Quasim *et al.*
Bulletin of the National Research Centre (2023) 47:82
https://doi.org/10.1186/s42269-023-01055-4

Bulletin of the National Research Centre

REVIEW

Open Access

Herbal rodent repellent: a dependable and dynamic approach in defiance of synthetic repellent

Md. Asad Quasim[1], Abhishek Kumar Karn[1], Sujata Paul[1], El Bethel Lalthavel Hmar[1] and Hemanta Kumar Sharma[1*]

Abstract

Background Rodents are the most common and diverse order of mammals, the most troublesome pest in agriculture, gardening, forestry, and public products, and to blame for the spread of many illnesses to humans and animals. In terms of rodenticidal exposure, rodenticide use is only to kill the rodent, not to repel it. On the other hand, herbal rodent repellents are compounds that, by taste, odour, or both, keep rodents away from human habitat and prevent diseases spread due to them. Herbal rodent repellents are more potent, economical, biodegradable, and do not persist in the soil or water, and they also have a broad range of other biological properties.

Main body of the abstract Rodents are a prevalent and harmful pest that accounts for more than 2277 species distributed all over the world. The growing public awareness of the ethical and animal welfare problems associated with traditional pest animal control methods has progressively switched to non-lethal alternatives for the management of rodents. This article promotes herbal rodent repellents due to the various reported toxic effects of synthetic rodenticides on human health and the environment. The review discusses some of the important herbs that have the potency to repel rodents thereby raising awareness for the use of non-toxic methods for pest control. Data from different database like PubMed, Google Scholar, Research Gate, PLOS One, and others were retrieved, and then, an extensive literature review was carried out to prepare the article.

Short conclusion From the information provided, it can be concluded that rodenticide poisoning could cause a serious public health issue with a high case death rate. Increasing public understanding of rodenticide toxicity, as well as stringent monitoring of rodenticide sales and use, might assist to reduce indiscriminate use and poisoning. Therefore, herbal rodent repellents, due to their least toxicity, could provide a safe and dynamic approach over the use of synthetic rodenticides.

Keywords Rodent, Agriculture, Pest management, Rodenticide, Herbal repellent

Background

Rodents are one among the most problematic mammalian pests, causing major pre-harvest losses worldwide (Hansen et al. 2016), with about 46 genera and 128 species reported in India (Parshad 1999). Rodents are considered the most common and varied group of mammals (Bala, Bindu Bala, and Babbar 2019). Except for Antarctica, every continent has a wide variety of animals (Witmer et al. 2022). Despite the fact that wide varieties of rodents are known to destroy crops and other public properties (Wondifraw et al. 2021). In a published publication, the Indian Grain Storage Management and Research Institute (IGMRI) reported

*Correspondence:
Hemanta Kumar Sharma
hemantasharma123@yahoo.co.in
Full list of author information is available at the end of the article

4.75% rodent damage to grain storage (Bala, Bindu Bala, and Babbar 2019). Rodents are also carriers of diseases such as viruses, fungi, and bacteria and are associated with human health issues. At least 80 zoonotic diseases transmitted by rodents have been identified (Singla et al. 2014). Only a few synthetic rodenticide products are now on the market since they are responsible for the majority of toxicoses in companion animals. There have been reports of rodenticide toxicoses in several different countries (Rached et al. 2020). Natural rodent repellents are preferable to synthetic rodenticides because they have fewer negative effects on human health and the environment and have better repelling activity (Mendoza et al. 2020). The essential oils of several plant species have been tested to establish their efficiency as an important natural resource for repelling pests (Sharma et al. 2019).

Main text

Rodent species

Rodents are a severe nuisance in horticultural and commercial environments (Bala et al. 2019). There are about 40% of all mammals in India (Gorbunova et al. 2008). There are 18 species that have commensal and horticultural irritations (for example, *Bandicota. bengalensis, Tatera indica, Millardia meltada, Meriones hurrianae, Gerbillus gleadowi, Rattus nitidus, Nesokia indica, Rattus. Rattus, Rattus norvegicus, Mus musculus,* etc.) in Himachal Pradesh, Punjab, Madhya Pradesh Gujarat, Rajasthan, Uttar Pradesh, Bihar, Andhra Pradesh, Tamil Nadu, Kerala and the north-eastern hill areas and other regions of India (Nada et al. 2016). In India, there are 18 different varieties of rodents that are bugs in farming, agriculture, forestry, animal and human habitation, and rural and urban storerooms, and around 5% of rodent species are dangerous to humans (Hansen et al. 2016; Sharma et al. 2019).

The mouse belongs to one of five rodent families. *Muridae* is the most prevalent family, and it has a great number of species (approximately 1082) (Mendoza et al. 2020). *Muridae* is divided into four subfamilies: Old World rats and mice (*Murinae*), New World rodents and mice (*Sigmodontiae*), voles (*Arvicolinae*), and hamsters (*Cricetinae*). jerboas, bouncing mice (*Zapodidae*), and Dormice (*Gliridae and Seleviniidae*) are examples of different families (*Dipodidae*) (Gorbunova et al. 2008). House rats (*Rattus rattus*) and house mice (*Mus musculus*) are important commensal species, but brown rats (*Rattus norvegicus*) are invasive species around the world due to their intimate relationship with people (Islam et al. 2021). Whereas Cape mole rats live alone and social mole rodents live in large colonies, naked mole rodents and regular mole rodents (genus *Cryptomys*) are social and inhabit vast colonies (Gorbunova et al. 2008). The Asian house rat (*Rattus tanezumi*) is the closest sister group to the black rat (Yu et al. 2022). The Indian mole rodent *Bandicota bengalensis* is a significant bug in South Asia (Saini et al. 1991). Major species of rodent found in India are summarized (Sharma et al. 2019; Mumtaz et al. 2022) in Table 1.

Agriculture losses by rodents

According to several discoveries, rodents damage pests in public goods, agriculture, and the food business (Neena Singla et al. 2022). Rodent outbreaks result in severe losses that put people's access to food in danger (Kumar et al. 2021). Rodents have a wide range of harmful impacts, including pre-harvest crop destruction and post-harvest damage to stored materials and structures (Phukon et al. 2019). Rodents frequently cause crop

Table 1 The major rodents species found in India

Species	Colour	Average wt (gm)	Body shape/size	Muzzle (mouth part, nostril)	Tail	Feeding
Mus musculus (House mouse)	Grey	12–20	Small	Slender (Sharp)	The tail is equal to the body and head	Omnivorous
Rattus rattus (Black rat)	Black	100–120	Slender	Pointed	The tail is longer than Body and head	Omnivorous
Rattus norvegicus (Brown rat)	Brown	250–300	Heavy set	Blunt	Tail is more limited than body and head	Omnivorous
Bandicota bengalensis (Indian mole rat)	Brownish or Brownish grey	350	Large	Broad and rounded	Tail is more limited than the head and body length	Omnivorous
Bandicota indica (Greater bandicoot rat)	Brownish to blackish	0.5–1000	Large	Broad and short	Tail is more limited than its head	Omnivorous
Suncus murinus (Indian musk Shrew)	Grey to blackish	23–147.3	Small	Muzzle is tapers, narrow, and long rostrally	A piece smaller at the tip and thick at the base	Insectivorous

damage before harvest in Asia and Africa (Hansen et al. 2016). Rodents may destroy almost any crop planted anywhere on the globe, including cereal grains, potatoes, vegetables, sugarcane, alfalfa, tree fruits, cotton, and many more (Witmer et al. 2022). In India, rats and mice contaminate food products with their urine, excrement, and hair, negatively affecting their quality and quantity. At the same time, they are being stored, causing at least $5 billion in annual grain losses (Herawati et al. 2021; Ganjeer et al. 2021). According to a previous report, up to 450 kg/ha of various grains suffered damage due to improper food handling (Phukon et al. 2019).

There have been reports of up to 100% loss of *oyoungul* wheat, 34% loss of grain, and Maize crops damaged by 20% in Western Kenya (Hansen et al. 2016). Estimates reveal a 15–40% loss in pulses and oil seeds, 13–29% in roots, 9–48% in coffee, and 21–60% in cotton due to rat damage in Ethiopia. The survey also discovered a 26.4% loss of maize harvests in central Ethiopia, a 9–44% loss of wheat in northern Ethiopia, and a half-harvest loss in Ethiopia's east. Rattus and Mus, which are commensal rodents, generally do less damage than other rodent species in the region, although their impact can range from 1 to 15%, and it can be much greater on certain islands. The quantity of grain swallowed by rodents in Asia alone would provide enough nutritious food for 200 million humans for a year, as an example of the incredible amounts of rat damage that may occur (Witmer et al. 2022; Wondifraw et al. 2021).

