Crop Protection 181 (2024) 106673

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

From problem to progress: Rodent management in agricultural settings of sub-Saharan Africa and calling for an urban perspective

Ambroise Dalecky[a,b,*,1], Ibrahima Sow[a,b,c], Abdoul Aziz Ibrahim Danzabarma[d,e], Madougou Garba[f], Jonas Etougbétché[g], Sylvestre Badou[g], Henri-Joël Dossou[g], Cheikh Tidiane Niang[a,b,c], Ousmane Diene[h], Idrissa Diallo[i], Mohamed Seyidna Ali Saghiri[j], Mohamed El Hady Sidatt[k], Frank van Steenbergen[l], Amadou Bocar Bal[b,c], Luwieke Bosma[l], Gualbert Houéménou[g], Solimane Ag Atteynine[m], Karmadine Hima[d], Gauthier Dobigny[e,n,1], Yonas Meheretu[o,p,1]

[a] IRD, Aix Marseille Univ, LPED, Marseille, France
[b] BIOPASS 2, IRD, UGB, Cirad, ISRA, Saint-Louis, Senegal
[c] UFR S2ATA, Université Gaston Berger, Saint-Louis, Senegal
[d] Faculté des Sciences et Techniques, Université Abdou Moumouni, Niamey, Niger
[e] CBGP, Univ Montpellier, CIRAD, INRAE, Institut Agro, IRD, Montferrier-sur-Lez, France
[f] Direction Générale de la Protection des Végétaux, Niamey, Niger
[g] Ecole Polytechnique d'Abomey-Calavi, Laboratoire de Recherche en Biologie Appliquée, Unité de Recherche sur les Invasions Biologiques, Université d'Abomey-Calavi, Cotonou, Benin
[h] Direction de la Protection des Végétaux, Dakar, Senegal
[i] Service National d'Hygiène, Saint-Louis, Senegal
[j] Direction de la Protection des Végétaux, Nouakchott, Mauritania
[k] FAO Sub Regional Office, Tunis, Tunisia
[l] MetaMeta Research B.V., Wageningen, The Netherlands
[m] Laboratoire de Rodontologie, Institut d'Economie Rurale, Bamako, Mali
[n] Institut Pasteur de Madagascar, Unité Peste, Antananarivo, Madagascar
[o] Department of Biology and Institute of Mountain Research & Development, Mekelle University, Mekelle, Ethiopia
[p] Department of Wildlife, Fish & Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden

A R T I C L E I N F O

Keywords:
Africa
Agricultural intensification
Ecologically based rodent management
Pest management
Rodenticides
Rodents
Urbanization

A B S T R A C T

In sub-Saharan Africa, agricultural intensification and urbanization have increased the risk of proliferation of rodents in rural and urban habitats. Management of rodent populations is a challenge in terms of food security and public health. However, conventional efforts to manage rodents are currently reactive and based on the inadequate use of synthetic chemical rodenticides, including first- and second-generation anticoagulants and acute rodenticides. This approach carries substantial environmental and health risks and has yielded limited success in terms of reduction of rodent populations sustainably. In this paper, which is the second part of a diptych, we advocate for a shift towards more sustainable and environmentally friendly approaches, such as Ecologically-Based Rodent Management (EBRM), as a realistic alternative to synthetic rodenticides. This method is based on a good knowledge of habitat use, species diversity and population dynamics of major rodent pests, and involves community-based interventions aimed at reducing rodent abundance to economically and hygienically acceptable levels in the long term. We present for the first time a comprehensive compilation of published and unpublished information derived from observational field studies conducted in Ethiopia, Niger, Nigeria, Benin, Mali, Mauritania and Senegal with the aim to provide an overview of EBRM case studies in these countries of sub-Saharan Africa. This paper intends to serve as a catalyst for change, encouraging the transformation of rodent management practices towards sustainable methods. We aim at stimulating further research

* Corresponding author. IRD, Aix Marseille Univ, LPED, Marseille, France.
E-mail address: ambroise.dalecky@ird.fr (A. Dalecky).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.cropro.2024.106673
Received 9 January 2024; Received in revised form 21 March 2024; Accepted 22 March 2024
Available online 28 March 2024

and interventions that promote EBRM in Africa, ultimately fostering more environmentally conscious and effective solutions.

1. Introduction: Ecologically-Based Rodent Management – a realistic and environment-friendly alternative to synthetic chemical rodenticides[2]

Rodent-related pest issues in sub-Saharan Africa, both in agricultural and urban habitats, are a matter of significant concern. In agricultural settings, rodent infestations persistently undermine crop yields and food security (Swanepoel et al., 2017). In urban areas, commensal rodents are widespread, often establishing their habitats inside or in immediate proximity to human dwellings, posing significant challenges to public health and overall well-being (Dobigny and Morand, 2022; Ecke et al., 2022). The prevailing rodent management strategies primarily hinge on synthetic chemical rodenticides (Swanepoel et al., 2017; Constant et al., 2020; Sow et al., 2023), which, although providing short-term relief, come with adverse effects on both human health and the environment, raising concerns regarding their long-term sustainability and safety.

This paper is the second part of a diptych, with the first part (Dalecky et al., 2023) highlighting the adverse impacts of synthetic rodenticides extensively used against pest rodents in Sub-Saharan Africa, encompassing both agricultural and urban settings. In response to these concerns, here we emphasize the urgency for a shift away from synthetic chemical rodenticides towards more sustainable and environment-friendly rodent management approaches, such as the Ecologically-Based Rodent Management (EBRM), as a realistic alternative to synthetic rodenticides.

EBRM relies on a good understanding of the diversity, behavior, ecology and population dynamics of rodents as well as the perceptions, uses and practices of human populations towards rodent pest species (Singleton et al., 1999a, 2010, 2021; Singleton, 2014; Palis et al., 2011). It mobilizes a panel of various rodent management methods, developed for specific rodent species based on their respective seasonal space use and population dynamics, which are integrated into robust community-based implementation protocols adapted to local situations (Fig. 1). These methods may comprise biological (e.g., predators, botanical rodenticides or repellents), ecological (e.g., habitat management), mechanical (e.g., selective trapping or removal), agronomic (e.g., crop rotation) and cultural (e.g., hunting, rodent-proof storage facilities) actions to be implemented at different key times of the year that will depend on the breeding season, population dynamics and habitat use of different rodent species, and on the local socio-economic and agricultural calendars. It entails the local appropriateness and full integration of proactive methods into routine agricultural, conservation and environmental management practices as an alternative to the reactive use of synthetic chemical rodenticides that usually follows high rodent infestations and damages. Importantly, following its very community-based nature, EBRM incorporates local socio-economic and environmental constraints potentially associated with pest rodent management (or absence of management) by local stakeholders, whatever they may be (e.g., farmers, inhabitants, firm owners, as well as local, national and international authorities and decision makers) (Palis et al., 2011). Thus, EBRM is expected to provide science-guided solutions to (1) the lack of effective, affordable and integrated conventional methods for sustainable management of rodent pests, (2) the risks associated with the use of chemical rodenticides, including the evolution of resistance by rodents against the chemicals, and (3) the increased focus on human and environmental health-friendly value chains in the context of the requirement of increased food production.

Championed essentially by Singleton and his colleagues, EBRM has been successfully implemented and evaluated in the last two decades in Southeast Asian agro-ecosystems, especially rice farming systems (Singleton et al., 1999a, 2010, 2021; Singleton, 2014; Palis et al., 2011; Brown et al., 2007; Brown and Khamphoukeo, 2007; Ninh et al., 2022; My Phung et al., 2013), where socio-cultural structures and practices greatly facilitate community-based approaches and the extension of EBRM by local farmers (Palis et al., 2011). EBRM was trialled recently in rural areas of Southern and Eastern Africa and Madagascar at a much smaller scale (Belmain et al., 2008; Taylor et al., 2008; Constant et al., 2020; Rahelinirina et al., 2023) and, to our knowledge, attempts are still lacking in a wide range of countries, especially in Central and West Africa (see Supplementary Material, Appendix A). In addition, arguments to anticipate EBRM acceptance, adoption and appropriation by African farmers are lacking and extra studies are still required to evaluate further its pertinence and long-term sustainability in rural Africa (Makundi and Massawe, 2011). Furthermore, we are not aware of any EBRM activity formally tested in African urban settings, but see Taylor et al. (2008) for a first attempt focusing on household sanitary aspects.

