J Vet Sci. 2024 Nov;25(6):e81
https://doi.org/10.4142/jvs.24098
pISSN 1229-845X·eISSN 1976-555X

Narrative Review
Zoonotic Disease

Zoonotic importance of ecto- and endoparasites in rodents in Malaysia: a review

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OPEN ACCESS

Received: Mar 21, 2024
Revised: Jul 24, 2024
Accepted: Aug 21, 2024
Published online: Nov 22, 2024

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ABSTRACT

Importance: Rodents, particularly those inhabiting urban areas, are sources of infections that cause major human diseases. The number of recorded zoonotic infections has increased in recent decades, exacerbating public concerns. Zoonotic diseases in humans, such as capillariasis, hymenolepiasis, and toxoplasmosis, are life-threatening in severe cases, particularly in immunocompromised individuals. A thorough understanding of pathogens, particularly the parasites infecting rodents, is critical for predicting future zoonotic disease outbreaks and developing effective mitigation strategies. This review summarizes the information on parasites in rodents inhabiting Malaysia to identify the knowledge gaps that could serve as a foundation for future research.
Observations: Thirty-eight previous parasite studies in rodents conducted in Malaysia were reviewed, and 44 ectoparasites species and 58 endoparasites species across 19 rodent species were revealed. Six ectoparasite and eight endoparasite species were identified as zoonotic among these parasites. Morphological identification of parasite species typically succeeded only at the genus level because of their identical morphological characteristics. However, these studies used a molecular approach to identify parasites at the species level using species-specific primers. The pathological findings of various organs of infected rodents were also summarized, including gross and histological lesions exhibited by parasites.
Conclusions and Relevance: This review highlights the list of parasites infecting rodents in Malaysia, provides information on the molecular and pathological findings from previous studies, and identifies some of the limitations and knowledge gaps that suggest future research to address the issues, including the paucity of information on blood parasites, molecular, and histopathological studies of parasites in rodents.

Keywords: Ectoparasites; endoparasites; Malaysia; rodents; zoonosis

INTRODUCTION

Rodents are a mammalian group that has adapted well to various habitats worldwide. They comprise 29 families, 468 genera, and over 2,052 species [1]. Among the 29 families, species

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Conflict of Interest
The authors declare no conflicts of interest.

Funding
This research was supported by the Ministry of Higher Education of Malaysia research grant (FRGS/1/2020/SKK06/UPM/02/16) and Universiti Putra Malaysia research grant (UPM/GP-IPS/2021/9705100).

Data Availability Statement
The datasets used and analysed during the current study are available from the corresponding author upon reasonable request.

from the Family *Muridae* are highly successful and dominate most of the world because they can quickly adapt and exploit new situations. Rodents belonging to the family *Muridae* are the largest group of mammals in Malaysia [2].

Synanthropic rodents live in close proximity to humans and are regarded as vertebrate pests because of their behavior in destroying food crops, resulting in financial losses [3]. They harbor zoonotic pathogens, which have raised public and veterinary concerns, such as bacteria, viruses, and parasites, which later increase the potential of pathogen spillover and the transmission of zoonotic diseases [4]. Most emergent and re-emerging infectious diseases of humans are caused by zoonosis, which allows the transmission of infection from animals to humans [5]. Consequently, zoonotic infections, particularly those associated with rodents and other wild animals, seriously threaten human health and well-being [6].

In recent decades, an upsurge in the number of zoonotic infections has been documented. Nevertheless, zoonotic diseases have emerged for many reasons, including habitat alteration, overpopulation, and mass migration of populations caused by natural or man-made calamities [7]. Urban cities provide the optimal habitats for many wild animals, increasing regular contact with humans in the urban environment, particularly residential areas, becoming a major concern for zoonotic disease emergence [8]. For example, urban cities that provide abundant food and breeding space promote the infestation of rodents in this area [9]. As stated previously, rodents harbored various zoonotic pathogens, including bacteria, viruses, and parasites. On the other hand, this review focused on parasites in rodents that might be transmitted to humans and contribute to human fatalities. Rodent-borne parasitic diseases are caused by ectoparasites (fleas, lice, ticks, mites, and chiggers) and endoparasites (nematodes, cestodes, trematodes, acanthocephalan, intestinal protozoa, and blood protozoa). Parasitic zoonotic pathogens, such as *Toxoplasma gondii, Hymenolepis nana*, and *Hymenolepis diminuta*, have attracted considerable attention as significant zoonotic pathogens because of their ability to induce diseases in immunocompromised persons [10,11].

