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From Problem to Progress: Management of Rodents in Urban and Agricultural Settings in Sub-Saharan Africa

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Abstract: The prevalent use of synthetic chemical rodenticides (both 1st or 2nd generation anticoagulants and acute rodenticides) is the primary method for managing rodents in sub-Saharan Africa. However, this practice poses substantial health and environmental risks and often fails to yield significant, sustainable reductions in rodent pest populations. In this paper, the second one of a two-part series, we advocate for a more responsible and sustainable approach to rodent management in urban and agricultural settings in sub-Saharan Africa. We propose a shift towards environmentally friendly rodent management strategies, specifically emphasizing the adoption of Ecologically-Based Rodent Management (EBRM) as a viable alternative to synthetic chemical rodenticides. EBRM relies on a comprehensive understanding of pest rodent biology, ecology, and behavior, along with the implementation of a range of community-based interventions. These actions are designed to ensure the consistent reduction of rodent pest populations to economically and hygienically acceptable levels. By embracing EBRM, we not only anticipate a reduction in the social impacts of pest rodents in a cost-effective manner but also a significant decrease in the risks posed by rodents and synthetic chemical rodenticides to human health and the environment. This paradigm shift towards EBRM promises a more sustainable and responsible approach to rodent management in sub-Saharan Africa.

Author summary: In sub-Saharan Africa, urbanization and agricultural intensification have increased the risk of proliferation of rodents in urban and rural habitats. Management of rodent populations is a challenge in terms of food security and public health. However, traditionally, efforts to manage rodents are reactive and based on inadequate use of synthetic chemical rodenticides. This approach carries substantial environmental and health risks and has yielded limited success in terms of reduction of rodent populations. In response, we

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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 rodent biology and involves community-based interventions aimed at reducing rodent abundance to economically and hygienically acceptable levels in the long term. We present a comprehensive compilation of published and unpublished information derived from observational field studies conducted in Ethiopia, Benin, Niger, Nigeria, 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 hope to stimulate further research and interventions that promote EBRM in the socio-ecosystems of Africa, ultimately fostering more environmentally conscious and effective solutions.

Keywords: Africa; ecologically based rodent management; field rodents; pest management; rodent control; rodenticides; rodents; synanthropic rodents

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1. Introduction: Ecologically-Based Rodent Management – An Environment-Friendly Alternative to Synthetic Chemical Rodenticides

Rodent-related issues in sub-Saharan Africa, both in urban and agricultural habitats, are a matter of significant concern. 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. In agricultural settings, rodent infestations persistently undermine crop yields and food security. The prevailing rodent management strategies primarily hinge on synthetic chemical rodenticides, 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 one of a two-part series, with the first part [1] highlighting the adverse impacts of synthetic rodenticides extensively used against pest rodents in Sub-Saharan Africa, encompassing both urban and agricultural settings. In response to these concerns, here we emphasize the urgency for better control over the use of synthetic chemical rodenticides and advocated for a shift 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 [2-6]. It mobilizes a panel of various rodent management methods that are integrated into robust community-based implementation protocols adapted to local situations. These methods may comprise biological (e.g., predators, botanical rodenticides or repellents), ecological (e.g., habitat management), mechanical (e.g., selective trapping), agronomic (e.g., crop rotation) and cultural (e.g., hunting, rodent-proof storage facilities) actions that must sometimes be implemented at different key times of the year, (e.g., rodent population dynamics, 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). 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.

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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 [2-9], where socio-cultural structures and practices greatly facilitate community-based approaches and the extension of EBRM by local farmers [4]. EBRM was trialled recently in rural areas of Southern and Eastern Africa at a much smaller scale [10-12] and, to our knowledge, attempts are still lacking in a wide range of countries, especially in Central and West Africa (see Supplementary material, S1 Table). In addition, the big picture has not been drawn yet [13], so arguments to anticipate its acceptance, adoption and appropriation by African farmers are lacking and extra studies are still required to evaluate further the pertinence and long-term sustainability of EBRM in rural Africa. Furthermore, we are not aware of any EBRM activity formally tested in African urban settings, but see [11] for a first attempt focusing on household sanitary aspects.