In this paper, we draw from various examples across sub-Saharan Africa, encompassing Ethiopia, Niger, Nigeria, Benin, Niger, Mali, Mauritania and Senegal, in addition to well-documented case studies from Southern and Eastern Africa (Appendix A). Through these case studies, we aim for the first time (i) to investigate and analyze the factors that hinder the translation of accumulated scientific knowledge into concrete and sustainable rodent management measures with a particular focus on the Sahelian African region, and (ii) to illuminate the pressing needs and prospects for advancements in the field of rodent management, with a particular emphasis on the role of EBRM in sub-Saharan Africa.

2. Materials and methods

The study commenced with a synthesis in the form of a narrative review of both published and unpublished literature focusing on rodent management in various sub-Saharan African regions. To ensure a comprehensive, albeit not exhaustive, picture, we considered examples from a wide geographical span within sub-Saharan Africa, focusing on Ethiopia, Niger, Nigeria, Benin, Mali, Mauritania and Senegal. A diverse range of data was collected from these countries, with a particular emphasis on case studies related to EBRM. The collected dataset was subjected to comparative analysis to assess the pressing needs and prospects for advancements in the field of rodent management, particularly focusing on the role of EBRM in sub-Saharan Africa. This compilation aimed to give an overview of EBRM case studies in regions beyond those typically documented in Southern and Eastern Africa (see Appendix A) and a well-rounded perspective on rodent management practices in sub-Saharan Africa, highlighting the significance of EBRM as an alternative to synthetic rodenticides.

3. Results and discussions

3.1. EBRM in rural Africa, with special emphasis on Sahelian region

3.1.1. The Ethiopian EBRM experience

In rural Africa, various EBRM practices have been trialed. In the Amhara Region of Ethiopia, an EBRM package was tested in 2019 with smallholder farmers engaged in a mixed cropping system (growing wheat, barley and potato in small plots ranging from 0.5 to 3 ha, coupled with animal husbandry), where the main pest rodents belonged to *Arvicanthis* and *Mastomys* genera (Tilahun et al., 2022). Prior to the

[2] A French version of the manuscript is available as Supplementary Material, Appendix B.

introduction of EBRM, farmers and extension workers claimed severe rodent damage (>25%) (our unpublished data). Long before the introduction of EBRM, farmers in the region had already organized into 63 Watershed User Associations (WUAs), registered under the regional government and are responsible for watershed management (mainly soil and water conservation practices) as a community, covering a total area of about 120,000 ha. Watershed groups involve all farmers who own adjacent crop fields and grazing lands in a particular watershed (catchment) area. These groups had a well-organized system in place and were best suited to operating community-based EBRM at an appropriate scale for rodent management. The first and most important part of the EBRM activities was time for training and action planning co-constructed with the WUA committees, who then passed it on to all their members. In action planning, they incorporated the timing of the EBRM actions in the lean season (i.e., when rodent populations are still at low density) and the importance of collective action (e.g., they made by-laws that a household who did not join in a collective activity such as flooding rodent burrows, would pay a penalty). Because there was already established strong sense of community via the WUA, this was quite effective.

The activities incorporated into the EBRM package encompassed a range of measures, including (i) maintaining loose soil and water conservation structures, with a specific focus on stone bunds and terraces (which was previously reported to provide shelter for rodents; Meheretu et al., 2014), (ii) clearing grasses and bushes in the vicinity of these bunds and terraces to create an open strip of land measuring 1–2 m that enhances the visibility of rodents to their natural predators, (iii) implementing deep ploughing techniques to disrupt rodent habitats and burrows, (iv) employing strategies such as flooding and plugging rodent holes and burrows to curtail their population, (v) establishing stone traps to kill rodents, (vi) utilizing domestic cats, predominantly within homesteads, as a natural predator of rodents, and (vii) storing grains in locally made, rodent-proof storage structures to safeguard against rodent infestations.

These activities were combined with the development of a biorodenticide (BR) that was applied through watershed level campaigns involving all members from land preparation to harvest. The BR was formulated using air-dried plant parts sourced from two locally available plant species, with no chemical or additive used during its formulation (our unpublished data). Testing of the BR was conducted against three pest rodent species (*Arvicanthis niloticus*, *Mastomys awashensis*, *Rattus rattus*) under controlled laboratory conditions (TheWaterChannel, 2023). While the first two rodent species are well known pests in agricultural fields in Ethiopia (Meheretu et al., 2014), the latter is a common post-harvest commensal pest species (Meheretu et al., 2022).

Our independent post-implementation survey (unpublished data), involving participants from the watershed campaigns, indicated that farmers perceived that rodent damage had been cut by a magnitude of up to 50% after two years of EBRM practicing. Additionally, the survey indicated that through horizontal learning (a form of knowledge exchange and skill sharing that occurs within a community or among neighboring communities through a peer-to-peer approach), the uptake of the EBRM practices saw an increase of up to threefold in the neighboring watersheds that were not initially included in our EBRM campaigns. This suggests that the knowledge and success of these initiatives have spread effectively within the local agricultural community, benefiting a broader region beyond the project's initial scope. The demand for the BR product has increased significantly and to meet this increased demand and empower local entrepreneurs, about a dozen women small-scale enterprises (SMEs) have been trained by MetaMeta (a social enterprise working with smallholder farmers) in 2020 and 2021 to produce package and sell the BR to fellow farmers at local scale at an affordable price. The production cost of the BR by the SMEs was about €1.50 per 250g jar. Furthermore, in comparison, in northern Ethiopia, farmers typically spend an annual average of €3–12 per hectare on pesticides (Meheretu et al., 2022). The authors also highlighted that farmers are willing to spend up to €9 to purchase a kitten as a preventive measure against stored-grain damage by rodents. In sub-Saharan Africa, farmers are willing to pay €3–10/ha for effective rodent management products per cropping season (AGRA, 2017).

Unlike synthetic rodenticides, BRs are inherently less harmful to the environment and non-target species since their active ingredients are largely volatile and quickly degradable, hence less persistent in the food chain and less dangerous for the environment (see Wen et al. (2022) and references therein). Although more rigorous investigations are needed, unlike synthetic chemical rodenticides, BRs usually are composed of a complex panel of co-acting molecules that work together to toxify rodents. This makes them less prone to the development of resistance against them. Efforts are underway to ensure wider use of the BR in Ethiopia as well as to extend this innovative approach to other African

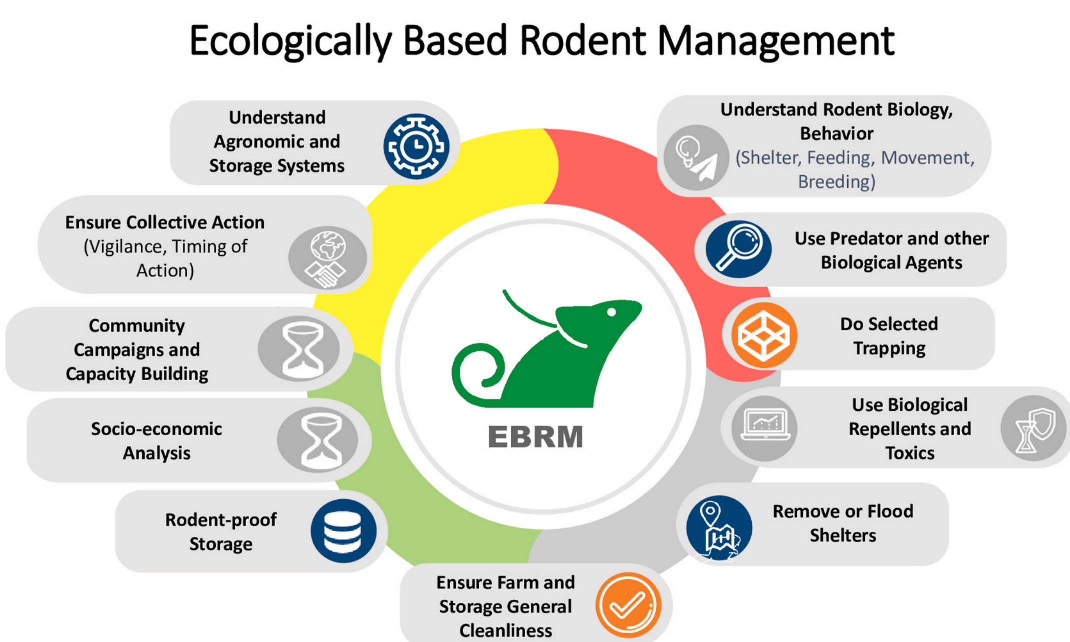

Fig. 1. Summary of potential community-based activities in the Ecologically-Based Rodent Management (EBRM) toolkit.

countries. There is enormous scope to make EBRM the standard rodent management method in Ethiopia and beyond as it holds great promise for sustainable and environmentally friendly pest management practices, benefiting both agriculture and the broader ecosystem.