The emergence of zoonotic diseases, such as murine typhus, capillariasis, blastocystosis, hymenolepiasis, Ebola, SARS, and recently COVID-19, have alarmed the public and authorities. Therefore, knowledge of zoonotic pathogens is critical for predicting future zoonotic disease outbreaks. In Malaysia, numerous studies regarding parasites in rodents have been conducted and recorded since the early 1930s. Therefore, this review collected baseline information on parasites in rodents inhabiting Malaysia based on 20 years of previous studies to identify the knowledge gaps indicating future directions for future research.

METHODS

Databases, search strategy, and articles screening

This study searched for published studies on parasites in rodents in Google Scholar, PubMed, Science Direct, and Scopus. Text word searches were also conducted using keywords on the desired topic, including “parasite,” “ectoparasite,” “endoparasite,” “Malaysia,” “rodent,” and “zoonosis.” Articles that were duplicated or irrelevant to the topic were not reviewed. Sixty-two articles were retrieved from a database search from 2003 to 2023. The numbers were reduced to 48 after removing duplicates in the retrieved data. After screening, 10 articles were excluded, decreasing the number to 38.

Exclusion and inclusion criteria

Although the inclusion criteria were articles of an original research study with no methodological restrictions, any article related to ecto- and endoparasite in rodents in Malaysia and articles reported in the English language were included. The publication period was 20 years (2003–2023) to achieve the review objectives. The findings of parasite studies from the 20-year period were still relevant and sufficient to answer the review objectives. Overall, 38 articles on the desired topic were retrieved and reviewed.

OBSERVATIONS

Overview of parasite studies in rodents conducted in Malaysia

Studies of parasites in Malaysia were documented as early as the 1930s [12]. Subsequently, many studies were recorded on the different types of parasites, including ectoparasites and endoparasites, from various regions across Malaysia. **Fig. 1** presents the distribution of parasite studies in rodents across Malaysia over the past 20 years.

Despite having a substantial amount of data on parasite studies in rodents, there are some limitations from the previous studies, such as the small sample size, lack of information on blood parasites, molecular works, and histopathological studies in rodents will be discussed in this review.

Thirty-eight available published parasite studies in rodents conducted in Malaysia over the past 20 years were synthesized, summarized, and categorized based on the types of parasites in **Tables 1** and **2**. Various methods and techniques have been used to detect and identify ectoparasites and endoparasites species in rodents. Methods included fur combing, direct examination, skin scraping, immature ticks rearing, and molecular

