


Spatial Distribution of Tick Acaricide Resistance in Uganda: A Focus on *Rhipicephalus appendiculatus* and *Rhipicephalus decoloratus* Tick Species

Joseph Byaruhanga^{1,2*}, Patrick Vudriko¹, Benedicto Byamukama¹, Fred Odua^{1,3}, Yvette Ssebunya⁴, Rashid Kassim Njalira¹, Christine Nabbale^{1,4}, Sharon Amita¹, Martin Angwe¹, Saviour Dralabu¹, Maria Agnes Tumwebaze¹, Dickson Stuart Tayebwa¹, Anthony Mugisha^{1,5}

¹Research Center for Tropical Diseases and Vector Control, Department of Veterinary Pharmacy, Clinics and Comparative Medicine; School of Veterinary Medicine and Animal Resources; College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University, Kampala, Uganda

²Department of Biosecurity, Ecosystems and Veterinary Public Health, College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University, Kampala, Uganda

³Production Department, Nakasongola District Local Government, Nakasongola, Uganda

⁴Department of Animal Health, Ministry of Agriculture, Animal Industry and Fisheries, Entebbe, Uganda

⁵Department of Livestock Industrial Resources, College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University, Kampala, Uganda

Email: *jbyaruhanga01@gmail.com

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Abstract

Acaricide use remains a key intervention for the control of ticks in the tropical countries such as Uganda. However, the use of acaricides for tick control has recently been complicated by the emergence of acaricide resistance. This study provides an update on spatial distribution of acaricide resistance in *Rhipicephalus appendiculatus* and *Rhipicephalus decoloratus* ticks in Uganda. A country-wide cross-sectional study in which cattle ticks were collected from 37 districts representing the major regions of Uganda was conducted. A total of 201 tick populations were tested against discriminating concentration of deltamethrin (0.05 mg/ml), amitraz (0.25 mg/ml) and a combination of chlorpyrifos and cypermethrin (0.5/0.05 mg/ml) following FAO's larval packet test (LPT) method. The resultant acaricide susceptibility data was used to generate acaricide resistance maps with ArcGIS software for desktops version 10.8. Gen-



erally, both tick species showed highest acaricide resistance against deltamethrin, followed by amitraz and combination of chlorpyrifos and cypermethrin, at 80.1%, 57.7% and 52.2%, respectively, across tick populations sampled in all regions of Uganda. Multiple acaricide-resistant (resistance to at least two classes of acaricide) *R. appendiculatus* and *R. decoloratus* tick populations were widely distributed in the Central, Western and Southwestern regions of Uganda. However, both tick species from the Eastern and Northern regions of Uganda were largely susceptible to the acaricide classes tested. However, the combination of chlorpyrifos and cypermethrin had a better combined effect on *Rhipicephalus* ticks collected from the Central, Western and Southwestern regions of Uganda. This study confirmed that both single and multiple acaricide resistance by *R. appendiculatus* and *R. decoloratus* against deltamethrin, amitraz and combination of chlorpyrifos and cypermethrin was widely distributed across the central, southwestern and western cattle corridor of Uganda. We propose the strengthening of national capacity for the surveillance of tick acaricide resistance at the regional and national levels. The competent authority may consider developing a national acaricide zoning and rotation plan to promote the sustainable use of chemical acaricides for the control of ticks in the country. Implementing strict animal movement control could also reduce the spread of acaricide-resistant ticks in the country.

Keywords

Ticks, *Rhipicephalus appendiculatus*, *Rhipicephalus decoloratus*, Acaricides, Tick Resistance, Uganda, Spatial Distribution, Map

1. Introduction

Ticks are ectoparasites that feed on the blood of mammals and transmit various disease-causing pathogens that affect livestock production and health [1]. Generally, ticks are responsible for causing major losses to the livestock sector due to direct effects such as reduced weight gain, milk yield and hide quality and indirect effects such as transmission of tick-borne diseases (TBDs) such as East Coast fever (ECF), anaplasmosis, babesiosis and heart water [2] [3]. *Rhipicephalus* ticks (*Rhipicephalus appendiculatus* and *Rhipicephalus decoloratus*) are potent vectors responsible for the transmission of major TBDs of veterinary significance in Uganda. Similarly, *Rhipicephalus* ticks are more prevalent on Ugandan farms than other tick genera [4]. Among the *Rhipicephalus* tick species, *Rhipicephalus appendiculatus* and *Rhipicephalus decoloratus* are the most prevalent species on the majority of farms in Uganda [5]-[8]. It is these same tick species which are implicated in the challenge of tick acaricide resistance in the country as reported by several scholars [9]. Therefore, effective control of these tick species remains a key priority for Ugandan farmers. However, their control continues to be hampered by the ever-growing challenge of tick acaricide resistance in the various regions of the

country.

The tick acaricide resistance challenge has been reported not only in Uganda but also in the entire East African region and is a major threat to livestock production and health in the region [10]. The emergence and spread of tick acaricide resistance within the region has been attributed to several factors, such as the misuse and overuse of acaricides, the lack of effective tick resistance surveillance systems, the poor quality and adulteration of acaricides, the inadequate regulation and enforcement of tick control and acaricide use policies, the limited knowledge and awareness of farmers and stakeholders, and the socioeconomic and environmental factors that influence tick infestation and management [11] [12].