3.1.2. Opportunities for EBRM in Sahelo-Sudanian Western Africa

In West Africa, such experiences in the realm of EBRM are almost non-existent, although a few isolated attempts have begun to provide elements that could contribute to integrated EBRM strategies. For instance, the traditional pitfall traps, locally called "Kornaka" traps, used by Sahelian farmers, appear to be promising to reduce pest gerbil (*Gerbillus nigeriae*) populations in extensive pluvial millet fields in Central Niger. As evidence, during a brief trial, 37 captures were made with a sampling effort of 147 trap nights using Kornaka traps, resulting in a capture rate of 25.2%. In comparison, 22 captures were achieved for a sampling effort of 1280 trap nights using locally-made wire mesh traps, with a capture rate of only 1.7%. This illustrates that the Kornaka traps were 15 times more effective than the wire mesh traps in trapping gerbils in pluvial millet fields (Hima et al., 2019).

Additionally, in response a to a shortage of chemical rodenticides, Crop Protection officers in Ogo (Matam, Senegal) experimentally tested pitfall traps during a participatory farmer action that lasted over 10–15 days in four localities in 2021 (B. Diouf, pers. comm., Feb. 2022). This small scale, preliminary demonstration resulted in notable rodent captures and was perceived as a promising method by most participants. However, the effectiveness of this method has not been precisely quantified, and some farmers expressed concerns about the labor intensity of this method compared to the relatively straightforward application of synthetic chemical rodenticides (B. Diouf, pers. comm., Feb. 2022).

In Northern Senegal, through rigorous decade-long rodent monitoring in agricultural fields and ongoing collaboration with crop protection experts, substantial progress has been achieved in the understanding of rodent related challenges and the potential for implementing EBRM (Bori and Dalecky, 2021; Niang et al., 2022). Notably, this long-term monitoring data has unveiled key insights, such as the identification of specific agronomic and physical factors within irrigated rice fields in the delta of River Senegal that strongly favor rodent populations. These factors include features like accumulations of thorn bushes used as hedges (Fig. 2 A) and the presence of densely vegetated dikes, bunds, and irrigation canals (Fig. 3A–B). In terms of risk assessment, estimated by the Adjusted Odds Ratio, the abundance of each of the two main rodent pests affecting rice crops (*Mastomys huberti* and *Arvicanthis niloticus*) significantly increased with several environmental factors (Niang et al., 2022). For each single additional percentage of vegetation cover (for an average cover estimate of 67.4% and a range of 3.1%–97.5% over a total of 267 sampled fields), the factor of increase in rodent populations was 1.02 (Niang et al., 2022). Pest

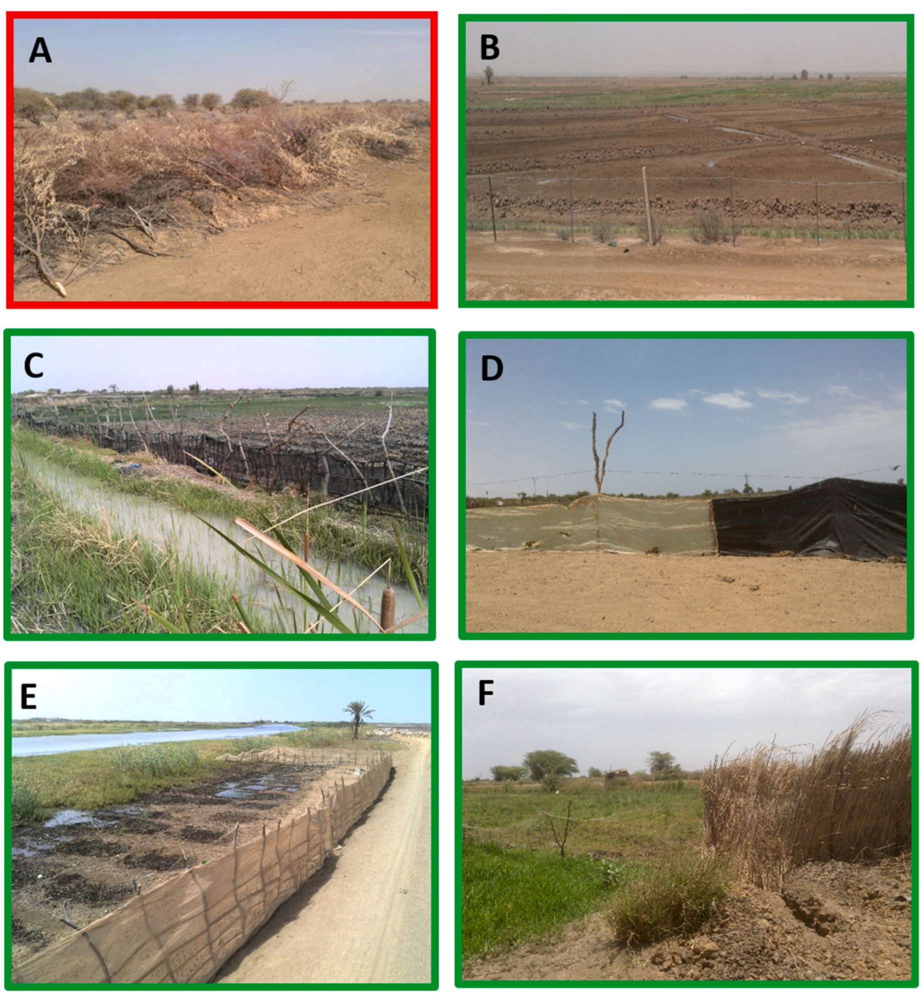

Fig. 2. Examples of rodent-favorable and unfavorable fences in cultivated plots in the River Senegal valley.
(A) An example of a rodent-favorable (in red) refuge made from a pile of thorny branches. (B–F) a range of fences that that deter (unfavorable to) rodents (in green): (B) a wire-mesh fence on the edge of an off-season rice paddy, after cleaning the dikes and bunds; (C) used drip pipes braided into fence; (D) a fence of barbed wire covered with recycled pans of greenhouse and of agricultural mulching sheets; (E) a fence made of fish nets overlaid with recycled pans of greenhouse sheets; (F) wire mesh covered with fish nets (left) and weaved palisade made of harvested proliferative aquatic *Typha* (right).

Fig. 3. Illustration of contrasted conditions in irrigated areas of the Senegal River delta.
(A, B) Presence of vegetation favorable to rodents on dikes (red arrows) alongside irrigation canals. (C, D) Controlled vegetation on dikes (green arrows) along canals, achieved through the removal of grasses and bushes near the dikes to create an open strip of land that could enhance the visibility of rodents to predators.

rodents also exploit uncultivated parcels or edges of fields, where they find shelter and reproduce before invading rice fields (Niang et al., 2022). This underscores the potential benefit of improved land preparation and management of fallow lands adjacent to cultivated fields to mitigate rodent infestation and associated damages. Conversely, there are situations that appear to be less favorable to rodents, corresponding to those where shelters are rare and vegetation is well-controlled on dikes and other irrigation structures (Fig. 3C–D).

From these observations, several physical and agronomic elements of EBRM can be proposed (see Makundi and Massawe (2011) for more information). These may include replacing hedges made from thorny bush branches and random shrubs with tightly woven barriers made from materials like fishnets, recycled greenhouse sheets, or braided recycled drip pipes (as already practiced by some farmers), or employing more durable options such as wire mesh or barbed wire (Fig. 2B–F). Other potential measures include frequent mowing of grasses on dikes and irrigation channels, refraining from planting crops on dikes, crop rotation, composting of crop residues, and implementing minimal tillage practices targeting rodent burrow systems following crop harvests. Given that there are plenty of diurnal and nocturnal birds of prey in Sahelo-Sudanian rural fields, additional promising measures to explore include favoring these predators of rodents with actions such as the setting of wooden perches and owl nest boxes.