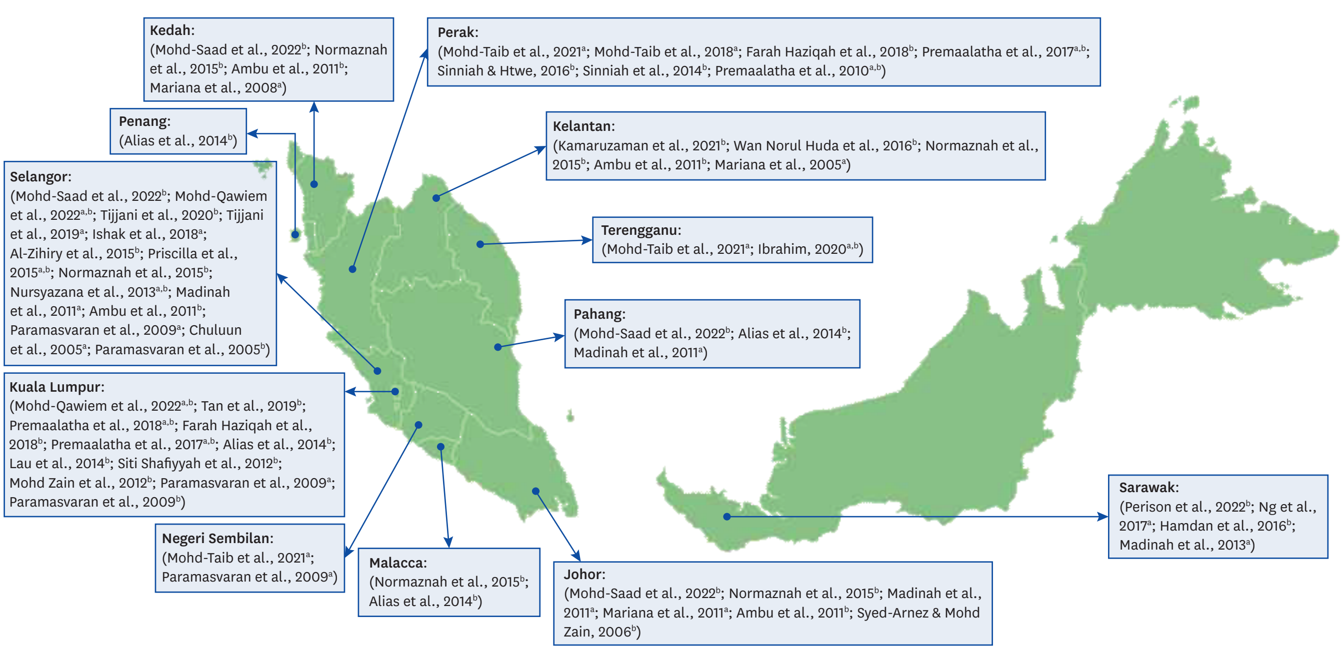

Fig. 1. Distribution of parasites studies in rodents conducted across Malaysia over the past 20 years.
[a]The ectoparasite study; [b]The endoparasite study; [a,b]Both ectoparasite and endoparasite studies.

https://doi.org/10.4142/jvs.24098

approaches for ectoparasites detection while blood smear, buffy coat, necropsy, formalin-ether concentration technique, fecal floatation, direct examination of the stool, immunofluorescent antibody test, *in vitro* cultivation, molecular approach, and

Table 1. Ectoparasites in rodents in Malaysia identified in studies conducted from 2003 to 2023