Over the years, tick control in Uganda has relied on the use of chemical acaricides [13]. The widespread and indiscriminate use of acaricides has led to the emergence of tick resistance, which has become a major challenge for the entire livestock industry of Uganda [12]. Tick resistance to acaricides is defined as the ability of ticks to survive exposure to acaricides at concentrations that are normally lethal to susceptible ticks. Resistance can be detected via various methods, such as molecular assays and biochemical assays. Acaricide resistance was first reported in Uganda in 1970 against organochlorine toxaphene by *Rhipicephalus decoloratus* and *Rhipicephalus evertsi evertsi* [14]. Between 2012 and 2016, a team of researchers at Makerere University reported the emergence of multiple acaricide-resistant ticks in southwestern Uganda, the dairy hub of Uganda [15]. Since then, several scientific studies have been conducted to fully understand the challenge of tick resistance to acaricides in Uganda. Some studies have assessed the genetic basis of tick resistance to various classes of acaricides, especially deltamethrins and amitrazs. At a regional level, a recent systematic review conducted to assess the status of acaricide resistance in Africa reported a limited number of published studies about tick acaricide resistance in Uganda [16]. However, compared with other African countries outside South Africa, Uganda had more studies reporting on various aspects of tick acaricide resistance, such as risk factors. Epidemiological studies have also been conducted to investigate the risk factors associated with tick resistance in Uganda [11] [12] [15] [17]. However, none of those studies provided a national picture of the geographical distribution of tick resistance other than a picture of the specific study areas, which, in most cases, were selected purposively on the basis of farmer reports and complaints about ticks that did not respond to acaricides. Therefore, a country-wide study to assess the geographical distribution of tick acaricide resistance by tick species and acaricide class has long been overdue. Mapping tick resistance in Uganda is expected to provide a much-needed national picture of the burden of tick acaricide resistance to guide policy and planning for the country's livestock sector. Therefore, the purpose of this country-wide study was to map the distribution of tick acaricide resistance in *R. appendiculatus* and *R. decoloratus* ticks against commonly used classes of acaricides in various regions of Uganda.

2. Methods

2.1. Study Area

A total of 37 districts were sampled in all 5 regions of Uganda (Figure 1). The central region, which combines the northern and southern Buganda sub regions, was represented by 11 districts (Sembabule, Gomba, Masaka, Kyotera, Lyantonde, Nakaseke, Nakasongola, Lwero, Mukono, Kayunga, and Rakai), with a total of 106 cattle farms sampled. The Eastern region, which combines the Busoga, Sebei, Bugisu and Teso sub regions, was represented by 6 districts, which included Jinja, Iganga, Mbale, Sironko, Kapchorwa and Kumi. A total of 59 farms were sampled from the Eastern region. The Mbarara, Isingiro, Rukungiri, Sheema, and Buhweju districts represented the southwestern region, which comprises the Ankole and Kigezi sub regions, with a total of 50 farms sampled. Similarly, the Kasese, Ntoroko, Kabarole, Kamwenge, Kiryandongo, Masindi, Buliisa, Kyankwani, and Hoima districts were sampled from the western region (comprising the Tooro, Bunyoro and Rwenzori sub regions), with a total of 89 farms sampled. The northern region, which combines the Acholi, Lango, Karamoja and West Nile sub regions, was represented by the Moroto, Kotido, Adjumani, Gulu, Lira and Arua districts.

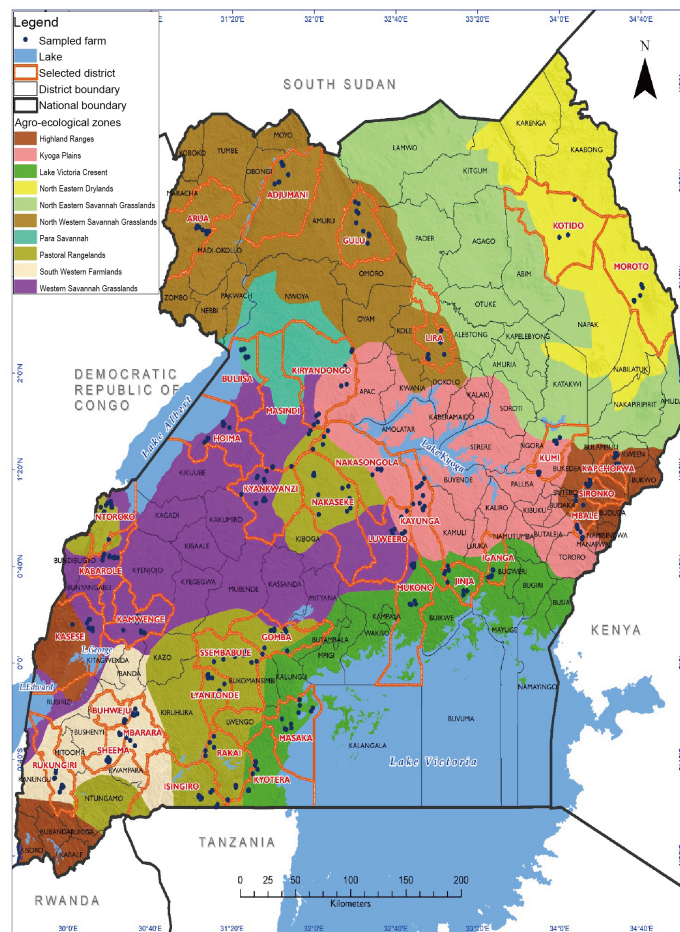


Figure 1. Map of Uganda showing the study areas.

2.2. Criteria for Cattle Farm Selection

In each of the selected districts, the two sub counties with the highest number of cattle were identified with the help of the district veterinary officer. From each of the sub counties, one parish with the highest number of cattle was identified with the help of the subcounty extension officer. A list of cattle farms in each of the selected parishes was generated by the extension officer, and five cattle farms were selected randomly from the pool. The selected farms were informed, and a request to visit their farms was made by the extension officer. Those who refused to participate were replaced by other randomly selected farms. Appointments were made with the farm owner to visit the farm to collect ticks and relevant data (GPS coordinates and farm address).

