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Rodents in agriculture and public health in Malawi: Farmers' knowledge, attitudes, and practices

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Given that rodents are responsible for nearly 280 million cases of undernutrition worldwide and that about 400 million people are affected by rodent-associated zoonoses annually, management of rodent populations that are agricultural pests and/or reservoirs of pathogens is a major food security and public health matter. In sub-Saharan Africa, the median crop loss due to rodents is about 16% in the field and around 8% during storage. The impact on public health is not well-established, albeit over 60 zoonotic diseases can be spread to humans *via* rodents. Therefore, focusing on rodent-related community knowledge, attitudes, and practices is crucial to establishing robust baseline information as a springboard for future targeted studies. The study was conducted in September 2020 in Lilongwe and Nkhata Bay districts in Central and Northern Malawi, respectively. A semi-structured questionnaire, focus group discussions, and interviews with key informants were used. Farmers reported rodents were a major problem for staple crops (maize, rice, and cassava) and the main species responsible were the Natal multimammate mouse (*Mastomys natalensis*), silver mole-rat (*Heliophobius argenteocinereus*), and house mouse (*Mus musculus domesticus*). Awareness of rodent-associated health risks is very low, as exemplified by reports of rodent–human bites, eating rodent-contaminated food, and processing and consumption of wild rodents in poor hygienic conditions, and these practices were flourishing when Malawi was a bubonic plague endemic country. Rodent management is less practiced, and when practiced, it is symptomatic. It is considered a matter of individual households and typically relies on the use of rodenticides and insecticides without proper dosage and user instructions. We recommend rigorous campaigns to create better awareness among the public regarding the impacts of rodents on agriculture and community health and the need for community engagement for effective rodent management. A paradigm shift is needed by adapting and adopting practices of ecologically-based rodent management and reducing dependence on synthetic chemical rodenticides.

KEYWORDS

rodents, crop damage, health risk, pest management, Malawi

1 Introduction

About 280 million cases of undernourishment could be prevented worldwide through effective management of pre- and post-harvest losses by rodents (Meerburg et al., 2009b). In addition, about 400 million people are affected by rodent-associated zoonoses annually (Meerburg et al., 2009a). Therefore, the management of rodent populations that are major agricultural pests and also reservoirs of pathogens is important to improve food security and public health. In sub-Saharan Africa, Swanepoel et al. (2017) estimated median crop loss due to rodents at 16% in the field and 8% during storage based on a meta-analysis of 124 scientific papers. The scale of public health risk specifically to sub-Saharan Africa is not well established and there is little awareness of the >60 zoonotic diseases that rodents could potentially spread to humans through direct contact or indirectly *via* ectoparasites (fleas, ticks) and their excreta (Meerburg et al., 2009b; Luis et al., 2013). Despite these reports of the impact of rodents on crop yields and public health, much basic information on the topic is still lacking in many sub-Saharan African countries. This has significant implications for food security and public health, which remain major concerns in these regions. This study focuses on the vulnerability of smallholder farmers in Malawi to rodent impacts due to the lack of effective rodent management methods.

Agriculture is the backbone of the Malawian economy. Approximately 80% of crop production in Malawi is produced by smallholder, subsistence farmers (i.e., farms of less than 2 ha) (GoM, 2010; Fan and Rue, 2020). Maize and cassava are the two most important staple crops in Malawi in terms of production volume and use (FAO, 2021). Cassava is the most important staple food in the districts along the shores of Lake Malawi. Cassava is also a commercial crop in other districts such as Lilongwe. Vertebrate pests cause crop losses during production in agricultural fields and during storage (Witmer, 2007). In Malawi, they damage about 8% of potential agricultural production in smallholder farmers' fields (Deodatus, 2000); monkeys, rodents, and large herbivores are the most important pest species in cereal and legume crops. On the other hand, little is known about public perceptions about health risks associated with rodents, the state of human–rodent contacts, and the prevailing management actions in zoonotic-risk settings. Elsewhere, studies have shown that public perceptions of rodents in agriculture and public health vary, and this has led to detailed studies on rodents as both pests in agriculture and risks to public health (Makundi et al., 2005; Brown et al., 2008; Meheretu et al., 2010; Meheretu et al., 2011; Palis et al., 2011; Stuart et al., 2011).