Parasite(s)	Host(s)	Habitat(s)	Reference(s)
Flea			
Xenopsylla cheopis[a]	*Rattus rattus diardii, Rattus tiomanicus, Rattus norvegicus*	Urban	[13-15]
Lice			
Polyplax sp., *Polyplax spinulosa*[a]	*Rattus rattus diardii, Rattus tiomanicus, Rattus norvegicus, Rattus muelleri, Rattus sabanus, Rattus argentiventer, Leopoldamys sabanus, Maxomys whiteheadi*	Urban, semi-urban, rice field, island, forest	[14-22]
Hoplopleura sp., *Hoplopleura pacifica*[a], *Hoplopleura dissicula, Hoplopleura pectinata*	*Rattus rattus diardii, Rattus tiomanicus, Rattus norvegicus, Rattus argentiventer, Rattus exulans, Sundamys muelleri, Maxomys whiteheadi, Callosciurus notatus*	Urban, semi-urban, island	[14-16,19,21,23,24]
Linognathus sp.	*Rattus norvegicus*	Urban	[21]
Ticks			
Amblyomma sp., *Amblyomma cordiferum*	*Rattus rattus diardii, Rattus tiomanicus, Sundamys muelleri, Maxomys whiteheadi, Maxomys rajah, Leopoldamys sabanus, Lariscus insignis*	Urban, coastal, forest, rice field	[14,25-27]
Ixodes spp., *Ixodes granulatus*[a]	*Rattus rattus diardii, Rattus tiomanicus, Rattus norvegicus, Rattus argentiventer, Rattus bowersi, Sundamys muelleri, Leopoldamys sabanus, Maxomys whiteheadi, Maxomys rajah, Maxomys surifer, Sundasciurus tenuis, Callosciurus notatus, Lariscus insignis*	Urban, semi-urban, rice field, island, coastal, forest	[14,15,18,19,23-29]
Haemaphysalis spp.,[a]*Haemaphysalis hystricis*	*Rattus rattus diardii, Rattus tiomanicus, Rattus norvegicus, Rattus bowersi, Sundamys muelleri, Leopoldamys sabanus, Maxomys rajah, Maxomys surifer, Maxomys whiteheadi, Lariscus insignis*	Urban, forest, coastal, rice field	[14,15,18,24-27,29]
Dermacentor sp., *Dermacentor auratus, Dermacentor atrosignatus*	*Rattus rattus dardii, Rattus tiomanicus, Rattus bowersi, Sundamys muelleri, Maxomys whiteheadi, Maxomys surifer, Maxomys rajah, Leopoldamys sabanus, Sundasciurus tenuis, Callosciurus notatus, Lariscus insignis*	Urban, semi-urban, forest, coastal, rice field	[14,18,25-27,28]
Rhipicephalus sp.	*Maxomys rajah*	Forest	[29]
Mites			
Laelaps spp., *Laelaps echidninus, Laelaps nuttali, Laelaps sedlaceki, Laelaps sculpturatus, Laelps aingworthae, Laelaps sanguisugus, Laelaps flagellifer, Laelaps insignis, Laelaps mercedae, Longolaelaps whartoni, Longolaelps longulus*	*Rattus rattus diardii, Rattus norvegicus, Rattus tiomanicus, Rattus muelleri, Rattus exulans, Rattus argentiventer, Rattus bowersi, Rattus exulans, Sundamys muelleri, Leopoldamys sabanus, Maxomys whiteheadi, Maxomys rajah, Maxomys surifer, Niniventer cremoriventer, Callosciurus notatus, Lariscus insignis*	Urban, semi-urban, forest, coastal, island, rice field	[13-19,22-27,29,30]
Ornithonyssus spp., *Ornithonyssus bacoti*[a]	*Rattus rattus diardii, Rattus norvegicus, Rattus tiomanicus, Rattus argentiventer*	Urban, island	[13-15,19]
Listrophoroides sp.	*Rattus rattus diardii, Rattus norvegicus, Rattus tiomanicus, Rattus argentiventer, Rattus bowersi, Rattus exulans, Sundamys muelleri, Maxomys rajah, Maxomys whiteheadi, Leopoldamys sabanus, Callosciurus notatus*	Semi-urban, island, forest, coastal, rice field	[14,16,19,23,29]
Myocoptes musculinus	*Rattus norvegicus*	Urban	[20]
Notoedres muris	*Rattus rattus diardii*	Urban	[14]
Echinonyssus nasutus	*Maxomys surifer*	Forest	[26]
Radfordia sp.	*Rattus norvegicus*	Urban	[21]
Demodex sp.	*Rattus* spp.	Urban	[31]
Chiggers			
Gahrliepia (walchia) spp., *Gahrliepia (walchia) naniparma, Gahrliepia (gahrliepia)* spp., *Gahrliepia fletcheri*	*Maxomys surifer, Maxomys rajah, Maxomys whiteheadi, Sundamy muelleri, Leopoldamys sabanus, Niniventer cremoriventer, Lariscus insignis*	Urban, forest, coastal, rice field	[14,18,25,26]
Ascoschoengastia spp., *Ascoschoengastia indica*	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Maxomys whiteheadi, Callosciurus notatus*	Urban, semi-urban, coastal, forest	[14,26]
Leptotrombidium spp., *Leptotrombidium deliense*[a]	*Rattus rattus diardii, Rattus tiomanicus, Maxomys surifer, Maxomys whiteheadi, Sundamys muelleri, Leopoldamys sabanus, Callosciurus notatus, Lariscus insignis*	Forest, coastal	[14,18,25,26]
Walchiella spp., *Walchiella oudemansi*	*Rattus rattus diardii, Maxomys surifer, Leopoldamys sabanus, Callosciurus notatus, Lariscus insignis*	Urban, forest, coastal, rice field	[14,18,26]
Eutrombicula wichmanni	*Rattus tiomanicus, Leopoldamys sabanus*	Forest	[25]
Doloisia spp.	*Maxomys rajah*	Forest	[26]

[a]Zoonotic parasite.

histopathological examination for endoparasites detection. Forty-four and 58 ectoparasite and endoparasite species were recorded in 19 rodent species in Malaysia.

