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Tick treatment practices in the field: Access to, knowledge about, and on-farm use of acaricides in Laikipia, Kenya

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A B S T R A C T

The prevention of tick-borne diseases is a major challenge for livestock production globally. Tick control strategies include the use of acaricides, but the prescribed strategies do not achieve the desired results in several countries, including Kenya. To better understand how tick treatment practices, contribute to reported tick treatment failures, we assessed livestock owners' acaricide procurement, level of knowledge about acaricides and tick resistance, and how they apply acaricides. We also assessed the quality of the commonly available acaricides. We focused on three livestock systems in Laikipia County, Kenya: two private ranches; one community ranch whose members communally graze their cattle and acquire and apply acaricides; and individual livestock owners in two pastoral communities who individually graze their cattle and acquire and apply acaricides. Through interviews and focus group discussions we assessed; access to acaricides, livestock owners' knowledge, and acaricide use practices; interview data were triangulated with participant observations (n = 107). We analysed nine commonly used acaricides to determine the active ingredient concentration and we determined the concentration of active ingredients in acaricide dilutions collected on farms. All livestock owners had access to and used chemical acaricides for tick control, predominantly amitraz-based. Private ranchers bought one amitraz-based acaricide in bulk directly from the manufacturer, while all other livestock owners bought from agrovet shops. The livestock owners acquired knowledge about acaricides from their own experiences and through experience-based recommendations from peers, but not from the technical information provided by the manufacturers and agrovet shops. All pastoral livestock frequently changed acaricide brand and active ingredient class. A large majority of pastoralists (86%) mixed acaricide brands within and across active ingredient classes; a smaller majority (56%) mixed acaricides with crop pesticides and insecticides. Our lab tests confirmed the content description on the labels bought from agrovet shops. However, on-farm acaricide dilutions from all three livestock systems deviated from the level recommended for effective treatment. If too diluted, the acaricide does not kill ticks, promoting resistance development. If too concentrated, this increases environmental contamination and raises public health concerns. Livestock owners lack a technical understanding of the functioning of acaricides, compromising their use and effectiveness. The widely adopted mixing of acaricides with insecticides and pesticides raises serious health concerns.

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1. Introduction

Livestock farming plays an important role in providing food, income and cultural identity for the sustenance of many societies across the world (Ghosh et al., 2007; (Jongejan and Uilenberg, 2004)). However, ticks and tick-borne diseases (TTBDs) are an increasing threat to livestock production systems, affecting approximately 80% of the world's cattle population, particularly in the tropics and subtropics (de Castro et al., 1997; Mukhebi et al., 1992). Ticks kill livestock through tick-borne diseases and cause livestock loss through their attachment to animal hides and blood feeding activity, leading to wounds that affect hide quality and damage the udder, leading to mastitis (Abbas et al., 2014; Vudriko et al., 2016). This reduces the productivity of livestock herds and negatively affects farmers' livelihoods.

Tick control techniques such as manual plucking, dipping, spraying, pasture management and vaccines have been used to control TTBDs (Chenyambuga et al., 2010; Dantas-Torres et al., 2012). However, the direct application of acaricides to host animals through dipping and spraying remains the most common technique (Abbas et al., 2014; (Walker, 2014). In Kenya, the Department of Veterinary Services (DVS), under the Ministry of Livestock, was responsible for tick control across the country from the colonial government era until the enactment of the structural adjustment polices (SAPs) in 1991 (Keating, 1983; Wamukoya, 1992). The DVS tick control programme ensured that cattle dips were provided with acaricides, and continuous quality monitoring through supervision by dip attendants. From this monitoring in areas (zones) where resistance had been reported, the DVS recommended the discontinuation of observed resistant active ingredients. This zoning was communicated through internal memos from the District Veterinary Officer, which never made to be gazetted as policy. The DVS advisory and monitoring role in tick control ceased, and enforcement of the identified zoning control of acaricide sale and use became impossible (Mutavi et al., 2018). With the onset of individual tick control by livestock owners, it was assumed that they had the necessary knowledge of acaricide use and application. Agrovet shops replaced the DVS as acaricide providers and were now deemed the new source of technical acaricide knowledge.

Successful tick control using acaricides relies on the livestock owner's knowledge of tick biology, acaricides chemical groups and correctly follow acaricide application instructions. This includes knowing how to mix the correct ratio of acaricides with water to obtain the recommended concentration of active ingredients (AI) for effective tick control. This application instructions are provided on the various acaricide products information labels. The question, however, is whether and how livestock owners read, interpret and apply this information, and how this affects the effectiveness of tick treatments.

The relative number of ticks killed after treatment defines the efficacy of an acaricide. Acaricide efficacy is achieved by ensuring the correct concentration of AI (given as the emulsifiable concentrate (EC) percentage in acaricide products), the correct mixing ratio of acaricide concentrate with water according to the product label guidelines, and appropriate acaricide application techniques. Over the years, acaricides of different chemical groups have been introduced: arsenics, organochlorides, organophosphates, amidines and synthetic pyrethroids, partly in response to stricter safety standards (Keating, 1983; Vallero and Letcher, 2012), and partly in response to increased tick resistance (Bardosh et al., 2013; (Beugnet and Franc, 2012); De Meneghi et al., 2016; FAO, 2004; Faza et al., 2013; ;(Solomon and Kaaya, 1996) Thullner et al., 2007). Each group has different modes of action to kill ticks ((Beugnet and Franc, 2012) Fishel, 2018; IRAC, 2020). Organophosphates, amidines, synthetic pyrethroids and combinations of AIs have been favoured for their relative safety to animals and the environment, and are therefore now the most commonly available acaricide AIs on the market ((Beugnet and Franc, 2012) de Castro et al., 1997; De Meneghi et al., 2016). The consistent use of one AI class is recommended, until treatment failures are experienced, and a switch is made to a different class. This practice is referred to as acaricide AI class rotation (Thullner et al., 2007).

Livestock owner reports of perceived treatment failures in the study area (Mutavi et al., 2018) and other parts of the country (Latif et al., 1991; Mugambi et al., 2012; (Solomon and Kaaya, 1996); Vudriko et al., 2016) necessitated the study of acaricide use practices and the resulting effectiveness. In this study, we define effectiveness as a function of the quality of the acaricide product, the correct use of the product, and the acaricide knowledge source and base of livestock owners. This study aims to answer the following questions: (i) Which acaricides do livestock owners buy?, (ii) What is their level of knowledge about acaricides?, (iii) How do livestock owners apply acaricides (use)?, and (iv) What is the quality of the commonly available acaricides and the acaricide dilutions applied by livestock owners?

1.1. Study area

This study was carried out in the Kenyan rangelands of Laikipia County, at the foot Mt Kenya see Fig. 1, an open shrubland savanna with approximately 400 mm to 750 mm of yearly rainfall across two rainy seasons (Government of Kenya, 2013). Our field observations and samples were taken from Laikipia East and North constituencies.