Wild Indian house rats (*Rattus*) pose a significant hazard to agricultural development in West Bengal (Sharma et al. 2019). Rodent prevalence in rice farms in India ranges from 0.44 to 60.8%. This study discusses four mouse species found in rice fields in Assam. *Bandicota bengalensis* was the most prevalent species, accounting for 36.60% of the total overflow, with *B. indica* accounting for 19.08%. *Rattus sikkimensis* at 5.82% and *Mus booduga* at 15.42%. According to Assam research in 2015–2017, the pumpkin had the greatest live burrow count (LBC) of field rodents (36.60%) in a cropping pattern that included rice and vegetables, followed by potatoes (34.40%), peas (29.90%), brinjal (28.80%), and carrots (24.00%). The vegetables that produced the most damage were potatoes (14.46%), peas (14.0%), and pumpkins (12.20%). The amount of grain stored by lesser bandicoot rodents has been shown in India, Pakistan, and Bangladesh due to their irritation level and negative financial impact on rice and wheat output (Phukon et al. 2019). Rodents damage 4 to 26% of groundnuts in India. Rodents damaged up to 85% of the crops in Gujarat, while rodent activity reduced groundnut yield in Panjab by roughly 50 kg/ha (Ganjeer et al. 2021). These are generally identified as the leading rice irritant in Southeast Asia, behind only weeds (Htwe et al. 2019). Rats and mice can destroy up to 4.9% of rice, 6.4% of sugarcane, 3.9% of groundnuts, 4.5% of wheat, 5.9% of peas, and 10.7% of winter maize in India's Panjab area (Kaur et al. 2019).

According to Malhi and Prashad's research, there was a pre-harvest and post-harvest loss of around 4.31% of wheat and 4.64% of rice. Moreover, rodents (Indian gerbil, *Tatera indica*, soft-furred field rats, *Millardia meltada*, and *B. bengalensis*) affected high-protein seeds (pulses and oilseeds) like moong, arhar, and lentil pods, soybeans, and Bengal gramme. *Rattus* damages cocoa, cardamom, and coconut plants by 10–32%. In 1996, the Indian government formed a commission to document storage losses of 9.33% of food supplies and 2.5% due to rats. The overall post-harvest loss of wheat might reach 4.75%, according to national studies done by IGMRI, with rodents accounting for 0.59% of the loss (Rao 2003).

Rodents associated with human health & environmental problems

Rodents are also responsible for transmitting various diseases of humans and animals and improving defencelessness to viral, fungal, and bacterial infections such as Rat-bite fever, *salmonellosis*, the plague, *toxoplasmosis, Capillaria hepatica, leishmaniasis, and leptospirosis* that resembles *Lassa fever, taeniasis, haemorrhagic fever with renal syndrome* (HFRS), *zoonotic babesiosis;* and the hantavirus cardiopulmonary syndrome (HCPS) and South American Haemorrhagic Fevers (SAHF) both brought on by *Hantavirus* and other *Arenaviruses*; a number of complicated bacteria, including *Mycobacterium tuberculosis* and *Lyme disease*, *Escherichia coli, Mycobacterium microti,* agents of *tularemia, listeriosis*, tick-borne relapsing fever, *Q fever*, *ehrlichiosis, bartonellosis,* others (Sharma et al. 2019; Gorbunova et al. 2008; Nakayama et al. 2019). Parasites include *toxoplasmosis, giardiasis*, and *echinococcus* infection (Hansen et al. 2016). In 2016, the World Health Organization (WHO) highlighted the notice's urgently innovative work for mentioning serious new disorders that might lead to a worldwide public health emergency (Nimo-Paintsil et al. 2019). Rodent-borne illnesses are transferred either directly or indirectly. Indirect transmission occurs when people are infected by polishing off food and drink contaminated by their faeces or urine. Still, direct transmission occurs when people are infected by biting or breathing in the microorganism containing the rat bite (Biswas 2018).

Pathogens from *Gliridae, Dipodidae (Gerbilinae, Murinae, and Dendromurinae), Muridae*, and other rodent families (33 species) are transmitted to humans (Singla et al. 2013). More rodents increase the possibility of people coming into contact with them and, if necessary, the risk of transmitting highly contagious diseases. The brown and dark rats (*Linneaus, Rattus rattus, Berkenhout,* and *Rattus norvegicus*) originates in Asia and are found near people worldwide today. Pathogenic bacteria transported by rodents included *Yersinia pestis, Bartonella*, and *Hantavirus*. Both dark and brown rats have acquired a variety of macro parasites outside of their natural habitats. As a result, they act as efficient disease carriers among wildlife, domesticated animals, vectors, and humans (Strand et al. 2019; Griffiths et al. 2022). The oriental house rodent (*Rattus tanezumi*) is the source of *rickettsial* infections as well as *Hantaviruses, Trypanosoma spp., Bartonella spp.*, and *Leptospira spp.,* (Prompiram et al. 2020). *Mus musculus* has carried 14 illnesses, *Rattus rattus* has carried 13 diseases, *Meriones persicus* has carried 7 diseases, *Apodemus species* has carried 5 diseases, *Tatera indica* has carried 4 diseases, *Rhombomys Optimus* has carried 3 diseases, *Cricetulus migratorius* has carried 3 diseases, and *Nesokia indica* has carried 2 diseases (Rabiee et al. 2018). *Lassa viruses* (LASV) are caused by a variety of rodent species, including *Mastomys erythroleucus, Mastomys natalensis*, *Mastomys natalensis, Hylomyscus pamfi,* and *Mastomys erythroleucus* (Nimo-Paintsil et al. 2019). Bank voles (*Myodes glareolus Schreber*) and Wood mice (*Apodemus sylvaticus Linnaeus*) are hosts to many rodent-borne illnesses, including *Borrelia afzelii, Borrelia miyamotoi, Babesia microti*, and *Neoehrlichia mikurensis* (Krawczyk et al. 2020). Ectoparasite transmission agents are rodents. Scrub typhus and other typhus are caused by ectoparasites, which are present in vegetable food in India. Ectoparasites spread quickly during the rainy season, then in the winter and summer (Samuel et al. 2020, 2021).

Plague, one of the oldest, most startling, and most stunning pestilential rodent-borne zoonotic illnesses, continues to be a serious general medical problem in multiple countries across the world (Griffiths et al. 2022), and the disease is caused by *Yersinia pestis*, an *Enterobacteriaceae* family member (Ganjeer et al. 2021). The plague was one of three global epidemic diseases subject to International Health Rules and notifiable to the WHO (Biswas 2018). The plague has spread over North and South America, Asia, and Africa. The multimammate rat (*Mastomys natalensis*) is primary source of direct or indirect transmission of the Lassa virus, which causes an exceedingly fatal haemorrhagic fever in people in West Africa. In September and October 1994, a fresh epidemic of plague in India sickened roughly 4000 people, with approximately 10 fatalities (Parshad 1999). There are two types of rodents that are typically responsible for plague transmission in India: the *smaller bandicoot, Bandicota bengalensis*, and the house rat, *Rattus rattus* (Namala et al. 2022). The National Institute of Communicable Diseases (NCDC) recognised evidence of plague disease among small vertebrates of various species, including *Rattus* (0.54%), *Tatera indica* (4.76%), *Bandicota bengalensis* (0.6%), and *Funumbulus palmarum* (8.0%), during their expanded examinations in 1970 (Biswas 2018).

The subfamilies *Murinae* and *Arvicolinae* of hantavirus-carrying rodents cause *HFRS,* whereas *Neotominae* and *Sigmodontinae* induce *HCPS*. *HFRS* has also been connected to the *Puumala virus*, an *arvicoline-borne virus*. The *Hantaan* and *Seoul viruses,* which have a worldwide distribution, are hosted by *Apodemus agrarius* and *Rattus norvegicus* (Ganjeer et al. 2021). The *Seoul hantavirus* (SEOV), which causes severe sickness, has been found mostly in brown rats in China and Southeast Asia but also in other parts of the world. The illness caused by *SEOV* is known as *HFRS*, and it is characterised mostly by high fever, weakness, and severe kidney problems, with a fatality rate of 2–3% (Strand et al. 2019; Griffiths et al. 2022). According to research, more than 2000 persons in Brazil have been diagnosed with *hantavirus pulmonary syndrome* (HPS) (Ganjeer et al. 2021), and six *hantavirus* genotypes (*Araraquara, Anajatuba, Castelo dos Sonhos, Juquitiba, Laguna Negra, and Rio Mamore viruses*) have been found. These viruses are spread by wild rodent species (*Calomys callidus, Oligoryzomys mattogrossae, Oligoryzomys nigripes, Oligoryzomys utiaritensis, Necromys lasiurus,* and *Oligoryzomys microtisare*) (Fernandes et al. 2019).

