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Optimisation of integrated control of ticks and tsetse flies in mixed game and livestock interfaces in Queen Elizabeth National Park, Uganda

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Abstract

Background Mixed Game and Livestock Interfaces (MGLIs) in and around conservation areas like Queen Elizabeth National Park (QENP) have typanosomosis, tsetse flies, Ticks and Tick-Borne Diseases (TTBDs) as major constraints to livestock productivity. There were no cheaper community-based methods for controlling both ticks and tsetse flies. It was against this background that this study was done.

Methods A weekly restricted spraying of cattle using vectocid ® for 6 months was done in MGLIs in QENP for controlling both ticks and tsetse flies. Before technology introduction, a baseline survey was done to establish livestock productivity, tsetse infestation and cattle tick burdens, prevalence of tick-borne diseases (TBDs) and trypanososmosis, morbidity and mortality rates due to TBDs and trypanososmosis; and the economic cost due to TTBDs, tstetse flies and trypanosomosis. Later the above parameters were monitored to quantify the impact.

Results After intervention, infestations by *Rhipicephalus appendiculatus* (14.8 ± 0.8 / cattle), *Ambylloma variegatum* (0.8 / cattle) and *Rhipicephalus evertsi* (0.2/ cattle) decreased by 43.2%, 50% and 100% respectively. However, *Rhipicephalus microplus* and *Rhipicephalus decoloratus* infestations grew by 1000% and 400% respectively. Tsetse fly catches per trap after 72 h decreased from 14.2 to 0. The trypanosomosis prevalence in cattle decreased from 7.3% to none. The farmer reported prevalence of tryapanosomosis reduced from 31.6% to 1.1%; East Coast Fever (ECF) reduced from 12.3% to 4.3%; heartwater and anaplasmosis reduced from 4.5% and 0.7% respectively, to 0. The mortality rate of cattle due to tryapnosomosis was reduced from 7.2% to 0; ECF reduced from 3.2% to 0.6%; anaplasmosis and heartwater reduced from 0.1% and 1.1% respectively to 0. Annual mortality loss per cattle herd due to trypanosomosis and TBDs reduced by 88.3% from USD 1,571.3 to USD 184.1 after intervention. Before intervention tryapnosomosis, ECF, anaplasmosis and heartwater constituted 70.6%, 17.7%, 11.1% and 0.6% of this loss respectively. However, after intervention there was mortality loss of only USD 35.9 which occurred due to ECF. The annual economic cost of ticks, tsetse flies, TBDs and trypnosomosis decreased from USD 1,916.8 to USD 302, with return of investment of 23.

Conclusions The introduced technology was effective for control of tsetse flies, *R. appendiculatus*, *R. evertsi* and *A. variegatum*; but not for *R. decoloratus* and *R. microplus*.

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Keywords Integrated control, Deltamethrin products, Ticks, Tsetse flies, Mixed game -livestock interfaces, Queen Elizabeth National Park

Background of study

Mixed Game and Livestock Interfaces (MGLIs) in and around conservation areas like Queen Elizabeth National Park (QENP) have typanosomosis, tsetse flies, ticks and tick-borne diseases (TTBDs) as major constraints to livestock productivity. Around QENP, a prevalence of 40.2% of trypanosomosis among cattle and tsetse fly infestation density of 30.2 catch per trap after 72 h was reported in Karusandara sub county, Kasese District, Uganda [1]. Earlier studies done around Lake Mburo National Park, Uganda found TTBDs being a major problem with a high challenge occurring from September to March and recommended intensive strategic tick control during this period [2–5]. Controlling of tsetse flies, trypanosomosis and ticks in MGLIs in Uganda is being constrained by cattle and wildlife sharing grazing and watering areas. Whereas pastoral and agro-pastoral communities inhabiting these areas try to control ticks and trypanosomosis in cattle, wildlife remain as a source of ticks and trypanosomes. This brings conflict between cattle production and wildlife conservation. Before this study, there was neither a cheaper sustainable optimized package for controlling tsetse flies, typanosomosis and TTBDs in MGLIs in Uganda nor was there any attempt to develop, introduce and roll out a community participation-based control strategy.

It was against this background that this study was designed and conducted to demonstrate the profitability of community participation in strategic integrated control of both tsetse flies and ticks by restrictive spraying of vector predilection sites [6] on cattle among the Basongora pastoral cattle keeping communities in Kasese District in QENP using dual purpose deltamethrin product -vectocid® (deltamethrin 50g, CEVA Tunisia). Deltamethrin products have one month residual effect on sprayed cattle. As the sprayed cattle graze, any tick and tsetse fly which gets in contact with them would be killed. The sprayed cattle were used as mobile targets which cleaned up the area of ticks and tsetse flies, thereby reducing the incidence of TBDs and trypanosomosis in livestock. This would increase productivity of livestock and even reduce the costs for controlling TTBDs, tsetse and trypanosomosis thereby increasing household incomes, food security and gender equity hence promoting coexistence of wildlife and livestock in this area. Maintenance of optimal populations of wildlife in this interface would promote tourism and also adoption of community-based and experiential tourism thereby further boosting household incomes. These outcomes were in line with Uganda National Development Program (NDP III) objectives addressing Uganda development agenda [7] and United Nations Sustainable Development Goals (SDGs) 1, 2, 5 and 15 [8].