The area has different livestock systems: private commercial ranches, community ranches and individual pastoralists, making it possible to study a range of acaricide use practices and knowledge bases in the different systems. Our study compared the three dominant livestock management systems in the area: private ranches ($n = 2$), with an integrated cattle management system; a community ranch ($n = 1$) and pastoral communities ($n = 2$), where livestock owners graze their cattle and acquire and apply acaricides individually. The two private ranches keep livestock for commercial beef production, with a cattle herd of 5000 and 7000 respectively, grazed in groups of 100. The community group ranch, which is owned by community members, has 587 registered households and 4970 cattle managed collectively. For the purpose of this study, we focused on the tick control organization for cattle that were collectively owned by the group ranch members. The members elect a committee that is responsible for running the ranch, including tick control. We could not establish the number of community members of the non-organized pastoral community, owing to their pastoral nomadic nature at the time of our visits, however 24 *bomas* were engaged in this study. The ranches and communities were all visited between 2016 and 2019.

2. Materials and methods

A mixed methodological approach was used to answer the research questions. A total of 24 semi-structured interviews with 24 pastoral livestock owners, 2 livestock managers from the private ranches and 10 committee members from the community ranch were held. In addition, four focus group discussions were held with 83 cattle owners in 4 villages. All the interviewees were male, and 7% of the participants in the focus group discussions were female (from one village in the organized community ranch; the other three villages were not formally organized and did not have any female participants). Participant observation was used to triangulate data from the interviews and the focus group discussions, and chemical lab analysis was conducted to test the quality of the acaricide products from the agrovet shops and the acaricide dilutions sampled from the farms.

Contact with the respondents was sought by obtaining consent and access through the county veterinary office, the local administrative chief, the community group management committee and the farm managers at the private ranches. Oral consent was obtained from all study participants before the interviews. The interviews were held at homesteads or in the pastures where cattle owners could be found grazing their cattle. This was necessitated by the fact that cattle owners left home early in the morning and returned late in the evening. The

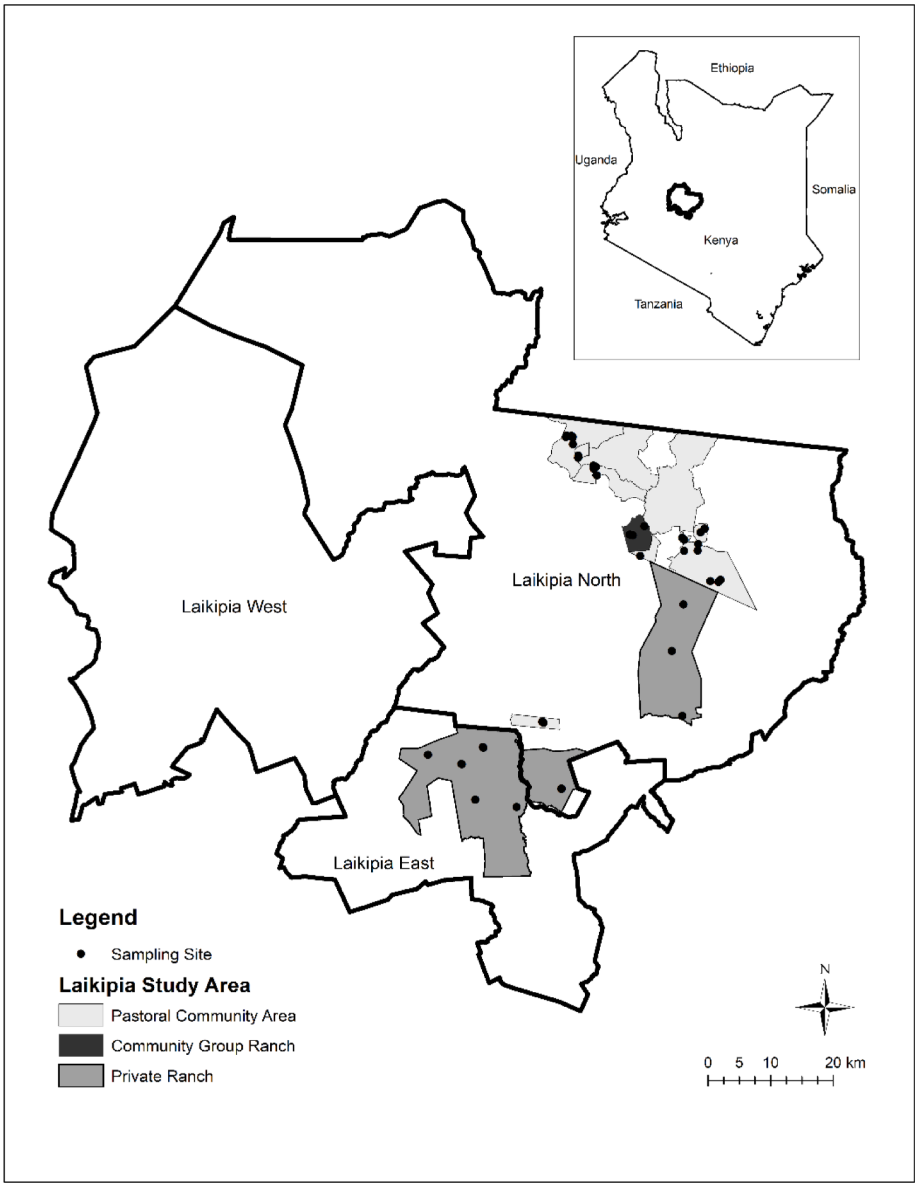

Fig. 1.. Project site. Laikipia county map showing the sampling points inside private ranches, community group ranch and pastoral community areas.

interviews were scheduled to coincide with acaricide application days to enable observation of acaricide mixing habits, application techniques and equipment used. Acaricide dilution samples were collected on these days for laboratory analysis.

2.1. *Availability of acaricide products and access by users*

Seven agrovet shops in the project area were visited, without prior notice, and the shop owner or attendant (depending on who was available) was interviewed and observed while dispensing products to clients. We asked whether the owner was a licenced veterinary doctor and possessed (i) a County business permit, (ii) certifications from the Pest Control and Products Board, and (iii) certification from the Kenya Plant Health Inspectorate Service (KEPHIS). The interview questions focused on which acaricide brands were available, which brands were most requested and why, acaricide price fluctuations, dispensing attendant qualifications, and information requested by the livestock owners. We also tested the shop owner's or attendant's understanding of the acaricide AI molecules and how this related to rotation practices. We observed the interaction and conversations between the dispensing attendant and the livestock owners in the agrovet shops using an observation checklist. A focus group discussion brought together six agrovet owners (not all who participated in the interview attended the focus group discussions) and the county director of livestock to explore acaricide use practices and knowledge shared in the agrovet shop. We subsequently checked the list of available and accessible acaricides against the licensed products list of the Pest Control Products Board, the regulatory body responsible for registering and licencing pest control products in Kenya (PCPB, 2018).