2.3. Sampling Procedure

Upon arrival at the farm, a short meeting took place between the research team, extension officer and farmer to explain the purpose of the study and to obtain informed consent from the farmer to participate in the study. The administration of the semi-structured questionnaire for assessing the acaricides used for tick control was conducted for each farm visited. The GPS coordinates for each of the selected farms were collected and recorded among the farm details. Randomly selected cattle were mobilized and restrained using cattle crushes, and in farms where cattle crushes were absent, ropes were used to restrain the cattle for tick collection across the various predilection sites (ears, udder, dewlap, head, neck, brisket abdominal region, tail, fore and hind legs) for species identification and chemical tick assays.

2.4. Laboratory Tick Sample Processing

Tick sorting and taxonomy were conducted with the aid of a stereomicroscope following the taxonomical [18] at the Research Center for Tropical Diseases and Vector Control (RTC), College of Veterinary Medicine, Animal Resources & Biosecurity, Makerere University. Engorged female ticks of the same species from the same farm were selected and incubated in groups of 3 - 4 ticks per culture tube and labeled. The incubation tubes containing the ticks were transferred to an incubator set at $27^{\circ}\text{C} \pm 1^{\circ}\text{C}$ and 80% relative humidity. The incubation process was monitored daily to ensure that the conditions remained constant and to check for possible egg laying and egg hatching. The larvae were left to mature for 10 - 14 days after hatching, and would be ready for acaricide bioassays.

2.5. Larval Packet Test

To determine the susceptibility of the tick larvae to acaricides, we adopted the FAO's recommended larval packet test [19] and was performed from the Research Center for Tropical Diseases and Vector Control (RTC).

2.5.1. Acaricides Used

Commercial formulations of commonly used classes of acaricide in Uganda were

selected. These included Synthetic pyrethroids (deltamethrin), amidines (amitraz) and co-formulations (combination of chlorpyrifos and cypermethrin). The use of commercial formulations is recommended for large scale acaricide resistance surveillance programs (countrywide) involving over 200 tick populations. Also, use of technical grade (chemical reference standards) is not economically feasible in a resource constrained country due to associated high costs of obtaining the reference chemicals. To address issues regarding the quality of commercial formulations, we sourced the products directly from the importer (local technical representative of the manufacturer) whose products undergo regular quality assessment by the regulator for compliance. For internal quality assurance, susceptible populations of larvae of *Amblyomma variegatum* were exposed to the recommended concentration of each of the commercial acaricide formulations. Only those that achieve the 100% mortality within 24 hours are used in the experiments.

2.5.2. Solvent Preparation

A mixture of trichloroethylene (TCE) and analytical grade olive oil was prepared in a ratio of 2:1 respectively. The solvent was prepared.

2.5.3. Preparation of Acaricide Solution

The manufacturer's recommended concentration (discriminating concentration (DC)) was considered the diagnostic dose for all the chemicals tested. The FAO recommended larval packet test (LPT) was adopted for the acaricide susceptibility tests. The recommended (manufacturer) concentrations of deltamethrin, amitraz and the co-formulated acaricides (chlorpyrifos + cypermethrin) used in this study were 0.05 mg/ml, 0.25 mg/ml, and 0.5:0.05 mg/ml (chlorpyrifos: cypermethrin), respectively. Each tick population was exposed to the recommended concentrations of all three classes of acaricides.

2.5.4. Preparation of Substrate

Filter paper (Whatman No. 1, Whatman, Madstone, United Kingdom) was used as a substrate for deltamethrin, and a combination of chlorpyrifos and cypermethrin and Nylon fabric was used for amitraz. The LPT was conducted following methods previously published by several scholars [15].

2.6. Data Management and Analysis

The LPT results were assessed after 24 hours of incubation of the packets. The numbers of living and dead ticks were counted and recorded for each chemical, each tick species and each replicate. Mortalities were expressed as percentages of the total number of larvae exposed to the acaricide. The data from the laboratory tests and the Global Positioning System (GPS) coordinates for the sampled farms were transferred into Microsoft Excel software, where percentage mortalities were calculated. From the percentage mortality results, a given tick population was categorized as susceptible if the percentage mortality value was $\geq 90\%$ or resistant if the percentage mortality was $< 90\%$. Resistant tick populations were further categorized as single resistance or multiple acaricide resistance. A tick population re-

sistant to only one class of acaricide was categorized as single acaricide resistance whereas those that were resistant to at least two acaricide classes were categorized as multiple acaricide resistance.

2.7. Tick Acaricide Resistance Maps

The acaricide resistance maps were generated on the basis of tick species and acaricide classes across all regions of Uganda using ArcGIS® software for desktops version 10.4.1. The GPS data (coordinates) were plotted in ArcGIS® software to generate the locations of the farms. Statistics for each district were generated via geostatistical techniques in ArcGIS® software. The results were presented at the district level and were visualized via charts and graduating colors. The red and maroon colors represent resistance, whereas the green color represents susceptibility.

2.8. Ethical Considerations

Informed consent was obtained from farm owners or their representatives as evidence of voluntary participation in the research. The researchers upheld the principles of confidentiality and anonymity. The cattle were handled humanely at all stages of tick collection to ensure that welfare was guaranteed.

3. Results

3.1. Acaricide Classes for Tick Control in Uganda

Out of the 357 farms sampled in all the regions of Uganda, 37.5% (134), 32.5% (116), 20.4% (73), 2.0% (7) and 1.7% (6) were using acaricides in the classes of co-formulations, amidines, synthetic pyrethroids, organophosphate and crop agrochemicals for tick control on their farms respectively (**Figure 2**). Interestingly, 6% (21) of the farms were not using any of the chemicals for tick control.