Rickettsiae is an intracellular microbe in rats that is carried by *arthropod* vectors and is impacted by rodent species as natural reservoir hosts. Murine, and tick typhus are agents that responsible for causative infections such as R*ickettsiae, Rickettsia honei, Rickettsia typhi*, and *Orientia tsutsugamushi*, which are communicated from the rodent (Griffiths et al. 2022). The Armed Forces Research Institute of Medical Sciences (AFRIMS) revealed that the irregular frequency of scrub typhus in people was 7.11 and 5.82 per 100,000 population during 2018 and 2019 (Prompiram et al. 2020).

Leptospirosis is a widespread zoonotic illness carried by wild and urban rodents, and it is caused by 26 pathogens produced by *Leptospira species* (Ganjeer et al. 2021; Griffiths et al. 2022). In India, three rodent species have been identified as being implicated in this illness: *Rattus norvegicus, Rattus,* and *B. bengalensis* (Nada et al. 2016). Patients suffering from *leptospirosis* illness frequently have lung bleeding, hepatic failure, and renal failure (A. Sharma et al. 2020). In 2013, there were 71 fatal instances, and in 2014, there were 92. Over the last 10 years, *leptospirosis* outbreaks have been widespread in India. (Ganjeer et al. 2021).

The *lymphocytic choriomeningitis virus* (LCMV) is the virus responsible for *lymphocytic choriomeningitis* and discovered by Armstrong and Lillie in 1933, the viral infection carried by rodents. LCMV is a family *Arenaviridae* and member of the *Arenavirus genus* (Pal et al. 2022; Kinsella and Monk 2012). The reservoir hosts for LCMV include the house mouse (*Mus musculus*), the wood mouse (*Apodemus sylvaticus*), and the yellow-necked mouse (*Apodemus flavicollis*). Infected rodent bites, inhalation of aerosolized body fluid droplets, or infusion of contaminated substances into open wounds, the eyes, or the mouth can all result in human transmission (Pal et al. 2022; Emonet et al. 2007).

Crimean–Congo haemorrhagic fever (CCHF) is an infection caused by ticks that carry the *Crimean–Congo haemorrhagic fever virus* (CCHFV), which is a member of the family *Nairoviridae* and the genus *Nairovirus*. CCHF is essential to the tick life cycle because it has been isolated from rodents. 10,000 to 15,000 cases of *CCHF* are reported annually in Asia, Balkans and Africa, according to the WHO (Ganjeer et al. 2021). From 2011 to 2019, Gujarat, India, documented *CCHF* cases. Jodhpur, Jaisalmer, and Sirohi districts in Rajasthan, India, all reported *CCHF* outbreaks between August 2019 and November 2019 (Sahay et al. 2020).

Toxoplasma gondii (*T. gondii*) is an intracellular protozoan and is the cause of *toxoplasmosis*, a widespread illness in both people and animals. Rodents act as intermediate and reservoir hosts for *T. gondii* during maintenance and transmission (Ganjeer et al. 2021). When humans eat rodents as food, as is the case in many human cultures, *toxoplasmosis* can be transferred directly from rodents to humans (Galeh et al. 2020). According to research on *toxoplasmosis* in humans, latent *toxoplasmosis* affects almost a third of the world's population. Different species of rodents are associated with human health issues and the environment (Ganjeer et al. 2021), summarized in Table 2.

Environmental and human health problems associated with synthetics rodenticides

Rodenticides are primarily used in industrialized countries to manage commensal rodents such as house mice (*Mus spp*.), roof rats (*Rattus rattus*), and brown rats (*Rattus norvegicus*) for sanitary and public health reasons, in agricultural animal husbandry, in the food industry, and to a lesser extent for storage and material preservation (Regnery et al. 2019). Rodenticides are the most widely used approach in this country to manage the rodent problem (Okoniewski et al. 2021). Two primary rodenticide categories are anticoagulants and non-anticoagulants (Valchev et al. 2008). They can be grouped based on their modes of administration, such as poisoned baits, lethal gases, and contact foams, and their rates of action, such as acute, subacute, and chronic (Regnery et al. 2019). Acute rodenticides whose toxicity and effectiveness against rodents have been evaluated include zinc phosphide, aluminium phosphide, barium carbonate, arsenic trioxide, strychnine alkaloid, thallium sulphate, α naphthyl thiourea (ANTU), norbormide, scillirocide, sodium fluoroacetate, and gophacide. Bromethalin (0.005% or 0.01%), flupropadine, calciferol (ergocalciferol, vitamin D2), and cholecalciferol (vitamin D3) are subacute rodenticides. The only anticoagulant rodenticides are hydroxy coumarins or indane-dione compounds (Thiagesan et al. 2022; Fisher et al. 2019). Anticoagulant rodenticides (ARs) often harm a specific organ according to its mode of action, resulting in coagulopathy. Second-generation anticoagulant rodenticides (SGARs) are still categorized hazadious for reproduction. However, this has lately been called into doubt because they do not transfer to the foetus as much as first-generation anticoagulant rodenticides (FGAR), but instead, accumulate in the liver (Hohenberger et al. 2022; Hindmarch et al. 2018). The effects of first-generation anticoagulant rodenticides are cumulative and long-lasting. Warfarin (0.025%), fumarin (0.025%), coumatetralyl, diphacinone, and chlorophacinone are only a few of the chemicals that can successfully decrease rodent populations. SGARs such as difenacoum, brodifacoum (0.005%), bromadiolone, flocoumafen, and difethialone (0.0025%) have improved our capacity to control rodents (Topping et al. 2016; Elmeros et al. 2019). SGARs have a stronger binding affinity to the target enzyme Vitamin K epoxide reductase (VKOR) in the liver, resulting in a longer retention duration in the rodents' bodies. (Rattner et al. 2021; McGee et al. 2020).

One among the most often used non-anticoagulant rodenticides is bromethalin, a highly potent neurotoxin. It is dangerous because mitochondrial oxidative phosphorylation becomes uncoupled, resulting in a decrease in the quantity of adenosine triphosphate (ATP) that is readily available (Thiagesan et al. 2022). The liver swiftly converts it into a more dangerous metabolite. Rodenticide baits with vitamin D3 are available over the counter in a variety of brands. Upon intake, vitamin D-binding proteins in the liver rapidly absorb cholecalciferol. In animals, the major pathophysiological consequence of cholecalciferol overdose is hypercalcemia. The effects of *hypercalcemia* on excitable tissues may result in soft tissue mineralization (Zafalon et al. 2020). Zinc phosphide (2%) concentration is the most often used acute rodenticide. The establishment of bait shyness and the lack of a strong treatment limits its application. Its use is typically advised when there are no known toxicological problems with non-target species (Sangle et al. 1987). The principal intoxicant is phosphine gas, which is produced in the stomach when zinc

Table 2 The following table provides vector-borne diseases along with an illustration of the kind of pathogen that promote the disease in the host