2.2. *Understanding acaricide knowledge source and use practices*

To unravel livestock owners understanding and use of acaricides and to establish whether this compromised product label guidelines, we asked them which acaricide brand they had last used, their preferred brands, and any other acaricide brands and/or insecticide or pesticide that they had used for tick control in the last six months. This data was used to classify the commonly used acaricides by AI group for acaricide rotation by cattle owners. This data was complemented with data from agrovet shops in the study area concerning the most commonly requested and purchased acaricides. We asked pastoralists where they purchased acaricides from, how often, and what their preferred acaricide brands are, if any, and why.

Other important variables concerning acaricide use practices include: the method of acaricide application, the acaricide dilution ratio and the equipment used to measure acaricides. We also asked about mixing habits, to judge how precisely the manufacturer's instructions were followed to obtain the required concentration (classified as 'use of measuring cylinder', 'use of bottle top' and 'use of eye'). The quantity of acaricide mix used to spray an individual and the acaricide application interval were also noted, to determine whether individual animals received the recommended five litres per application. We checked that all parts of the body were sprayed (Mutavi et al., 2018; section 2.3).

We also examined consistency in the use of the preferred acaricide, the mixing of two or more acaricide formulations and/or the mixing of acaricides with pesticides or insecticides, to understand the consistency in the use of AIs. A change in acaricide brand within the same AI group or between groups in a four-month interval was considered bad practice.

2.3. Quality of acaricide products and acaricide dilutions

To assess the quality of the commonly available acaricides and acaricide mixtures applied by livestock owners, nine of the most bought and used acaricide brands were selected for chemical analysis. Correct treatment requires that acaricides be diluted with water to the recommended concentration as indicated in the manufacturer's instructions provided on the acaricide label. For ease of use, all the sampled acaricide brands come with a calibrated measuring cylinder. The sampled acaricides were analysed to examine whether the label claim of AI EC matched the product label contents (see procedure described below). Hence, they were analysed for the concentration of AI (% by volume) present in the EC. A match in EC would satisfy the market standards for an efficient acaricide if applied according to the manufacturer's instructions. The EC percentage of AI is used to guide the dilution of acaricides to the required concentration to achieve effectiveness at field.

In addition, 51 acaricide dilutions that had been prepared by cattle owners to spray cattle were sampled from the private ranches, the community ranch and individual pastoral livestock owners. The samples from the community ranch (1) and individual cattle owners (13) were taken after the acaricides had been thoroughly mixed with water in 20 l cans immediately prior to spraying. The samples from the private ranches (37) were taken from different spray races and at various times: at the start, middle and end of the spraying. This was done to determine whether the concentration of AI varies within a single spraying activity. The dilutions were transported and stored in plastic sampling bottles and analysed at the DVS lab in Kabete. Due to challenges concerning the availability of lime, only the samples from one private ranch were stabilized with lime during transport and storage.

The nine sampled acaricides represented four acaricide AI group molecules. We used the concentration of the EC of each stocked acaricide bottle (see Table 1: Registered acaricide products commonly stocked and used for tick control in Laikipia, Kenya) to test whether it met the licensed EC claim. Three subsamples were taken from each bottle and transferred into code-labelled 50 ml volumetric flasks. Each flask was half filled with ethyl acetate, and 200 μl of acaricide EC was pipetted into the 50 ml volumetric flasks. Ethyl acetate was then added up to the 50 ml mark and vortexed for one minute. Adding ethyl acetate before the EC ensured that it mixed well and did not stick to the sides. The samples were then transferred to code labelled vials for gas chromatography analysis. We employed one sample t-test technique to test for differences between the mean of the observed values and the claimed EC for each acaricide.

Using technical grade stock solutions of AIs (amitraz, alpha-cypermethrin, cypermethrin and a combination of cypermethrin and chlorpyrifos), five ppm levels (100, 200, 300, 400, 500) of each AI standard were prepared:

$$C1V1 = C2V2$$

where $C1 =$ concentration 1; $V1 =$ volume 1; $C2 =$ concentration 2; $V2 =$ volume 2

The ppm concentration of AI in each preparation was determined using gas chromatography–mass spectrometry using the GCMS-TQ8040 Shimadzu machine. The concentration was quantified using the Postrun Analysis software from Shimadzu to determine the retention time of AIs using a flame ionization detector. Nitrogen was used as a carrier gas and an inert gas as an analyte. AIs separated depending on their masses and the concentration was recorded in ppm. Each AI has a recommended ppm concentration in diluted form to achieve acaricide efficacy (e.g. 250 ppm for amitraz).

Analysis of the 51 acaricide dilutions sampled from farms involved testing the pH value then measuring the AI concentration again using gas chromatography-mass spectrometry. An alkaline pH gives stability to the solutions. Ethyl acetate was used to extract the acaricide from the mix in triplicate per sample, then 40 ml of ethyl acetate was added to 40 ml of the acaricide mixture, which was mixed with 10 g of sodium chloride (NaCl) in a fume chamber and shaken to mix well. This was then transferred into mixing cans and put in a shaker for 60 min. The mixture was then extracted into centrifuge tubes and centrifuged for 10 min. The supernatant was transferred into labelled 5 ml glass vials for GC analysis as explained above.

Table 1.
Registered acaricide products commonly stocked and used for tick control in Laikipia, Kenya.

Acaricide group	Active ingredient	Trade name	Licensed use	Application method
Carbamate	Carbaryl 7.5%	Sevin dudu dust®	Ticks and fleas on cats and dogs	Dust
Organophosphate	Chlorfenvinphos	Steladone®	Ticks	Spray/dip
Formamidines	Amitraz	Bye®	Ticks	Spray
		Triatix ®	Ectoparasites	Spray/dip
		TAKTIC ®	Ticks	Spray/dip
		Norotraz®	Ticks	Spray/dip
		Actraz®	Ticks	Hand spraying
		Twigatraz®	Ticks	Spray
		Almatix®	Ticks	Spray/dip
		Tikatraz®	Ticks	Spray/ dip
		Tixfix®	Ticks	Spray/dip
Pyrethroids	Alpha-cypermethrin	Alfapor®	Ticks	Spray
		Cypertix®	Ticks	Spray/dip
	Cyhalothrin 5%	Grenade®	Ticks, flies, lice and keds on cattle, goats, sheep and pigs	Spray/dip
	Deltamethrin	Delete®	Ticks, fleas, mites	Spray/dip
	Cypermethrin	Ectomin®	Ticks, fleas, mites	Spray/dip
Combination	Chlorpyrifos 50% + Cypermethrin 5%	Duodip®	Ticks	Spray

2.4. Statistical analysis

All the data was entered into Excel, cleaned and input into SPSS for statistical analysis. We carried out a *t*-test of the claimed active ingredient concentration versus the observed means from our lab analysis of the active ingredients in the acaricides.