The recurrence of major damages to food crops, caused by recurring events of particularly high rodent pest abundances, has led West African states and/or international institutions to repeatedly seek external expertise since the 1970s to assess the critical situation and propose sustainable rodent management strategies (Giban, 1967; Bernard, 1976; Fall, 1976; Duplantier, 1987; Gramet, 1989). The rodent outbreak observed in the Senegal River valley during 2020–2021 is illustrative of how the lessons that could have been learned from historical events and the wealth of scientific knowledge accumulated over the years have yet to be translated into concrete, effective, and sustainable management measures. Although it is likely late, the FAO has for the first time adopted an interdisciplinary approach, combining socio-economic, biological, and ecological perspectives, to carry out an assessment of rodent impacts and human needs in an emergency situation (Bori and Dalecky, 2021). Of 111,643 ha cultivated with rice in 2020, 14–37%, depending on the region, were reported to have been affected by rodents, mainly *Arvicanthis niloticus*, *Mastomys huberti* and *Mastomys erythroleucus*. This translates to an estimated loss of around 84,000 tons of paddy rice for a single cropping year, or 6–35% of the total expected rice production, depending on the region. The production loss was estimated at €26.5 million (ca. US$ 31.4 million in 2020–2021), directly affecting nearly 40,000 households or 270,000 people, which accounted for 11–14% of the population of these regions (Bori and Dalecky, 2021). Subsequent appraisals have outlined a lack of expertise and logistical constraints in national Crop Protection services, which limited the efforts for targeted interventions, but offer scope for future improvement.

In Senegal and Mauritania, Crop Protection officers have recently been trying to raise awareness among farmers, to encourage them to carry out preventive measures against rodent pests in their fields. However, there is a growing need for these actions to be better organized and implemented at a larger scale. These initiatives should ideally be incentive-based and accompanied by thorough follow-up assessments to gauge their effectiveness. Recently, an integrated rodent management strategy was formulated in Mauritania (Garba et al., 2021). Recognizing the importance of these efforts, the FAO has extended its support by launching two intervention projects in Mauritania and Senegal. These projects aim to increase awareness among farmers about the risks associated with the use of synthetic rodenticides for rodent control. Instead, they promote the adoption of alternative integrated management strategies based on a deep understanding of rodent population dynamics, both in terms of spatial distribution and temporal fluctuations.

An illustrative example of actions implemented in February 2022 in Mauritania involved mechanical/physical management methods such as clearing the vegetation used by rodents in dykes in rice fields, followed by the installation of mosquito nets on the dykes over rodent burrows, and then the mechanical exclusion of rodents trapped by the mosquito nets while flooding of burrows (Fig. 4). These management actions were implemented during the lean season which is a period of reproductive

Fig. 4. Awareness-raising and mechanical rodent control actions in Mauritania carried out in 2022.
(A) Clearing the vegetation on dykes. (B) Installation of mosquito nets on the dykes over rodent burrows. (C) Flooding of burrows with water and removal of rodents captured in the nets. (D) Result of a session of mechanical control.

rest for *Arvicanthis niloticus* and *Mastomys* spp., the main rodent pest species in these irrigated agroecosystems, and were combined with setting up pitfall traps. To support these efforts and make rodent management a collective community action, national and regional authorities have introduced strong incentives where the allocation of inputs, such as fertilizers, are linked to farmers' active participation in rodent management activities. Additionally, the authorities have considered imposing fines for those who refuse to participate.

In Mali, the Rodentology Laboratory of the Institute of Rural Economics is currently actively engaged in conducting practical research activities in rural areas in line with public policies. They aim to evaluate the impact of four distinct rodent management methods on agricultural yields in the Baguineda (Mali) irrigated rice farming area where the main pest species belong to *Arvicanthis* and *Mastomys* genera, i.e., optimized chemical control, trapping sessions conducted in conjunction with collective actions implemented by farmers prior to the annual peak in rodent abundance, leveraging the repellent effect of predator odors, and testing the efficacy of a local plant identified as potentially toxic to rodents based on their traditional knowledge.

Other innovative methods that have been developed in Southeast Asia and tested at small scale in East Africa, may have a promising future in Western Africa. For example, the community trap barrier system (cTBS) is an in-field rodent management method that can be used by irrigated rice farming communities (Singleton et al., 1999b). It involves the establishment of a rectangular trap crop three weeks before the rest of the fields are planted so that rodents from the surrounding areas are attracted to it. This trap crop is fenced with plastic sheeting which has multiple holes through which rodents can pass, and rodents are trapped using multiple-capture traps set at the holes. Field studies in irrigated rice cropping systems in Southeast Asia (Singleton et al., 2003) and East Asia (Wang et al., 2017) have shown that this method reduces the abundance of rodents over a large area surrounding the trap crop which reduces damage and increases yield. It has been shown in Tanzania that a 20 m × 20 m cTBS significantly reduces rodent abundance over an area of up to 16 ha of irrigated rice fields, leading to an increase in rice yield by 41% (Mulungu et al., 2020). A simplified variant of cTBS, known as LTBS (Linear Trap Barrier System), has been tested in Asia (Wang et al., 2017; Stuart et al., 2020), and a pilot study has been conducted in the Senegal River delta (Sow et al., 2023; Bosma et al., 2024). LTBS comprises a stretch of plastic fencing with a minimum length of 100 m long, which is partly buried underground to a depth of 5–10 cm to deter rodents from tunneling underneath. Above ground, the fencing stands at a height of 60–70 cm. LTBS is installed to intercept rodent movements into or within crop fields by exploiting the innate tendency of certain rodent species to move along physical barriers, such as walls or fences (Wang et al., 2017). Unlike cTBS, LTBS does not require setting up trap crops to attract rodents. To the best of our knowledge, such alternative rodent management methods have not been formally tested in West Africa and their impact in terms of rodent management and rice production still need to be evaluated within the context of the prevailing farming system in West Africa.

There are also other promising methods, such as the use of improved hermetic grain storage bags (e.g., International Rice Research Institute (IRRI) bags, Purdue Improved Crop Storage (PICS) bags), which provide a better grain storage opportunity to farming communities against rodent and insect damage to stored grain, and increase storage life by limiting spoilage and the build-up of aflatoxins (Baributsa and Cristine, 2020; Baoua et al., 2016; Williams et al., 2014).

Importantly, while some rodent management actions may be efficient to decrease rodent abundances and mitigate their deleterious impacts (Singleton et al., 1999a,b, 2010, 2021; Singleton, 2014; Palis et al., 2011; Brown et al., 2007; Ninh et al., 2022; My Phung et al., 2013; Belmain et al., 2008), they may inadvertently conflict with crucial socio-economic aspects. To achieve local suitability and adoption, first, it is imperative to ensure that the direct costs of implementing EBRM are lower than the overall impacts caused by rodent infestations. This also holds true for the perceived gains and losses by farmers, not only their monetary values. Second, the timing of the management needs to be aligned with the local agricultural calendar in order to facilitate mobilization of resources for the task. Moreover, to ensure greater effectiveness, the management actions should be initiated during periods when the rodent population is at a low density (such as the lean period before they reproduce), rather than waiting until outbreaks occur, when the population has become too large to control. Third, one should be very cautious about the interrelationships between rodent management actions aligned with the cropping calendar and the cattle breeding systems, especially in the Sahelian region where pastoralism is widespread and a critical activity, encompassing food, cultural, and economic aspects. For instance, in the Sahelian pastoralist livestock production system, grazing stubble plays an important role and, provided that overgrazing is avoided, the practice greatly contributes to soil fertility by adding manure. Moreover, livestock can remove spilled grain and trample the ground upsetting rodent burrows. In such a context, post-harvest actions such as field clearing and tillage, while effective for reducing pest rodent populations, may have detrimental effects on conservation agricultural practices and on domestic animals, including meat, milk, and leather production. Some cattle breeders also mentioned the risk of having cattle wounded by pitfall traps (i.e., Kornaka) while wandering at night (K. Hima, pers. obs.). To minimize such risks and address potential conflicts with local residents, grazing stubble could be timed and incorporated into other activities of field clearance and pitfall trap may be covered (i.e., closed) during periods of cattle grazing. In summary, the success of EBRM in this region will strongly depend upon finding a delicate balance between socio-economic gains and investments, taking into account the interplay between rodent management, agriculture, and cattle breeding systems.