Sl. No.	Diseases	Pathogenesis	Reservoir/carrier	References
01	Leptospirosis	*Leptospira icterohaemorrhagiae*	*Bandicoots Rattus rattus, Rattus norvegicus, Bandicota bengalensis, Nesokia indica, Mus musculus, Apodemus spp., Meriones libycus, Rhombomys opimus*	Sharma et al. (2019), Ganjeer et al. (2021), Rabiee et al. (2018)
02	Plague	*Yersina pestis*	*Tatera indica, Bandicota bengalensis, Meriones persicus, Meriones libycus, Mus platythrix, Mus booduga, Meriones vinogradovi, Meriones tristrami, Rattus rattus,*	Sharma et al. (2019), Rabiee et al. (2018), Bordes et al. (2015)
03	Rocky Mountain Spotted Fever	*Rickettsia rickettsia*	*Domestic and wild rodents*	Sharma et al. (2019), Ganjeer et al. (2021)
04	Salmonellosis	*Salmonella spp., Salmonella enteritidis*	*Mus Musculus, Rattus rattus, Rattus norvegicus*	Ganjeer et al. (2021), Rabiee et al. (2018)
05	Kyasanur Forest Disease (KFD)	*KFD Virus (Gen. Flavivirus), Flaviviridae*	*Small Rodents*	Sharma et al. (2019), Ganjeer et al. (2021), Bordes et al. (2015)
06	Yersiniosis	*Yersinia pseudotuberculosis, Yersinia entero-colitica*	*Rattus rattus, Rattus norvegicus*	Rabiee et al. (2018)
07	Leishmaniasis	*Leishmenia donovani, Leishmania infantom, Leishmania major, Leishmania tropica*	*Meriones persicus, Cricetulus migratorius, Meriones libycus, Rhombomys opimus, Tatera indica, Mus musculus, Nesokia indica, Gerbillus sp., Meriones hurrianae, Mesocricetus brandti, Rattus rattus, Ruttus norvegicus*	Sharma et al. (2019), Ganjeer et al. (2021), Bordes et al. (2015)
08	Venezuelan Equine Encephalitis (VEE)	*VEE Virus (Gen.Alphavirus)*	Wild Rodents'*: Sigmoden spp., Prochimys spp., Peromuscus spp., Oryzomys spp.*	Sharma et al. (2019), Bordes et al. (2015), Goei-jenbier et al. (2013)
09	Venezuelan Haemorrhagic fever	*Guanarito virus, Arenaviridae*	Cotton Rat*: Sigmodon alstoni* Cane Mouse*: Zygodontomys brevicanda*	Sharma et al. (2019), Ganjeer et al. (2021), Goei-jenbier et al. (2013)
10	Toxoplasmosis	*Toxoplasma gondii*	*Rattus rattus, Rattus norvegicus*	Ganjeer et al. (2021), Bordes et al. (2015)
11	Tick-borne Encephalitis (TBE)	*TBE Virus, Flaviviridae*	*Wild rodents*	Sharma et al. (2019), Ganjeer et al. (2021), Bordes et al. (2015)
12	Tick-borne relapsing fever	*Borrelia spp.*	*Rattus norvegicus*	Rabiee et al. (2018)
13	HFRS	*Hantavirus, Puumala virus, Dobrava virus, Seoul virus*	*Rodents*	Sharma et al. (2019), Ganjeer et al. (2021), Bordes et al. (2015), Goeijenbier et al. (2013)
14	Q fever	*Coxiella burnetii*	*Rodents*	Sharma et al. (2019), Ganjeer et al. (2021), Rabiee et al. (2018)
15	Lassa Fever	*LASV, Arenaviridae*	*Rodents': Mastomys natalensis*	Sharma et al. (2019), Ganjeer et al. (2021)
16	Scrub Typhus	*Rickettsia tsutsugamushi, Orientia tsutsuga-mushi*	*Rattus spp.*	Sharma et al. (2019), Ganjeer et al. (2021), Goei-jenbier et al. (2013)
17	Listeriosis	*Listeria spp., Listeria monocytogens*	*Rodents*	Ganjeer et al. (2021), Rabiee et al. (2018)
18	Lyme disease	*Borrelia burgodorferi*	*Rodents*	Ganjeer et al. (2021), Rabiee et al. (2018), Bordes et al. (2015)
19	Bartonellosis	*Bartonella spp.*	*Mus musculus*	Rabiee et al. (2018)
20	Rickettsial pox	*Rickettsia akari*	*Mus musculus*	Ganjeer et al. (2021)
21	Tuberculosis	*Mycobacterium tuberculosis complex*	*Mus musculus*	Rabiee et al. (2018)

Table 2 (continued)

Sl. No.	Diseases	Pathogenesis	Reservoir/carrier	References
22	Murine typhus	*Rickettsia typhi (mooseri)*	*Rattus norvegicus, Rattus rattus, Rattus exulans*	Sharma et al. (2019), Ganjeer et al. (2021)
23	Babesiosis	*Babesia spp., Babesia microti*	*Meriones persicus, Rattus norvegicus, Mus musculus*	Ganjeer et al. (2021), Bordes et al. (2015)
24	Hepatitis E	*HEV, Calciviridae*	*Rodents*	Ganjeer et al. (2021), Rabiee et al. (2018)
25	Tularemia	*Francisella tularensis*	*Microtus paradoxus, Tatera indica*	Ganjeer et al. (2021), Rabiee et al. (2018), Bordes et al. (2015)
26	Crimean–Congo Haemorrhagic fever	*CCHF, Bunyaviridae family*	*Allactaga williamsi, Mus musculus, Meriones crassus*	Ganjeer et al. (2021), Rabiee et al. (2018)
27	Boutonneuse Fever	*Rickettsia sibirica* *Rickettsia conori* *Rickettsia australis*	*Rattus spp.*	Sharma et al. (2019)
28	Chagas Disease	*Trypnosoma cruzi*	*Rodents*	Sharma et al. (2019), Ganjeer et al. (2021), Bordes et al. (2015)
29	Lymphocytic Choriomeningitis (LCMV) (Armstrong's disease)	*LCMV, Arenaviridae*	*Mus musculus*	Sharma et al. (2019), Ganjeer et al. (2021)
30	Cryptosporidiosis	*Cryptosporidium spp.*	*Mus musculus, Mus norvegicus, Rattus rattus,*	Ganjeer et al. (2021), Bordes et al. (2015)
31	Giardiasis	*Giardia lamblia (Giardia duodenalis)*	*Rodents*	Ganjeer et al. (2021)
32	Fasciolosis	*Fasciola hepatica, Fasciola gigantica*	*Rodents*	Rabiee et al. (2018)
33	Taeniasis	*Taenia spp.*	*Mus musculus, Rattus norvegicus, Rattus rattus, Apodemus spp.*	Ganjeer et al. (2021), Rabiee et al. (2018)
34	Hepatic capillariasis	*Capilaria hepatica*	*Meriones persicus, Mus musculus, Rattus rattus, Rattus norvegicus, Cricetulus migratorius*	Rabiee et al. (2018)
35	Hymenolepiasis (Rodentolepiasis)	*Rodentolepis nana, Rodentolepis diminuta*	*Rattus rattus, Rattus norvegicus, Mus musculus, Rhombomys opimus, Tatera indica, Apodemus spp., Meriones persicus, Microtus socialis, Cricetulus migratorius*	Rabiee et al. (2018)
36	Alveolar echinococcosis	*Echinococcus multilocularis*	*Microtus transcaspicus, Ochotona rufescens, Mus musculus, Crocidura gmelini, Apodemus spp.*	Rabiee et al. (2018)
37	Gongylonemiasis	*Gongylonema spp.*	*Rattus norvegicus, Rattus rattus*	Rabiee et al. (2018)
38	Trichuriasis	*Trichuris spp.*	*Mus musculus, Rattus norvegicus, Rattus rattus, Tatera indica*	Rabiee et al. (2018)
39	Argentine Haemorrhagic Fever	*Junin Virus*	Rodents': *Calomysmusculinus, C.Laucha, Akodonazarae*	Sharma et al. (2019)
40	Angiostrogyliasis A nematode disease of the CNS	*Arastrongy luscantonensis*	*Rattus and Bandicota Spp*	Sharma et al. (2019)
41	Machupo-Haemorrhagic fever	*Machupovirus*	*Calomyscallosus*	Sharma et al. (2019)
42	Encephalo-myocarditis	*EMC Virus*	*Rats and Mice*	Sharma et al. (2019)