Materials and methods

Study area description

The study was undertaken in wildlife-livestock interfaces in and around Queen Elizabeth National Park (QENP) among the Basongora pastoral livestock keeping communities in Kasese District, western Uganda. QENP is the second largest park and tourist attraction in Uganda and it is also World Heritage Site [9]. It has a diversity of wild animals consisting of various mammals, reptiles and birds. Wild animals of special interest are lions, buffaloes, leopards, elephants and primates. This park has two lakes: Lake George and Edward containing fish and other reptiles such as Nile crocodile, boomslang and mole snakes among others. The other third lake, is Lake Katwe, which is a salt lake which is an attraction for both animals and humans. Inside the park there are human settlement enclaves of fishing communities and livestock keepers. Also at the periphery outside QENP there are pastoral livestock keepers. Historically, for a long time, this area has been heavily infested with tsetse flies which are vectors of animal trypanosomosis (Nagana) and human trypanososmosis (sleeping sickness). The study area is mainly savannah grasslands and woodlands interspersed with bush thickets. The pastoralists practice communal grazing exposing their livestock to tsetse flies bites and heavy tick infestations. The area has warm tropical climate with temperature remaining nearly constant throughout the year, being 28°C / 32°F during day time and falling to 18°C / 64°F at night. It doesn't have a real dry season. It has a wet season from March—May and from August—December. Much less rain is seen in June-July and January – February.

Research design

This was participatory action research, carried out in three phases namely: baseline survey, sensitisation and training of farmers and extension staff; and technology transfer and adaptation.

Four study sites were selected for the study: Kyakitaale site in Kabatooro subcounty, Maruti site in Nyakantoozi subcounty, Hamukungu site in Lake Katwe subcounty and Kabukero site in Kasundara subcounty. Maruti and

Kabukero were outside the park; and Kyakitaale and Hamukungu were inside the park.

The sample size for households to participate in the study was determined using a formula [10].

$$N = Z^2PQ/e^2$$

Where:

$$Q = 1 - P$$

$$Z = 1.96$$

e = confidence level = 0.05; *P* = assumed that 95% of farmers knew that ticks and tsetse flies were a problem. Minimum sample size of 73 was determined but to increase accuracy the households were increased to 80. At each study site, 20 households were selected. The study sites were purposively selected with the help of field veterinary and entomology extension staff based on their history of working as groups. The households to participate in the study in each study site were also purposively selected with the help of field veterinary and entomology extension staff; and local village administrators based on their willingness to participate.

Forty farmers (10 per site) with cattle herds spraying weekly and an additional group of 10 herds spraying every two weeks for 3 months in Maruti site in Nyakantoozi subcounty were selected to be monitored monthly on how effectively they applied the technology with the help of the extension staff. Five ear tagged cattle per farmer were monitored. Cattle were sprayed using 5% vectocid® (deltamethrin 50 g Ceva Interchem, Tunis, Tunisia**),** diluted at rate of 1 ml of vectocid to 1 L of water. One litre, 1.5 L and 2 L of diluted insecticide wash was sprayed at tick predilection sites under the belly, in between legs and around the ears of calves, sub-adults and adult cattle respectively.

Baseline survey

Before introduction of the technology, a baseline survey was conducted to determine livestock productivity, tsetse infestaion density, tick burdens, prevalence of tick-borne diseases (TBDs) and trypanososmosis, morbidity and mortality rates due to TBDs and trypanososmosis; and economic cost due to TTBDs, tstetse flies and trypanosomosis. This was determined using participatory methods (focus groups discussions and key informant interviews) and use of a structured questionnaire. Tsetse fly densities and tick infestation levels were determined by trapping and doing cattle half body counts, respectively. Ticks were examined, identified using a stereo microscope to species level and counted using already known protocols [11, 12]. Five tsetse traps were set up at cattle grazing areas of each farmer group and left in position for 72 hrs. The tsetse flies were trapped using pyramidal traps, identified and counted using already known described protocol [13]. These procedures were repeated in subsequent two trips during the monitoring phase.

Initially, blood samples were taken from 200 head of cattle and ear tagged for future monitoring. Ten milliliters of blood were taken from the jugular vein. Both the haematocrit centrifugation technique and the buffy coat technique were carried out to diagnose cattle with trypanosomosis. All the cattle found infected with trypanosomes were treated with Berenil® (diminizene aceturate) at 7.00 Mg / Kg body weight to clearup trypanosome infections.

During the baseline survey, participatory methods and questionnaire interviews, were used to gather information on herd characteristics, methods used for tick and tsetse control, dynamics of TTBDs, tsetse and trypanosomosis; treatment and control of TBDs and trypanosmosis. Also assessed were losses due to TTBDs, tsetse and trypanosomosis; age specific mortality rates, weight loss, milk loss, live salvage sale losses; reduced calving rates, calf survivability rates, live off-take rates and losses in livelihoods (household income and food security). Before interviews, farmers were trained on how cardinal pathognomonic clinical signs of trypanosomosis and TBDs present in sick cattle.