Rodent management efforts in Malawi focus on mainly reducing their impact on stored grain, especially maize, by improving traditional grain storage methods (e.g., grass-thatched wooden granaries, locally called "khokwe") (personal observation). Farmers are encouraged to attach metal sheet collars around the stands of the khokwes to protect them from rodents. Improved storage technologies such as metallic silos and Purdue Improved Crop Storage (PICS) bags are not commonly used by subsistence farmers due to their high prices compared to woven polypropylene bags and khokwe (see, for example, Maonga et al., 2013; Farnworth et al., 2020). Furthermore, the technologies have been introduced to Malawian farmers recently and have yet to be widespread across subsistence farmers. PICS bags are triple-layer sealed plastic bags that cut off oxygen supply from the environment to create hermetic conditions (see Baoua et al., 2012; Baoua et al., 2018). They primarily aim to manage insect pests in the storage of dry grain.

There has been little focus on the impact of rodents on crop yields during production in Malawi, and the public health risks associated with them have not been fully considered. Furthermore, since effective management of rodents is a communal and not an individual matter (Singleton et al., 2021), it is important to document the knowledge, attitudes, and practices (KAP) of these farmers regarding rodents in Malawi. It is also important to document the rodent species that occur in Malawi's agroecosystems. The objectives of this study were i) to gain insights into farmers' knowledge of rodent pests; ii) to identify rodent species that occur locally in agroecosystems in Malawi and cause damage to fields and stored crops; iii) to explore perceptions of rodents in relation to public health risks; and iv) to explore rodent management practices and general sociocultural perceptions about rodents in Malawi.

2 Materials and methods

2.1 Study area and survey design

The survey was carried out in two districts: Lilongwe and Nkhata Bay in central and northern Malawi. These two districts represent two agroecological zones. Nkhata Bay is in the high altitude and high rainfall agroecological zone, while Lilongwe belongs to the medium altitude and medium rainfall agroecological zone. In Nkhata Bay, the average annual rainfall is 1,490 mm and falls mainly between December and April. In Lilongwe, the average annual rainfall varies between 800 and 1,200 mm (GoM, 2016). In both districts, agriculture is the primary source of livelihood. Arable farming is predominantly rain-fed. The level of mechanization in agriculture is low, and the handheld hoe is the main agricultural tool.

For administrative purposes, each district is further divided into Extension Planning Areas (EPAs). There are seven EPAs in Nkhata Bay and 19 EPAs in Lilongwe. In each district, we surveyed an EPA based on the known presence of rodents and their infestation in the fields. In Lilongwe, we selected Mitundu EPA, and in Nkhata Bay, we selected Chintheche EPA. The survey was conducted in September 2020. For data collection, we used a combination KAP surveys, focus group discussions (FGDs) and key informant interviews (KIIs). For the Lilongwe survey, we randomly selected 39 farmers (24 men and 15 women) and surveyed them using a semi-structured questionnaire completed by an interviewer. We surveyed 40 farmers, but one response was dropped because of some erroneous responses. Thirty other farmers (including 15 men and 15 women) were selected from each district for FGDs, all identified on the recommendations of the EPAs' extension officers. Six FGDs were conducted in each district, each with five men or five women. We used a prepared list of questions for the FGDs. Unfortunately, we were unable to conduct a KAP survey in Nkhata Bay due to logistical problems. However, a KIIs were conducted with six agricultural extension workers to complement the survey and fill in some of the gaps.

2.2 Rodent trapping

A purposive sampling method was used to increase the likelihood of capturing rodents in order to gain a quick overview of locally occurring rodent species. Standard Sherman live traps (7.5 × 9.0 × 23.0 cm, HB Sherman Trap Inc., Tallahassee, USA) and locally made snap traps were used to sample rodents. In addition, one or two local "mouse hunters" were engaged to dig the rodents out of their burrows (Figure 1). Traps were set in the evening (between 16:30 and 18:00) and checked for catches the next morning (between 06:00 and 08:00). On average, we set seven traps, a combination of Sherman and local snap traps, per site (n = 7) in a transect line in the fields (see Table 5 for trapping sites). Transect lines were not linear but were positioned along sections of fields that might be used by rodents as nesting or foraging sites. The traps were baited with a mixture of roasted soybeans and peanut butter. The traps were set only once per site during the dry season between June and September 2020.