Table 2. Endoparasites in rodents in Malaysia identified in studies conducted from 2003 to 2023

Parasite(s)	Host(s)	Habitat(s)	Reference(s)
Nematode			
Nippostrongylus spp., *Nippostrongylus brasiliensis*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus muelleri, Rattus exulans, Rattus tiomanicus, Rattus argentiventer*	Urban, island	[4,13,17,19,21,32,33]
Strongyloides spp., *Strongyloides ratti*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus, Sundamys muelleri, Maxomys surifer, Maxomys rajah, Maxomys whiteheadi*	Urban, semi-urban	[13,20,21,31,34-36]
Capillaria spp., *Capillaria hepatica*[a]	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus muelleri, Rattus exulans, Rattus tiomanicus, Rattus argentiventer, Rattus bowersi, Sundamys muelleri, Maxomys surifer, Maxomys rajah, Maxomys whiteheadi, Leopoldamys sabanus*	Urban, semi-urban, forest	[4,13,17,21,33,36-41]
Angiostrongylus cantonensis, Angiostrongylus malaysiensis	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus tiomanicus, Rattus argentiventer, Rattus exulans, Rattus sabanus*	Urban, semi-urban, rice field, island	[19,22,32,36,40]
Mastophorus muris	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus, Rattus argentiventer, Leopoldamys sabanus*	Urban, semi-urban, island	[4,19,32,36]
Heterakis sp., *Heterakis spumosa*	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus, Rattus argentiventer, Maxomys rajah, Maxomys surifer, Maxomys whiteheadi*	Urban, semi-urban, island	[4,19,32,36]
Hepatojarakus malayae	*Rattus rattus diardii, Rattus norvegicus, Rattus bowersi, Rattus tiomanicus, Rattus argentiventer, Sundamys muelleri, Leopoldamys sabanus, Maxomys rajah*	Island, forest	[19,37]
Syphacia muris	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus, Rattus argentiventer, Sundamys muelleri, Maxomys rajah, Maxomys surifer*	Urban, semi-urban, island	[4,19,32,36]
Heligmonellidae sp.	*Rattus exulans, Rattus tiomanicus, Sundamys muelleri, Leopoldamys sabanus, Maxomys rajah, Maxomys surifer, Maxomys whiteheadi*	Semi-urban	[36]
Trichuris spp.	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus*	Urban	[13,20,40]
Syphacia spp.	*Rattus rattus diardii, Rattus norvegicus*	Urban	[13]
Ascarididae spp.	*Rattus* spp.	Urban	[21]
Gongylonema neoplasticum	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus*	Urban, semi-urban	[4,32,36]
Pterygodermatites sp., *Pterygodermatites whartoni/tani*	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans*	Urban	[4,32]
Physaloptera sp.	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Maxomys rajah, Maxomys surifer*	Urban, semi-urban	[4,36]
Rictularia tani	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Maxomys rajah, Maxomys surifer*	Urban, semi-urban	[4,36]
Trichostrongylus sp.	*Rattus bowersi, Sundamys muelleri, Leopoldamys sabanus, Maxomys rajah*	Forest	[37]
Streptophagus sp.	*Rattus bowersi, Sundamys muelleri, Leopoldamys sabanus, Maxomys rajah*	Forest	[37]
Cyclodonstomum purvisii	*Sundamys muelleri, Maxomys whiteheadi*	Semi-urban	[36]
Filarioidea sp.	*Maxomys surifer*	Semi-urban	[36]
Globocephalus connorfilii	*Leopoldamys sabanus*	Semi-urban	[36]
Subulura andersoni	*Maxomys rajah, Maxomys surifer*	Semi-urban	[36]
Cestode			
Hymenolepis sp., *Hymenolepis nana*,[a]*Hymenolepis diminuta*,[a]*Hymenolepis sabnema*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus muelleri, Rattus exulans, Rattus tiomanicus, Rattus sabanus, Rattus argentiventer, Sundamys muelleri, Leopoldamys sabanus, Maxomys surifer*	Urban, semi-urban, rice field, island, forest	[4,13,17,19,21,22,32,33,36,37,40,42]
Taenia taeniaformis,[a]*Hydatigera taeniaeformis*,[a]*Hydatigera parva*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus muelleri, Rattus exulans, Rattus tiomanicus, Rattus argentiventer, Sundamys muelleri, Leopoldamys sabanus, Maxomys surifer, Maxomys rajah*	Urban, semi-urban, island, forest	[4,17,19,21,32,36-38,40,42]
Toxocara spp.	*Sundamys muelleri, Leopoldamys sabanus, Maxomys surifer, Maxomys rajah, Maxomys whiteheadi, Niniventer cremoriventer*	Semi-urban	[35]
Raillietina sp.[a]	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans*	Urban	[4]
Aspiculuris tetraptera	*Rattus norvegicus*	Urban	[20]

(continued to the next page)

Table 2. (Continued) Endoparasites in rodents in Malaysia identified in studies conducted from 2003 to 2023