3. Results

3.1. Availability of acaricide products and access by users

3.1.1. Agrovet shops

Data were obtained from two types of cooperating agrovet shops: (i) permanent shops ($n = 4$), located in major towns and shopping centres (Nanyuki, Ilpolei and Doldol), and (ii) mobile shops ($n = 4$) (accessed on market day at Doldol), which move between towns to set up shop on market days in the region. Another four agrovet shops, at the time not run by the owners, were uncooperative and did not share data. Of the eight respondents from the agrovet shops, four were mobile shop owners and four were shop attendants in permanent shops. While the permanent agrovet shops had all the required licenses to operate, this was difficult to ascertain for the mobile agrovet shops, as the respondents refused to answer or to provide proof. Of the eight respondents, 38% (permanent shops=2, mobile shops=1) were trained and certified in animal health and understood the different AI molecules and the drug classes that they belong to. They did not, however, know how often AIs should be rotated. However, 62% of the respondents, i.e., permanent shops=2, mobile shops=3, had not received any specialized training on animal health and were selling animal health products as a business venture or were untrained, and employed to run the shops on behalf of the business owners, who were trained and certified but had other formal employment or businesses to run. We occasionally visited pharmacies ($n = 4$) licensed to only stock human health drugs and noted that they also stocked acaricides, as they always considered themselves competent to dispense animal health products as they had some basic knowledge of biology and chemistry. The differentiating factor between permanent agrovet shops and mobile shops is that the permanent shops had better storage facilities, while mobile agrovets had suboptimal storage and selling conditions, exposing acaricides to weather elements such as direct sunlight, which can compromise the quality of the acaricides sold.

Visits to and interviews with agrovet shop attendants and owners confirmed that acaricide products with different AIs are available for sale, as presented in Table 1. There was no noticeable difference in the brands of acaricides sold in permanent and mobile shops. These acaricides are all licensed by the Pest Control Products Board. All of the available acaricides were licensed for tick control in livestock and application by spraying or dipping, except for one: Sevin dudu dust, a carbamate that is licensed for tick control in dogs and cats but that is sold and used for tick control in livestock. Table 1 shows the acaricide brands available, the AI group, the licensed use and the recommended application method.

3.1.2. Sourcing of acaricides by cattle owners

The FGDs and interviews confirmed that all livestock owners had access to and used predominantly amitraz-based chemical acaricides, while a few preferred synthetic pyrethroids, organophosphates or a combination of acaricides. Table 2: Acaricide brands commonly used by interviewed cattle owners; numbers refer to the number of interviewed cattle farmers, Laikipia, Kenya, summarizes the most recently used and preferred acaricides of cattle owners.

Pastoral livestock owners sourced acaricides from both permanent and mobile agrovet shops. The two private ranches exclusively used amitraz-based acaricides (Tikatraz and Triatix) that were sourced in bulk directly from the manufacturers. The community ranch pastoralists consistently used the same acaricide brand for six months. In contrast, the individual livestock owners, including those who are members of the community group, often changed acaricide brand and class depending on their preference, availability at market, and cost. As a result, 88% of respondents mixed acaricide brands within and across AI groups. Furthermore, 56% of respondents reported having mixed acaricides with crop pesticides and insecticides during the six-month period prior to the interview, to obtain better treatment results. The choice of acaricide brand was motivated by its perceived efficacy based on personal experience, availability, cost and the seller's recommendation, in order of importance. Individual livestock owners reported sharing or borrowing acaricides amongst themselves. For example, if someone was unable to obtain acaricides from the agrovet or if they had a small amount left over, they would borrow from a neighbour to obtain the required concentration. This involved mixing different products from different or the same AI class.

Table 2.
Acaricide brands commonly used by interviewed cattle owners; numbers refer to the number of interviewed cattle farmers, Laikipia, Kenya.

Question: acaricide last used	Active ingredient	Available acaricides	Acaricide last used ($n = 27$)	Preferred acaricide ($n = 27$)	Used in the last six months
Private ranchers ($n = 2$)	Amitraz	Tikatraz®	1	1	
		Triatix®	1	1	
Communal ranchers ($n = 1$)	Amitraz	Actraz®	1	1	2
Individual pastoral livestock owners ($n = 24$)	Amitraz	Bye Bye®	3	2	9
		Triatix®	3	2	8
		Taktic®			
		Norotraz®	3	4	5
		Actraz®	4	5	7
		Twigatraz®			1
		Almatix®	9	7	8
		Tikatraz®			
		Tixfix®			
	Alphacypermethrin	Alfapor®	1		1
		Cypertix®			4
	Cyhalothrin	Grenade®			1
	Deltamethrin	Delete®			1
	Cypermethrin	Ectomin®			7
	Chlorpyrifos 50% + Cypermethrin 5%	Duodip®	1	4	3
Insecticides /pesticides used in tick control by pastoral livestock owners	Carbaryl 7.5%	Sevin dudu dust®			2
	Chlorpyrifos	Pyrenix®			1
	Diazinon	Diazinon®			1
	Chlorpyrifos	Gladiator®			1

3.2. Source of acaricide knowledge

Livestock owners commonly entered agrovet shops to ask for their preferred brands and their preferred alternatives, relying on their own or their peers' experiences. They did not actively seek advice on acaricide brands from the agrovet shops. They acquired their knowledge about acaricide brands (i) from their own experience after using different brands, (ii) through recommendations from their peers on what worked or did not work for them, and (iii) from agrovets' recommendations when requested. Pastoral livestock owners did not appear to have active knowledge on the AI strength classes, in contrast to private ranch owners. Furthermore, 62% of pastoral livestock owners sought tick control knowledge from their peers, while 38% sought knowledge from agrovet shop attendants. Pastoralists had not received any tick control information from DVS veterinary officers or researchers prior to this study.

3.3. Acaricide use practices

Table 3 summarizes the acaricide use and application practices observed during field visits, participant observations and as reported in interviews with livestock owners. Spraying was the main acaricide application technique. Individual livestock owners used hand sprayers, while private ranches used spray races.

3.3.1. Private ranches

Private ranches use spray races as they spray between 800 and 1200 heads of cattle at one time and have sufficient water availability. Spray races are sited in different parts of the ranch to reduce the cattle walking distance to the spray race and to cater for grazing rotations within the ranch. The two private ranches had similar acaricide dilution practices. Acaricide was mixed with water at a ratio of 1:500 and in an amount to match the size of the sump tank and the number of cattle to be sprayed. Each litre of acaricide concentrate was mixed with 10 l of water then poured into the sump while the water was circulated to ensure thorough mixing and sufficient air pressure was confirmed. Then, 250 ml of acaricide was mixed with 10 l of water and added to the tank after every 100 cattle heads had been sprayed. Once spraying was completed, the dip was washed, and the sump emptied and cleaned ready for the next spraying activity. Some spray races had functional soak pits to drain the dip wash into while others let it flow openly to follow the natural water ways, feared to potentially contaminate natural water sources downstream. Most of the existing soak pits were however clogged from years of use without proper maintenance, hence they leaked and did overflow to surrounding environment, a potential health risk.