In this paper, we draw from various examples across sub-Saharan Africa, encompassing Senegal, Mauritania, Mali, Niger, Nigeria, Benin, and Ethiopia, in addition to well-documented case studies from Southern and Eastern Africa (S1 Table). Through these case studies, we aim (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. Results and Discussions

2.1. EBRM in Sub-Saharan African Cities and Their Immediate Peripheries

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 [14, 15]. 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. For instance, in a series of 376 villages and towns that have been investigated from 1983 to 2014 in Senegal, rodents were trapped in 94.6% of the 700 indoor sampling sessions [16]. In a cross-sectional survey involving 500 residents to investigate community awareness and attitudes toward rodent control concerning Lassa fever in the city of Osogbo (Nigeria), 90.9% of residents in this slum communities reported having encountered rodents within their homes [17]. 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 hours. The primary natural host for the Lassa 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 [18]. 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 79-94% 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 respectively 58 of 68 (85.3%) and 64 of 65 (98.4%) trapping sessions [19]. 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 [20]. These data highlight the very close proximity between rodents and human beings in sub-Saharan African cities.

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 in Lagos (Nigeria), plague in Antananarivo (Madagascar) and

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Dakar (Senegal) in the early 20th century), see [21, 22]. 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. Besides, 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. This results not only in non-negligible extra costs to households [12, 20], but also in 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 [23]. Studies highlight the multifaceted and significant economic burdens of rodents in urban communities across Africa [12, 20]. These burdens include agricultural losses due to crop 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.

Note that in such urban socio-ecosystems, EBRM has been poorly tested [24]. Urban areas represent very peculiar sociological (e.g., socio-cultural heterogeneity, challenges to identify recognized and representative local leaders, complex house ownership and rental systems) and ecological (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) environments [25]. 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 [24]). The task at hand appears formidable, and we believe that well-coordinated, multidisciplinary interventional research is urgently needed in this regard.

2.2. EBRM in Rural Africa, with Special Emphasis on Sahelian Region

2.2.1. The Ethiopian EBRM Experience

In rural areas, some EBRM programs have been tested. In the Amhara Region of Ethiopia, MetaMeta, a Dutch social enterprise working with smallholder farmers in several countries, introduced an EBRM package [26, 27] in 2019 for smallholder mixed cropping systems (growing wheat, barley and potato coupled with animal husbandry cultivating in small plots of land, on average ranging from as little as 0.5 to a few hectares). Prior to the introduction of EBRM, farmers and extension workers claimed severe rodent damage (>25%) (our unpublished data). Long before the EBRM introduction, 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 to take 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 lower 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

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terraces (which previously believed to provide shelter for rodents), (ii) clearing grasses and bushes in the vicinity of these bunds and terraces to create an open strip of land measuring 1-2 meters that enhance 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 application of a newly developed bio-rodenticide (a plant origin product proven to toxify rodent pests, our unpublished data waiting for patenting procedures for publication) implemented in the form of campaigns in the watershed areas, where all members of the watersheds were involved, starting from the time of land preparation to harvesting. In close collaboration with rodent scientists, MetaMeta developed the bio-rodenticide (BR) using extracts derived from a combination of two locally available plant species, with no chemicals or additives used during the BR formulation, which has been tested in the form of a powder delivered as bait mixed linseed [28]. Its palatability, efficacy and potential harm to non-target species and the environment have been tested in the laboratory in Ethiopia. The palatability and efficacy tests were done on three rodent species (*Arvicanthis niloticus, Mastomys awashensis, Rattus rattus*), under controlled laboratory condition, resulting in cumulative average mortality rate of ≥ 74% at 96 hours. Furthermore, the median lethal dose (LD50) for combination, dosed at 120 mg/g was 11.35g. Pending publication of the full results in a subsequent paper, our independent post-implementation survey involving participants from the watershed campaigns indicated that farmers perceived that rodent damages had been cut by a magnitude of up to 50% after two years of EBRM practicing. Moreover, the survey also 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 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 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 [29]. 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 [30].

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 [31] and references therein). Although this probably deserves rigorous investigations, 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 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.

2.2.2. 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

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farmers, appear to be promising to reduce pest gerbil populations in extensive pluvial millet fields in Central Niger. As evidence, during a brief trial, 37 captures were made in just three nights using 49 Kornaka traps, resulting in a capture rate of 25.2%. In comparison, 22 captures were achieved in five nights with 256 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 [32].