Table 3 Toxicity caused from different rodenticides in human and other species

Sl. No.	Rodenticides	Toxicity/symptoms	References
1	Difenacoum, Warfarin, brodifacoum, chlorophacinone, and bromadiolone	*Haematuria, Haemoptysis, Epistaxis*, Flank pain, Easy bruising, Intracranial *haemorrhage*	Park (2014)
2	Coumatetralyl	High or frequent exposure might impair the blood's capacity to clot, resulting in haemorrhage. Easy bruising, nosebleeds, bleeding gums, and/or blood in the urine or stool are all symptoms. Coumatetralyl may cause a skin allergy	Hindmarch et al. (2018)
3	Chlorophacinone	*Polyuria, Polydipsia*, Vomiting, Renal failure, *Encephalopathy*	D'Silva et al. (2019)
4	Bromethalin	It operates as a neurotoxic, affecting both the central and peripheral nervous systems, since a shortage of ATP produces an increase in fluid surrounding neuron sheaths	Pasquale-Styles et al. (2006), Coppock (2013)
5	Norbormide	Causes Ischaemia resulting in organ failure followed by animal expiration	D'Silva et al. (2019)
6	Thallium	Tremor, *Ataxia*, Distal motor weakness, *Diplopia, Nystagmus*, Hyperpigmentation, Cranial nerve dysfunction, peripheral neuropathy, seizure	Yu et al. (2018)
7	Fluoroacetamide	Seizures, *Hypocalcemia*, Cerebellar atrophy or cerebral, Shock, Worsening metabolic acidosis, refractory to resuscitation,, Hepatic dysfunction, *Dysrhythmias*, Kidney injury	Wang et al. (2016)
8	Strychnine	Uncontrollable muscle spasms, *Trismus, Risus sardonicus, Opisthotonos, Rhabdomyolysis, Lactic acidosis, Hyperthermia*	Singhapricha et al. (2017)
9	Zinc and Aluminium Phosphide	*Acute gastritis, Cardiac arrhythmias, Haemorrhagic pulmonary oedema*, Respiratory failure, Intravascular haemolysis with *methemoglobinemia*, Hepatotoxicity, Metabolic acidosis, Respiratory alkalosis, Renal failure	Sangle et al. (1987), Yogendranathan et al. (2017)
10	Elemental Phosphorus	*Acute gastroenteritis*, Skin or mucosal burns, Phosphorescent faeces or emesis (smoking stool), *Dysrhythmias*, Hepatotoxicity, Renal failure	Ravikanth et al. (2017)
11	Arsenic	Vomiting, Bloody diarrhoea, Taste of garlic in the tongue, Hypotension, Prolonged QT segment, Delirium, seizures, coma, Renal injury	Zubair et al. (2017)
12	Barium Carbonate	Gastroenteritis, Hypertension, Cardiac arrhythmias, Shortness of breath, Muscle paralysis	Ghose et al. (2009)
13	Tetramethylene Disulfotetramine (TETS, Tetramine)	Convulsions, Coma, Respiratory failure, *Arrhythmias*	Rice et al. (2017)
14	Pyriminil, N-3-pyridylmethyl-N-p-nitrophenyl Urea (PNU)	Kussmaul breathing, *Hypotension, Encephalopathy*, Lethargy	D'Silva et al. (2019)
15	Cholecalciferol (Vitamin D3)	*Polyuria, Polydipsia, Vomiting, Renal failure, Encephalopathy, hypercalcemia*	Koul et al. (2011)

phosphide reacts with moisture and acid. It is believed that phosphine gas serves as a "universal protoplasmic poison" (Yogendranathan et al. 2017). Rodents are controlled with alpha-chlorohydrin (–CH) (0.5%), which has long-term negative effects on reproduction (Atta et al. 2021). It is suggested as part of the Integrated Pest Management (IPM) package for controlling rodents in crops with moderate rodent infestation levels (Elmeros et al. 2019). Aluminium phosphide pellets are effective for controlling field rats. Nevertheless, due to the increased toxicity of the chemical to non-target species and the absence of an antidote, the Indian government has banned its usage (Nada et al. 2016). Moreover, vitamin D compounds are less toxic to non-target species, and cortisol and sodium sulphate are indications of accidental poisoning in these animals (Nakayama et al. 2019).

An appropriate dose of anticoagulant rodenticide must be taken to properly extend the impact of interrupting the vitamin K cycle and affecting the blood clotting mechanism. Poisoned animals die as a result of internal bleeding. Two newly published edited books aim to consolidate information on environmental issues connected to the use of anticoagulant rodenticides for rodent control. These provide information about their chemistry, toxicity, and environmental consequences. Since anticoagulant rodenticides affect all vertebrates, there is a significant risk of unintentional poisoning of wild and domestic animals (Rattner et al. 2021; Berny et al. 2010). SGARs can enter the food chain through many different pathways. The bromadiolone that earthworms absorb from the soil, for example, can bioaccumulate and cause secondary poisoning in a variety of species that consume earthworms (Berny et al. 2010; Lemus et al. 2011). According to research done between 1998 and 2015, 2694 out of 4891 (55%) non-target animals had chronic AR accumulation in their livers (Nakayama et al. 2019). In 2013, the Canadian Federal Pest Management and Regulation Agency (PMRA) amended its standards for the use of ARs to reduce non-target species exposure and poisoning, as well as harm to people and their pets (Elmeros et al. 2019).

It is noted that despite the enormous risks and hazards, they represent to the environment and human health, as well as the negative impact they have on the target species' capacity to reproduce and resistance development (Rattner et al. 2021). Numerous studies have shown that rodenticides used in the field to protect plants and native species expose both target and non-target species to the same levels of toxicity (Schlötelburg et al. 2020). Anticoagulant poisoning, severe thrombocytopenia, haemophilia, or liver failure can all be lethal. Rodenticide usage has frequently resulted in unanticipated secondary poisoning of human health and non-target animals worldwide (Topping et al. 2016; Elmeros et al. 2019). The American Association of Poison Control Centres' documented 12,886 cases of rodenticide exposure National Poison Data System (Thiagesan et al. 2022). In the USA, there were around 10,000 unanticipated human rodenticide intake cases in 2017. There were 5186 reported occurrences of anticoagulants, 182 of which were caused by rodenticides with a warfarin-like action (Thiagesan et al. 2022; Hohenberger et al. 2022). Bromethalin was the second-most-often used rodenticide, with 1196 incidences. They noticed that rodenticide residues were often found in non-target animals throughout the world. Between 1998 and 2015, there was a residual deposit of rodenticides in the livers of 2694 out of 4891 (or 55%) of the non-target animals studied. Of them, raptors posed the greatest danger of poisoning (Okoniewski et al. 2021). Metal phosphides, particularly aluminium phosphide, are northern India's most popular rodenticide poison used for self-harm. According to Sharma's research, which examined trends in poisoning in the regions of the north of Jammu and Kashmir and Chandigarh between 1994 and 2000, 181 cases (54.35%) of metal phosphide consumption were identified, with aluminium phosphide being the most prevalent kind. The fatality rate was likewise quite high in these conditions. Rat poisons are a crucial factor in a significant number of poisonings in South India. In a study done in a tertiary care centre in south India, rodenticides were shown to be responsible for 11.33% of all poisoning cases. The death rate for those people was 33.3% (Thiagesan et al. 2022). Different synthetic rodenticide-related toxicity is highlighted in Table 3.

Various herbal used for rodent repellent activity

Plant-based repellents are the most effective in controlling rodents. Several secondary metabolites from plants have also shown potential as rodent deterrents. Plant secondary metabolites (PSM) are widely used as a non-lethal control technique for rodent pest species. It has to initially be a very efficient approach, followed by one that is practical, efficient, and economical. Despite the fact that there are over 100,000 individual terpene plant components, only a limited number of these chemicals have been thoroughly tested for rodent repellence (Fischer et al. 2013). Several plant species' essential oils have been examined to determine their efficacy as a useful natural resource for bugs repellent. Rodent repellents are compounds that, by taste, odour, or both, prevent animals from eating or biting. They are simple to remove, biodegradable, and do not remain in the soil or water (Asadollahi et al. 2019).

Plants with potential essential oils used as repellents include *Cymbopogon spp., Ocimum spp., Thymus spp., Eucalyptus spp.*, and others. They can aid in the prevention of rodent damage to grains held in warehouses, seeds sown in agriculture fields, and seedlings in nurseries (Mendoza et al. 2020; Nerio et al. 2010). Chilli, peppermint oil, camphor oil, wintergreen oil, geranium oil, and bergamot oil were tested as repellents against adult male Wistar rats (Nada et al. 2016; Singla et al. 2014). Rodent-repellent activity has also been demonstrated for tuba (*Croton tiglium*), neem leaves, *Gliricidia* bark and leaves, vitex leaves, and chilli powder. Eucalyptus is especially beneficial since it is considered non-toxic to humans and has many other beneficial pest control properties (Ganjeer et al. 2021; Degu et al. 2020). *Eucalyptus* essential oils have several medicinal and industrial uses. Antiviral, fungicidal, insecticidal, and herbicidal capabilities are among the many bioactivities of the oils (Batish et al.