3.2. EBRM in sub-Saharan African cities and their immediate peripheries

Food losses and health problems associated with rodent pests also have an impact beyond cultivated fields and rural areas *sensu stricto*. Indeed, in the context of rapidly expanding cities and increasing urban demographics, larger and larger surfaces of peri-urban (and sometime inner city) areas are dedicated to food production (Davies et al., 2021; Oura et al., 2023). In addition, in the Global South, rapid urbanization may sometimes remain difficult to control, thus making urban management and basic services rare or even absent from large, highly populated and often informal urban settings where inhabitants are highly vulnerable (UN Habitat, 2019). This leads to rodent proliferation and subsequent exacerbation of rodent-human interactions (Dobigny and Morand, 2022). As such, urban areas and their suburbs should not be neglected from a crop protection perspective, given the development of peri- and intra-urban market gardening and the widespread practices of animal husbandry and of (often unsecured) crop storage by households in sub-Saharan African cities (Orsini et al., 2013; Battersby and Watson, 2018). At the urban and sub-urban levels, rodent infestations are projected to intensify in sub-Saharan Africa since 1.2 billion people in Africa will be city-dwellers by 2050, with most of them living in densely populated, precarious and unhealthy areas (UN Habitat, 2014, 2019). In these urban settings, a few highly competitive and often invasive commensal rodent species, such as rats (*Rattus* spp.) and mice (*Mus musculus*), typically dominate and cause damage to urban gardens and significant post-harvest crop losses, including inside many rodent-infested households where food stocks may be massively damaged. In urban marginalized urban areas, commensal rodents are a constant presence inside or in close proximity to human dwellings, with enormous infestation rates and health risks associated with rodent-borne zoonotic diseases. As an illustration of widespread presence of rodent in urban areas, in a series of 376 villages and towns that were investigated from 1983 to 2014 in Senegal, rodents were trapped in 94.6% of the 700 indoor sampling sessions (Dalecky et al., 2015). In a cross-sectional survey involving 500 residents to investigate community awareness and attitudes toward rodent control concerning Lassa fever virus in the city of Osogbo (Nigeria), 90.9% of residents in slum communities reported having encountered rodents within their homes (Adebimpe, 2015). More than half of the respondents (55.4%) stated that they had witnessed rodents moving freely inside their residences. Furthermore, 43.3% reported observing a rodent inside their homes within the past 24 h. The primary natural host for the Lassa fever virus is the multimammate mouse, *Mastomys natalensis*, which is a dominant rodent species in human dwellings in this area. In Niamey (Niger), out of 178 human dwellings investigated in 18 districts between December 2009 and May 2011, 134 (75.3%) were found to be infested with small mammals, while 96.5% of 170 inhabitants interviewed there mentioned rodent-associated problems in their dwellings (Garba et al., 2014). In Bamako (Mali), small mammals were captured in 350 of 403 (86.8%) houses sampled in 11 districts of the six city center communes (sampling conducted between October 2021 and October 2022), and between 79 and 94% of households surveyed in eight peripheral districts (100 households/district; surveys conducted between March and May 2022) reported seeing rodents in their dwellings in the last 30 days (S. Ag Atteynine, L. Granjon et al., unpublished data). In Cotonou (Benin), during repeated sampling sessions in two deprived districts within the city (10–12 households per district, sampling conducted between November 2016 and June 2018), rodents were captured in 58 of 68 (85.3%) and 64 of 65 (98.4%) trapping sessions, respectively (Dossou et al., 2022). In a 2018 survey involving 36 residents from the two districts, a majority of the residents (91.7%) reported having seen rats in their homes (Odou, 2018). These data highlight the very close proximity between rodents and human beings in sub-Saharan African cities.

Moreover, studies highlight the multifaceted and significant economic burdens of rodents in urban communities across Africa (Constant et al., 2020; Odou, 2018). These burdens include losses due to food destruction and contamination, costly infrastructure damage resulting from gnawing and burrowing, increased healthcare expenses linked to the spread of rodent-borne diseases, as well as expenses associated with pest control measures and waste management. Moreover, the presence of rodents can lead to loss of livelihood for small businesses and reduced productivity among residents. The stress and anxiety caused by rodent infestations can decrease productivity at home, work places and school, resulting in economic losses for individuals and the community (see Lee et al. (2024) and references therein). Despite their abundance and everyday nuisances in urban settings in Africa, coordinated actions against urban rodents have been only taken in response to cases of large epidemics of zoonotic diseases in major cities (e.g., Lassa fever virus in Lagos (Nigeria), bubonic plague in Antananarivo (Madagascar) and Dakar (Senegal) in the early 20th century (Sorel and Armstrong, 1929; Cazanove, 1932)). Such reactive interventions are resource-demanding, usually planned by health authorities with limited background about rodent biology and behavior, and essentially relying on the massive application of chemical rodenticides or other lethal controls. Furthermore, rodent management is conducted by the individual households, in most cases using chemical rodenticides sold in informal local markets and typically in a total absence of coordination between neighboring households. Such actions not only result in non-negligible extra costs to households (Constant et al., 2020; Odou, 2018), but also have a very poor success rate in reducing rodent populations, due to factors such as the lack of effective control products and/or application protocols as well as immediate re-infestation of treated areas by rodents from untreated neighboring houses (Pertile et al., 2022).

Note that in such urban socio-ecosystems, EBRM has received limited testing (Awoniyi et al., 2022, 2024). Urban areas present unique sociological (e.g., socio-cultural heterogeneity, challenges in identifying recognized and representative local leaders, complex house ownership and rental systems) and environmental challenges (e.g., densely populated and highly human-modified habitats, numerous but scattered spots of food stock and garbage dumping sites, highly prolific commensal rodents with poorly documented eco-ethologic and population dynamics characteristics) (Parsons et al., 2020). These specific features of urban areas require a thorough identification, testing and evaluation of specifically-designed EBRM tools for this type of socio-ecosystem (see for example Awoniyi et al., 2022, 2024). Integrating EBRM into such multistakeholder research efforts could provide valuable insights and solutions for effectively managing urban rodent populations while considering the diverse socio-cultural and ecological dynamics at play. The task at hand appears formidable, and we believe that well-coordinated, multidisciplinary interventional research is urgently needed in this regard.

4. Conclusion

The successful implementation of EBRM entails building on locally adapted communication and awareness raising campaigns aimed at mobilizing stakeholders (see Scobie et al. (2023) for an example in Madagascar). Various media channels can be used, including audio broadcasting (Le Fur and Granjon, 2018; CERISE project, 2018a; Meheretu, 2022); theatre plays and documentaries (Le Fur and Granjon, 2018; CERISE project, 2018b; Bâ et al., 2018); and the distribution of brochures and practical guides (Engdayeh et al., 2020; TheWater-Channel, 2020; University of Greenwich, 2016). To do so, it should be possible to rely on already existing stakeholder networks, including local/rural radios, farmer cooperatives, community health centers, as well as collaborations with Crop Protection Services, hygiene departments, and other agricultural or extension services closely connected to farmers.

Community coordination of all practices should be strongly encouraged. In both rural and urban settings, the priority management objectives should revolve around limiting or eliminating potential rodent shelters and food sources while also preventing (or excluding) rodents from approaching and accessing available resources. For this aim, it is crucial to understand the distinctive behavior, population dynamics and ecology of the different rodent species that may represent pest organisms. In practice, EBRM approaches need to be tailored specifically for these species. As such, there might be subtle but critical differences in EBRM approaches for different rodent species and socio-ecosystems, rather than a single turnkey solution. The timing of the implementation of the actions, adapted to the parameters of rodent population dynamics, should be carefully planned in consultation with stakeholder communities, taking into account for their knowledge, attitude and practice. Approaches such as focus group interviews (see Supplementary Material, Appendix C), can be employed to align the implementation with community dynamics, ensuring maximum impact on the rodent population before the onset of the breeding season and subsequent population proliferation.

Considering that EBRM is in its early stages of development in sub-Saharan Africa, and recognizing the current lack of coordination among small-scale trials conducted in several countries across the continent (Appendix A), we call for the establishment of a collaborative community of knowledge and practice. A willingness to share and pool skills, available experience and resources, as well as endogenous and scientific knowledge should characterize such a "green rodent control" community. We propose that an agenda for this network could be based on two primary objectives: (i) to promote EBRM in Africa, particularly through the networking of academics working in this field across the continent, and (ii) to stimulate the development of interventional research programs on EBRM in different African socio-ecosystems.

Funding

This research was funded by RVO (the Netherlands Enterprise Agency) through MetaMeta Research B.V., The Netherlands, for the studies in Ethiopia; by FAO (Food and Agriculture Organization of the United Nations), grants TCP/MAU/3707, SFER/GLO/301/MUL and TCP/OSRO/INT/102/BEL in Senegal and Mauritania; by A*MIDEX/FR ECCOREV - OT-Med - ITEM, R2P and R2P-RPM projects in Senegal; by CNRST, FCRIT 2018 in Mali; by BELMONT FORUM, SCARIA project for studies in urban settings; by IRD and OSU Institut Pythéas, ObsMiCE the West African Observatory on small Mammals as indicators of Environmental Changes (Dalecky and Salmon, 2017).