Additionally, in response a to a shortage of chemical rodenticides, Crop Protection officers in Ogo (Matam, Senegal) experimented 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). The additional labor requirements raised concerns, particularly in comparison to experiences in Asia [33].

In Northern Senegal, through a 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 [34, 35]. Notably, this research has unveiled key insights, such as the identification of specific agronomic and physical factors within irrigated rice fields that strongly favor rodent populations. These factors include features like accumulations of thorn bushes used as hedges (see Fig 1 A) and the presence of densely vegetated dikes, bunds, and irrigation canals (refer to Figs 2 A-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*) has shown a significant increase associated with environmental factors over a decade of monitoring in the Delta of River Senegal [34]. 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 stands at 1.02 [34]. Pest rodents also exploit uncultivated parcels or edges of fields, where they find shelter and reproduce before invading rice fields [34]. 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 are well-controlled on dikes and other structures (Figs 2 C-D).

From these observations, several elements of EBRM can be proposed (see for more information [13]). 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 used drip pipes (as already practiced by some farmers), or employing more durable options such as wire mesh or barbed wire (refer to Figs 1 B-F). Other potential measures include activities such as mowing grass 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.

The recurrence of major damages to food crops since the 1970’s, caused by recurring events of particularly high rodent pest abundances, has led West African states and/or international institutions to repeatedly call external expertise for assessing the critical situation and propose sustainable strategies for rodent management [36-40]. The rodent outbreak observed in the Senegal River valley during 2020-2021 is very 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 too late the FAO took for the first time an interdisciplinary approach, integrating combining socio-economic, biological, and ecological perspectives [35].

Of the total area of 111,643 ha cultivated with rice, 14 to 37% were reported to have been affected by rodents, depending on the region. This translates to an estimated loss of around 84,000 tons of paddy rice for a single cropping year, or 6 to 35% of the total expected rice production, depending on the region. The production loss was estimated at €26.5 million (ca. US$ 31.4million in 2020-2021), directly affecting nearly 40,000 households or 270,000 people, which accounted for 11 to 14% of the

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population of these regions [35]. Subsequent appraisals have outlined a lack of expertise and logistical constraints in national Crop Protection services, which present opportunities for targeted interventions.

In Senegal and Mauritania, Crop Protection officers have recently been trying to raise awareness among farmers, to encourage them 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 has been formulated in Mauritania [41]. 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 2022 in Mauritania involved mechanical/physical management methods such as clearing the vegetation used as hiding places 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 3); and use of pitfall traps. To support these efforts, national and regional authorities have introduced strong incentives where the allocation of inputs, such as fertilizers, are lined 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 (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, 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 [42]. 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 along the holes. Field studies in irrigated rice cropping systems in Southeast Asia have shown that this method reduces the abundance of rodents over a large area surrounding the “trap crop” which reduces damage and increases yield [43, 44]. It has been shown in Tanzania that a 20m x 20m 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% [45]. A simplified variant of cTBS, known as LTBS (Linear Trap Barrier System), has been tested in Asia [44, 46], and a pilot study is currently underway in the Senegal River delta [47]. LTBS comprises a stretch of plastic fencing with a minimum length of 100m long, which is partly buried underground to a depth of a few 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 fence [44]. 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 food production, health and environmental risk still needs to be quantified. Note that both cTBS and LTBS are likely to be most effective in irrigated rice fields and may encounter limitations when dealing with agile climbing rat species. Therefore, it is crucial to understand the specific behavior of rodent species in the fields under consideration. 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 damages, limit spoilage and reduce aflatoxin contamination [48-50].

Importantly, while some rodent management actions may be efficient to decrease rodent abundances and mitigate their deleterious impacts [2-10], they may inadvertently conflict with crucial socio-economic aspects. To ensure local suitability and adoption, first, it is imperative 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 shall be aligned with the local agricultural calendar in order to facilitate mobilization of resources for the task. Besides, 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 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 effect 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.