2.3 Data analysis

To understand the relationships between respondents' demographic characteristics and their knowledge of rodent pests,

FIGURE 1
A "mouse-hunter" searching for rodents in a suspected burrow in a maize field in Lilongwe.

descriptive statistics such as percentages and cross-tabulations were conducted in SPSS version 27. Data from the questionnaire survey were analyzed separately from those from the FDGs and KIIs. Each captured rodent was photographed from different angles for taxonomic identification. This was done using morphological keys, local names provided by farmers, and a comparison with the collections of the National Museum of Malawi. We followed the taxonomy of Monadjem et al. (2015) and Wilson et al. (2017).

2.4 Ethical approval

Ethical approval to conduct the study was obtained from the Lilongwe University of Agriculture and Natural Resources. Captured animals were handled following the ethical policies and guidelines approved by the university Animal Care and Use team. Informed consent was obtained from all participants involved in the survey.

3 Results

3.1 Questionnaire survey

3.1.1 Farmers' demographic profiles

Women accounted for about 39% of the respondents (Table 1). Most of the respondents (82%) were between 25 and 59 years old and married. About 40% of the respondents had completed primary school and 69% were living off agriculture. The average household size was five to six people in Lilongwe and three to four people in Nkhata Bay. The average land ownership was 0.5–1.0 ha in both districts. Cross-tabulations of the demographic profiles of respondents with various aspects of respondents' knowledge, attitudes, and practices (KAP) regarding rodents showed that characteristics such as education, marital status, household size, and income did not significantly influence respondents' KAP.

TABLE 1 Demographic profiles of the respondents surveyed by questionnaire (n = 39).

Attribute	Response	Proportion of respondents (%)
Gender	Female	38.5
	Male	61.5
Age of head of household (HH) (years)	14–24	8
	25–40	41
	41–59	41
	≥60	10
Marital status of HH head	Single	8
	Married	69
	Divorced	8
	Widowed	15
Education attainment of HH head	None (illiterate)	31
	Primary education	41
	Secondary education	21
	Tertiary education	8
Main occupation of HH head	Farming (crop/livestock)	69
	Salaried employment	8
	Self-employed off-farm	15
	Casual laborer on/off-farm	8
Main source of income of HH head	Merchant/business owner	26
	Farmer	64
	Daily paid laborer	10
Family size	1–2	8
	3–4	33
	5–6	41
	>7	18
Land holding size (ha)	0.5–1	72
	1.1–2	18
	2.1–2.5	5
	2.6–3	3
	>3	2

3.1.2 Farmers' knowledge of rodent problems

While about 67% of the respondents considered rodents recurrent agricultural pests, 33% considered them occasional pests (Table 2). Rodents were more likely to be considered a problem in homesteads (67%) than in fields (13%), and 72% of respondents reported encountering rodents in homesteads, compared to 26% in fields. Most respondents (77%) could distinguish between rodents in homesteads and in fields. In both homesteads and fields, rodents move mainly at night. In fields, rodents were perceived as more problematic in monocultures (51%) than in mixed crops (33%). The crops most frequently infested by rodents were maize and groundnuts. The total crop loss (field and storage) for all crops grown in the study area per cropping season and household was estimated at about 1% of total production. In addition to food crops, rodents were also reported to damage household dwellings and property, including doors, roofs, clothing, chairs, and money.

3.1.3 Farmers' perceptions on temporal rodent population changes and health risks

While 56% of the respondents believed that rodent populations were increasing over time, 21% of the respondents had the opposite view (Table 3). The main factors cited for the increase in the rodent population were the presence of an abundant food supply and the lack of coordinated rodent management measures. The hunt for rodents and trapping were cited as the main reasons for the decline in the rodent population. Note that about two-thirds of the respondents (64%) did not attribute the decline in rodent populations to any factor. Similarly, 46% of respondents did not attribute the increase in rodent populations to any factor.

Occasional seasonal rodent outbreaks were reported by 87% of respondents. Such outbreaks occur in the first months of the dry season (May–October), just after the end of the rainy season. The respondents felt that the abundant supply of food (seeds, flowers, roots, etc.) that often accompanies bumper production years at the beginning of the dry season contributes to their increase and ultimately to seasonal outbreaks.

The majority of respondents (95%) detected rodent holes and runways in crop fields and newborns in homesteads and crop fields. Respondents were of the opinion that rodents were near homesteads (36%), in grain fields (13%), and in holes (36%) during dry and lean periods. A majority of the respondents (90%) said rodents can bite people, while 50% said rodents can

TABLE 2 Farmers' knowledge of rodent problems and the extent of the problem (n = 39).