The private ranches consistently applied acaricides every seven days. Spraying activities were rotated across the different spray race to ensure that all the herds were sprayed. To guarantee the quantity of acaricide applied per head of cattle, the spray nozzles were placed at differing angles to ensure that the cattle were sufficiently covered with the spray mix all over their bodies.

3.3.2. Community group ranch

Even though the community ranch said that they sprayed 21–25 heads of cattle per 20 l of diluted acaricide, it was observed that they sprayed up to 30 animals. Based on the list of acaricides used in the past six months, all cattle owners used different acaricide brands within the same AI group or other groups over a six-month period. Reasons for this included: failure to access the preferred acaricide brand at the agrovet shop; an increase in price of the preferred brand, hence opting for the next available one within their budget; and observed reduced efficacy from the preferred brand, prompting a switch to a new product. Results show that amitraz is the predominant AI molecule of acaricides bought and used by farmers.

3.3.3. Pastoralists

The pastoralists collaborate closely to control ticks, as can be seen by the activities that they organize. Pastoral livestock owners predominantly use hand pumps to apply acaricides. The pumps are owned individually, but they may be shared with friends and neighbours who do not own a pump. On spraying days, mainly Saturdays and Sundays, they plan the spraying order or bring their livestock to a central location where they spray together. This ensures that no cattle miss a spraying day just because the owner does not have a pump.

When asked, 46% of the pastoralists reported spraying weekly, 50% fortnightly and 4% on a monthly basis. Focus group discussions confirmed that most pastoralists preferred to spray on a weekly basis, although this varied from season to season depending on the weather. Reasons given for a change in spraying schedule included: rainfall in the morning of the planned spray day, as a result of which pastoralists rationalized that the rain would wash away the acaricide and be 'wasted', and a lack of money to purchase acaricides that week. To dilute the acaricides with water, pastoralists use calibrated cylinders (58%), acaricide bottle tops (29%) and 'by eye' (13%) to measure the

Table 3.
Acaricide use and application technique.

Theme	Question	Response	Individual pastoralist *n* = 24	Community ranch *n* = 1	Private ranch *n* = 2
Method of tick control	Method of acaricide application used	Spray race			2
		Hand spraying	24	1	
	Equipment used for acaricide application	Spray race pump			2
		Hand pump	24	1	
	Equipment used for acaricide measuring	Calibrated cylinder	14	1	2
		Acaricide bottle top	7		
		'By eye'	3		
Acaricide application interval	How often do you spray/apply acaricide?	Weekly	11		2
		Fortnightly	12	1	
		Monthly	1		
	Number of cattle sprayed with 20 litres of acaricide mixture?	0–5	0		
		6–10	2		
		11–15	3		
		16–20	9		
		20–25	10		
		25–30	0		
Knowledge access	Source of advice on tick control	Peer	15		
		Agrovet attendant	9		
		DVS veterinary officer	0		
		Researcher	0		2

acaricides. Calibrated cylinders are provided with the acaricide bottle and an information label guides users on dilution ratios. Pastoralists who used the bottle tops added the acaricide to water to their discretion or according to the number provided (if using the measuring cylinder) in the information label. Those who measured 'by eye' added the acaricide to water until it changed colour to milky white – the colour of the emulsified concentrate.

When asked about any other tick control products used in the past six months, pastoral cattle owners mentioned crop pesticides and insecticides, Sevin dudu dust, Pyrenix, Diazinon and Gladiator used together with an acaricide. The motivation to mix was to increase 'perceived efficacy'. Ectomin was mentioned in interviews and identified on field visits as the main acaricide mixed with other perceived 'weak' acaricides, mainly from the amitraz group. Sevine dudu dust is an acaricide that is licensed for the treatment of ticks and fleas in dogs and cats, to be applied by dusting their living areas. However, livestock owners were seen mixing it with EC acaricides to reportedly treat fleas *(viroboto)* and lice (*chawa*) in cattle, particularly in calves and goat kids. In other instances, the powder was reportedly dusted directly onto the animal's body, contrary to use directions to dust the animal's living area.

When asked how much acaricide dilution they used to spray an individual, 42% of pastoralists said that they sprayed 21–25 cattle with 20 l of acaricide spray wash, 38% said between 16 and 20 cattle, 3% said between 11 and 15 cattle, and 2% sprayed up to 10 cattle. In focus group discussions, the pastoralists unanimously agreed to spraying 21 to 25 individuals with 20 l of acaricide spray wash. The quantity of acaricide dilution recommended for an individual is 5 l, to ensure sufficient cleaning over the whole body.

3.4. Measured efficacy of purchased and applied acaricide dilutions

3.4.1. Efficacy at shop: EC label claim

Seventeen acaricide brands were identified as commonly available from permanent and mobile agrovet shops. Nine of these were also identified as commonly used brands in the interviews, FGDs and observations, and were therefore sampled for chemical analysis. These nine brands belonged to four AI groups: amitraz ($n = 5$), Alpha-cypermethrin ($n = 2$), Cypermethrin ($n = 1$) and a combination (Chlorpyrifos+Cypermethrin) ($n = 1$). We found that the concentration of AIs in the sampled acaricides matched the content description on the labels, as shown in Table 4

Most of the acaricides tested met the EC claim range as recommended by DVS. The DVS protocol allows a deviation of +/−1 from the claimed EC. Thus, an absolute difference greater than 1 (Almatix (+1.5) and Twigatraz (+2)) shows a stronger-than-recommended concentration, while Duodip (−1.2) has a lower concentration. These results were consistent with other data obtained from the DVS Kabete chemistry lab. The products were properly labelled and contained the solutions indicated.

Table 4.
Emulsifiable concentrate of acaricides (% by volume) as claimed by the manufacturer and as analysed in this study based on $n = 3$ subsamples for each acaricide brand. The t-value reports the statistical difference between the claimed and the analysed concentration.

Active ingredient	Acaricide brand name	Claimed value	Observed mean	Absolute difference	t-value
Amitraz	Actraz	12.5	13.1	+0.6	2.3
	Almatix	12.5	14	+1.5	6.1*
	Bye Bye	12.5	13.3	+0.8	3.8
	Triatix	12.5	13.4	+0.9	2.3
	Twigatraz	12.5	14.5	+2.0	4.4*
Alpha-cypermethrin	Alfapor	10	9.2	−0.8	1.4
	Cypertix	10	9.3	−0.7	2.4
Cypermethrin	Ectomin	10	10.2	+0.2	1.2
Combination (Chlorpyrifos+ Cypermethrin)	Duodip	27.5	26.2	−1.2	2.1*

3.4.2. Efficacy at farm: acaricides dilutions applied

Of the 51 samples collected and analysed, 47 had amitraz as the AI, one alpha-cypermethrin, one cypermethrin and two a combination of acaricides (Duodip) (private ranches = 37, pastoralists = 13 and community ranch = 1). Of the 47 amitraz-based samples, one had been mixed with the crop pesticide Oshothion, one with the insecticide Gladiator, and two with another acaricide. Farmers claimed that this mixing increased the efficacy of the treatment. Oshothion and Gladiator were perceived to be highly effective as their treatment effects had been 'seen' with pests and insects (ants). Ectomin and Duodip were perceived to be highly effective acaricides (Swahili: *'kali sana',* meaning 'very strong'), and therefore believed to increase the efficacy of perceived weaker acaricides such as Actraz and Norotraz. Ectomin, Gladiator and Oshothion were believed to kill fleas and other ectoparasites on livestock with more efficacy, hence the tendency to add them to acaricides for spraying. Ectomin (a synthetic pyrethroid) is a registered acaricide that is licensed for the control of fleas, ticks and termites by spraying or dipping (see Table 1). Gladiator (chlorpyrifos) and Oshothion (malathion) were preferred for their ability to kill fleas, even though they are only licensed for use on termites and crop aphids.