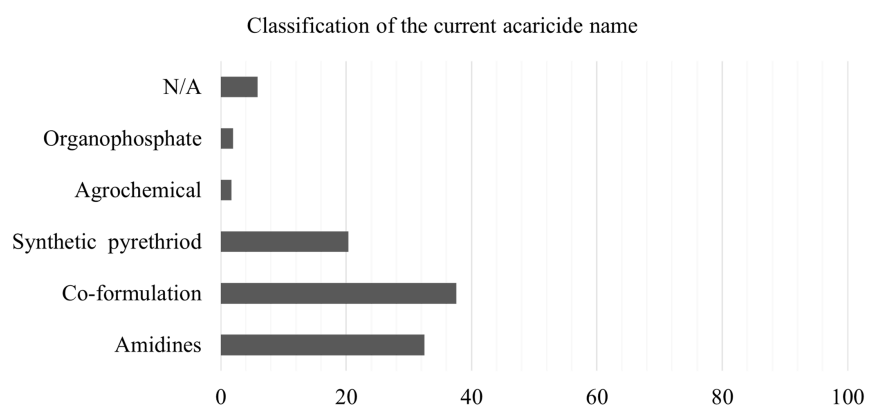


Figure 2. Acaricide classes commonly used for tick control on cattle farms in Uganda.

3.2. Acaricide Resistance Profile for Major Tick Species in Uganda

A total of 201 tick populations were tested using standard LPT test. Generally,

acaricide resistance was detected for all the major acaricide classes commonly used for tick control on farms in Uganda (Table 1). The highest percentage (80.1%) of tick populations tested in the country were resistant to deltamethrin (a synthetic pyrethroid). Contrary, the 201 tick populations tested exhibited lower resistance against amitraz (57.7%) and co-formulated acaricides containing cypermethrin plus chlorpyrifos (52.2%). In terms of susceptibility, 47.8% of the tick populations tested were susceptible to co-formulated acaricides containing cypermethrin plus chlorpyrifos.

At the regional level, a total of 44 populations of *R. decoloratus* ticks were tested from the southwestern region. They were highly (100%) resistant to deltamethrins and amitrazs (88.6%). On the contrary, majority (79.5%) of the *R. decoloratus* tick populations tested from the southwestern region were susceptible to co-formulated acaricides containing cypermethrin and chlorpyrifos. Similarly, *R. appendiculatus* tick populations (n = 14) from the southwest were also highly resistant to deltamethrin (100%) but largely susceptible to amitraz (92.9%).

The *R. decoloratus* tick populations (n = 25) from the Central Region were highly resistant to all three classes of acaricides commonly used in Uganda, with 100%, 96% and 96% of the populations tested showing resistance to deltamethrins, coformulated acaricides (cypermethrin and chlorpyrifos) and amitrazs, respectively. The results for *R. appendiculatus* tick populations were not different from those observed for *R. decoloratus* tick populations for deltamethrins and co-formulated acaricides (cypermethrin and chlorpyrifos). However, *R. appendiculatus* tick populations (n = 44) were largely (75%) susceptible to amitrazs.

The *R. decoloratus* tick populations (n = 18) from the western region were highly resistant to both deltamethrins (100%) and amitrazs (94.4%). Only half of the tested populations of *R. decoloratus* ticks from the western region were susceptible to co-formulated acaricides (cypermethrin and chlorpyrifos). Moreover, *R. appendiculatus* tick populations (n = 25) from the same region presented quite different results, with a simple majority (of the tested populations) being susceptible to deltamethrins (64%) and coformulated acaricides (56%). However, 72% of the same tick species population was resistant to amitrazs (Table 1).

Although a total of four tick species were tested from Eastern region, the majority of the tick populations tested were *R. decoloratus* (n = 9), which exhibited high (89%) resistance to deltamethrins, followed by both amitrazs and coformulated acaricides at 55.5%. We detected acaricide resistance to deltamethrins among the *Hyalomma spp.* population tested. Similarly, we detected amitraz resistance among the *R. evertsi evertsi* tick population tested from the Eastern Region. The *R. appendiculatus* tick populations (n = 2) from the Eastern Region were resistant to deltamethrins and co-formulated acaricides. The tick populations from the northern region, including *R. evertsi evertsi*, *Hyalomma spp.* and *R. appendiculatus*, were highly (100%) susceptible to all three major acaricide classes commonly used in Uganda (Table 1).

Table 1. National acaricide resistance profiles of *Rhipicephalus appendiculatus* and *Rhipicephalus decoloratus* tick populations.

Region	Tick response to acaricides							N
	Acaricide classes	Deltamethrin		Cypermethrin + Chlorpyrifos		Amitraz		
	Tick species	R (%)	S (%)	R (%)	S (%)	R (%)	S (%)	
Southwest	<i>R. decoloratus</i>	44 (100)	0	9 (20.5)	35(79.5)	39 (88.6)	5 (11.4)	44
	<i>R. appendiculatus</i>	14 (100)	0	13 (92.9)	1 (7.1)	1 (7.1)	13 (92.9)	14
Central	<i>R. decoloratus</i>	25 (100)	0	24 (96)	1 (4)	24 (96)	1 (4)	25
	<i>R. appendiculatus</i>	41 (93.2)	3 (6.8)	33 (75)	11 (25)	11 (25)	33 (75)	44
Western	<i>R. decoloratus</i>	18 (100)	0	9 (50)	9 (50)	17 (94.4)	1 (5.6)	18
	<i>R. appendiculatus</i>	9 (36)	16 (64)	11 (44)	14 (56)	18 (72)	7 (28)	25
Eastern	<i>R. decoloratus</i>	8 (89)	1 (11)	5 (55.5)	4 (44.5)	5 (55.5)	4 (44.5)	9
	<i>R. appendiculatus</i>	1 (50)	1 (50)	1 (50)	1 (50)	0	2 (100)	2
	<i>R. evertsi evertsi</i>	1 (50)	1 (50)	0	2 (100)	0	2 (100)	2
	<i>Hyalomma</i> spp	0	1 (100)	0	1(100)	1 (100)	0	1
Northern	<i>R. decoloratus</i>	0	12(100)	0	12 (100)	0	12 (100)	12
	<i>R. appendiculatus</i>	0	1 (100)	0	1 (100)	0	1 (100)	1
	<i>Hyalomma</i> spp	0	4 (100)	0	4 (100)	0	4 (100)	4
Total (%)		161(80.0)	40 (20.0)	105 (52.2)	96 (47.8)	116 (57.7)	85 (42.3)	201

Keywords: R = Resistant, S = Susceptible and N = Tick populations tested.