Parasite(s)	Host(s)	Habitat(s)	Reference(s)
Trematode			
Zonorchis sp.	*Leopoldamys sabanus, Maxomys rajah*	Semi-urban	[36]
Fibricola ramachandrani	*Rattus tiomanicus*	Semi-urban	[36]
Acanthocephalan			
Moniliformis moniliformis	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus tiomanicus, Maxomys whiteheadi*	Urban, semi-urban	[4,32,36,40]
Intestinal protozoa			
Giardia spp., *Giardia duodenalis*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus argentiventer, Rattus exulans, Rattus tiomanicus*	Urban	[17,40,43]
Cryptosporidium spp., *Cryptosporidium muris, Cryptosporidium meleogridis, Cryptosporidium parvum*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus argentiventer, Rattus exulans, Rattus tiomanicus*	Urban	[40,43]
Toxoplasma gondii[a]	*Rattus* spp., *Rattus rattus diardii, Rattus bowersi, Rattus argentiventer, Rattus exulans, Rattus tiomanicus, Maxomys rajah*	Urban, rice field, forest	[40,44]
Entamoeba histolytica[a]/*Entamoeba dispar*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus argentiventer, Rattus exulans, Rattus tiomanicus*	Urban	[33,40,45]
Conoidasida spp.	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus*	Urban	[13,20,21]
Blastocystis sp.[a]	*Rattus* spp., *Rattus norvegicus*	Urban	[20,21,46]
Trichomonas sp.	*Rattus* spp., *Rattus norvegicus*	Urban	[20,21]
Sarcocystis spp.	*Rattus* spp.	Urban	[40,47]
Eimeria spp.	*Rattus rattus diardii, Rattus norvegicus*	Urban	[13]
Blood protozoa			
Trypanosoma sp., *Trypanosoma lewisi*	*Rattus* spp., *Rattus rattus diardii, Rattus norvegicus, Rattus argentiventer, Rattus exulans, Rattus tiomanicus, Rattus annandalei*	Urban	[13,21,33,48,49]
Plasmodium sp.	*Rattus rattus diardii, Rattus norvegicus, Rattus exulans, Rattus annandalei*	Urban	[48]
Hepatocystis sp.	*Rattus tanezumi*	Urban	[50]
Hepatozoon ophisauri	*Rattus tanezumi*	Urban	[50]

[a]Zoonotic parasite.

These studies were conducted in various regions across Malaysia with different target samples, including urban and non-urban rodents and ectoparasite and endoparasite species. Twenty-nine studies were conducted on urban rodents, while 12 were conducted on non-urban rodents (rice fields, coastal, island, and forest areas). Consequently, data on parasites infecting rodents in Malaysia has been documented. Despite the numerous studies conducted across Malaysia, there is a lack of published studies on parasites in rodents from Sabah, a state of east Malaysia located in the northern region of Borneo. The most recent parasite study in rodents conducted in Sabah was in 1976 [13], with most studies focusing on non-rodent parasite hosts such as orangutans and civets. Similarly, no parasite study was reported in rodents in Perlis, the smallest state of Malaysia located on the northwest coast of Peninsular Malaysia. The parasite study in Perlis was conducted in 1977, and the hosts were humans, cats, and mosquitoes [14].

Ectoparasites infestation in rodents inhabiting Malaysia

Tonsy [15] asserted that external or ectoparasites inhabit the exterior of their hosts, commonly affixing themselves to the skin, feathers, hair, gills, and other parts. Generally, ectoparasites attach to the skin to feed and do not infest the host for their entire lives. They either feed on feathers, hair, skin, and secretions or suck blood and lymph fluids. Most ectoparasites are arthropods, which are invertebrates with jointed legs and hard exterior skeletons, such as lice, ticks, fleas, bugs, flies, and mosquitoes [16]. In Malaysia, 19 available studies discussed ectoparasite infestations in rodents for the past 20 years [13-55]. These studies were conducted in various habitats, including urban, semi-urban, forest, island, rice fields, and coastal areas, all across Malaysia, ranging from Johor to Kedah, including the state of Sarawak.