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3. Conclusion

The successful implementation of EBRM entails building on locally adapted communication and awareness raising campaigns aimed at mobilizing stakeholders. Various media channels can be used, including audio broadcasting [51, 52]; theatre plays, [53, 54]; and the distribution of brochures and practical guides [55-57]). 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 the 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. The timing of the implementation of the actions should be carefully planned in consultation with communities, taking into account for their knowledge, attitude and practice. Approaches such as Focus Group interviews (Fig 4), 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 at its infancy stage of development in sub-Saharan Africa, and recognizing the current lack of coordination among the small-scale trials done in several countries across the continent (see Supplementary material, S1 Table), we call for the establishment of a collaborative community of knowledge and practice. Such a community should be characterized by a shared, with the willingness and the pooling of skills by available experience, resources, as well as endogenous and scientific knowledge. In line with this vision, a "Green Rodent Control" network, inspired by the Ethiopian initiative, has recently been formalized recently for sub-Saharan Africa (see the provisional expert network hit map from the Rodent Green website: www.rodentgreen.com). This network has two primary objectives: (i) promoting EBRM in Africa, especially through the networking of academics working in the field across the continent, and (ii) fueling the development of interventional research programs on EBRM in various African socio-ecosystems.

4. Material and Methods

4.1. Methods and Scope of the Research

The study commenced with a comprehensive review of both published and unpublished literature focusing on rodent management in various sub-Saharan African regions. To ensure a comprehensive view, we considered examples from a wide geographical span within sub-Saharan Africa, including countries such as Senegal, Mauritania, Mali, Niger, Nigeria, Benin, and Ethiopia. A diverse range of data was collected from these regions, with a particular emphasis on case studies related to EBRM. The collected data 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 a comprehensive overview of EBRM case studies in regions beyond those typically documented in Southern and Eastern Africa and well-rounded perspective on rodent management practices in sub-Saharan Africa, highlighting the significance of EBRM as an alternative to synthetic rodenticides.

4.2. Ethics Statements

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. 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 [58]. 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 [59] 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.