3.3. Distribution of Acaricide-Resistant *R. appendiculatus* Ticks in Uganda

The findings revealed that the multiple acaricide-resistant *R. appendiculatus* tick populations were widely distributed in the majority of the districts located in the Central, Western and Southwestern regions of Uganda. However, acaricide susceptible *R. appendiculatus* tick populations were detected in Kasese and Ntoroko districts (Western region) and in the districts of Sheema, Kazo and Kiruhura (South-western region). The *R. appendiculatus* ticks from the Eastern and Northern regions of Uganda were largely susceptible to all the major acaricide classes commonly used in Uganda (Figure 3).

3.4. Distribution of Acaricide-Resistant *R. decoloratus* Ticks in Uganda

The multiple acaricide-resistant *R. decoloratus* tick populations were confirmed to be widely distributed within the southwestern, western and central regions of Uganda. Within the southwestern and western regions, acaricide susceptible *R. decoloratus* tick populations were only detected in some farms located in Rakai and Buliisa districts respectively. On the other hand, the eastern and northern regions were still largely free of acaricide-resistant *R. decoloratus* tick populations. The ticks collected from the northern region were highly susceptible to all the major acaricide classes commonly used in Uganda (Figure 4). However, multi

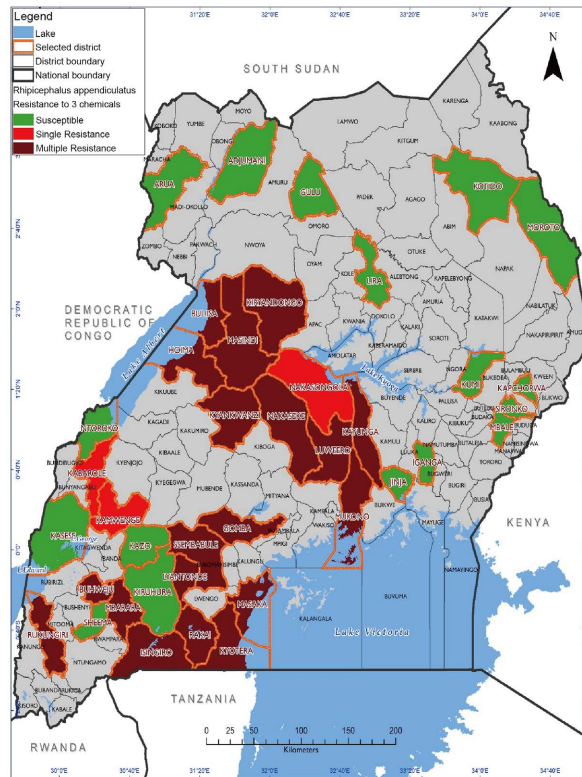


Figure 3. Map of Uganda showing the general distribution of acaricide resistant *Rhipicephalus appendiculatus* ticks.

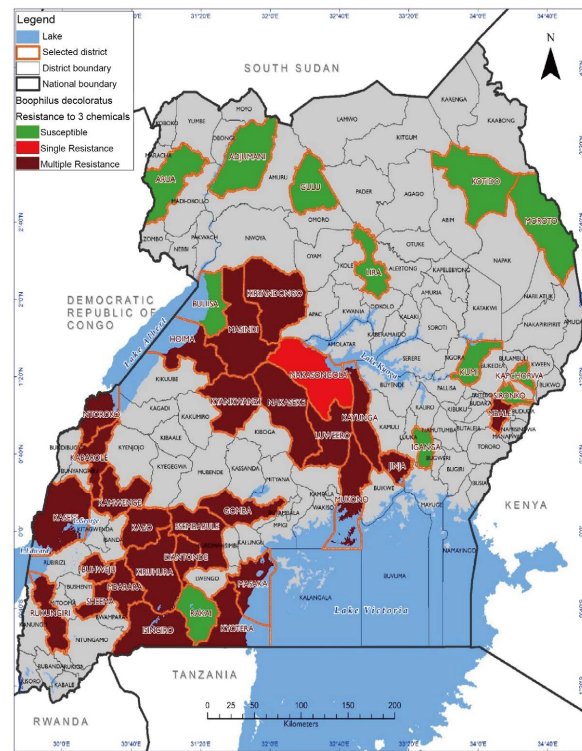


Figure 4. Map of Uganda showing the general distribution of acaricide resistant *Rhipicephalus decoloratus* ticks.