Ethics approval/declarations

Studies in Senegal were carried out within the framework of the general convention on cooperation in scientific and technical research between the Republic of Senegal and the French Republic (17 January 1974), of the memorandum of understanding on cooperation between the government of Senegal and ORSTOM (07 February 1991), of the agreement between Senegal and IRD (04 January 2019) and of the agreement on scientific and technical cooperation concluded between IRD and UGB (23 November 1999, extended in 2005, 2010, 2015 and 2020). Studies in Benin were conducted under the research agreement between the Republic of Benin and IRD (30 September 2010, renewed on 06 April 2017) and between IRD and Abomey-Calavi University (30 September 2010, renewed on 03 July 2019). In Niger, the work was conducted with the national crop protection service (DGPV) and University of Niamey (UAM) and authorized by the scientific partnership agreement 301027/00 between IRD and the Republic of Niger. The work in Mauritania was conducted with the national crop protection service (DPV, Ministry of Rural Development) under the Food and Agriculture Organization of the United Nations (FAO) projects SFER/GLO/301/MUL (assignment order TF.SFWDD.TFAA428618269, 26 February 2021), TCP/MAU/3707 and TCP/OSRO/INT/102/BEL, on request from the government of the Islamic Republic of Mauritania. Studies in Mali were conducted with the national institute of rural economy (IER) following authorization/DGA/22/11/03/22 (14 November 2022) from the Ministry of Rural Development of the Republic of Mali under approval 2023.072/MSDS-CNESS (03 April 2023) of national ethics committee for health and life sciences (CNESS), and authorization 0076/M.CVI-DB (14 March 2022) from the Ministry of Territorial Administration and Decentralization, Bamako District Governorate under approval 18/2021/CE-INSP (03 November 2021) of ethics committee of the national institute of public health (INSP). The experiments conducted in Ethiopia were carried out in compliance with the ethical policies and guidelines of the Committee for Animal Care and Use at Mekelle University, Ethiopia. Permits and guidelines for fieldwork were obtained from the Bureau of Agriculture, NRCM Directorate in the Amhara Regional state.

Consent to participate

All field investigations were performed with written and/or oral agreement from adequate institutional and traditional authorities, as well as the systematic prior explicit consent of residents when rodent trapping was conducted inside private places. None of the rodent species sampled in the present study had protected status (IUCN, CITES, and national regulations). Animals were treated in a humane manner, with consideration for the welfare of individuals, following the guidelines from the American Society of Mammalogists (Sikes et al. 2016). Given that rodents captured in cities and in cultivated fields were pests of stored food and crops, and potential hosts of pathogens, they could not be ethically released at the place of capture from the point of view of local inhabitants. Whenever necessary, small mammals were euthanatized by cervical dislocation once trapped in accordance with Annex IV of the Directive 2010/63/EU (22 September 2010) of the European Union on the protection of animals used for scientific purposes. Sampling procedures were conducted following the guidelines of Mills et al. (1995) under the supervision of senior authors as qualified scientists with designer levels in animal experimentation and in the use of non-housed wildlife for scientific purposes, certified by approval numbers B34-169-1 (decree 06 XIX 277, 05 December 2006) and C34-169-1 (decree 12 XIX 077, 25 July 2012) from Departmental Directorate for Population Protection (DDPP-Hérault) French Republic, accreditation numbers I-34UnivMontp-F1-12 of 30 April 2012 (validated 24 September 2012), I-75-MNHN-F1-15 of 17 June 2015 (validated 15 November 2021) according to decree 2013-118 (01 February 2013) from the French Ministry of Agriculture on the protection of animals used for scientific purposes.

CRediT authorship contribution statement

Ambroise Dalecky: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Ibrahima Sow:** Investigation, Data curation. **Abdoul Aziz Ibrahim Danzabarma:** Investigation, Data curation. **Madougou Garba:** Investigation, Data curation. **Jonas Etougbétché:** Investigation, Data curation. **Sylvestre Badou:** Investigation, Data curation. **Henri-Joël Dossou:** Investigation, Data curation. **Cheikh Tidiane Niang:** Investigation, Data curation. **Ousmane Diene:** Writing – review & editing, Project administration, Funding acquisition. **Idrissa Diallo:** Conceptualization. **Mohamed Seyidna Ali Saghiri:** Investigation, Data curation. **Mohamed El Hady Sidatt:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Frank van Steenbergen:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Amadou Bocar Bal:** Writing – review & editing, Supervision. **Luwieke Bosma:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Gualbert Houéménou:** Supervision, Project administration, Funding acquisition. **Solimane Ag Atteynine:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Karmadine Hima:** Supervision, Investigation, Data curation. **Gauthier Dobigny:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Yonas Meheretu:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We would like to thank Valérie Golaz (INED-LPED), Marc Egrot (IRD-LPED) and the organizers of the international conference "Mise en œuvre des politiques publiques et pesticides dans les Suds" that took place in Oct. 2021 at Bouaké, Ivory Coast, project PoPPesCI (Politiques publiques et pesticides en agriculture urbaine), for having stimulated the writing of this paper.

Appendix. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2024.106673.

References

Adebimpe, W.O., 2015. Community awareness and perception towards rodent control: implications for prevention and control of Lassa Fever in urban slums of South-Western Nigeria. Malta Journal of Health Sciences 26–32. https://www.um.edu.mt/library/oar//handle/123456789/5051.

AGRA, 2017. Africa Agriculture Status Report: the Business of Smallholder Agriculture in Sub-saharan Africa, p. 180 (Issue 5). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).

Awoniyi, A.M., Venegas-Vargas, C., Souza, F.N., Zeppelini, C.G., Hacker, K.P., Carvalho-Pereira, T., et al., 2022. Population dynamics of synanthropic rodents after a chemical and infrastructural intervention in an urban low-income community. Scientific Reports 12, 10109. https://doi.org/10.1038/s41598-022-14474-6.

Awoniyi, A.M., Barreto, A.M., Argibay, H.D., et al., 2024. Systematic surveillance tools to reduce rodent pests in disadvantaged urban areas can empower communities and improve public health. Sci. Rep. 14, 4503. https://doi.org/10.1038/s41598-024-55203-5.

Bâ, K., Granjon, L., Cisse, M.N., Faye, C., Sene, K., 2018. Des Envahisseurs au Sahel. DEFCCS, IRD. https://www.youtube.com/watch?v=kC5r94LWiWU. (Accessed 22 February 2024).

Baoua, I.B., Amadou, L., Bakoye, O., Baributsa, D., Murdock, L.L., 2016. Triple bagging hermetic technology for post-harvest preservation of paddy rice *Oryza sativa* L. in the Sahel of West Africa. J. Stored Prod. Res. 68, 73–79. https://doi.org/10.1016/j.jspr.2016.04.006.

Baributsa, D., Cristine, M., 2020. Developments in the use of hermetic bags for grain storage. In: Advances in Postharvest Management of Cereals and Grains. Burleigh Dodds Science Publishing, pp. 171–198. https://doi.org/10.19103/AS.2020.0072.06.

Battersby, J., Watson, V., 2018. Urban Food Systems Governance and Poverty in African Cities, first ed. Routledge. https://doi.org/10.4324/9781315191195.

Belmain, S.R., Dlamini, N., Eiseb, S., Kirsten, F., Mahlaba, T., Makundi, R., et al., 2008. The ECORAT project: developing ecologically-based rodent management for the southern African region. Int. Pest. Control 50, 136–138. http://www.projects.nri.org/ecorat/docs/Int._Pest_Control.pdf.

Bernard, J., 1976. Les dégâts de rongeurs dans le bassin du fleuve Sénégal et dans d'autres régions de la République du Sénégal. FAO, Rome, Italie: OMVS, PNUD, p. 34.

Bori, A., Dalecky, A., 2021. Rapport d'évaluation de l'impact et des besoins en situation d'urgence à la suite de l'infestation des rongeurs au Sénégal et en Mauritanie en 2020-2021. Food and Agriculture Organization of the United Nations 40. https://doi.org/10.13140/RG.2.2.13813.70887.

Bosma, L., Sow, I., Meheretu, Y., Dalecky, A., 2024. Enhancing rice field resilience: Pioneering ecologically-based rodent management in the Senegal River delta. https://thewaterchannel.tv/thewaterblog/enhancing-rice-field-resilience-pioneering-ecologically-based-rodent-management-in-the-senegal-river-delta/. (Accessed 9 March 2024).