Question	Response	% Response	Chi-square	d.f.	*p*-value
How serious are rodent pest problems in agriculture?	Recurring pests	66.66	0.554	1	0.457
	Occasional pests	33.33			
Where are rodents a problem?	Crop fields	12.82	2.628	2	0.269
	Homestead	66.66			
	Both areas	20.51			
Can you differentiate between homesteads and field rodents?	Yes	76.92	4.459	2	0.108
	No	23.07			
Are the homesteads and field rodents the same or different?	Same	17.94	4.045	2	0.132
	Different	82.05			
When do rodents move in crop fields?	During the night	61.53	3.179	2	0.204
	During the day	30.76			
	We do not know	7.69			
When do rodents move into homesteads?	During the night	87.17	0.002	1	0.960
	During the day	12.82			
	We do not know	–	–	–	–
Where do you mostly encounter rodents?	In crop fields	25.64	1.414	2	0.493
	Homesteads	71.79			
	Both home and fields	2.56			
For field rodents, in which cropping system do you encounter the most?	Mixed-cropping system	33.33	0.116	2	0.943
	Monocropping system	51.28			
	Both cropping systems	15.38			
Do rodents damage other properties, in addition to food stuff?	Yes	87.17	3.990	1	0.136
	No	12.82			
Which properties damaged by rodents most?	Plastic based properties	12.82	1.036	2	0.596
	Clothes	51.28			
	All the above	35.89			

TABLE 3 Farmers' perceptions on temporal and spatial rodent population changes.

Question	Response	% Response	Chi-square	d.f.	*p*-value
Are rodent numbers changing over time?	Yes, increasing through time	56			
	Yes, decreasing through time	21			
	Did not notice the change	23	0.507	2	0.776
If increasing, what are the reasons?	Presence of food in the houses/fields	49	0.720	2	0.698
	Lack of controlling methods	12			
	We do not know	41			
If decreasing, what are the reasons?	Food shortages in houses/fields	13	5.038	2	0.081
	Lots of catching/trapping	23			
	We do not know	64			
Do you encounter rodent nests, holes, or runways in crop fields?	Yes	95	1.467	1	0.226
	No	5			
If so, where do you encounter more rodent nets or holes or runways?	Crop fields	51	0.191	2	0.909
	Homesteads	31			
	Equally in both	17			
Do you encounter juvenile rodents?	Yes	92	2.835	2	0.242
	No	5			
	Did not notice	3			
Where do you see more juvenile rodents?	Crop fields	28	2.836	2	0.242
	Homesteads	42			
	Equally in both	30			
During dry periods where do they stay and what do they eat?	In houses	36	3.140	3	0.371
	In fields	13			
	In holes	36			
	We do not know	15			
Are there diseases transmitted by rodents to humans or livestock?	Yes	20	0.517	2	0.772
	No	36			
	We do not know	44			

also bite livestock. About 80% of the respondents did not know of any diseases transmitted by rodents to humans or livestock (Table 3). Ticks (23%) and fleas (57%) were the most frequently mentioned ectoparasites carried by rodents.

A large majority of the respondents (59%) said that they would not avoid food that has been contaminated with rodents, compared to 38% of the respondents who would avoid such food (Table 4). The reason for avoiding rodent-contaminated food was fear of various diseases. In contrast, those who do not avoid food contaminated with rodent droppings gave three reasons: i) that rodent-contaminated food may be the only food available to the household (46%), ii) that they believe that rodent droppings do not cause diseases (28%), and iii) that rodents are a food source in themselves (5%).

3.1.4 Farmers' knowledge of storage and rodent management methods

About 84% of the respondents said that they stored their produce in plastic buckets and woven polypropylene bags in the house. Khokwes were the main storage facilities outside homesteads. However, only 46% of the respondents said that the storage facilities were effective against rodents. About one in two respondents had heard of the latest technologies for grain storage. Purdue Improved Crop Storage (PICS) bags were the new grain storage technology most frequently mentioned (33%), followed by metal silos (12%). The Malawi government has approved PICS bags as an improved alternative storage option since February 2016.