For participatory methods, focus group discussions (FGDs) were held with eight farmers groups with aid of checklist of questions. Two farmer groups per site of six to eight farmers were selected for FGDs. While interviews with six key informants were done with the aid of interview guide. The questionnaire was pretested among sixteen farmers in the study area with the help of extension staff who were conversant with the local Basongora language. The final questionnaire developed after pretesting, was translated to the local Basongora language and administered to farmers with the help of extension staff. The interviews with farmers and key informants were conducted after obtaining consent from them by signing a consent form. Questionnaire interviews were administered to all selected study farmers.

Sensitisation and training of farmers

Farmers, extension workers, civic and community leaders were sensitized about the need and benefits of controlling tsetse fly, ticks, trypanosomosis and TBDs. They were trained on how to make tentative diagnosis of trypanosomosis and TBDs using clinical signs. Later they were also trained on methods of controlling tsetse and ticks through restrictive spraying of cattle once a week using vectocid®- deltamethrin product. Farmers were trained in spray pump maintenance, insecticide dilution rates and proper spraying of tick predilection sites. Later the technology was introduced and launched at all the four sites among the 80 farmers.

Monitoring implementation and impact of the technology

Tick counts and blood samples were taken monthly from ear tagged cattle. The effect of technology on reducing levels of infestation of ticks and tsetse flies; TBDs and trypanosomosis prevalence and improvement of productivity of cattle were also monitored using special designed record forms. In addition, production records were taken under supervision of group leaders and extension workers. Records taken included cattle herd age disease dynamics, treatment given, calvings, milk output, sales, new entries and herd growth.

Data analysis

Total and standard tick counts, tsetse fly catches and trypanosomosis incidences were compared among treatment groups and sites. Descriptive statistical analysis and analysis of variance test were performed. Economic cost caused by TTBDs, tsetse flies and trypanosomosis before and after adoption of the technology were quantified. Return of investment of adoption of the technology was also calculated.

Annual economic cost due to ticks, tsetse flies, TBDs and trypanosomosis per cattle herd was taken as a summation of mortality loss due trypanosomosis and TBDs, cost of dual spraying of cattle with vectocid®, trypanosomosis prophylaxis treatment using Samorin® (isometamidium chloride), treatment costs for trypanosomosis and ECF, milk loss due to trypanosomosis and heartwater; and salvage sale loss due to trypanosomosis.

Cattle herd mortality loss due to trypanosomosis and ECF was taken as sum of different age specific mortality losses. Age specific mortality loss was taken as product of number of cattle of specific age group which died and specific age group market price during one year period which was denoted as $\sum_{i=1}^{5} X_i$ where by:

1 = Mortality loss in calves
2 = Mortality loss in steers
3 = Mortality loss in heifers
4 = Mortality loss in adult cattle
5 = Mortality loss in bulls

Milk loss per herd to due to trypanosomosis and heartwater was taken as a product of milk yield lost in a herd in litres for each disease and market price of milk per litre. Herd milk loss was taken as product of milk loss per lactating cow with ratio of cattle in herd which were lactating during the one year period.

Cattle herd salvage sale loss due trypanosomosis was taken as sum of different age specific salvage sale losses. Age specific loss was taken as a product of number of cattle of specific age group which were salvage sold and price difference between real market price and salvage sale price during one year period. Specific cattle herd salvage sale loss was denoted as $\sum_{i=1}^{5} X_i$ where by:

1 = Salvage sale loss in calves
2 = Salvage sale loss in steers
3 = Salvage sale loss in heifers
4 = Salvage sale loss in adult cattle
5 = Salvage sale loss in bulls

Return of investment was determined to demonstrate profitability of optimization of integrated control of tsetse flies using vectocid® visa-viz maintaining status quo. Return of investment was taken as ratio of excess financial benefit accrued due to additional investment (weekly vectocid® spraying of cattle) divided by the cost of additional investment. It can also be expressed as percentage.

Results

Cattle farming system characterisation and practices

The mean household size was 10.9 ± 1.1. The mean livestock herd sizes per household were as shown in Table 1. Cattle herd age structure, sale-offtake and average market prices were as shown in Table 2.