Chemical analysis of the acaricide mixes showed quantities of AIs that were higher or lower than the level recommended for effective treatment in all three livestock systems. We took 14 samples from the community group ranch and individual pastoral livestock owners: seven in February and seven in April/May. Very low to negligible traces of amitraz were detected in the seven samples collected in February. Of the remaining seven samples, one was cypermethrin (188 ppm) and one was alpha-cypermethrin (223 ppm), both of which were above the recommended doses of 100 ppm and 50 ppm respectively. The other samples were amitraz-based: three were below 250 ppm, and three above (262, 268 and 840 ppm), as seen in Fig. 2. These results clearly show that livestock owners mix the acaricides with water at concentrations that are either below or above the recommended concentrations, resulting in washes that are too weak or too strong.

Concentrations both beneath and above the recommended 250 ppm were observed in the samples from the private ranches, as shown in Fig. 3. Note that we missed the end sample for the Sid site and all the samples for the Mor sites in the August series. In almost every case, we observed that concentrations were higher in the start sample, although not necessarily above 250 ppm. AI concentrations progressively decreased in samples taken at the middle and the end of spraying, and concentrations at the end of the spray exercise were consistently below 100 ppm.

This depletion in the AI concentration is known as stripping. Stripping is the process whereby AI concentration is lost and is measured when the concentration of acaricide in the fluid draining from an animal is less than the concentration of AI in the fluid used in treatment (George et al., 2004). It implies that individuals sprayed at the start are treated with a higher concentration of AI than individuals in the last group. Samples from one spray race (Sir) were consistently high in the April/May series, with a value at the end of spraying of 743 ppm. The livestock ranch manager suspected that this high concentration may be due to an error in the calibration of the tank, leading to incorrect acaricide dilution calculations or a high dose of acaricides being used. One start sample had a very high concentration (Sir, 1945 ppm), which could be attributed to the improper mixing of acaricide and water before sampling.

4. Discussion

Keating (1983) gave a comprehensive overview of ticks by chemical

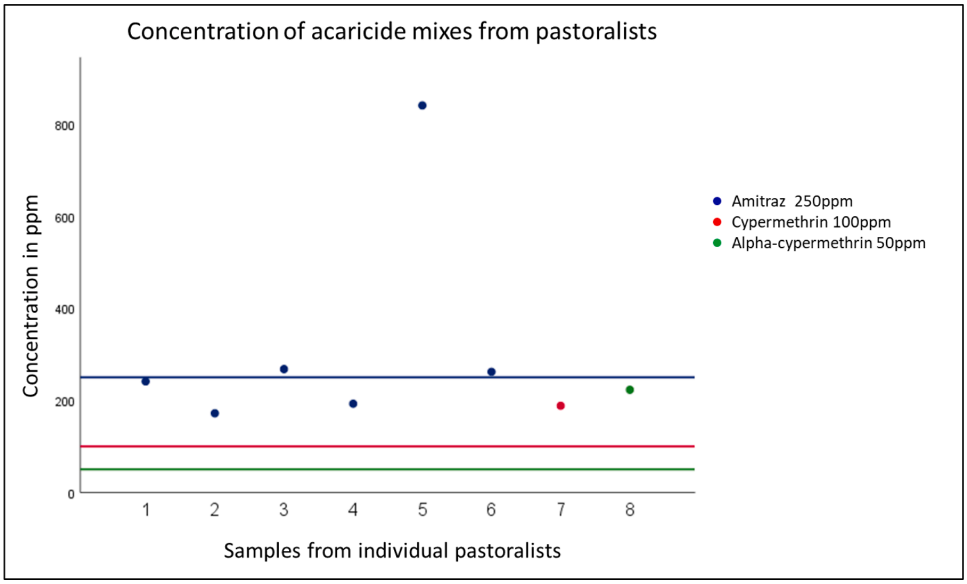

Fig. 2.. Concentration of acaricide active ingredient (AI in ppm=ml/l) in acaricide dilutions sampled from pastoralists. The dots refer to the detected sample concentrations and the coloured horizontal lines depict the recommended dose concentration for each active ingredient to achieve efficacy: blue for amitraz, red for cypermethrin and green for alpha-cypermethrin.

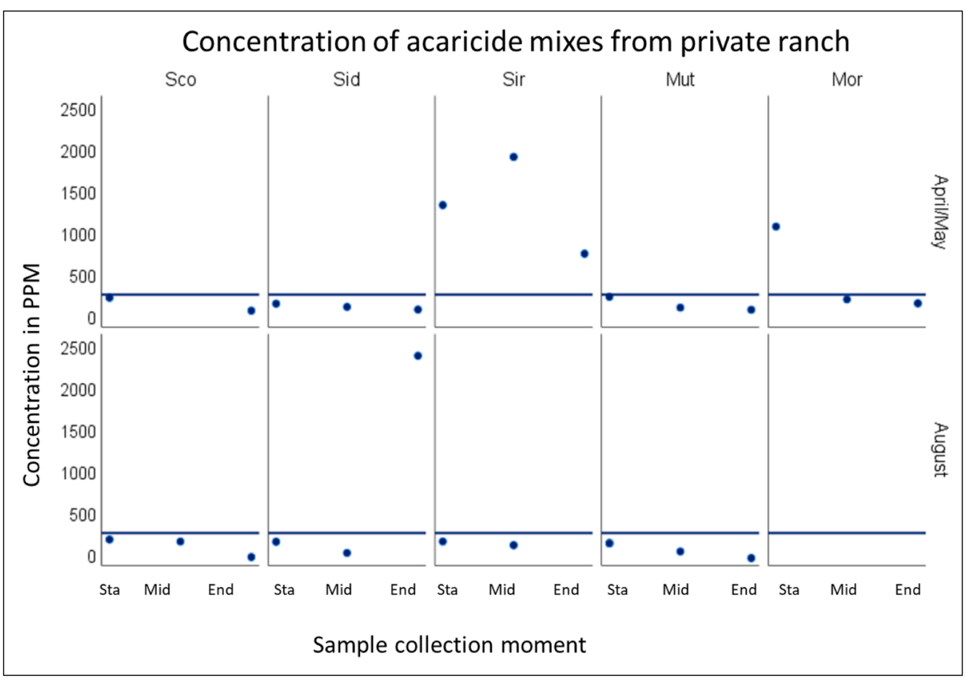

Fig. 3.. Concentration of acaricide wash as mixed at private ranch collected at the start, middle and end of a spray activity (ppm=ml/l). Acaricide washes were sampled from five different sites (Sco, Sid, Sir, Mut and Mor) in one private ranch in the months of April/May and August. The figure shows the concentration at each site as sampled at three different collection moments (start, middle and end) of a single spray exercise. Note that we missed the end sample for Sid site and all the samples for the Mor site in the August series.