Brown, P., Khamphoukeo, K., Sonekham, Invanh, Simone, Vison, et al., 2007. Development of rodent management strategies for the upland farming system in Lao PDR. Lao Journal of Agriculture and Forestry 15, 124–145. https://www.researchgate.net/publication/288964018.

Brown, P.R., Khamphoukeo, K., 2007. Farmers' knowledge, attitudes, and practices with respect to rodent management in the upland and lowland farming systems of the Lao People's Democratic Republic. Integr. Zool. 2, 165–173. https://doi.org/10.1111/j.1749-4877.2007.00055.x.

Cazanove, F., 1932. Le problème du rat dans le territoire de Dakar et dépendances. Annales de Médecine et de Pharmacie Coloniales 30, 108–144. https://www.biusante.parisdescartes.fr/histmed/medica/cote?131132x1932x30.

CERISE project, 2018a. Scientific information on invasive rodents in Senegal. https://www.youtube.com/watch?v=sHH7F10oto4. (Accessed 22 February 2024).

CERISE project, 2018b. Theater play in local towns of Senegal. https://www.youtube.com/watch?v=AQpJDKCdB4o&t=378s. (Accessed 22 February 2024).

Constant, N.L., Swanepoel, L.H., Williams, S.T., Soarimalala, V., Goodman, S.M., Massawe, A.T., et al., 2020. Comparative assessment on rodent impacts and cultural perceptions of ecologically based rodent management in 3 Afro-Malagasy farming regions. Integr. Zool. 15, 578–594. https://doi.org/10.1111/1749-4877.12447.

Dalecky, A., Bâ, K., Piry, S., Lippens, C., Diagne, C.A., Kane, M., et al., 2015. Range expansion of the invasive house mouse *Mus musculus domesticus* in Senegal, West Africa: a synthesis of trapping data over three decades, 1983–2014. Mamm Rev. 45, 176–190. https://doi.org/10.1111/mam.12043.

Dalecky, A., Garba, M., Ibrahim Danzabarma, A.A., Etougbetche, J., Badou, S., Dossou, H.J., et al., 2023. Prolifération de rongeurs dans les milieux urbains et agricoles d'Afrique subsaharienne. Le côté obscur des rodenticides chimiques de synthèse. Environnement, Risques & Santé 22, 205–211. https://doi.org/10.1684/ers.2023.1731 ([With an English version as supplementary material: Rodent proliferation in urban and agricultural settings of sub-Saharan Africa. The dark side of synthetic chemical rodenticides]).

Dalecky, A., Salmon, A., 2017. ObsMiCE : observatoire ouest-africain des petits Mammifères indicateurs des Changements Environnementaux. Documentary film (14 min 43 sec). LPED, October 2017. https://vimeo.com/280952095. (Accessed 22 February 2024).

Davies, J., Hannah, C., Guido, Z., Zimmer, A., McCann, L., Battersby, J., Evans, T., 2021. Barriers to urban agriculture in sub-Saharan Africa. Food Pol. 103, 101999 https://doi.org/10.1016/j.foodpol.2020.101999.

Dobigny, G., Morand, S., 2022. Zoonotic emergence at the animal-environment-human interface: the forgotten urban socio-ecosystems. Peer Community Journal 2, e79. https://doi.org/10.24072/pcjournal.206.

Dossou, H., Le Guyader, M., Gauthier, P., Badou, S., Etougbetche, J., Houemenou, G., et al., 2022. Fine-scale prevalence and genetic diversity of urban small mammal-borne pathogenic *Leptospira* in Africa: a spatiotemporal survey within Cotonou. Benin. Zoonoses and Public Health 69, 643–654. https://doi.org/10.1111/zph.12953.

Duplantier, J.-M., 1987. Rapport sur la mission au Sénégal effectuée du 30 mai au 6 juin 1987. ORSTOM, Montpellier, France, p. 5.

Ecke, F., Han, B.A., Hörnfeldt, B., et al., 2022. Population fluctuations and synanthropy explain transmission risk in rodent-borne zoonoses. Nat. Commun. 13, 7532. https://doi.org/10.1038/s41467-022-35273-7.

Engdayeh, G., Meheretu, Y., Tilahun, T., Wondmnow, B., Bosma, L., van Steenbergen, F., 2020. Practical guideline. Effectively controlling rats with ecological methods.