The two main methods used to manage rodents in the fields were trapping (45%) and hunting (31%). One-third of the respondents indicated that these methods were often effective against rodents, while 28% of the respondents indicated that these methods were occasionally effective. In the homesteads, rodents were managed using Indomethacin tablets (61%), Temik powder (18%), and traps (31%) (more on Indomethacin tablets and Temik powder in the discussion).

3.2 Focus group discussions

3.2.1 Farmers' knowledge of rodent issues and extent of the problem

In both districts, rodent populations were perceived to change over time, increasing in times of rich harvests and

TABLE 4 Attitudes and practices of the respondents in Lilongwe towards food contaminated by rodents.

Question	Response	% respondents	Chi-square	d.f.	*p*-value
Do people avoid rat contaminated foodstuff	Yes	38	0.759	2	0.684
	No	59			
	We do not know	3			
Why do people avoid rat contaminated foodstuff?	Fear of various diseases	37	2.306	1	0.316
	We do not know	63			
Why do people not avoid rat contaminated foodstuff?	It does not cause any disease	28	0.897	3	0.826
	Rat itself is a relish	5			
	Lack of enough food	46			
	We do not know	21			

decreasing in lean times and when there was drought locally. Rodent populations also decrease when there is too much rain. In Lilongwe, maize was the main crop cultivated, while in Nkhata Bay it was cassava. Tomatoes, sweet potatoes, Irish potatoes, groundnuts, soya beans, and field beans are also grown in both districts. Maize was grown as an intercrop with beans or pumpkins. Groundnut, cassava, and rice were cultivated as monocrops. The reported average annual production (maize or cassava) was between 50 and 250 kg per household in both districts. However, this low productivity was not enough to feed a household of three to six people for a whole year. Therefore, many families engage in off-farm activities to compensate for the deficit.

All participants in FGDs, regardless of sex and location, considered rodents a problem. In the fields, rodents were perceived to be problematic during maize sowing and germination and groundnut harvesting. However, compared to rice, rodents were not perceived as a major problem in cassava fields. They also agreed that rodents were more problematic in homesteads than in fields.

3.2.2 Farmers' perception of health risks posed by rodents

All FGD participants in Nkhata Bay agree that they know that rodents can transmit certain diseases to humans. In Lilongwe, on the other hand, only half of the participants thought rodents were vectors of human diseases. In Nkhata Bay, participants said that rodents occasionally bite people and domestic animals, unlike in Lilongwe, where rodent bites are common. In rural Lilongwe, people and domestic animals such as chickens and sometimes goats sleep in the same house. In addition, dwellings for domestic animals have been built very close to human dwellings. This is to protect the animals from thieves. In Nkhata Bay, only chickens that lay eggs sleep in the house. In both districts, participants said that rodent bites were more common during the rainy season (November–April) than during the drier months. Half of them also knew that rodents carry ectoparasites such as ticks, lice, and fleas. The other half did not know about the ectoparasites that rodents carry.

3.2.3 Farmers' knowledge of rodent management methods

Farmers in both districts stored their produce in woven polypropylene bags (costing ~US$ 0.25 per 50 kg bag), metal silos (~ US$ 62 per 100 kg silo), and plastic buckets. The PICS bags cost ~US$ 2.4 per 100 kg bag. However, participants pointed out that metal silos and PICS bags are not widely used in most parts of Malawi. Khokwes were the main outdoor storage facilities. On average, grains were stored for 4–6 months in Lilongwe but for 7–9 months in Nkhata Bay. In Nkhata Bay, metal silos and plastic buckets were considered effective against rodents. Bags were cited as the least effective in protecting agricultural produce from rodents. In Nkhata Bay, no cultural plant-based methods were mentioned for rodent management. Instead, the use of Temik powder against rodents was confirmed. The poison is mixed with food and applied in areas where rodents are active, such as the kitchen and food storage areas. There was no standard application, so the preparation of the poison mixture was at the discretion of the individual farmer. Rodent management was a matter for individual households and not a matter for the community. The concept of natural enemies of rodents was acknowledged by mentioning domestic cats, birds of prey, and snakes, the former being particularly useful in homesteads.