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References

1. Dalecky A, Garba M, Ibrahim Danzabarma AA, Etougbetche J, Badou S, Dossou HJ, et al. Prolifération de rongeurs dans les milieux urbains et agricoles d'Afrique subsaharienne. Le côté obscur des rodenticides chimiques de synthèse [Rodent proliferation in urban and agricultural settings of sub-Saharan Africa. The dark side of synthetic chemical rodenticides]. Environnement, Risques & Santé. 2023; 22(3): 205-211. https://doi.org/10.1684/ers.2023.1731
2. Singleton GR, Leirs H, Hinds LA, Zhang Z. Ecologically-based management of rodent pests–re-evaluating our approach to an old problem. In Ecologically-based Management of Rodent Pests. Singleton GR, Leirs H, Hinds LA, Zhang Z, editors. Australian Centre for International Agricultural Research (ACIAR), Canberra. 1999; 17-29.
3. Singleton GR. Rodent outbreaks: ecology and impacts. Int. Rice Res. Inst.; 2010. 289 p. http://irri.org/knowledge/publications/irri-books/rodent-outbreaks-ecology-and-impacts
4. Palis FG, Singleton GR, Brown PR, Huan NH, Umali C, Nga NTD, et al. Can humans outsmart rodents? Learning to work collectively and strategically. Wildl Res. 2011; 38(7):568-78. https://doi.org/10.1071/WR10226
5. Singleton GR. Ecologically-Based Rodent Management 15 Years On: A Pathway to Sustainable Agricultural Production. Proceedings of the Vertebrate Pest Conference. 2014; 26(26). https://doi.org/10.5070/V426110594
6. Singleton GR, Lorica RP, Htwe NM, Stuart AM. Rodent management and cereal production in Asia: Balancing food security and conservation. Pest Management Science 2021; 77:4249–4261. https://doi.org/10.1002/ps.6462
7. Brown PR, Khamphoukeo K. Farmers' knowledge, attitudes, and practices with respect to rodent management in the upland and lowland farming systems of the Lao People's Democratic Republic. Integrative Zoology. 2007; 2(3):165-73. https://doi.org/10.1111/j.1749-4877.2007.00055.x
8. Ninh HN, Aragon C, Palis F, Rejesus R, Singleton G. Yield and Income Effects of Ecologically-based Rodent Management in Mekong River Delta, Vietnam. Journal of Contemporary Asia 2022; 13. https://doi.org/10.37801/ajad2016.13.2.4
9. My Phung NT, Brown PR, Leung LKP. 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. Agricultural Systems 116, 69-76. https://doi.org/10.1016/j.agsy.2012.11.003
10. Belmain SR, Dlamini N, Eiseb S, Kirsten F, Mahlaba T, Makundi R, et al. The ECORAT project: developing ecologically-based rodent management for the southern African region. International Pest Control. 2008; 50(3):136-8. https://doi.org/10.5073/jka.2011.432.091
11. Taylor PJ, Arntzen L, Hayter M, Iles M, Frean J, Belmain S. Understanding and managing sanitary risks due to rodent zoonoses in an African city: beyond the Boston Model. Integrative Zoology. 2008; 3(1):38-50. https://doi.org/10.1111/j.1749-4877.2008.00072.x
12. Constant NL, Swanepoel LH, Williams ST, Soarimalala V, Goodman SM, Massawe AT, et al. Comparative assessment on rodent impacts and cultural perceptions of ecologically based rodent management in 3 Afro-Malagasy farming regions. Integrative Zoology. 2020; 15(6):578-94. https://doi.org/10.1111/1749-4877.12447
13. Makundi RH, Massawe AW. Ecologically based rodent management in Africa: potential and challenges. Wildl Res. 2011; 38(7):588-95. https://doi.org/10.1071/WR10147
14. Habitat UN. October 6 World Habitat Day. Voices of slums. Background paper. 2014. 6 p.
15. UN Habitat. World urbanization prospects: the 2018 revision. 2019. 126 p.
16. Dalecky A, Bâ K, Piry S, Lippens C, Diagne CA, Kane M, et al. Range expansion of the invasive house mouse *Mus musculus domesticus* in Senegal, West Africa: a synthesis of trapping data over three decades, 1983–2014. Mammal Review. 2015; 45(3):176-90. https://doi.org/10.1111/mam.12043
17. Adebimpe WO. 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. 2015; 26-32. https://doi.org/10.14614/LASSANIGERIA.2.1.26
18. Garba M, Kane M, Gagare S, Kadaoure I, Sidikou R, Rossi JP, et al. Local perception of rodent-associated problems in Sahelian urban areas: a survey in Niamey, Niger. Urban Ecosystems. 2014; 17(2):573-84. https://doi.org/10.1007/s11252-013-0336-x