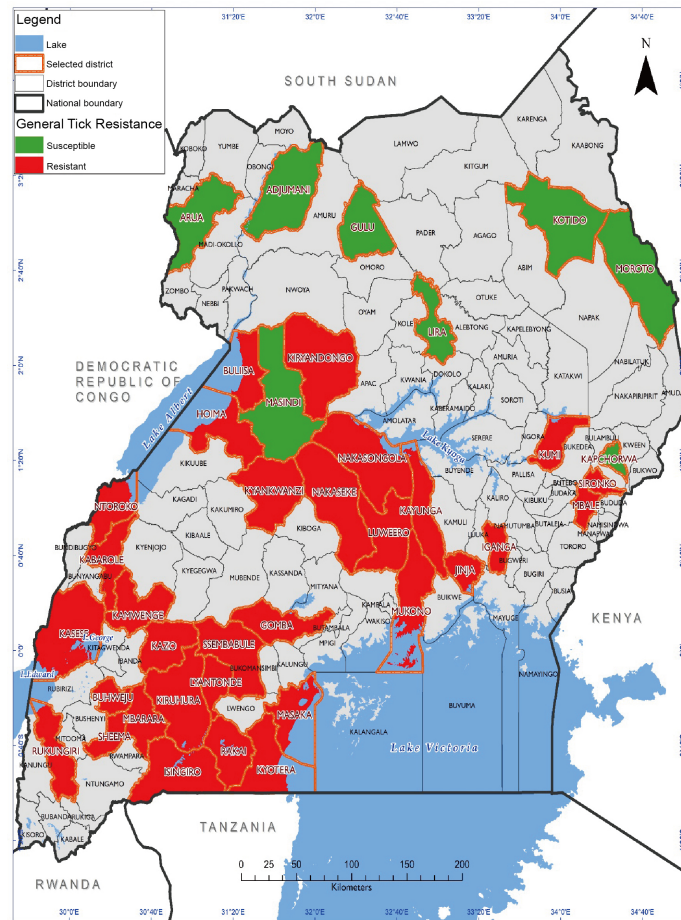


Figure 8. Map of Uganda showing the general distribution of acaricide-resistant and acaricide-susceptible *Rhipicephalus* ticks in Uganda.

4. Discussion

Rhipicephalus appendiculatus and *Rhipicephalus decoloratus* are the most important tick species affecting cattle health and productivity in Uganda and all over the East African region [4] [6]-[8]. They play an important role as potent vectors of common TBDs for cattle such as ECF, anaplasmosis and babesiosis. The control of these ticks remains a key priority for farmers to prevent tick-borne diseases. The findings of the present study are supported by several studies that reported high levels of resistance to deltamethrins, organophosphates and amitraz in *Rhipicephalus decoloratus* and *Rhipicephalus appendiculatus* ticks in a few districts within the cattle corridor of Uganda [3] [11] [14] [15] [20].

The findings further revealed that *Rhipicephalus* ticks from the Eastern and Northern regions of Uganda were fairly susceptible to all the three acaricides used in this study. This could be explained by farm practices, which promote less use of acaricides in terms of the frequency of application or poor acaricide application practices [9] [13]. Regions where farmers rarely applied acaricides on their cattle were associated with more susceptible ticks than are regions where farmers spray their cattle regularly and routinely. Low acaricide use in these regions could also

be attributed to the local breeds of cattle (Short East African Zebu) largely kept by the majority of the farmers under communal grazing systems [11]. The local breeds tend to tolerate tick infestations and to a certain extent they are able to tolerate TBDs [21]. Strategies for controlling tick acaricide resistance considering the different tick species and different contexts have been proposed by previous scholars [19] [22]-[25].

The rapidly growing challenge of acaricide resistance in the country could be partly explained by farmers' practices regarding tick control [9]. Several studies have reported the use of inappropriate pumps and poor animal restraint structures, such as bomas, during acaricide application. In addition, the introduction of new animals on farms, haphazard use of acaricides, mixing of acaricides with other agrochemicals (crop pesticides) and unnecessary decreases in acaricide application intervals have also been reported among farms with confirmed acaricide resistance [17]. Additionally, the use of low or high acaricide concentrations compared with the manufacturers' recommended concentrations, communal grazing, failure to practice proper rotational grazing and limited knowledge of farmers about tick control and general knowledge of rational acaricide use could be drivers of acaricide resistance in Uganda. The majority of the above factors have been well articulated in reports published by previous scholars [9].

The wide distribution of multiple acaricide-resistant *Rhipicephalus* ticks across major cattle-keeping regions in Uganda could be attributed to unregulated and uncoordinated animal movements within the country and across porous borders, which could have contributed to the spread of resistant ticks across the different regions of Uganda. Haphazard animal movement patterns could be accelerated by government programs such as restocking programs for specific regions and programs that provide and distribute livestock to households for poverty alleviation, such as operation wealth creation (OWC), national agricultural advisory services (NAADS) and the Parish Development Model (PDM). Other factors that may have contributed to unregulated animal movements within the country could also include cultural practices such as the exchange of cattle for dowry payments, the acquisition of breeding animals from different regions and the donation of livestock.

The wide distribution of multiple acaricide resistance involving more than one class of acaricide could be attributed in part to the existing gaps in the general regulation of veterinary products in the country where the market is littered with all classes of acaricides without any marketing restrictions [26]. For example, the current practice of veterinary pharmaceutical companies distributing and supplying acaricides up to farms could be encouraging the irrational sale and use of acaricides in the country. Some reports of adulteration of acaricides and the practice of repackaging and relabeling crop pesticides as acaricides could have further complicated the situation [13]. Regulatory gaps in relation to testing every batch of imported or locally manufactured acaricides and conducting active post-market surveillance to establish the efficacy of these acaricides remain a major weak-

ness that could contribute to the widely distributed acaricide resistance the country is experiencing [13] [27]. The other potential contributing factor to the widely distributed acaricide resistance in Uganda could be the limited number of laboratories with the capacity to conduct acaricide resistance testing and surveillance, which hinders the practice of evidence-based acaricide tick control and acaricide rotation [27].

Other factors, such as the lack of a national acaricide zoning and rotation plan and policy to guide the country on rational acaricide use and acaricide resistance management, could have contributed to the current challenge of widespread tick acaricide resistance in the country. Failure to coordinate and conduct active surveillance for tick acaricide resistance across the country for the purpose of early detection of resistance remains a key gap in the control of ticks and TBDs in Uganda. Similarly, the lack of standards regarding on-farm tick control equipment and infrastructure remains a key gap and is a key driver for the development of acaricide resistance at the farm level [27] [28].

The widespread challenge of tick acaricide resistance in Uganda may pose serious negative impacts on national cattle herds in terms of animal health, animal welfare, productivity and profitability of cattle and dairy enterprises. With the spread of acaricide resistance throughout the country involving two major tick species, outbreaks of major tick-borne diseases could become rampant and lead to significant economic losses at the local and national levels [5] [10] [29]. The TBDs are likely to continue causing unprecedented mortalities and morbidities in cattle, as the country continues to search for innovative new tick and TBD control measures to address the challenge of tick acaricide resistance [29]. Some of the innovative integrated approaches to controlling acaricide resistant ticks include; anti tick vaccines, triple combo therapeutic approach, use of ECF vaccines and exploring some of the vector infection control technologies (VICT).