control in Kenya, capturing the chemical groups gazetted by the government and resistance reported until 1981. To our knowledge, there are no published, integrated studies on acaricide availability, farmers' knowledge and on-farm acaricide use in Kenya following the end of the official DVS tick control programme in 1991. Post 1991, Wesonga et al. (2010) qualitatively assessed tick and tick borne disease prevalence, tick load and frequency of tick control as constraints to livestock production accompanied by serological surveys. Mugambi et al. (2012) studied farmers' perception of ticks as disease vectors and acaricide usage in a pastoral and agro-pastoral farming systems in Kenya through semi-structured interviews. We have gone further and assessed livestock owners' acaricide procurement traits, their level of knowledge about acaricides and tick resistance, how they apply (use) acaricides on-farm, and we also assessed the quality of the commonly available acaricides and concentration of the acaricide dilutions they make.

The study sites visited are served by agrovet shops that are well stocked with acaricides and other animal health products. The livestock owners also had access to mobile agrovet shops on market days. This meant that, what could not be found in one shop could be found in another or in a mobile shop. All the products sold were licensed in Kenya by the Pest Control Products Board (see Table 1). Given the good coverage of agrovet shops and the availability of acaricides, pastoral communities can access acaricides even when they migrate their livestock away from homesteads. It is however important to note that mobile shops may not store acaricide products in optimal conditions and the quality of these products may therefore be compromised before they are sold. Also, agrovet shop attendants who are not trained in animal health are not well placed to provide product use information and specific advice. Our findings show a sustained problem as identified by Mugambi et al. (2012), which is that farmers often find the information provided by agrovet attendants confusing. Mugambi et al. attributed this to the lack of qualified agrovet attendants, who are hired by the owners of the agrovets to manage the agrovet shops. Private paraprofessionals are trained as support staff to professional veterinarians; consequently, their activities need to be monitored by a professional veterinarian (Oruko et al., 2000). We cannot stress enough the importance of this regarding the information and advice offered to livestock owners.

Also, of concern is that human health practitioners dispense animal health products without proper animal health training. A lack of specialized knowledge on animal health care jeopardizes the quality of the advice provided to cattle owners. Even if the knowledge of AI molecules is similar for both animal and human drugs, specialized knowledge on their specific mode of action, use and efficacy in livestock is needed (IRAC, 2020).

With regards to acaricide knowledge at the ranches, the 'tick team' (employees responsible for tick control) receive informal training on acaricide handling, dilution and storage (Mutavi et al., 2018). Such training is reserved for the employees responsible for tick control. As much as the training prepares them for the spraying exercises, it does not allow the ranch to monitor the performance of the AI molecules used and their efficacy level. Ranches are however often visited by researchers, so that ranch employees can have the opportunity to update their knowledge base in interaction, structured trainings would equip them with more knowledge and facilitate knowledge exchange.

Individual livestock owners (mainly pastoralists) and community group ranches rely on experiential knowledge, and peers are their main source of information about ticks. The agrovet shops, which could act as an information node, unfortunately have shop attendants who are not trained in animal health care and lack the technical knowledge to properly advise farmers. Therefore, different people have different types of knowledge. We can see declining trust in Agrovets as information source as Mugambi et al. (2012) states that in the absence of extension services, farmers in Kajiado district relied on agrovet attendants who provide information which farmers often found confusing, which farmers attributed to unqualified agrovet attendants hired by the owners of the agrovets to manage the agrovet shops. Unqualified attendants is a pestering problem over the years and greatly compromises quality of knowledge shared. DVS veterinary officers and trained animal health experts have good levels of knowledge, and cattle owners have their own experiential knowledge, however no or little knowledge exchange takes place. This prevents those with technical knowledge from having the opportunity to rectify risky practices amongst cattle owners. This reality should be questioned, and ways should be found for the different types of knowledge to be shared between stakeholders through an adequate platform.

As observed on the community group ranch and amongst individual pastoral livestock owners, poor acaricide application can contribute to efficacy loss. To achieve the recommended concentration when hand spraying, it is essential to measure acaricides correctly and practices such as using bottle tops and assessing the concentration based on a change in colour are likely to result in incorrect concentrations, and therefore dilutions that are too strong or too weak for effective treatment. This is compounded by difficulties in achieving a constant pressure in the spraying process and covering all parts of the animal's body equally. Both communal and individual livestock owners use hand pump sprays which they fill with various concentrations; no stripping is experienced as the dripping wash from animals is not recycled but emptied within minutes and no mechanical stirring occurs. In addition, most livestock owners spray less frequently than the FAO's recommended seven days (FAO, 2004). This could also be a major contributor to treatment failure, adding to selective pressure for tick resistance.

We also observed a division of labour in tick control responsibilities. Normally, the men bought the acaricides, the women fetched water, and the men pumped and sprayed. To optimize tick control, a better understanding of gender roles and decision-making around tick control at the household level would be useful. This is also important as gender roles are linked to decision-making concerning pasture use and which animal are grazed where and when, and it is at these grazing grounds that ticks proliferate, and livestock pick them up.

We found that most of the products used had amitraz as the AI, and therefore belonged to the formamidine class. Livestock owners changed between products of the same acaricide class when they thought that one product was less effective. It is important to note that acaricides that belong to the same AI chemical group trade under different product brand names. Therefore, livestock owners need to be aware that acaricides in the same class have a similar mode of action, and that they should change to a different class when treatment failure is observed. An over-reliance on amitraz could lead to selection pressure for resistance and ongoing resistance monitoring is therefore required to rotate the AI used as recommended. This is in contrast to the findings of Vudriko et al. (2016) in Uganda, where synthetic pyrethroids are the dominant acaricide molecules used. There is generally a lack of understanding amongst livestock owners concerning the different classes of acaricide AI molecules, their functioning and how they should be rotated. It is important that this is remedied, as continued rotation within one class after repeated long-term tick exposure to one chemical will lead to the development of resistance to that chemical. This mirrors the findings of Vudriko et al. (2018) from Uganda who found similar malpractices in acaricide rotation. This draws us close to what concerns expressed by Keating (1983) that poor use of acaricides will accelerate the development of resistance and we may not have available other alternatives for tick control in future.

