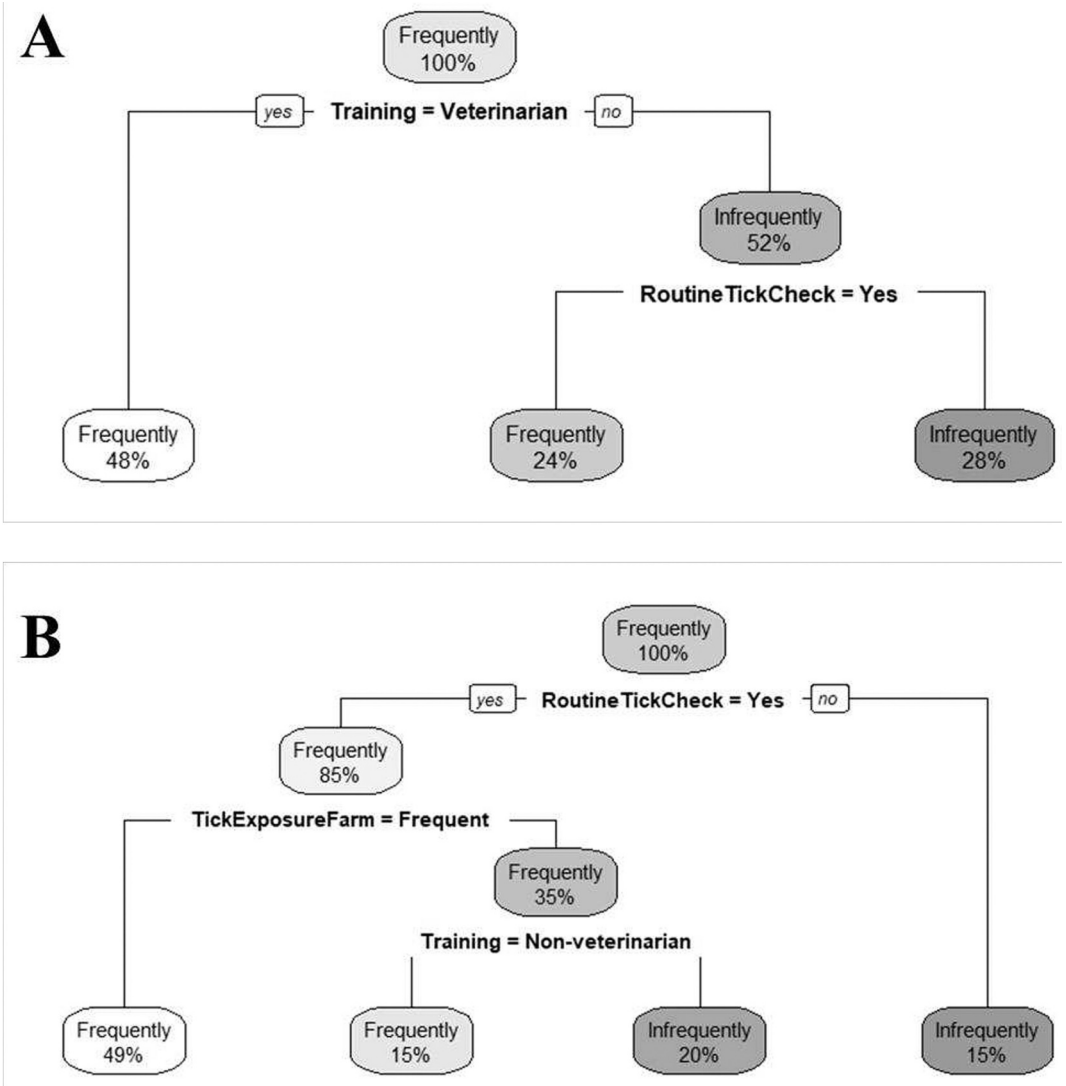

Fig. 2. Classification trees that describe associations among knowledge, attitudes, exposures, practices, and training for A) small animal professionals ($n = 58$) and B) large or mixed animal professionals ($n = 71$), who participated in a survey regarding ticks and tick-borne diseases in Ohio. The response variable was the frequency of discussion with clients regarding tick prevention (a "practices" question). For small animal professionals, predictors were training (veterinarian versus non-veterinarian) and routine tick checking of patients (yes versus no). For large or mixed animal professionals, predictors were personal tick exposure on farm (frequently versus infrequently), training and routine tick checks of patients. For interpretation, branches to the left are read as "yes" to the variable displayed at node immediately prior. Percentages of professionals are shown.

4. Discussion

Our study described the knowledge, attitudes, exposures, and practices regarding ticks and tick-borne diseases (TBDs) of veterinary professionals (veterinarians and non-veterinarians), a high-risk occupational group. Professionals generally considered ticks and TBDs as health hazards but had significant knowledge gaps. Nevertheless, they did practice prevention to varying degrees. Interestingly, knowledge regarding tick biology and attitudes regarding tick or TBD health risks did not associate with practices. However, we did find that veterinarian status (versus non-veterinarian) and routine tick checks of patients were the most important predictors of frequent discussions with clients regarding tick prevention for small and large or mixed animal professionals, respectively.

Most professionals considered themselves as "beginner" or "average" at identifying tick species with half being comfortable to some degree at identifying life stages. Only a minority correctly reported how ticks find hosts or which life stages require blood, which has serious implications for effective prevention. Professionals felt most comfortable identifying three species they considered present in the state, although others, such as the Lone star tick, were considered less identifiable despite establishment in Ohio [4]. Although other TBDs co-occur, most considered Lyme disease as the only TBD present in Ohio, a trend likely fueled by its greater regional focus [27,28]. This was surprising because most professionals reported that they had diagnosed animal anaplasmosis in Ohio. Perhaps reminding