Table 4 Repellent effect of various herbal extracts

PSMs	Plant(s)/compound(s)	Effective rodent species	Outcome	References
Essential oils and Terpenoids	Black pepper oil [*Piper nigrum (L.)*], Bergamot oil, Buchu oil, Fennel oil [*Foeniculum vulgare, (L.) Mill.*], Grass-tree oil, (R)-(+) Limonene, Neem oil (*Azadirachta indica, A. Juss.*), Chinese geranium oil [*Pelargonium graveolens (L'Her)*], onion oil [*Allium cepa (L.)*], Garlic oil [*Allium sativum (L.)*], Bisabolol [*Matricaria chamomilla, (L.)*], Carvacrol [*Origanum vulgare, (L.)*], Eugenol [*Syzygium aromaticum, (L.)*]	*Microtus arvalis, Mus musculus, squirrels, Arvicola amphibius, Woodchucks (Marmota monax L.), Wistar rats (Rattus norvegicus), Arvicola amphibius, Water vole (Arvicola amphibius)*	Repellent effect	Hansen et al. (2016), Fischer et al. (2013)
Alkaloids and Alkylamides	Szechuan pepper oil (*Zanthoxylum piperitum*), capsaicin (*Capsicum species*), Quinolizidine alkaloids (QA) e.g., sparteine, angustifoline, lupanine, ormosanine, panamine	*Rattus norvegicus, Dasyprocta leporina*	Repellent effect	Hansen et al. (2016), Stefanini et al. (2020)
Phenolics	Anthraquinone, Cinnamic acid, Cinnamamide, Ferulic acid, Creosote resin, stilbenes	*Microtus arvalis, Mus musculus, Neotoma albigula, Castor canadensis, Rattus norvegicus, Neotoma lepida, Neotoma stephensi, Microtus agrestis*	Repellent effect	Hansen et al. (2016), Epple et al. (2001)
Tannins	*Quercus crispula*, Tannic acid	*Sciurus niger, Sciurus carolinensis, Sciurus carolinensis, Octogon degus, Phyllotis darwini, Apodemus speciosus*	Repellent effect	Hansen et al. (2016)

2008). Pesticidal action is attributed to the presence of 1,8-cineole, eucamalol, p-cymene, -pinene, -terpinene, -terpineol, limonene, linalool, alloocimene, and aromadendrene chemicals in eucalyptus oil (Singla et al. 2014). Capsaicin, the major component of chilli peppers, is one of these products on the market; however, it is fairly expensive and must be accessible in relatively high quantities (2%). Sulphurous odours from predator pee or excretions are also beneficial (Singla et al. 2013).

Several kinds of chemicals have been considered in a rodent study, aside from studies that utilized entire plants or plant compounds. They consist of terpenoids, glucosinolates, phenolics, alkaloids, alkyl amides, (di)carboxylic acids, terpenoids, and essential oils (Hansen et al. 2016). These compounds are described in Table 4.

Integrated pest management (IPM)

IPM has long been employed in treating plant and invertebrate pests (Witmer et al. 2022). It has not been used as frequently in pest control. The most effective, beneficial, and efficient strategy is often utilised to minimize rodent damage. Shooting and capturing bigger animals, such as ungulates and carnivores, are required. It involves the use of rodenticides or traps for rodents. While rodents can adapt and evolve in a variety of ways in response to a single management technique, this remains true. They may eventually cease to be startled by repellents and scary devices. These treatments may render toxicants physically or genetically unaffected. Rodents developed resistance to first-generation anticoagulants when they were used often. This encouraged creating and demanding second-generation anticoagulants (Gorbunova et al. 2008). The IPM of rodent populations comprises considering the pest rodent's biology, population dynamics, and ecology; habitat management, which considers the biotic and physical environment; and people management, which considers both human activities and land uses. Fortunately, techniques for assisting rodent judgements have been created to aid in integrating all of these elements (Piacenza et al. 2011).

Implementation of preventative measures, non-lethal methods, and combinations of ways to manage rodent populations and damage has been less common, despite the fact that combinations of techniques may prove to be more efficient and popular with the general public. Crop losses can be reduced by managing sanitization in the context of general agriculture (Baldwin et al. 2013). There should be no adjacent protective cover places, such as brush heaps or rock piles, and rodents should not be able to obtain pet food, human food waste, or animal feed. Combining few rodent barriers with enhanced hygiene may result in additional damage reduction. Further recommendations, such as "ecologically based" rodent control, may be found in the study (Damalas et al. 2011).

Conclusion

As it is known that rodent pests on livestock farms can cause large financial losses owing to food spoilage and damage. Consequently, they can have major deleterious impacts on both human and animal health. And even short-term rodenticide usage affects a diverse variety of small non-targeted mammal species. Therefore, PSMs might be used to keep rodents out of crops and storage places by repelling them or employing appealing aromas that draw them to alternative habitats. Attractants can also help with bait acceptance and trap efficacy. However, some of the obstacles in developing herbal rodent repellents include ensuring long-term efficacy, avoiding harmful environmental effects, and addressing fundamental economic challenges. Thus, further research on the identification of active components, field testing and toxicity studies are required before endorsing the active fraction of herbal extracts to develop eco-friendly insect vector control agents. These developments may bring benefits such as the most recent effective repellents, long-lasting barriers, biological control, fertility management, and habitat change, to mention a few. Hence, this review will aid the researchers in comprehending the value, potential position, and function of repellents derived from plants to prevent diseases.

Abbreviations

IGMRI	Indian Grain Storage Management and Research Institute
LBC	Live burrow count
HFRS	Haemorrhagic fever with renal syndrome
HCPS	Hantavirus cardiopulmonary syndrome
SAHF	South American Haemorrhagic Fevers
WHO	World Health Organization
LASV	Lassa viruses
NCDC	National Institute of Communicable Diseases
SEOV	Seoul hantavirus
HPS	Hantavirus pulmonary syndrome
AFRIMS	Armed Forces Research Institute of Medical Sciences
LCMV	Lymphocytic choriomeningitis virus
CCHF	Crimean–Congo haemorrhagic fever
CCHFV	Crimean–Congo haemorrhagic fever virus
KFD	Kyasanur forest disease
VEE	Venezuelan equine encephalitis
TBE	Tick-borne encephalitis
HEV	Hepatitis E virus
CNS	Central nervous system
EMC	Encephalo-myocarditis
ANTU	Alpha naphthyl thiourea
AR	Anticoagulant rodenticide
FGAR	First-generation anticoagulant rodenticide
SGAR	Second-generation anticoagulant rodenticide
VKOR	Vitamin K epoxide reductase
ATP	Adenosine triphosphate
IPM	Integrated pest management
PMRA	Pest Management and Regulation Agency
PNU	N-3-pyridylmethyl-N-p-nitrophenyl urea
PSM	Plant secondary metabolite

Acknowledgements
Not applicable.

Author contributions
HKS conceptualized, synthesized the review strategy, supervision, and reviewed the manuscript. MAQ and AKK contributed to the content significantly in the preparation, drafting and edited the manuscript. SP and ELH reviewed and edited the manuscript. All authors read and approved the final manuscript.

Funding
No funding organization in the public, private, or non-profit sectors provided a particular grant for this work.

Availability of data and materials
The data and materials for writing this manuscript are retrieved from PubMed, Google Scholar, Research Gate, PLOS One, and others journal search engine.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors do not have any competing interests.

Author details
[1]Department of Pharmaceutical Sciences, Faculty of Science and Engineering, Dibrugarh University, Dibrugarh, Assam 786004, India.

Received: 2 May 2023 Accepted: 29 May 2023
Published online: 09 June 2023

References

Asadollahi A, Khoobdel M, Zahraei-Ramazani A, Azarmi S, Mosawi SH (2019) Effectiveness of plant-based repellents against different anopheles species: a systematic review. Malar J 18(1):1–20. https://doi.org/10.1186/s12936-019-3064-8
Baig M, Farah S, Atkulwar A, Searle JB (2022) Genomic analysis reveals subdivision of black rats (Rattus Rattus) in India, origin of the worldwide species spread. Genes 13(2):1–7. https://doi.org/10.3390/genes13020267
Bala B, Bala CB, Babbar BK (2019) Development and testing of methyl anthranilate based formulations against rodents. J Entomol Zool Stud 7(1):1586–1595
Baldwin RA, Salmon TP, Schmidt RH, Timm RM (2013) Wildlife pests of California agriculture: regional variability and subsequent impacts on management. Crop Prot 46:29–37
Batish DR, Singh HP, Kohli RK, Kaur S (2008) Eucalyptus essential oil as a natural pesticide. For Ecol Manag 256(12):2166–2174
Berny P, Velardo J, Pulce C, D'amico A, Kammerer M, Lasseur R (2010) Prevalence of anticoagulant rodenticide poisoning in humans and animals in france and substances involved. Clin Toxicol 48(9):935–941
Biswas S (2018) Plague in India: a review. J Commun Dis 50(3):60–75
Bordes F, Blasdell K, Morand S (2015) Transmission ecology of Rodent-Borne diseases: new frontiers. Integr Zool 10(5):424–435
Coppock R (2013) Advisory: bromethalin rodenticide—no known antidote. Can Vet J 54(6):557–558
Damalas CA, Eleftherohorinos IG (2011) Pesticide exposure, safety issues, and risk assessment indicators. Int J Environ Res Public Health 8:1402–1419