Twenty-three point nine percent (23.9%) of adult cows were salvage sold due to trypanosomosis at average price of USD 118.7 ± 2.2 per head. Mean calving rate was 15.5%. The main forms of herd off-take were sales and mortality. The overall herd sale off-take was 11.8%. The percentage of farmers who perceived the following diseases as a major constraint affecting their cattle were 87% for trypanosomosis, 91.3% for ECF; 52.5% for anaplasmosis and 30.4% for heartwater. The average cattle milk yield was 1.7 ± 0.2 L during wet season; 1.2 ± 0.2 L during dry season. Milk price of milk

Table 1 Mean livestock numbers ± standard error per household

Study site	Livestock species			
	Cattle	Goat	Chicken	Ducks
Kabatooro	32.1 ± 4.3	3.6 ± 1.3	4.3 ± 1.4	3.6 ± 1.2
Nyakantoozi	64.3 ± 18.8	11.7 ± 2.1	14.2 ± 3.5	0
Hamakungu	27.7 ± 6.4	9.3 ± 3.5	2.2 ± 1	0
Kasundara	73 ± 21.2	28.8 ± 13.9	12 ± 1.5	0
Overall	41.3 ± 8	8.2 ± 1.3	7.9 ± 1.6	1.3 ± 0.5

Table 2 Cattle percentage herd age structure, sale offtake off-take and average market prices ± standard error before intervention

Age category	% herd composition	% sale offtake	Average market price (USD)
Adult cows	52	12.4	382.9 ± 15.7
Heifers	19.9	6.4	326.4 ± 25.6
Steers	8.2	36.2	275.3 ± 17,0
Calves	16.2	0	158 ± 22.2
Bulls	3.7	30.8	447.9 ± 56.6

was USD 0.3 per litre. Reduction of milk yield per head of cattle due to trypanosomosis was 46.7%.

In this study area, it was compulsory that all cattle were prophylactically treated 3 times a year against trypanosomosis using Samorin®. Each sacket was costing USD 8.3 and was used to treat 10 cattle. There were no tsetse control practices being employed.

Tick control was done by whole body spraying weekly using Milbitraz® (cyclic amidines) and Amitraz (triapentadiene). Usually, 2–3 L of diluted wash was sprayed per cattle. There was reported tick acaricide resistance in the area, with farmers resorting to using agro-chemicals for spraying cattle. They used a crop pesticide Acellamectin which belonged to avermectin family of macrocyclic lactone.

Morbidity rate, mortality rate and case fatality of trypanosomosis, ECF, anaplasmosis and heartwater

The morbidity rate, mortality rate and case fatality of trypanosomosis, ECF, anapalsmosis and heartwater affecting cattle during baseline survey, trip 1 (3 months after) and trip II (6 months after) as reported by farmers were as shown in Tables 3, 4, 5 and 6 respectively. No case of babesiosis was reported.

Variation of tick counts and tsetse fly trap catches

The mean whole body tick species counts per head of cattle per site during the baseline survey and after intervention were as shown in Tables 7 and 8 respectively. Before intervention, the major tick species recovered were *R. appendiculatus* constituting 91.3% of total ticks recovered, followed by *Ambylloma variegatum* 4.9%, *R. evertsi* 1.2%, *R. decoloratus* 1.2% and *R. microplus* 0.4%. After intervention, 70% of the total ticks recovered were *R. appendiculatus*, 8.3% *R. decoloratus*, 18.3% *R. microplus* and 3.4% *A. variegatum*. No *R. evertsi* was recovered.

During baseline survey, the composition of total counts of *R. appendiculatus* recovered were 89.2% adults of which 20.5% were engorged. After intervention, there was a very highly significant ($P = 0.00000$; $F = 70.9$; df 1, 325)

Table 3 Percentage morbidity rate, mortality rate and case fatality of trypanosomosis affecting cattle

Age category	Morbidity rate			Mortality rate			Case Fatality Rate		
	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II
Adult cows	33.1	1.4	1.1	11.7	1.1	0	35.2	80	0
Heifers	36.9	0	0	4.3	0	0	11.5	0	0
Steers	41.4	3.4	0	3.4	3.4	0	8.3	100	0
Calves	20.7	3.4	0	0	0	0	0	0	0
Bulls	115	3.8	0	0	3.8	0	0	100	0
Overall	31.6	1.7	1.1	7.2	1	0	22.7	58.3	0

Table 4 Percentage morbidity rate, mortality rate and case fatality of ECF affecting cattle

Age category	Morbidity rate			Mortality rate			Case Fatality Rate		
	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II
Adult cows	0.8	0.5	0	0.8	0	0	100	0	0
Heifers	8.5	0	0	2.1	0	0	25	0	0
Steers	0	0	0	0	0	0	0	0	0
Calves	62.1	26.6	8.6	14.7	4.2	3.4	23.6	40	31.6
Bulls	7.7	0	0	0	0	0	0	0	0
Overall	12.3	4.3	1.5	3.2	0.7	0.6	26.4	36.4	31.6

Table 5 Percentage morbidity rate, mortality rate and case fatality of anaplasmosis affecting cattle

Age category	Morbidity rate			Mortality rate			Case Fatality Rate		
	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II
Adult cows	0	0	0	0	0	0	0	0	0
Heifers	0.7	0	0	0	0	0	0	0	0
Steers	0	0	0	0	0	0	0	0	0
Calves	3.4	0	0	0.9	0	0	25	0	0
Bulls	0	0	0	0	0	0	0	0	0
Overall	0.7	0	0	0.1	0	0	2	0	0

Table 6 Percentage morbidity rate, mortality rate and case fatality of heartwater affecting cattle