participants of their clinical experience by switching the order of these questions may have avoided this discrepancy. The gaps in knowledge regarding tick biology and TBD epidemiology we identified mirrored other veterinary surveys from U.S. and abroad [5,28–33]. Whether these gaps are the result of a limited veterinary curriculum or continuing education is unclear and warrants further investigation.

Attitudes towards tick risks to human health were cautionary even when most professionals were exposed to ticks infrequently or rarely regardless of practice type. Importantly, tick exposures occurred most frequently at work, significantly underscoring the occupational nature of TBDs for this population, which is also highlighted elsewhere [30]. Additionally, most professionals in large or mixed animal practice considered ticks or TBDs as severe hazards to their patient populations. African swine fever was the only foreign TBD that was thought by most to present greatest risk for introduction into Ohio, which is reasonable given its spread abroad [34]. However, it is unclear if participants attributed this risk entirely to tick-borne transmission. Moreover, bovine theileriosis was reported by most as only having the potential for introduction, which is surprising because it has been diagnosed in nearby states, unlike African swine fever [14]. Overall, professionals infrequently encountered ticks but still demonstrated cautionary attitudes, the latter agreeing with some studies [28,30] but disagreeing with others [35].

It was encouraging to find that most professionals routinely checked patients for ticks and that most of those who wrote certificates of veterinary inspection thought that infestation precluded transportation. Continuing along a positive vein, most large or mixed animal professionals used at least two personal prevention measures on farms. Although small animal professionals frequently discussed tick prevention with clients, aligning with studies in Canada [28] but not Alaska, U.S. [33], 20% of large or mixed animal professionals engaged in these discussions only when they found ticks on animals. The latter is problematic because ticks could still be present in the environment. Oral or injectable preventatives were recommended by most, which could partially be due to ease of application, a feature that was important to clients when choosing preventatives. Although aligning recommendations with client needs is critical for compliance, it does not necessarily lead to better client practices [36].