Degu S, Berihun A, Muluye R, Gemeda H, Debebe E, Amano A, Abebe A, Woldkidan S, Tadele A (2020) Medicinal plants that used as repellent, insecticide and larvicide in ethiopia. Pharm Pharmacol Int J 8(5):274–283
D'Silva C, Krishna B (2019) Rodenticide poisoning. Indian J Crit Care Med 23:S272–S277
Elmeros M, Bossi R, Christensen TK, Kjær LJ, Lassen P, Topping CJ (2019) Exposure of non-target small mammals to anticoagulant rodenticide during chemical rodent control operations. Environ Sci Pollut Res 26:6133–6140
Emonet S, Retornaz K, Gonzalez JP, De Lamballerie X, Charrel RN (2007) Mouse-to-human transmission of variant lymphocytic choriomeningitis virus. Emerg Infect Dis 13(3):472–475
Epple G, Bryant BP, Mezine I, Lewis S (2001) Zanthoxylum piperitum, an Asian spice, inhibits food intake in rats. J Chem Ecol 27(8):1627–1640
Fernandes J, RickettsiosesOliveira RCD, RickettsiosesCoelho TA, Martins RMB, Caetano KAA, Horta MAP, RickettsiosesLemos ERSD (2019) Rodent-Borne viruses survey in rural settlers from central Brazil. Mem Inst Oswaldo Cruz 114:1–5
Fischer D, Imholt C, Pelz HJ, Wink M, Prokop A, Jacob J (2013) The repelling effect of plant secondary metabolites on water voles, Arvicola amphibius. Pest Manag Sci 69(3):437–443
Fisher P, Campbell KJ, Howald GR, Warburton B (2019) Anticoagulant rodenticides, islands and animal welfare accountancy. Animals 9:1–10
Galeh TM, Sarvi S, Montazeri M, Moosazadeh M, Nakhaei M, Shariatzadeh SA, Daryani A (2020) Global status of toxoplasma gondii seroprevalence in rodents: a systematic review and meta-analysis. Front Vet Sci 7:1–13
Ganjeer T, Patyal A, Shakya S, Parkar SS, Shukla A, Chandrakar C, Naik V (2021) Rodent borne zoonoses: a brief review. Pharma Innov 10(8):721–725
Ghose A, Sayeed AA, Hossain A, Rahman R, Faiz A, Haque G (2009) Mass barium carbonate poisoning with fatal outcome, lessons learned: a case series. Cases J 2(12):1–4
Goeijenbier M, Wagenaar J, Goris M, Martina B, Henttonen H, Vaheri A, Reusken C, Hartskeerl R, Osterhaus A, Van Gorp E (2013) Rodent-Borne hemorrhagic fevers: under-recognized, widely spread and preventable-epidemiology, diagnostics and treatment. Crit Rev Microbiol 39(1):26–42
Gorbunova V, Bozzella MJ, Seluanov A (2008) Rodents for comparative aging studies: from mice to beavers. Age 30(2–3):111–119
Griffiths J, Yeo HL, Yap G, Mailepessov D, Johansson P, Low HT, Siew CC, Lam P, Ng LC (2022) Survey of Rodent-Borne pathogens in singapore reveals the circulation of leptospira Spp., seoul hantavirus, and rickettsia typhi. Sci Rep 12(1):1–14
Hansen SC, Stolter C, Imholt C, Jacob J (2016) Plant secondary metabolites as Rodent repellents: a systematic review. J Chem Ecol 42(9):1–14
Herawati NA (2021) Diversity of rodent species and its potency as the vector for transmitting rodent borne parasitic disease in households. BIO Web Conf 33:1–10
Hindmarch S, Elliott JE, Morzillo A (2018) Rats! What triggers us to control for rodents? Rodenticide user survey in British Columbia, Canada. Int J Environ Stud 75(6):1011–1030
Hohenberger J, Friesen A, Wieck S, Kümmerer K (2022) In search of the holy grail of rodent control: step-by-step implementation of safe and sustainable-by-design principles on the example of rodenticides. Sustain Chem Pharm 25:1–19
Htwe NM, Singleton GR, Johnson DE (2019) Interactions between rodents and weeds in a lowland rice agro-ecosystem: the need for an integrated approach to management. Integr Zool 14(4):396–409
Islam MM, Farag E, Mahmoudi A, Hassan MM, Atta M, Mostafavi E, Alnager IA, Farrag HA, Eljack GEA, Bansal D, Haroun M (2021) Morphometric study of mus musculus, rattus norvegicus, and rattus rattus in Qatar. Animals 11:1–15
Kaur K, Singh R (2019) Population dynamics of Indian mole rat, bandicota bengalensis during different growth stages of paddy and wheat crops in Punjab. Int J Bio-Resour Stress Manag 10(3):227–232
Kinsella M, Monk C (2012) Lymphocytic choriomeningitis virus: an under-recognized cause of neurologic disease in the fetus, child, and adult. Semin Pediatr Neurol 19(3):1–13
Koul PA, Ahmad SH, Ahmad F, Jan RA, Shah SU, Khan UH (2011) Vitamin D toxicity in adults: a case series from an area with endemic hypovitaminosis D. Oman Med J 26(3):201–204
Krawczyk AI, van Duijvendijk GL, Swart A, Heylen D, Jaarsma RI, Jacobs FH, Fonville M, Sprong H, Takken W (2020) Effect of rodent density on tick and tick-borne pathogen populations: consequences for infectious disease risk. Parasit Vectors 13(34):1–17. https://doi.org/10.1186/s13071-020-3902-0
Kumar S, Bhowmick MK, Ray P (2021) Weeds as alternate and alternative hosts of crop pests. Indian J Weed Sci 53(1):14–29
Lemus JA, Bravo C, García-Montijano M, Palacín C, Ponce C, Magaña M, Alonso JC (2011) Side effects of rodent control on non-target species: rodenticides increase parasite and pathogen burden in great bustards. Sci Total Environ 409(22):4729–4734
McGee CF, McGilloway DA, Buckle AP (2020) Anticoagulant rodenticides and resistance development in rodent pest species—a comprehensive review. J Stored Prod Res 88:1–18. https://doi.org/10.1016/j.jspr.2020.101688
Mendoza H, Rubio AV, García-Peña GE, Suzán G, Simonetti JA (2020) Does land-use change increase the abundance of zoonotic reservoirs? Rodents say yes. Eur J Wildl Res 66(6):1–5
Nada AA, Hassabo AG, Mohamed AL, Mounier MM, Abou Zeid NY (2016) Liposomal microencapsulation of rodent-repelling agents onto jute burlaps: assessment of cytotoxicity and rat behavioral test. J Appl Pharm Sci 6(8):142–150
Nakayama SM, Morita A, Ikenaka Y, Mizukawa H, Ishizuka M (2019) A review: poisoning by anticoagulant rodenticides in non-target animals globally. J Vet Med Sci 81(2):298–313
Namala SR, Anusha B, Mohan Rao AMK, Sharma SN (2022) Impact of rodent outbreaks in rice paddies on incidence of rodent-borne zoonosis in human populations. J Commun Dis 54(2):33–38
Nerio LS, Olivero-Verbel J, Stashenko E (2010) Repellent activity of essential oils: a review. Biores Technol 101(1):372–378. https://doi.org/10.1016/j.biortech.2009.07.048
Nimo-Paintsil SC, Fichet-Calvet E, Borremans B, Letizia AG, Mohareb E, Bonney JH, Obiri-Danso K, Ampofo WK, Schoepp RJ, Kronmann KC (2019) Rodent-Borne infections in rural ghanaian farming communities. PLoS ONE 14(4):1–13
Okoniewski R, Neely S, Denn M, Djatsa A, Tran BN (2021) Rapid method for the detection of rodenticides in contaminated foods. J Chromatogr B Anal Technol Biomed Life Sci 1186:1–7
Pal M, Gutama KP, Singh S (2022) Lymphocytic choriomeningitis : an emerging and re-emerging Rodent-Borne viral zoonotic disease. J Adv Microbiol Res 3(2):01–04
Park J (2014) Can we more efficiently save patients with vitamin K-dependent coagulopathy caused by superwarfarin intoxication? Korean J Intern Med 29(4):430–433
Parshad VR (1999) Rodent control in India. Integr Pest Manag Rev 4(2):97–126
Pasquale-Styles MA, Sochaski MA, Dorman DC, Krell WS, Shah AK, Schmidt CJ (2006) Fatal bromethalin poisoning. J Forensic Sci 51(5):1154–1157
Phukon M, Borah RK (2019) Species composition of field rodents in rice-vegetable cropping system at upper Brahmaputra Valley Zone. Assam 7(4):1111–1118
Piacenza MF, Gómez MD, Simone I, Lamfri M, Scavuzzo CM, Calderón GE, Polop JJ (2011) Providing management options to control corn mouse (Calomys Musculinus) reservoir populations using a cohort structured model. Int J Pest Manag 57(4):255–265
Prompiram P, Poltep K, Pamonsupornvichit S, Wongwadhunyoo W, Chamsai T, Rodkvamtook W (2020) Rickettsiae exposure related to habitats of the oriental house rat (Rattus Tanezumi, Temminck, 1844) in Salaya Suburb, Thailand. Int J Parasitol Parasites Wildl 13:22–26
Rabiee MH, Mahmoudi A, Siahsarvie R, Kryštufek B, Mostafavi E (2018) Rodent-Borne diseases and their public health importance in Iran. PLoS Negl Trop Dis 12(4):1–20
Rached A, Moriceau MA, Serfaty X, Lefebvre S, Lattard V (2020) Biomarkers potency to monitor non-target fauna poisoning by anticoagulant rodenticides. Front Vet Sci 7:1–20
Rao AM (2003) Rodent problems in india and strategies for their management. In: Rats, mice and people: rodent biology and management, pp 203–12
Rattner BA, Harvey JJ (2021) Challenges in the interpretation of anticoagulant rodenticide residues and toxicity in predatory and scavenging birds. Pest Manag Sci 77(2):1–7
Ravikanth R, Sandeep S, Philip B (2017) Acute yellow phosphorus poisoning causing fulminant hepatic failure with parenchymal hemorrhages and contained duodenal perforation. Indian J Crit Care Med 21(4):238–242