Age category	Morbidity rate			Mortality rate			Case Fatality Rate		
	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II	Baseline	Trip 1	Trip II
Adult cows	8.1	0	0	1.9	0	0	0	0	0
Heifers	1.4	0	0	0.7	0	0	50	0	0
Steers	0	0	0	0	0	0	0	0	0
Calves	0	0	0	0	0	0	0	0	0
Bulls	0	0	0	0	0	0	0	0	0
Overall	4.5	0	0	1.1	0	0	25.0	0	0

Table 7 Mean total tick counts per cattle by species per site during the baseline survey

Site	*R. appendiculatus*	*R. evertsi*	*R. decoloratus*	*R. microplus*	*A. varieagatum*
Kabatooro	23.6 ± 1.6	0.94	0.2	0.34	0.94
Nyakantoozi	21.6 ± 2.8	0	0.4	0.16	0.52
Hamukungu	9.4 ± 1.2	0	0	0.06	1.34
Kasundara	6.6 ± 0.6	0	0	0.22	0
Overall	14.8 ± 0.8	0.2	0.2	0.22	0.8

Table 8 Mean cattle body tick counts by species per site after six months of spraying

Site	*R. appendiculatus*	*R. evertsi*	*R. decoloratus*	*R. microplus*	*A. varieagatum*
Kabatooro	5.6 ± 0.8	0.4	1.4	1.4	0.8
Nyakantoozi	13 ± 1.6	0	2.0	5.2	0.2
Hamukungu	14.2 ± 1.6	0	0.4	1.2	0
Kasundara	3.6 ± 0.6	0	0	1.4	0
Overall	8.4 ± 0.6	0	1.0	2.2	0.4

reduction of counts of total *R. appendiculatus* counts. *R. appendiculatus* total counts decreased by 43.2%; of which 94.1% were adult ticks with 6.9% being engorged. During baseline, the tick infestations were highest in Kabatooro and Nyakantoozi. After 6 months of spraying, adult *R. appendiculatus* counts were highest in Nyakantoozi and Hamunkungu.

Spraying every two weeks was not effective for controlling *R. appendiculatus* infestations with the population of adults increasing by 22.4% (from 21.6 ± 2.8 to 26.4 ± 1.8 body counts) of which 22.2% were engorged after 3 months of spraying.

After 6 months of spraying, the infestation by *R. microplus* increased by 1000% of which 69.7% of adult ticks recovered were engorged. *R. decoloratus* increased by 400%. Of *R. decoloratus* infesting cattle 39.1% were adults of which 50% were engorged and 60.9% were nymphs of which 60% were engorged. This indicated development of resistance to vectocid deltamethrin insecticide. The rate of increase of population of *R. decoloratus* (2.5 times) was much lower than of *R. microplus*, indicating that this tick was being displaced by *B. microplus*. *A. varieagtum* infestation reduced by 50%; with none of the ticks being engorged. No *R. evertsi* was recovered.

The tsetse fly (*Glossina pallidipes*) catches per trap after 72 h decreased from initial baseline mean catch of 14.2 to 2 after 3 months, and to 0 after 6 months. The *Trypanosoma species* prevalence in blood of cattle decreased by 40.1% from 7.3% to 4.3% after 3 months, and none detected after 6 months.

Economic cost due to ticks, tsetse flies, tick-borne diseases and trypanosomosis

The mean annual mortality loss (USD) due to TBDs and trypanosomosis per cattle herd before intervention was as shown in Table 9. After intervention, there was a mortality loss only due to ECF of USD 35.9. There was no mortality loss due to trypanosomosis. The projected mean annual economic cost due to ticks, TBDs and trypanosomosis per cattle herd before and after intervention was as shown in Tables 10 and 11 respectively. The benefits and return of investment for optimization of control of ticks, tsetse flies, TBDs and trypanosomosis were as shown in Table 12.

Discussion

The Basongora cattle farmers were sedentary pastoral households, who kept only indigenous Ankole Sanga cattle with average herd size of 41 per household. The observed herd size was similar to what has been observed in Buliisa district among the Bakungu cattle keeping communities, Uganda [14], among the Karamojong in Amudat and Kaabong districts, Uganda [15]. The herd structure was geared towards milk production and attaining herd growth. The cattle herd structure was similar to that found among the Bahima in Kiruhura district, Uganda [16, 17] and among the Bakungu in Buliisa district, Uganda [13]. The herd structure was contrary, to

Table 9 Mean annual mortality loss (USD) due to tick-borne diseases and trypanosomosis per cattle herd before intervention

Variable	Trypanosomosis	ECF	Anaplasmosis	Heartwater	Total
Adult cows	962.2	65.8	0.0	156.3	1,184.2
Heifers	115.3	56.3	0.0	18.8	190.5
Steers	31.7	0.0	0.0	0.0	31.7
Calves	0.0	155.4	9.5	0.0	164.9
Bulls	0.0	0.0	0.0	0.0	0.0
Total (USD)	1,109.3	277.5	9.5	175.0	1,571.3
% contribution	70.6	17.7	0.6	11.1	100

Table 10 Mean annual economic cost (USD) due to ticks, tick-borne diseases and trypanosomosis per cattle herd; and % contribution of each cost to total economic cost before intervention