3.2.4 Knowledge of rodent species and occurrence

Farmers in both districts indicated that they could distinguish rodent species on homesteads from those in the fields based on fur color, tail length, and body size. The field rodents were described as being gray in fur color, smaller in size, and having shorter tails than the homestead rodents. These descriptions match the external morphology of the field-caught rodents. We caught a total of 42 rodents: 22 in Nkhata Bay, and 20 in Lilongwe (Table 5). The rodent species most commonly caught was the Natal multimammate mouse, *Mastomys natalensis* (90.5%). The cosmopolitan house mouse, *Mus musculus domesticus* (7.1%), was only caught in Mitundu (Muwula village) and the silver mole rat, *Heliophobius*

TABLE 5 Rodent trapping per location and species. SR, Sherman trap; SP, Snap trap; MH, Mouse hunter.

District	Location	Trapping coordinates	*Mus musculus domesticus*				*Heliophobius argenteocinereus*				*Mastomys natalensis*			
			SR	SP	MH	Total	SR	SP	MH	Total	SR	SP	MH	Total
Lilongwe (n = 20)	Muwula village	14°12’07.3”S 33°48’51.1”E	–	3	–	3	–	–	–	–	–	1	3	4
	Chikhoswe village	14°12’55.8”S 33°45’40.4”E	–	–	–	–	–	–	–	–	–	1	5	6
	Kwachilu village	14°13’34.3”S 33°47’27.0”E	–	–	–	–	–	–	–	–	–	–	6	6
	Bunda Campus	14°11’18.8”S 33°46’24.9”E	–	–	–	–	–	–	–	–	1	–	–	1
Nkhata Bay (n = 22)	Mgodi	11°49’46.5”S 34°09’01.1”E	–	–	–	–	–	–	–	–	–	3	–	3
	Kawiya Estate	11°49’05.2”S 34°09’28.7”E	–	–	–	–	1	–	–	1	–	17	–	17
	Malaza	11°52’15.0”S 34°08’54.7”E	–	–	–	–	–	–	–	–	–	1	–	1
Overall						3				1				38

argenteocinereus (2.4%), was only caught in Chintheche (Kawiya Estate). In Lilongwe, rodents are a delicacy and people actively hunt them. However, rodents from homesteads are not eaten; only field rodents are.

3.3 Interview with key informants

These were the main findings from the key informant interviews (KIIs): (i) Rodents were often problematic in maize and groundnut fields during the cultivation phase and in storage. (ii) Rodent management was considered a matter for individual households; it was never treated as a community issue. In the absence of external funding or a project targeting a specific commodity, farmers typically do not collaborate on pest management. (iii) Ecologically-Based Rodent Management (EBRM) was not known and was never introduced as part of extension curricula. Therefore, extension workers' knowledge of rodents and rodent management was based on indigenous knowledge. (iv) The methods of rodent management known to extension workers were the same as those practiced by farmers. (v) They reported that they had no knowledge of plant-based "cultural" rodent management "method" and and claimed that there were no chemical rodenticides on the market that they could recommend to farmers. (vi) They often suggested that farmers focus more on reducing postharvest losses to rodents, especially in maize and groundnuts, than on reducing rodent damage in fields.

4 Discussion

Notwithstanding the limitations in sample size, trapping success, and seasonal replication, the study revealed several aspects regarding the knowledge, attitudes, and practices of the respondents in the two study districts in Malawi regarding rodents. In Lilongwe, rodents were a major problem, especially in maize and groundnut farming. In Nkhata Bay, rodents were not a major problem in cassava cultivation, the staple food of the region, compared to rice cultivation. However, in Nkhata Bay, farmers do not harvest mature cassava all at once, but rather gradually over a few weeks, leaving part of it in the fields. This provides a constant supply of food for rodents. On the contrary, rice is harvested all at once and stored indoors in woven polypropylene bags for a few months. This is because rice fetches an increase in price (over US$ 1 per kg) later in the year (October to December) than immediately after harvest. However, unguarded woven polypropylene bags have been found to be less effective in protecting grains from being eaten or contaminated by rodents. This is because rodents easily gnaw through them (see Mdangi et al., 2013; Mulungu, 2017; Baoua et al., 2018; Meheretu et al., 2022). Moreover, according to extension workers, the majority of the rice grown in the study areas is an aromatic variety that is more attractive to rodents compared to non-aromatic rice varieties. The Malawi government introduced PICS bags for rice farmers in order to reduce the relative losses caused by storing rice in woven polypropylene bags. However, we cannot corroborate how effective the PICS bags are against rodents compared to polypropylene bags since there is limited evidence available on this matter. It is also worth noting that the use of PICS bags is a relatively new technology in Malawi. This is because it has only been on the Malawian market for about four years. Therefore, it is not readily available. Similar to metal silos, the prohibitive prices of PICS bags are an important factor discouraging farmers from using this technology on a large scale in Malawi (Farnworth et al., 2020). Both storage methods are economically feasible for larger than average and productive farms where grain is stored for more than 6 months.