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19. Dossou H, Le Guyader M, Gauthier P, Badou S, Etougbetche J, Houemenou G, et al. 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. 2022. https://doi.org/10.1111/zph.12953
20. Odou SS. Nuisances des rongeurs à Cotonou: perceptions et organisations de la lutte par les habitants [License]. EPAC, Université d'Abomey-Calavi, Cotonou, Benin; 2018.
21. Sorel F, Armstrong. La lutte préventive contre la peste dans la circonscription de Dakar et dépendances durant l'année 1928. Annales de Médecine et de Pharmacie Coloniales. 1929; 27:64-72. https://www.biusante.parisdescartes.fr/histoire/medica/resultats/index.php?do=livre&cote=131132x1929x27
22. Cazanove F. Le problème du rat dans le territoire de Dakar et dépendances. Annales de Médecine et de Pharmacie Coloniales. 1932; 30:108-44. https://www.biusante.parisdescartes.fr/histoire/medica/resultats/index.php?do=livre&cote=131132x1932x30
23. Pertile AC, Lustosa R, Carvalho-Pereira T, Pedra GG, Panti-May JA, Oliveira U, et al. Evaluation of the impact of chemical control on the ecology of *Rattus norvegicus* of an urban community in Salvador, Brazil. PLoS ONE. 2022; 17(7):e0270568. https://doi.org/10.1371/journal.pone.0270568
24. Awoniyi AM, Venegas-Vargas C, Souza FN, Zeppelini CG, Hacker KP, Carvalho-Pereira T, et al. Population dynamics of synanthropic rodents after a chemical and infrastructural intervention in an urban low-income community. Scientific Reports. 2022; 12(1):10109. https://doi.org/10.1038/s41598-022-14474-6
25. Parsons MH, Jardine CM, Crowther MS, Himsworth CG. Editorial: Trends in Urban Rodent Monitoring and Mitigation: Improving Our Understanding of Population and Disease Ecology, Surveillance and Control. Frontiers in Ecology and Evolution. 2020; 7:522. https://doi.org/10.3389/fevo.2019.00522
26. Tilahun T, Engdayehu G, Wondmnow B, Bosma L. Establishing Ecological Based Rodent Management in Ethiopia – Part 3: Collective implementation and ways forward. 2022. https://thewaterchannel.tv/thewaterblog/establishing-ecological-based-rodent-management-in-ethiopia-part-3-collective-implementation-and-ways-forward/
27. Rodent Green Management. EBRM campaigns in Amhara region. 2023. https://www.rodentgreen.com/case-studies/ebrm-campaigns-in-amhara-region/
28. TheWaterChannel. Bio-Rodenticide. 2023. https://thewaterchannel.tv/videos/bio-rodenticide/
29. Meheretu Y, Ashenafi F, Kidane D, Welegerima K. Stored-grain losses and management practices among smallholder cereal farmers in Northern Ethiopia. International Journal of Pest Management. 2022; 68(1):59-68. https://doi.org/10.1080/09670874.2020.1795301
30. AGRA. Africa Agriculture Status Report: The Business of Smallholder Agriculture in Sub-Saharan Africa. (Issue 5). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA); 2017. 180 p.
31. Wen X, Yuan S, Li L, Dai Q, Yang L, Jiang F, Lin, X A. A Systematic Review and Meta-Analysis of the Inhibitory Effects of Plant-Derived Sterilants on Rodent Population Abundance. Toxins 2022, 14, 487. https://doi.org/10.3390/toxins14070487.
32. Hima K, Granjon L, Gauthier P, Ndiaye A, Brouat C, Dobigny G. Population Dynamics and Genetics of *Gerbillus nigeriae* in Central Sahel: Implications for Rodent Pest Control. Ecology and Evolutionary Biology. 2019; 4(4):45. https://doi.org/10.11648/j.eeb.20190404.11
33. Brown P, Khamphoukeo K, Sonekham, Invanh, Simone, Vison, et al. Development of rodent management strategies for the upland farming system in Lao PDR. Lao Journal of Agriculture and Forestry. 2007; 15, 124-145.
34. Niang CT, Kane M, Niang Y, Sarr N, March L, Tatard C, et al. 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. 2022;71:22015. https://doi.org/10.25225/jvb.22015
35. Bori A, Dalecky A. 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; 2021. 40 p. http://dx.doi.org/10.13140/RG.2.2.13813.70887.
36. Giban J. 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; 1967. 43 p. http://vminfotron-dev.mpl.ird.fr:8080/masto2_2/infos/043.pdf
37. Bernard J. Les dégâts de rongeurs dans le bassin du fleuve Sénégal et dans d'autres régions de la République du Sénégal. Rome, Italie: OMVS, PNUD, FAO; 1976. 34 p.
38. Fall MW. Rodent Control in Senegal: Present Problems, Future Needs. Denver, Colorado, USA: Denver Wildlife Research Center; 1976. 31 p. https://pdf.usaid.gov/pdf_docs/PNAAG459.pdf