Type of cost	Cost per category			% contribution
	Amount	Trypanosomosis	TTBDs	
Mortality loss	1,571.3	1,109.3	462.1	82.0
Tick control	27.2	0.0	27.2	1.4
Trypanosomosis prophylaxis treatment with Samorin®	165.8	165.8	0.0	8.6
Treatment costs for trypanosomosis	6.1	6.1	0.0	0.3
Treatment costs for ECF	7.8	0.0	7.8	0.4
Milk loss due to trypanosomosis	20.3	20.3	0.0	1.1
Milk loss due to heartwater	10.7	0.0	10.7	0.6
Salvage sale loss due to trypanosomosis	107.7	107.7	0.0	5.6
Total	1,916.8	1,409.1	507.7	
% contribution		73.5	26.5	

Table 11 Projected mean annual economic cost (USD) due to ticks, tsetse flies, tick-borne diseases and trypanosomosis per cattle herd; and % contribution of each cost to total economic cost after intervention

Variable	Amount	Trypanosomosis	TTBDs	% contribution
Mortality loss	35.9	0	35.9	11.9
Dual spraying of cattle with vectocid®	97.1	0	97.1	32.1
Trypanosomosis prophylaxis treatment	165.8	165.8	0	54.9
Treatment costs for trypanosomosis	0.8	0.8	0	0.3
Treatment costs for ECF	1.8	0.0	1.8	0.6
Milk loss due to trypanosomosis	0.7	0.7	0	0.2
Milk loss due to heartwater	0	0	0	0
Salvage sale loss due to trypanosomosis	0	0	0	0
Total	302	167.2	134.8	100.0
% contribution		55.4	44.6	

Table 12 Benefits (USD) and return of investment for optimisation of ticks, tsetse flies, TBDs and trypanosomosis control per household cattle herd

Percentage reduction of economic cost due to intervention	84.24
Baseline cost of spraying for tick control	27.2
Dual cost of control using vectocid®	97.1
Extra cost of investment	69.9
Net return of investment	1,614.8
Return of investment	23

what has been observed in Uganda in Teso region [18] and Tororo district [19] and in Kaabong in Karamoja [15] where cattle herd structure was to support land traction for crop growing. No sheep was kept in the study area due to cultural reasons which did not promote mutton local consumption and for sale. Also, the Basongora communities did not grow any crops. They solely depended on livestock for their livelihoods.

The overall herd percentage sale off-take was 11.8% of which the majority were steers and bulls. Most (23.8%) of adult cattle off-take was due to salvage sales caused by trypanosomosis ailment. A similar observation was made in Buliisa District, Uganda where trypanosomosis sick cattle were hurriedly sold [14].

The tick species infesting cattle in the study area was mainly *R. appendiculatus* followed by *A. variegatum, R. evertsi*, *R. decoloratus* and *R. microplus* in that descending order before intervention. This finding was similar to what was observed about ticks infesting cattle around lake Mburo National Park, Uganda, where *R. appendiculatus* was a major tick constituting 98.2% of ticks recovered infesting cattle [3, 4]. This was contrary to what was found [20] in high cattle density cattle keeping areas in Uganda in Karamoja region (in Kaabong, Amudat and Napak districts), Arua, Lyantonde and Nakaseke where only 47.4% of ticks infesting cattle was *R. appendiculatus*, followed by *A. variegatum* (15.3%), *A. lepidum* (15.3%), *R. evertsi*, (13.1%), *R. decoloratus* (2.5%) and R. *microplus* (1.9%). In another study done in Karamoja region [21], abundance *R appendiculatus* infesting cattle was found to be much less 37.3%, followed by *A. variegatum* 32.3%, *A. lepidum* (17.3%, *R. evertsi* (7.8%) and *R. decoloratus* 1.4%. A similar observation was earlier also made among cattle in Karamoja [22].

Based on abundance of vector tick populations in the study area, it became apparent that *R. appendiculatus* being a major tick, ECF was a major cattle tick-borne disease, followed by heartwater which was vectored by A. *variegatum. R. evertsi* was expected to vector anaplasmosis, heartwater and babesiosis. While *R. decoloratus* has been known to be a vector of babesiosis caused by *Babesia bigemina;* and *R. microplus* to be a vector of babesiosis caused by *B. bovis;* and anaplasmosis.

The initial baseline body mean body counts per head of cattle of *R. appendiculatus* and *A. variegatum* ticks decreased drastically upon weekly spraying of cattle with vectocid® for six months (Tables 7 and 8). No cattle infestation was recorded with *R. evertsi* after weekly spraying. This showed that weekly spraying using deltamethrin product vectocid® was effective for controlling *R appendiculatus*, *A. variegatum* and *R. evertsi.* However, spraying every two weeks was not effective for *R. appendiculatus* because its adult populations and proportion of those engorged recovered increased. This was in agreement with earlier findings [23] where it was found that *R. appendiculatus* was resistant to synthetic pyrethroids when applied according manufacturer's instructions of spraying after very two weeks.