5. Conclusion

The tick acaricide resistance challenge has been confirmed to be widely distributed throughout the whole country and involves the two major tick species (*R. appendiculatus* and *R. decoloratus*). Deltamethrins (synthetic pyrethroids) are the hardest hit acaricides by tick resistance across most regions of Uganda and across the two major tick species (*R. appendiculatus* and *R. decoloratus*). The amitraz class had minimal to no effect on *R. decoloratus* across many regions of Uganda. However, amitraz had some fairly good effects on *R. appendiculatus* across the different regions. Co-formulated acaricides (a combination of chlorpyrifos and cypermethrin) had a fairly greater combined effect on both *R. appendiculatus* and *R. decoloratus* ticks although high resistance of the two major tick species was also confirmed in the majority of regions of the country. We propose strengthening the national capacity for acaricide resistance detection and intervention to support tick resistance surveillance, tick acaricide resistance testing and intervention to support sustainable control of ticks and TBDs in the country. The competent au-

thorities could consider developing and implementing a national acaricide zoning and rotation plan to promote the sustainable use of chemical acaricides for the sustainable control of ticks in the country.

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Authors' Contributions

JB: conceptualized the research, field sample collection, tick identification, data analysis, manuscript writing and editing. BB: field sample collection, sample analysis and manuscript editing. FO, RKN, DST, MAT: field sample collection and manuscript editing. SA, MA, SD, and CN: laboratory sample analysis and data entry. YS: data management, manuscript writing and editing, VP: conceptualized the research, field sample collection, manuscript writing and editing. AM: conceptualized the research, manuscript writing and editing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Byaruhanga, J., Tayebwa, D.S., Eneku, W., Afayoa, M., Mutebi, F., Ndyababo, S., *et al.* (2017) Retrospective Study on Cattle and Poultry Diseases in Uganda. *International Journal of Veterinary Science and Medicine*, **5**, 168-174. <https://doi.org/10.1016/j.ijvsm.2017.07.001>
- [2] Tayebwa, D.S., Vudriko, P., Tuvshintulga, B., Guswanto, A., Nugraha, A.B., Gantuya, S., *et al.* (2018) Molecular Epidemiology of Babesia Species, Theileria Parva, and Anaplasma Marginale Infecting Cattle and the Tick Control Malpractices in Central and Eastern Uganda. *Ticks and Tick-borne Diseases*, **9**, 1475-1483. <https://doi.org/10.1016/j.ttbdis.2018.06.012>
- [3] Food, T., Irvin, A.D., Mcdermott, J.J. and Perry, B.D. (1996) Epidemiology of Ticks and Tick-Borne Diseases in Eastern, Central and Southern Africa.
- [4] Heylen, D.J.A., Kumsa, B., Kimbita, E., Frank, M.N., Muhanguzi, D., Jongejan, F., *et al.* (2023) Correction: Tick Communities of Cattle in Smallholder Rural Livestock Production Systems in Sub-Saharan Africa. *Parasites & Vectors*, **16**, 1-15.

- <https://doi.org/10.1186/s13071-023-05895-x>
- [5] Heylen, D.J.A., Kumsa, B., Kimbita, E., Frank, M.N., Muhanguzi, D., Jongejan, F., *et al.* (2023) Tick-Borne Pathogens and Body Condition of Cattle in Smallholder Rural Livestock Production Systems in East and West Africa. *Parasites & Vectors*, **16**, 1-12. <https://doi.org/10.1186/s13071-023-05709-0>
- [6] Etiang, P., Nalumenya, D., Ndekezi, C. and Ochwo, S. (2023) Distribution and Prevalence of Ixodid Tick Species (Acari: Ixodidae) Infesting Cattle from North-Eastern Uganda (Karamoja). *Research Square*, **10**, 1-16.
- [7] Akure, P.C. (2019) Tick Species Composition and Associated Haemoparasites of Cattle in a Semi-Arid Area of Karamoja, Uganda. University of Pretoria.
- [8] Muhanguzi, D., Byaruhanga, J., Amanyire, W., Ndekezi, C., Ochwo, S., Nkamwesiga, J., *et al.* (2020) Invasive Cattle Ticks in East Africa: Morphological and Molecular Confirmation of the Presence of *Rhipicephalus Microplus* in South-Eastern Uganda. *Parasites & Vectors*, **13**, 1-9.
- [9] Miyama, T., Byaruhanga, J., Okamura, I., Uchida, L., Muramatsu, Y., Mwebembezi, W., *et al.* (2020) Effect of Chemical Tick Control Practices on Tick Infestation and *Theileria Parva* Infection in an Intensive Dairy Production Region of Uganda. *Ticks and Tick-Borne Diseases*, **11**, Article 101438. <https://doi.org/10.1016/j.ttbdis.2020.101438>
- [10] Paucar-Quishpe, V., Pérez-Otáñez, X., Rodríguez-Hidalgo, R., Cepeda-Bastidas, D., Pérez-Escalante, C., Grijalva-Olmedo, J., *et al.* (2023) An Economic Evaluation of Cattle Tick Acaricide-Resistances and the Financial Losses in Subtropical Dairy Farms of Ecuador: A Farm System Approach. *PLOS ONE*, **18**, e0287104. <https://doi.org/10.1371/journal.pone.0287104>
- [11] Byaruhanga, J., Odua, F., Ssebunya, Y., Aketch, O., Tayebwa, D.S., Rwego, I.B., *et al.* (2020) Comparison of Tick Control and Antibiotic Use Practices at Farm Level in Regions of High and Low Acaricide Resistance in Uganda. *Veterinary Medicine International*, **2020**, 1-13. <https://doi.org/10.1155/2020/4606059>
- [12] Vudriko, P., Umemiya-Shirafuji, R., Okwee-Acai, J., Tayebwa, D.S., Byaruhanga, J., Jirapaththarasate, C., *et al.* (2017) Genetic Mutations in Sodium Channel Domain II and Carboxylesterase Genes Associated with Phenotypic Resistance against Synthetic Pyrethroids by *Rhipicephalus (Boophilus) Decoloratus* Ticks in Uganda. *Pesticide Biochemistry and Physiology*, **143**, 181-190. <https://doi.org/10.1016/j.pestbp.2017.07.009>
- [13] Okello-Onen, C.M.B. and Mwayi, W. (2003) Some Factors Affecting the Sustainability of Tick and Tick-Borne Disease Control in Uganda. Malpractice Associated with Acaricide Use. *Uganda Journal of Agricultural Sciences*, **8**, 30-33.
- [14] Kitaka, F. and Mwamachi, D.M. (1970) Resistance to Organochlorine Compounds in Ticks Infesting Cattle in Uganda. *Bulletin of Epizootic Diseases of Africa*, **18**, 25-30.
- [15] Vudriko, P., Okwee-Acai, J., Tayebwa, D.S., Byaruhanga, J., Kakooza, S., Wampande, E., *et al.* (2016) Emergence of Multi-Acaricide Resistant *Rhipicephalus* Ticks and Its Implication on Chemical Tick Control in Uganda. *Parasites & Vectors*, **9**, Article No. 4. <https://doi.org/10.1186/s13071-015-1278-3>
- [16] Githaka, N.W., Kanduma, E.G., Wieland, B., Darghouth, M.A. and Bishop, R.P. (2022) Acaricide Resistance in Livestock Ticks Infesting Cattle in Africa: Current Status and Potential Mitigation Strategies. *Current Research in Parasitology & Vector-Borne Diseases*, **2**, Article 100090. <https://doi.org/10.1016/j.crpvbd.2022.100090>
- [17] Vudriko, P., Okwee-Acai, J., Byaruhanga, J., Tayebwa, D.S., Omara, R., Muhindo,