Submitting a tick for identification was a common practice by most professionals. Those who had not done so, selected lack of awareness or costs as the main reason. Because programs where ticks can be submitted with no costs do exist [37], increasing awareness may encourage submissions. Our findings show that submission of tick photos would motivate more professionals to engage in surveillance, but photos do not allow for TBD testing and differentiation of similar species. Lastly, most professionals learned about ticks and TBDs through continuing education and school, but we found written literature and tick identification charts as the most preferred formats for learning new content. Because we did not specify in our survey the type of written literature, participants may have selected this option to signify any type of written materials, such as brochures or informational fact sheets.

Using classification trees, we found no associations among knowledge, attitudes, and practices of veterinary professionals. Such KAP associations may [7] or may not [33] exist within target populations, therefore generalizations are unreliable. For small animal professionals, we showed that level of training and routine tick checking of patients associated with frequency of prevention discussions with clients. Veterinarians were more likely to frequently discuss prevention, whereas non-veterinarians (technicians and assistants) were likely to do so only when they also practiced routine tick checking of patients. For large or mixed animal professionals, tick exposure on farms was also important. When routine tick checking of patients was not practiced, we identified a small group that infrequently discussed prevention. However, when tick checking was practiced, a large group discussed prevention frequently only when they experienced personal tick exposure frequently. These findings point to two recommendations for increasing the frequency of engaging in discussions regarding prevention with clients. Firstly, although a correlative relationship, the practice of routine tick checking of patients should be encouraged as it could increase frequency of discussions with clients. Secondly, educating large or mixed animal professionals how to best self-check for ticks will ensure they correctly assess personal exposures, which may increase frequency of discussions with clients.

Our study had a few limitations. Firstly, because our survey platform was invaded by "bots", which resulted in hundreds of fraudulent responses, it is possible that we unintentionally included some of these responses in our analyses although we attempted to avoid this error through systematic exclusion. Secondly, after exclusion of fraudulent and incomplete responses, we had a modest yet relatively small convenience sample, because >2500 veterinarians work in Ohio [38]. Thus, we may not have described all professionals in Ohio, which could lead to selection bias. Thirdly, responses were self-reported, hence our data may be susceptible to recall bias. To address these limitations, prospective survey studies should employ a probability-based design targeting a representative sample of veterinary professionals and should avoid blanket advertising on social media, if possible. Despite these deficiencies, we gathered valuable insights regarding knowledge, attitudes, exposures, and practices, of veterinary professionals in a state faced with expanding and invading ticks, a model for other regions experiencing similar trends, to inform targeted strategies for intervention.

We can place our findings within a "Health Belief Model" [39] context, a popular health planning framework, to promote prevention behaviors in our study's veterinary population. Our findings suggest that professionals perceive ticks and TBDs as serious hazards, but significant knowledge gaps may not sufficiently motivate confident tick identification and TBD testing, thereby serving as barriers. According to the "Health Belief Model," we may be able to further promote prevention behaviors through increasing veterinary professionals' motivation and confidence regarding local ticks and TBDs, by providing access to educational materials in preferred formats and reinforcing existing good practices.

In conclusion, we highlighted deficiencies among veterinary professionals in their knowledge regarding ticks and TBDs. Regardless, most still exhibited cautionary attitudes towards ticks and TBDs and practiced prevention. We provide recommendations that can be incorporated into

interventions embedded in social ecological theory for educating the veterinary community and broadly protecting animal, public and environmental health within a "One Health" context.

Authors contributions

RP, AA and AB contributed to the conception, design, and funding of the study; RP, SS, AB and AA contributed to the first questionnaire draft; AE and RP finalized questionnaire for dissemination; AE and RP led data collection; AE summarized and analyzed data and drafted the first manuscript version; RP, SS, AB and AA contributed to manuscript development and revision.

Declaration of Competing Interest

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

The electronic questionnaire that was disseminated to Ohio-based veterinary professionals and Tables S1-S9. Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2023.100592.

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