However, *R. microplus* and *B. decoloratus* were resistant to weekly spraying with the vectocid®. Their cattle infestation levels grew by1000% and 400% respectively. An earlier study done [23] reported *B. decoloratus* to be resistant to deltamethrin spraying in cattle dairy farms in western Uganda. This study has also shown that the population of *R. microplus* was growing fast displacing the *R. decoloratus*. This is due to the high invasive nature of this tick species [24] and quick development of acaricide resistance [25, 26]. *R. microplus* was first reported to occur in Uganda, in Kadungulu county, Serere district [26]. The ticks collected from cattle in this study area should be tested for acaricide resistance using Larval Packet Test and Adult Immersion Test [27]. Before intervention in this study area, tick acaricide resistance was marked with farmers resorting to spray cattle using crop pesticides which caused blindness among cattle sprayed [28].

Glossina pallidides was a major tsetse fly species infesting the study area. This is a savannah mortisan group of Glossina. This finding was in agreement with what was earlier found [29] where 95.5% of tsetse flies caught were *G. pallidides* and 0.5% were *G. fuscipes* (riverine tsetse) infesting the study area.

The introduced technology used was effective in that there was drastic reduction of tsetse flies with no infestation at study sites by six months. This ability of deltamenthrin products when sprayed on cattle to act as mobile targets was earlier also achieved in Serere district, Uganda [30]. It was shown that spraying every 2 weeks was effective against tsetse flies. However, according to the manufacturer's instructions, vectocid® spraying every 2 –4 weeks was effective for controlling tsetse flies.

The *trypanosome* infection in cattle was drastically decreased by the current intervention from 7.3% during baseline survey to none after 6 months of spraying. Earlier trypanosome prevalence study conducted in the study area using Polymerase Chain Reaction blood test found prevalence of *T. brucei* of 23% in cattle, 18.8% in goats; *T. congelense* 17.3% in cattle, 16.9% in goats and *T. vivax* 11.1% in cattle, 12.9% in goats [29]. This showed that goats which were not of interest of this study could act as a source of trypanosomes for cattle once they were treated. Goats should therefore also be sprayed with deltamethrin products. All goats, should be tested for trypanososme infection and all those found positive infected be treated with Berenil®. Thereafter, all goats should be prophylactically be treated against trypanosomosis using Samorin®.

Almost all farmers, in the study area, reported that trypanosomosis and ECF were major diseases affecting their cattle followed by anaplasmosis and heartwater. This was in agreement to what was observed in Soroti, Uganda [31]. Babesiosis was not a problem of cattle in the study area. Cattle had developed endemic stability to babesiosis. The same was true for Amudat district, Uganda [15].

Before intervention, prevalence of 31.6% of trypanosomosis was reported affecting all cattle age groups (Table 3). The mortality rate was 7.2% occurring in adult cows and sub-adult cattle. This reported prevalence was similar to what was found in Buliisa district, Uganda [14]. However, after intervention, the reported prevalence of trypanosomosis reduced by 93.4% from 82.4% to 1.1% and mortality rate was reduced by 100%. This was due to effective tsetse control and proper treatment of clinical cases using Berenil®.

ECF was disease of calves with high farmer reported prevalence rate of 62.1% before intervention, which was reduced by 86.2% after 6 months of intervention (Table 4). This was due to effective of *R. appendiculatus* control. Calves were the ones most affected. Mortality rate due to ECF was reduced by 84.3% from 3.2% to 0.6%. This was due to effective management of ECF clinical cases. This study has showed that the local adult indigenous local Sanga Ankole cattle had developed endemic stability to ECF. However, if action was to be taken to improve this local breed by crossing with dairy exotic breeds more specifically the Friesian and Guernsey breeds; and beef exotic Boran breed there should be a need to confer protection against ECF to the resultant crosses using Infection Treatment Method. This would be in agreement to what had earlier been done successfully among pastoralist Masai communities in Tanzania [32, 33], among dairy farmers in Bugabula county, Kamuli district, Uganda [34] and among cattle in Uasin County in Kenya [35].

There was low prevalence of anaplasmosis in the study area. The farmer reported prevalence of anaplasmosis was completely reduced from 0.7% to zero. Mortality rate was reduced from 0.1% to zero. This was due to low populations and effective control of vector *R. evertsi* tick. This tick species was completely controlled during the intervention. This trend could change with increase of *R. microplus*-the alternative pyrethroid resistant tick vector populations for anaplasmosis.

The reported prevalence of heartwater was reduced by 100% from 4.5% to 0. Cattle mortality due to heartwater was completely stopped from 1.1%. This was due to reduction of its vector *A. variegatum*. This was the second abundant tick before intervention in the study area.

No case of babesiosis was reported in the study area. A similar observation was made for cattle in Amudat in Karamoja [14]. This was due to low *R. decoloratus* and *R. microplus* vector populations [26, 36, 37]. This trend could drastically change when their populations infesting cattle surge up due to acaricide resistance coupled with introduction of virulent strain of *Babesia* organisms to cattle population. *R. decoloratus* has been known to be a vector of *B. bigemina* and *R. microplus* a vector of *B. bovis* [26, 36, 37].