- J.B., *et al.* (2018) Evidence-based Tick Acaricide Resistance Intervention Strategy in Uganda: Concept and Feedback of Farmers and Stakeholders. *Ticks and Tick-borne Diseases*, **9**, 254-265. <https://doi.org/10.1016/j.ttbdis.2017.09.011>
- [18] Walker, A.R. and Bouattour, A. (2014) Ticks of Domestic Animals in Africa: A Guide to Identification of Species. 2nd Edition, Bioscience Reports.
- [19] FAO (2004) Guidelines Resistance Management and Integrated Parasite Control in Ruminants.
- [20] Vudriko, P., Umemiya-Shirafuji, R., Okwee-Acai, J., Tayebwa, D.S., Byaruhanga, J., Bbira, J.S., *et al.* (2018) C190A Knockdown Mutation in Sodium Channel Domain II of Pyrethroid-Resistant *Rhipicephalus Appendiculatus*. *Ticks and Tick-Borne Diseases*, **9**, 1590-1593. <https://doi.org/10.1016/j.ttbdis.2018.08.007>
- [21] Gachohi, J., Skilton, R., Hansen, F., Ngumi, P. and Kitala, P. (2012) Epidemiology of East Coast Fever (*Theileria parva* Infection) in Kenya: Past, Present and the Future. *Parasites & Vectors*, **5**, Article No. 194. <https://doi.org/10.1186/1756-3305-5-194>
- [22] Bishop, R.P., Githaka, N.W., Bazarusanga, T., Bhushan, C., Biguezoton, A., Vudriko, P., *et al.* (2023) Control of Ticks and Tick-Borne Diseases in Africa through Improved Diagnosis and Utilisation of Data on Acaricide Resistance. *Parasites & Vectors*, **16**, Article No. 224. <https://doi.org/10.1186/s13071-023-05803-3>
- [23] Rodriguez-Vivas, R.I., Jonsson, N.N. and Bhushan, C. (2017) Strategies for the Control of *Rhipicephalus Microplus* Ticks in a World of Conventional Acaricide and Macrocytic Lactone Resistance. *Parasitology Research*, **117**, 3-29. <https://doi.org/10.1007/s00436-017-5677-6>
- [24] Abbas, R.Z., Zaman, M.A., Colwell, D.D., Gilleard, J. and Iqbal, Z. (2014) Acaricide Resistance in Cattle Ticks and Approaches to Its Management: The State of Play. *Veterinary Parasitology*, **203**, 6-20. <https://doi.org/10.1016/j.vetpar.2014.03.006>
- [25] Thullner, F., Willadsen, P. and Kemp, D. (2007) Acaricide Rotation Strategy for Managing Resistance in the Tick *Rhipicephalus (Boophilus) microplus* (Acarina: Ixodidae): Laboratory Experiment with a Field Strain from Costa Rica. *Journal of Medical Entomology*, **44**, 817-821. <https://doi.org/10.1093/jmedent/44.5.817>
- [26] National Drug Authority (2020) Veterinary Medicines Updates Bulletin.
- [27] FAO (2020) Response to Containment of Tick Resistance and Tick-Borne Diseases in Uganda.
- [28] Kasaija, P.D., Estrada-Peña, A., Contreras, M., Kirunda, H. and de la Fuente, J. (2021) Cattle Ticks and Tick-Borne Diseases: A Review of Uganda's Situation. *Ticks and Tick-Borne Diseases*, **12**, Article 101756. <https://doi.org/10.1016/j.ttbdis.2021.101756>
- [29] Tukahirwa, E.M., Perry, B.D., Rowlands, G.J. and Nagda, S.N. (2003) The Impact of Tick Control on the Productivity of Indigenous Cattle under Ranch Conditions in Uganda. *Tropical Animal Health and Production*, **3**, 237-247.