Ethiopia edition, 2020. https://metameta.nl/resources/manual-rodent-control. (Accessed 22 February 2024).
Fall, M.W., 1976. Rodent Control in Senegal: Present Problems, Future Needs. Denver Wildlife Research Center, Denver, Colorado, USA, p. 31. https://pdf.usaid.gov/pdf_docs/PNAAG459.pdf.
Garba, M., Abdellahi Tah, O.M., Breika, K., 2021. Stratégie de gestion intégrée des rongeurs en Mauritanie. FAO, p. 18.
Garba, M., Kane, M., Gagare, S., Kadaoure, I., Sidikou, R., Rossi, J.-P., et al., 2014. Local perception of rodent-associated problems in Sahelian urban areas: a survey in Niamey, Niger. Urban Ecosyst. 17, 573–584. https://doi.org/10.1007/s11252-013-0336-x.
Giban, J., 1967. Les rongeurs des cultures vivrières des régions du Niger. Inventaire des questions et projet d'un programme d'études en vue de la lutte. Secrétariat d'état aux affaires étrangères chargé de la coopération & République du Mali 43. http://vminfotron-dev.mpl.ird.fr:8080/masto2_2/infos/043.pdf.
Gramet, P., 1989. Proposition d'un programme de lutte à court, moyen et long terme à l'encontre des vertébrés ravageurs (Rongeurs et Oiseaux). FAO, p. 38 projet MAU/87/010.
Hima, K., Granjon, L., Gauthier, P., Ndiaye, A., Brouat, C., Dobigny, G., 2019. Population dynamics and genetics of *Gerbillus nigeriae* in central sahel: implications for rodent pest control. Ecology and Evolutionary Biology 4, 45. https://doi.org/10.11648/j.eeb.20190404.11.
Lee, M.J., Byers, K.A., Guo, X., Lee, L.K.F., Cox, S.M., Himsworth, C.G., 2024. Urban rats are the 'fall-guy': resident motivations for municipal rat complaints. PLoS One 19, e0296920. https://doi.org/10.1371/journal.pone.0296920.
Le Fur, J., Granjon, L., 2018. CERISE project - scenarios of rodent invasion in the sahel: global change impact on the expansion of the Nigerian gerbil and the house mouse in Senegal. http://projetcerise-ird-frb.fr. (Accessed 22 February 2024).
Makundi, R.H., Massawe, A.W., 2011. Ecologically based rodent management in Africa: potential and challenges. Wildl. Res. 38, 588–595. https://doi.org/10.1071/WR10147.
Meheretu, Y., 2022. Agriculture's rodent problem. TheWaterChannel, Episode 9. https://soundcloud.com/user-622446535. (Accessed 22 February 2024).
Meheretu, Y., Sluydts, V., Welegerima, K., Bauer, H., Teferi, M., Yirga, G., Mulungu, L., Haile, M., Nyssen, J., Deckers, J., Makundi, R., Leirs, H., 2014. Rodent abundance, stone bund density and its effects on crop damage in the Tigray highlands, Ethiopia. Crop Protect. 55, 61–67. https://doi.org/10.1016/j.cropro.2013.10.016.
Meheretu, Y., Ashenafi, F., Kidane, D., Welegerima, K., 2022. Stored-grain losses and management practices among smallholder cereal farmers in Northern Ethiopia. Int. J. Pest Manag. 68, 59–68. https://doi.org/10.1080/09670874.2020.1795301.
Mills, J.N., Childs, J.E., Ksiazek, T.G., et al., 1995. Methods for Trapping and Sampling Small Mammals for Virologic Testing. U.S. Department of Health & Human Services, Atlanta, USA. https://stacks.cdc.gov/view/cdc/11507.
Mulungu, L.S., Mchukya, B.M., Mnyone, L.L., 2020. Trap barrier system (TBS) as a new tool for rodent pest management in irrigated rice in Africa. In: Pests Control and Acarology. IntechOpen. https://doi.org/10.5772/intechopen.81828.
My Phung, N.T., Brown, P.R., Leung, L.K.P., 2013. Use of computer simulation models to encourage farmers to adopt best rodent management practices in lowland irrigated rice systems in an Giang Province, the Mekong Delta, Vietnam. Agric. Syst. 116, 69–76. https://doi.org/10.1016/j.agsy.2012.11.003.
Niang, C.T., Kane, M., Niang, Y., Sarr, N., March, L., Tatard, C., et al., 2022. Socio-environmental changes and rodent populations in lowland agroecosystems of the lower delta of the River Senegal, West Africa: results of observations over a decade, 2008-2019. Journal of Vertebrate Biology 71, 22015. https://doi.org/10.25225/jvb.22015.
Ninh, H.N., Aragon, C.T., Palis, F.G., Rejesus, R.M., Singleton, G.R., 2022. Yield and income effects of ecologically-based rodent management in Mekong River delta, Vietnam. Asian Journal of Agriculture and Development 13, 55–74. https://doi.org/10.37801/ajad2016.13.2.4.
Odou, S.S., 2018. Nuisances des rongeurs à Cotonou: perceptions et organisations de la lutte par les habitants. EPAC, Université d'Abomey-Calavi, Cotonou, Benin [License].
Orsini, F., Kahane, R., Nono-Womdim, R., Gianquinto, G., 2013. Urban agriculture in the developing world: a review. Agron. Sustain. Dev. 33, 695–720. https://doi.org/10.1007/s13593-013-0143-z.
Oura, K.R., N'dri, K.R., Fournet, F., Doudou, D.T., 2023. Le maraîchage intra-urbain à l'épreuve de la demande croissante des citadins en légumes : mésusage des pesticides et risques sanitaires à Bouaké (Côte d'Ivoire). Environnement, Risques & Santé 22, 230–242. https://doi.org/10.1684/ers.2023.1729.
Palis, F.G., Singleton, G.R., Brown, P.R., Huan, N.H., Umali, C., Nga, N.T.D., et al., 2011. Can humans outsmart rodents? Learning to work collectively and strategically. Wildl. Res. 38, 568–578. https://doi.org/10.1071/WR10226.
Parsons, M.H., Jardine, C.M., Crowther, M.S., Himsworth, C.G., 2020. Editorial: trends in urban rodent monitoring and mitigation: improving our understanding of population and disease ecology, surveillance and control. Frontiers in Ecology and Evolution 7, 522. https://doi.org/10.3389/fevo.2019.00522.
Pertile, A.C., Lustosa, R., Carvalho-Pereira, T., Pedra, G.G., Panti-May, J.A., Oliveira, U., et al., 2022. Evaluation of the impact of chemical control on the ecology of *Rattus norvegicus* of an urban community in Salvador, Brazil. PLoS One 17, e0270568. https://doi.org/10.1371/journal.pone.0270568.
Rahelinirina, S., Rahajandraibe, S., Rakotosamimanana, S., Rajerison, M., 2023. Assessing the effectiveness of intervention to prevent plague through community and animal-based survey. PLOS Glob Public Health 3 (12), e0002211. https://doi.org/10.1371/journal.pgph.0002211.
Scobie, K., Lambin, X., Telfer, S., Rasahivelo, M.F., Raheliarison, R.N., Rajerison, M., Young, J., 2023. Living with rodent pests: unifying stakeholder interests to prioritise pest management in rural Madagascar. People and Nature 5, 713–725. https://doi.org/10.1002/pan3.10438.
Sikes, R.S., the Animal Care and Use Committee of the American Society of Mammalogists, 2016. 2016 guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. J. Mammal. 97, 663–688. https://doi.org/10.1093/jmammal/gyw078.
Singleton, G.R., Leirs, H., Hinds, L.A., Zhang, Z., 1999a. Ecologically-based management of rodent pests–re-evaluating our approach to an old problem. In: Singleton, G.R., Leirs, H., Hinds, L.A., Zhang, Z. (Eds.), Ecologically-based Management of Rodent Pests, Australian Centre for International Agricultural Research (ACIAR), pp. 17–29. Canberra.
Singleton, G.R., Lorica, R.P., Htwe, N.M., Stuart, A.M., 2021. Rodent management and cereal production in Asia: balancing food security and conservation. Pest Manag. Sci. 77, 4249–4261. https://doi.org/10.1002/ps.6462.
Singleton, G.R., Sudarmaji, Brown, P.R., 2003. Comparison of different sizes of physical barriers for controlling the impact of the rice field rat, *Rattus argentiventer*, in rice crops in Indonesia. Crop Protect. 22, 7–13. https://doi.org/10.1016/S0261-2194(02)00060-1.
Singleton, G.R., Sudarmaji, Jumanta, Tran, Q.T., Nguyen, Q.H., 1999b. Physical control of rats in developing countries. In: Singleton, G.R., Hinds, L.A., Leirs, H., Zhang, Z. (Eds.), Ecologically-Based Management of Rodent Pests. Australian Centre for International Agricultural Research, Canberra, pp. 178–198. http://hdl.handle.net/102.100.100/212272?index=1.
Singleton, G.R., 2014. Ecologically-based rodent management 15 Years on: a pathway to sustainable agricultural production. In: Proceedings of the Vertebrate Pest Conference, vol. 26. https://doi.org/10.5070/V426110594, 26.
Singleton, G.R., Belmain, S.R., Brown, P.R., Hardy, B., 2010. Rodent outbreaks: ecology and impacts. Int. Rice Res. Inst. 289. http://books.irri.org/9789712202575_content.pdf.
Sorel, F., Armstrong, 1929. La lutte préventive contre la peste dans la circonscription de Dakar et dépendances durant l'année 1928. Annales de Médecine et de Pharmacie Coloniales 27, 64–72. https://www.biusante.parisdescartes.fr/histmed/medica/cote?131132x1929x27.
Sow, I., Kane, M., Kandé, O., Niang, Y., Meheretu, Y., Dalecky, A., 2023. Enhancing rice field resilience: pioneering ecologically-based rodent management in the Senegal River delta. [Poster]. In: The 14th African Small Mammal Symposium (ASMS), Namibia, 17-22 Sept. 2023. https://doi.org/10.5281/zenodo.8413726. Zenodo.
Stuart, A.M., Kong, P., Then, R., Flor, R.J., Sathya, K., 2020. Tailor-made solutions to tackle rodent pests of rice through community-based management approaches in Cambodia. Crop Protect. 135, 104717 https://doi.org/10.1016/j.cropro.2019.01.023.
Swanepoel, L.H., Swanepoel, C.M., Brown, P.R., Eiseb, S.J., Goodman, S.M., Keith, M., et al., 2017. A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: are we asking the right questions? PLoS One 12, e0174554. https://doi.org/10.1371/journal.pone.0174554.
Taylor, P.J., Arntzen, L., Hayter, M., Iles, M., Frean, J., Belmain, S., 2008. Understanding and managing sanitary risks due to rodent zoonoses in an African city: beyond the Boston Model. Integr. Zool. 3, 38–50. https://doi.org/10.1111/j.1749-4877.2008.00072.x.
TheWaterChannel, 2020. Ecologically based rodent management. https://thewaterchannel.tv/videos/ecologically-based-rodent-management/. (Accessed 22 February 2024).
TheWaterChannel, 2023. Bio-rodenticide. https://thewaterchannel.tv/videos/bio-rodenticide/. (Accessed 22 February 2024).
Tilahun, T., Engdayehu, G., Wondmnow, B., Bosma, L., 2022. Establishing ecological based rodent management in Ethiopia – Part 3: collective implementation and ways forward. https://thewaterchannel.tv/thewaterblog/establishing-ecological-based-rodent-management-in-ethiopia-part-3-collective-implementation-and-ways-forward/. (Accessed 22 February 2024).
UN Habitat, 2014. October 6 World Habitat Day. Voices of Slums. Background Paper, p. 6.
UN Habitat, 2019. World Urbanization Prospects: the 2018 Revision, p. 126.
University of Greenwich, 2016. Comment contrôler les rongeurs - en français. https://www.youtube.com/watch?v=uYB3pIuS1Fw. (Accessed 22 February 2024).
Wang, D., Li, Q., Li, K., Guo, Y., 2017. Modified trap barrier system for the management of rodents in maize fields in Jilin Province, China. Crop Protect. 98, 172–178. https://doi.org/10.1016/j.cropro.2017.03.025.
Wen, X., Yuan, S., Li, L., Dai, Q., Yang, L., Jiang, F., Lin, X.A., 2022. A systematic review and meta-analysis of the inhibitory effects of plant-derived sterilants on rodent population abundance. Toxins 14, 487. https://doi.org/10.3390/toxins14070487.
Williams, S.B., Baributsa, D., Woloshuk, C., 2014. Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination. J. Stored Prod. Res. 59, 190–196. https://doi.org/10.1016/j.jspr.2014.08.003.