Before intervention, the mean Economic Cost (EC) (Table 10) due to ticks, tsetse flies, TBDs and trypanosomosis per cattle herd was USD 1,916.8 annually of which 73.5% was due to costs caused by trypanosomosis losses. Eighty- point two percent (80.2%) of the EC was due to mortality losses caused by trypanosomosis and TBDs, of which 70.6%, 11.7%. 11.1% and 0.6% was due to trypanosomosis, ECF, heartwater and anaplasmosis respectively. This was in agreement with what was found in in Buliisa district, Uganda, that mortality loss was the major component of the economic cost which was caused by bovine trypanosomosis [13]

Before intervention, EC due to costs incurred by prophylaxis treatment of trypanosomosis using Samorin® was low, only 8.6%. EC due to salvage sale loss of sick cattle due to trypanosomosis was also low (5.6%). While losses incurred due to treatment of TBDs (0.4%) and trypanosomosis (0.3%) were negligible. Similarly, it was found that only 1.1% and 0.6% of EC was due to milk loss due to trypanosomosis and TBDs respectively. This was due to low daily milk yield of cattle being 1.7 L during wet season; and 1.2 L during dry season. Trypanosomosis was found to cause 46.7% reduction of milk yield.

After intervention, EC of trypanosomosis, tsetse flies, ticks and TBDs per cattle herd was reduced by 84.24% from USD 1,916.8 to USD 302 (Table 11). This was due to complete elimination of loss due to mortality caused by trypanosomosis, which was a major component EC observed before intervention. The EC after intervention was contributed mainly by three components: costs of trypanosomosis prophylaxis treatment with Samorin® (54.8%), investment in sprayings with vectocid® (32.1%) and mortality loss due to ECF (11.9%). There were no losses incurred due to salvage sale of cattle.

The net benefit of community adoption of new technology of spraying cattle with dual purpose vectocid® spray was USD 1,614.8 annually per cattle herd. This was saved from losses caused by trypanosomosis, tsetse flies, ticks and TBDs before the technology was introduced. The community adoption of this blended package for integrated control of ticks, tsetse flies, TBDs and trypanosomosis was profitable with a return of investment of 23 or 2300% (Table 12). The communal use of this package could further be reinforced by control of tsetse fly by using waterbuck repellent blend belt [38]. This technology incorporates a collar dispenser with distinct chemical odors extracted from waterbucks that repel tsetse flies away from cattle. The combination of these technologies could be tested in other heavily tsetse infested mixed game and livestock areas.

Conclusions

It becomes apparent that weekly restrictive spraying using vectocid®, could be used for integrated control of *R. appendiculatus*, *R. evertsi*, *A. variegatum* and tsetse flies. However, it was not effective in controlling *R. decoloratus* and *R. microplus*. These ticks had developed resistance to vectocid®. It was shown that, this technology could further be reinforced with prophylactic treatment of cattle against trypanosomosis using samorin® three times a year to form an integrated blended package for controlling ticks, tsetse flies, TBDs and trypanosomosis in MGLIs in Uganda like in Murchison Falls Park Conservation Area and Kidepo Valley National Conservation Area. The findings of this study, could further be investigated in a collaborative manner with other major stakeholders especially with Uganda Ministry of Agriculture Animal Industry and Fisheries; and Uganda National Agricultural Research Organisation.

Limitations of the study

The time period covered by the study was short. It would be appropriate to undertake a one-year study period. Also, during the baseline study, the accuracy of information got depended on recall memory of farmers. Farmers in the study area did not keep records. Due to financial constraint, it would have been appropriate to deploy portable mobile Polymerase Chain Reaction kits to monitor clinical cases of TBDs and trypanosomosis during the monitoring and adaptation phase of the study. The annual economic cost of ticks, tsetse flies, TBDs and trypanosomosis per herd of cattle were projections made based on the six- month study assuming that the conditions were the same in the other half of the year.

Abbreviations

ECF	East Coast fever
USD	United States Dollar
TBDs	Tick-Borne Diseases
MGLIs	Mixed Game and Livestock Interfaces
QENP	Queen Elizabeth National Park
TTBDs	Ticks and Tick-Borne Diseases
NDP III	Uganda National Development Program III
SDGs	Sustainable Development Goals
Mg	Milli gram
Kg	Kilogram
BWT	Body Weight
FDGs	Focus Group Discussions
EC	Economic Cost

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Authors' contributions
MO, CS and JN participated in crafting the research concept; MO, MO, CS, JN, DK, WE, FK did data collection; FK and SN did laboratory analysis of samples; MO did data analysis and preparation of initial draft paper; all authors reviewed the draft manuscript.

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Data availability
Available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
A written signed consent was obtained from the farmers to conduct research using their cattle and getting their full participation. The methods used for handling animals, obtaining samples, handling samples and test protocols carried on samples obtained from animals were approved by Makerere University, School of Veterinary Medicine and Animal Resources Institutional Animal Care and Use Committee Ref: SVAR-IACUC/120/2022 and Uganda National Council of Science and Technology Ref: A 365ES.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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