We noted several malpractices in acaricide use. Highly rampant is the practice of admixing, where livestock owners mix acaricides with other acaricides and/or pesticides or insecticides for perceived 'increased' efficacy. Livestock owners believe that this increases the strength of acaricides that they perceive to be weak, and therefore the effectiveness of their treatments. Insecticides and pesticides are considered to be more effective because of their success in killing crop pests and household insects. Mixing acaricides of different AI classes and/or with insecticides or pesticides can cause one AI to reduce the efficacy of the other, or they could complement each other and increase the efficacy. It is not clear what happens when these chemical groups are combined, and our lab analysis did not explore this possible dimension.

Another malpractice was the incorrect application of products. For example, Sevine dudu dust, which is licensed for tick and flea control in cats and dogs, is a powder product and should be applied by dusting the living area. However, it was reported and observed to be mixed with water and an acaricide or dusted directly onto the animal's body. Several cattle owners reported that goat kids and calves became dizzy and collapsed after being dusted with this product, which could be a sign of toxicity due to incorrect application practices. Samples of ectoparasites taken from livestock were identified to be lice and fleas at the DVS laboratory, Kabete. Mugambi et al. (2012) also reported the widespread misuse of acaricides, as the government no longer controls the type of acaricide used. This problem is further compounded by the fact that there are hardly any veterinary extension services to guide the farmers on acaricide application. Mugambi et al. observed that combining amitraz and SPs is a major cause of concern, as it is likely to reduce the effective life of the two acaricides through the rapid development of resistance to the two compounds. These malpractices can be explained as a lack of understanding of the mode of action of the AIs in acaricides, which is a technical knowledge gap amongst livestock owners.

Our results show high levels of suboptimal use practices in the different production systems, resulting in too low AI concentrations being applied to cattle, which probably reduces the efficacy of the treatment and poses resistance development risks. The AI concentration in the acaricide commercial products was adequate, but their concentrations in the sampled acaricide dilutions were either lower or higher than the recommended concentrations. We assume that if it is too low, it does not kill enough ticks and can contribute to resistance, and if it is too high, it may kill the ticks as intended but cause environmental contamination, be less cost effective and put people involved in the spraying process at unnecessary risk. It can also lead to selective pressure, eventually contributing to resistance development.

Private ranches used spray races with tanks, and the start concentration was on average 230 ppm. Though 250 ml was intermittently added after every 100 individuals had been sprayed, the end concentration was consistently below 100 ppm. This alludes to a high stripping rate of the AI. In the spray race, stripping increases with an increase in the number of animals treated in an individual spray exercise and is compounded by mechanical breakdown as the acaricide mix passes through the pumping system. Livestock managers at the private ranches were aware that the AI is stripped during the exercise, but they had not expected concentrations to be as low as less than 100 ppm at the end of the spray exercise. This raises the question of how protected the last batch of animals are. This problem could be addressed by: (i) reducing the number of animals sprayed in one exercise (from an average of 1000 to 500 individuals), (ii) increasing the replenishing amount after every 100 individuals, or (iii) recalibrating the spray tanks to ensure that correct water to acaricide ratios are used. It would therefore be useful to review the spray race protocol at ranches and to regularly monitor the AI concentration during the spraying process, to provide better recommendations.

Our findings show that acaricide product zoning is not implemented in the Kenyan market, despite the recommendations made to this effect, to reduce the development of resistance to certain AIs in specified areas. Under the tick control programme, the DVS comprehensively monitored resistance development by testing the dip wash strength in cattle dips. If resistance was observed, zoning guidance was given to stop the use of or change the acaricide AI to a stronger one, depending on the tick species and the AI in question (Mugambi et al., 2012; (Shah and Fernandes, 1986); Wamukoya, 1992). It is worth noting that this zoning advice was communicated in official memos or through advice from district veterinary officers, however, it was not officially introduced in policy guidelines. Studies from Uganda have recommended zoning acaricide use areas to reduce resistance development after resistance was observed in cattle regions across Uganda (Bardosh et al., 2013; Vudriko et al., 2016). However, while it is possible to implement zoning guidelines when dipping is centrally organized, when tick control is individually organised in a liberalized market, this can only be achieved through a policy guideline, strict monitoring of the products sold in the region, active monitoring and testing, and the updating of resistance information to all stakeholders.

Obtaining technical knowledge about acaricides appears to be compromised for pastoralists; we think that this may be due, in part, to the untrained Agrovet shop attendants and largely due to the collapse of the DVS extension services. We recommend a system change, including considerable improvement in the level of knowledge and understanding of Agrovet shop attendants, e.g. through training and certification and/or employment of certified staff.

We found that acaricide products at market met licencing qualification of effective products, however, we noted deviations from manufacturers use instructions by livestock owners on-farm, that compromised their expected effectiveness. We are worried about the widespread inappropriate frequent change of acaricide brands, leading to increased resistance of ticks. The mixing of acaricides with crop pesticides and insecticides is a straightforward health hazard for animals, humans, and the environment, which needs to be curbed. We urge the start of a OneHealth monitoring program to: i) assess the extent of damage done to humans, livestock and the environment and ii) to end these risky and damaging practices by livestock owners.

We therefore recommend mapping the status of tick resistance in the project area and identifying ways in which to bridge the technical tick information gap. Ideally, this would involve a system that monitors treatment failure and conducts lab surveillance, with a joint platform to facilitate discussions between veterinary officers, agrovets and livestock owners on best treatment practices over time in each region/zone.

Lastly, we recommend that a collective information system is set up involving livestock owners, Agrovet shops, DVS and the Department of Public Health, to share tick treatment experiences and to move towards effective tick treatment practices, with minimal health and environmental risks.

5. Conclusions

This study reveals that livestock farmers have access to acaricide products, either in bulk from the manufacturer or in smaller amounts through local Agrovet shops. The widely available and used acaricide products meet the manufacturer's claimed standards as provided on the products sold. However, livestock owners apply acaricide dilutions that are commonly above or below the recommended strength concentrations, which reduces the efficacy of the active ingredients in tick treatments. Furthermore, incorrect acaricide rotation schedules and inconsistent spray schedules undermine the residual effect and protection period offered by acaricides. This is compounded by inappropriate recommendations provided by unqualified and untrained agrovet shop attendants to livestock owners. Lastly, majority of livestock owners in our study mixed acaricides with insecticides and/or crop pesticides to purportedly increase effectiveness of tick treatment. This creates health hazards for people, animals and the environment. All these conditions cumulatively likely contribute to tick resistance development, which is not caused by the quality of acaricide products on the market, but by their improper use. We observed that different livestock owners have different forms of knowledge, but that there is little interaction and exchange of information, leading to information asymmetry. Our recommendations address the information asymmetry and the hazardous malpractices of acaricide use and mixing.

CRediT authorship contribution statement

Faith Mutavi: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **Ignas Heitkönig:** Methodology, Formal analysis, Visualization, Writing – review & editing. **Barbara Wieland:** Resources, Methodology, Writing – review & editing. **Noelle Aarts:** Supervision, Writing – review & editing. **Annemarie Van Paassen:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that there is no conflict of interest

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