Respondents indicated that the average annual yield per season per household for all crops they grow is 0.05–0.25 tonsper hectare, which they claimed to store for 4–6 months. This is a storage capacity of no more than 4–6 months. Based on the 2019 data for Malawi, the yield reported by respondents is far below the national average yield of 1.7 tons per hectare for maize (FAO, 2021). Respondents may have been reluctant to report the correct annual production in anticipation of food aid. For a household size of three to six people, 0.25 tons of grain is only enough for a few months. However, farmers reported that they rely on off-farm activities, such as temporary or seasonal work, to get wages and daily income to purchase extra food to make up for the deficit for the rest of the year.

In both districts, the estimated average loss of income due to rodents is approximately 1% (for non-outbreak seasons) of all crops grown per cropping season per household. This corresponds to a potential income loss of US$ 2–10 per household per cropping season, based on estimated yield and prevailing prices in local markets. However, based on our field observations, we suspect that the estimated loss is much lower than the actual loss. This is due to the extent of the rodent problem in the districts, the lack of significant rodent management measures (both in the fields and in storage), and the fact that most of the storage structures used were less rodent-resistant. There have been reports of underestimates of yield losses by rodents in farmers' surveys in Africa. In Kenya, people who have been farming maize for a longer time are more likely to report low estimates of losses from rodents (Ognakossan et al., 2016). In southern Ethiopia (Tomass et al., 2020) and in Nigeria (Zhang et al., 2018), lower yield loss estimates were correlated with higher annual production. Elsewhere, multiple factors, including farmers' reluctance and inability to quantify true damage figures, have been reported in studies in Asia and Australia (Singleton, 2003; Brown et al., 2020). Furthermore, Wood et al. (2018) conducted a study on crop protection, implementing the Green Innovation Centers for the Agriculture and Food Sector initiative in Malawi. Groundnuts and soybeans were the crops that were the focus of their study. They found that only 18% of the farmers surveyed considered rodents an important pest both in the fields and in storage. On the contrary, the extension workers they interviewed considered rodents to be a problem only in post-harvest. These different perceptions of rodents are reflected in the lack of extension services that focus on rodent management in the field. Rodent management messages focus on improved storage facilities and the use of domestic cats. We could not further confirm the estimated losses in the current study because of the lack of empirical data on damages and economic losses for Malawi and southern Africa in general. Nevertheless, the money lost would have been used to cover certain expenses related to rodent management (e.g., the purchase of traps).

Farmers perceive that rodents cause problems in both monocultures and mixed crops, but predominantly in monocultures. This is in contrast to the commonly accepted notion that mixed-crop fields attract more rodents than fields with the same crop because the former contain crops that mature at different times and provide a diverse shelter and food source (Massawe et al., 2005).

Based on our trapping efforts, observations of roasted field mice sold in local markets, and discussions with farmers and staff at the National Museum of Malawi, the main rodent species found in crop fields was the Natal multimammate mouse. The Natal multimammate mouse is one of the most widespread mammals in sub-Saharan Africa and is known throughout sub-Saharan Africa as a major agricultural pest, causing significant damage to staple crops (Coetzee, 1975; Leirs et al., 1996; Swanepoel et al., 2017). The species also harbors a variety of parasites, including RNA viruses, bacteria such as plague, and helminths (Vanden Broecke et al., 2021). On the other hand, homesteads and storage areas are predominantly infested by house mice. The house mouse is widespread in urban and rural dwellings and lives in close association with humans (Sked et al., 2022). It damages stored goods and food, residential structures, and household items. The species also poses a significant health risk to residents (Meerburg et al., 2009a). In root crop growing areas (e.g., cassava), the silver mole rat is the predominant rodent affecting yields. The silver mole feeds on root crops and builds burrows and tunnels in the fields (Katandukila et al., 2014).