Regnery J, Friesen A, Geduhn A, Göckener B, Kotthoff M, Parrhysius P, Petersohn E, Reifferscheid G, Schmolz E, Schulz RS, Schwarzbauer J (2019) Rating the risks of anticoagulant rodenticides in the aquatic environment: a review. Environ Chem Lett 17(1):215–240
Rice NC, Rauscher NA, Langston JL, Myers TM (2017) Behavioral intoxication following voluntary oral ingestion of tetraethylenedisulfotramine: dose-dependent onset, severity, survival, and recovery. Neurotoxicology 63:21–32. https://doi.org/10.1016/j.neuro.2017.08.009
Sahay RR, Dhandore S, Yadav PD, Chauhan A, Bhatt L, Garg V, Gupta N, Nyayanit DA, Shete AM, Singh R, Patil S (2020) Detection of African genotype in hyalomma tick pools during crimean congo hemorrhagic fever outbreak, Rajasthan, India, 2019. Virus Res 286:1–7
Saini MS, Parshad VR (1991) Control of the Indian mole rat with alpha-chlorohydrin: laboratory studies on bait acceptance and antifertility effects. Ann Appl Biol 118(1):239–247
Samuel PP, Govindarajan R, Krishnamoorthi R, Rajamannar V (2020) A study on ectoparasites with special reference to chigger mites on rodents/shrews in scrub typhus endemic areas of Kerala, India. Entomon 45(4):285–294
Samuel P, Paulraj RG, Krishnamoorthi R, Nagaraj J (2021) Ectoparasites of some wild rodents/shrews captured from scrub typhus reported areas in Tamil Nadu, India. Int J Acarol 47(3):218–221
Sangle SA, Thomas A, Verma S, Wadia RS (1987) Zinc phosphide poisoning. J Assoc Phys India 35(8):591–594
Schlötelburg A, Plekat A, Bellingrath-Kimura S, Jacob J (2020) Self-service traps inspected by avian and terrestrial predators as a management option for rodents. Pest Manag Sci 76(1):103–110
Sharma SN, Singh R, Kumawat R, Singh SK (2019) Rodents' as public health pests: identification, surveillance and its management. J Commun Dis 51(4):47–57
Sharma A, Ray S, Choudhury J, Tyagi R (2020) Leptospirosis onboard afloat unit: case report of an underreported infectious disease. J Marine Med Soc 22(1):96–100
Singhapricha T, Pomerleau AC (2017) A case of strychnine poisoning from a Southeast Asian Herbal remedy. J Emerg Med 52(4):493–495. https://doi.org/10.1016/j.jemermed.2016.10.007
Singla N, Kaur R (2014) Potential of citronella oil as rodent repellent measured as aversion to food. Appl Biol Res 16(2):191–198
Singla N, Thind RK, Mahal AK (2013) Potential of eucalyptus oil as repellent against house rat, rattus rattus. Int J Adv Res 1(10):220–229
Singla N, Thind RK, Mahal AK (2014) Potential of eucalyptus oil as repellent against house rat, rattus rattus. Sci World J 2014:1–7
Singla N, Singh R, Kaur N, Babbar BK (2022) Field efficacy of reduced active ingredient zinc phosphide formulation against rodents. Indian J Entomol 85(1):267–270. https://doi.org/10.55446/IJE.2021.367
Stefanini M, Charon M, Marchand PA (2020) Rodent repellents at a european union plant protection product level, an orphan use to consider. J Plant Prot Res 60(1):1–6
Strand TM, Lundkvist Å (2019) Rat-Borne diseases at the horizon. a systematic review on infectious agents carried by rats in Europe 1995–2016. Infect Ecol Epidemiol 9(1):1–9
Thiagesan R, Gopichandran V, Subramaniam S, Soundari H, Kosalram K (2022) Prevalence of type 2 diabetes among persons with disabilities in the South-East Asian region : a systematic review and meta-analysis. Curr Med Issues 7(4):129–133
Topping CJ, Elmeros M (2016) Modeling exposure of mammalian predators to anticoagulant rodenticides. Front Environ Sci 4(80):1–12
Valchev I, Binev R, Yordanova V, Nikolov Y (2008) Anticoagulant rodenticide intoxication in animals—a review. Turkish J Vet Anim Sci 32(4):237–243
Wang R, Zhuo L, Wang Y, Ren L, Liu Q, Liu L (2016) Lessons learned from poisoning cases caused by 2 illegal rodenticides: tetramine and fluoroacetamide. Medicine (united States) 95(41):4–7
Witmer G (2022) Rodents in agriculture: a broad perspective. Agronomy 12:1–6
Witmer GW, Burke PW, Jojola S, Nolte DL (2008) A Live trap model and field trial of a nutria (rodentia) multiple capture trap. Mammalia 72(4):352–354
Wondifraw BT, Tamene MY, Simegn AB (2021) Assessment of crop damage by rodent pests from experimental barley crop fields in Farta District, South Gondar, Ethiopia. PLoS ONE 16(8):1–10
Yogendranathan N, Herath HMMTB, Sivasundaram T, Constantine R, Kulatunga A (2017) A case report of zinc phosphide poisoning: complicated by acute renal failure and tubulo interstitial nephritis. BMC Pharmacol Toxicol 18(1):1–6
Yu HY, Chang C, Li F, Wang Q, Chen M, Zhang J (2018) Thallium in flowering cabbage and lettuce: potential health risks for local residents of the Pearl River Delta, South China. Environ Pollut 241:626–635
Yu H, Jamieson A, Hulme-Beaman A, Conroy CJ, Knight B, Speller C, Al-Jarah H, Eager H, Trinks A, Adikari G, Baron H (2022) Palaeogenomic analysis of black rat (Rattus Rattus) reveals multiple european introductions associated with human economic history. Nat Commun 13(1):1–13
Zafalon RVA, Ruberti B, Rentas MF, Amaral AR, Vendramini THA, Chacar FC, Kogika MM, Brunetto MA (2020) The role of vitamin D in small animal bone metabolism. Metabolites 10(12):1–21
Zubair M, Ahmad M, Qureshi ZI (2017) Review on arsenic-induced toxicity in male reproductive system and its amelioration. Andrologia 49(9):1–8

Publisher's Note