 doi:10.20944/preprints202301.0275.v3

39. Duplantier JM. Rapport sur la mission au Sénégal effectuée du 30 mai au 6 juin 1987. Montpellier, France: ORSTOM; 1987. 5 p.
40. Gramet P. Proposition d'un programme de lutte à court, moyen et long terme à l'encontre des vertébrés ravageurs (Rongeurs et Oiseaux). FAO, projet MAU/87/010; 1989. 38 p.
41. Garba M, Abdellahi Tah OM, Breika K. Stratégie de gestion intégrée des rongeurs en Mauritanie. FAO; 2021. 18 p.
42. Singleton GR, Sudarmaji, Jumanta, Tran QT, Nguyen QH. Physical control of rats in developing countries. In: Ecologically-Based Management of Rodent Pests. Singleton GR, Hinds LA, Leirs H, Zhang Z, editors. Canberra: Australian Centre for International Agricultural Research; 1999. p. 178-198. http://hdl.handle.net/102.100.100/212272?index=1
43. Singleton GR, Sudarmaji, Brown PR. Comparison of different sizes of physical barriers for controlling the impact of the rice field rat, *Rattus argentiventer*, in rice crops in Indonesia. Crop Protection. 2003; 22(1):7-13. https://doi.org/10.1016/S0261-2194(02)00060-1
44. Wang D, Li Q, Li K, Guo Y. Modified trap barrier system for the management of rodents in maize fields in Jilin Province, China. Crop Protection. 2017; 98:172-8. https://doi.org/10.1016/j.cropro.2017.03.025
45. Mulungu LS, Mchukya BM, Mnyone LL. Trap Barrier System (TBS) as a New Tool for Rodent Pest Management in Irrigated Rice in Africa. In: Pests Control and Acarology. IntechOpen; 2020. https://doi.org/10.5772/intechopen.81828
46. Stuart AM, Kong P, Then R, Flor RJ, Sathya K. Tailor-made solutions to tackle rodent pests of rice through community-based management approaches in Cambodia. Crop Protection. 2020; 135:104717. https://doi.org/10.1016/j.cropro.2019.01.023
47. Sow, I, Kane, M, Kandé, O, Niang, Y, Meheretu, Y, Dalecky, A. Enhancing rice field resilience: Pioneering Ecologically-Based Rodent Management in the Senegal River delta. [Poster]. The 14th African Small Mammal Symposium (ASMS), Namibia, 17-22 Sept. 2023. Zenodo. 2023. https://doi.org/10.5281/zenodo.8413726
48. Baributsa D, Cristine M. Developments in the use of hermetic bags for grain storage. In: Advances in postharvest management of cereals and grains. Burleigh Dodds Science Publishing; 2020. p. 171-98. https://doi.org/10.19103/AS.2020.0072.06
49. Baoua IB, Amadou L, Bakoye O, Baributsa D, Murdock LL. Triple bagging hermetic technology for post-harvest preservation of paddy rice *Oryza sativa* L. in the Sahel of West Africa. Journal of Stored Products Research. 2016; 68:73-9. https://doi.org/10.1016/j.jspr.2016.04.006
50. Williams SB, Baributsa D, Woloshuk C. Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination. Journal of Stored Products Research. 2014; 59:190-6. https://doi.org/10.1016/j.jspr.2014.08.003
51. CERISE project - scientific information on invasive rodents in Senegal. 2018. http://projetcerise-ird-frb.fr & https://www.youtube.com/watch?v=sHH7F10oto4
52. Meheretu Y. Agriculture's Rodent Problem. TheWaterChannel, Episode 9. Available online: https://soundcloud.com/user-622446535 (accessed on 12/01/2023).
53. CERISE project - Theater play in local towns of Senegal. 2018. Available online: http://projetcerise-ird-frb.fr & https://www.youtube.com/watch?v=AQpJDKCdB4o&t=378s (accessed on 12/01/2023).
54. Des Envahisseurs au Sahel / Invaders in the Sahel Available online: http://projetcerise-ird-frb.fr & https://www.youtube.com/watch?v=kC5r94LWiWU (accessed on 12/01/2023). 2018.
55. Engdayeh G, Meheretu Y, Tilahun T, Wondmnow B, Bosma L, frank van S. Practical Guideline. Effectively Controlling Rats with Ecological Methods. Ethiopia edition 2020, Available online: https://metameta.nl/resources/manual-rodent-control (accessed on 12/01/2023) Ethiopia edition 2020.
56. Rodent Green Management. Implementing Ecologically Based Rodent Management Available online: http://www.rodentgreen.com/ebrm/ (accessed on 12/01/2023).
57. Comment contrôler les rongeurs - en français Available online: https://www.youtube.com/watch?v=uYB3pIuS1Fw (accessed on 12/01/2023). University of Greenwich 2016.
58. Sikes RS & the Animal Care and Use Committee of the American Society of Mammalogists. 2016 guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. J. Mammal. 2016; 97: 663–688. https://doi.org/10.1093/jmammal/gyw078
59. Mills JN, Childs JE, Ksiazek TG et al. Methods for trapping and sampling small mammals for virologic testing. U.S. Department of Health & Human Services, Atlanta, USA 1995.

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