Respondents' knowledge of the public health risks posed by rodents was generally low. For example, when they found rodent droppings in food, a large proportion of respondents said they would not throw the food away. In areas where rodents are eaten by humans, rodents are processed and roasted in the field and in homesteads in unhygienic ways. This is without protective equipment such as face masks and gloves. These practices indicate that the respondents were not aware of the health risks posed by rodents. Hantaviruses and Lassa viruses are transmitted when virus-containing particles from rodent urine, feces, or saliva become airborne and are inhaled by humans (Watson et al., 2014; CDC, 2021). There is also a risk of leptospirosis disease, in which the disease-causing bacteria (*Leptospira interrogans*) are spread through the urine of infected rodents, which can enter water or soil (CDC, 2015). Rodents can also spread bubonic plague, an infectious disease caused by the bacterium *Yersinia pestis*, which can affect both humans and animals and is spread primarily through the bite of fleas that jump from rodents to humans (CDC, 2021). Note that Malawi is one of the countries in southern Africa where outbreaks of bubonic plague are occasionally reported. The last outbreak of bubonic plague was recorded in 2002 in the Nsanje district in southern Malawi (WHO, 2002).

In Malawi, zinc phosphide was the only rodenticide officially authorized for use in rural and urban settings (PCB, 2015). However, brodifacoum is also available in informal markets. Aluminum phosphide is also used for rodent management in rain-fed agriculture, food and tobacco processing and packaging warehouses, and empty warehouses (PCB, 2015). It should be noted that in regions where humans eat wild rodents, these poisons have been used primarily for rodent management in homesteads and storage. In regions where humans do not eat rodents, poisons have also been used in the fields. In the homesteads, rodents were managed using Indomethacin tablets, Temik powder, and traps. Indomethacin tablets (which contain indometacin as the active ingredient) were bought from local grocery stores, mixed with food, and applied in areas with rodent activity. Indomethacin is an anti-inflammatory drug prescribed to relieve pain in humans (Nalamachu and Wortmann, 2014). There have been reports of it being used as rat poison in other countries in Africa (see Maitai and Munenge, 2011; Zhelev et al., 2018). The same application method was used for Temik powder. Temik is an aldicarbe pesticide that belongs to the group of carbamates that kill insects by attacking their nervous systems. Unfortunately, respondents were unable to provide consistent application rates (e.g., dosages) and methods for the two.

We recommend sustained education campaigns to create better awareness among farmers and extension workers on the importance of rodent management in the fields and storage areas. The campaigns should also consider the importance of rodent management for public health. It is critical to intensify the dissemination of hermetic bags and other improved storage facilities. This will ensure that they are available to a large number of farmers at an affordable price. It is important to invest in research and innovation in order to introduce EBRM, which helps simultaneously reduce yield losses by rodents and the risks of rodent-associated infections in an environmentally friendly manner (Singleton et al., 1999; Makundi and Massawe, 2011; Singleton et al., 2021). EBRM is an approach that relies on a deep understanding of the diversity, behavior, ecology, and population dynamics of rodents as well as the perceptions and practices of humans (Singleton, 2014; Singleton et al., 2021). It mobilizes an array of rodent management methods that are integrated into robust community-based actions adapted to local situations. These methods may comprise biological (e.g., predators), ecological (e.g., habitat management), mechanical (e.g., selective trapping), agronomic (e.g., crop rotation), and cultural (e.g., hunting) actions that are sometimes implemented at different times of the growing season. EBRM enables sustainable agriculture and a resilient ecosystem by significantly reducing the accumulation of chemical rodenticides in the food chain and the environment. Additionally, it minimizes the development of resistance by rodents to rodenticides. The effectiveness of EBRM has been documented in Southeast Asian agroecosystems, especially in rice fields, where local farmers seem to largely favor using EBRM in a community-based approach (Singleton, 2014; Singleton et al., 2021). However, despite its promising potential, progress in implementing EBRM in Africa has been very slow, apart from recent small-scale trials in smallholder settings (see Makundi and Massawe, 2011; Swanepoel et al., 2017; Constant et al., 2020). There is still much to learn about EBRM in African settings, so more practical research is needed at scale to understand its full implications.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was reviewed and approved by Lilongwe University of Agriculture and Natural Resources.

Author contributions

TD, LB, and YM conceptualized the study and obtained funding. TD and NG did the fieldwork. TD performed data analysis. TD and YM wrote the draft manuscript. All authors contributed to the project ideas and manuscript completion, in doing so, all authors agree to be accountable for the content of the work. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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