Despite the extensive studies on the parasite in rodents, most were conducted with a small sample size of parasite hosts. Of 19 studies, only six examined the host with a sample size of more than 80 individuals [16,17,19,20,23,28]. In contrast, the remaining studies obtained a smaller sample size (< 80 individuals), as shown in **Table 1**. In natural infections, parasites often display an aggregated distribution pattern, with most host individuals harboring few parasites and a small number of individuals harboring many parasites [56]. Shvydka et al. [56] suggested that a sample size of 80 host individuals or more allows for an accurate and precise estimation of the mean abundance, whereas the median estimates showed a minimal bias for a host sample size in the range of 25 to 40 individuals, but the sampling distribution skewed to low values. In particular, for highly aggregated parasite data sets, a sample size of 10 host individuals results in unreliable estimations. Fitts [57] reported that a sample size that is too small may fault the actual effect of an experiment, while a sample size that is too high may result in the waste of resources and animals.

Various methods have been used to identify ectoparasites in rodents. As a result, numerous ectoparasite species that infested rodents in Malaysia consist of five groups: fleas, lice, ticks, and mites (further classified into a chigger group).

Ectoparasites of zoonotic importance in rodents

Among the ectoparasites listed in **Table 1**, the following are recognized for their zoonotic significance: *Xenopsylla cheopis* (flea); *Polyplax spinulosa, Hoplopleura pacifica* (lice); *Haemaphysallis* spp., *Ixodes granulatus* (tick); *Ornithonyssus bacoti* (mite); and *Leptotrombidium deliense* (chigger). This review emphasized the risk of the transmission of zoonosis from these ectoparasites of different genera and causative agents. Mustapha et al. [7] suggested there is a risk of disease transmissions, such as *Rickettsia typhi* and plague disease, to humans from *X. cheopis*, a flea group parasite, as underscored by the World Health Organization (WHO). This flea species raises a serious concern in the event of a plague outbreak, given its role as a primary vector. In addition, fleas have been implicated in transmitting murine typhus [28]. A thorough understanding of local flea species and their respective hosts is indispensable for evaluating the risk of human plague infection and developing appropriate control methods.

Polyplax spinulosa and *H. pacifica* are two lice species considered parasites of public health importance. These species are carriers of plague bacilli, facilitating the transmission of human diseases, such as tularemia and bartonellosis. In addition, they aid in the spread of murine typhus and plague among rat populations [14]. In Malaysia, *Rickettsia typhi* infections in humans were reported in 2013 and 2010. In March 2013, a 15-year-old boy who had been experiencing appetite loss for a week, myalgia, arthralgia, and minor headache was hospitalized at the University Malaya Medical Center (UMMC). In addition to having petechiae on his limbs, he exhibited conjunctival suffusion. Retrospective analysis of the rickettsial serology showed that he was positive for two rickettsial antigens, *R. typhi* and *R. rickettsii* [58]. Similarly, in June 2010, a 72-year-old woman residing on a farm on the east coast of Malaysia suffered from febrile sickness and interstitial lung fibrosis and was hospitalized in the UMMC. A molecular investigation confirmed an *R. typhii* infection, verifying the diagnosis of murine typhus disease [58]. The infection of this murine typhus disease could have a strong association with these ectoparasites: *X. cheopis, P. spinulosa, H. pacifica*, and *Haemaphysalis* sp. On the other hand, no reported cases of tularemia and bartonellosis infection in Malaysia.

https://doi.org/10.4142/jvs.24098

Haemaphysalis sp. and *I. granulatus* are medically important tick species. *Haemaphysalis* sp. contributes to the spread of various infections, including protozoa (Babesia), bacteria (Tularemia), *Rickettsia* sp., and arboviruses. Animal and human hosts may also experience stress and blood loss induced by their bites. On the other hand, *I. granulatus* serves as the primary vector for the Langat virus and has been implicated in the spread of other diseases such as babesiosis, human granulocytic anaplasmosis, and Lyme disease [7]. In the climate forest of Peninsular Malaysia, *Ixodes* sp. is responsible for the transmission of tick typhus and *Coxiella burnetii* infection (Q fever) to humans [16]. The first documented case of Q fever in Malaysia occurred in April 2007, involving a patient admitted to Penang Hospital after experiencing a two-week fever. The patient also had a history of handling a goat's abortus on his farm. The serological test confirmed the presence of IgM and IgG antibodies indicative of Q fever. The infection was transmitted through direct contact with the infected goat as he delivered the abortus of the goat without using personal protective equipment (PPE) [59].

Nursyazana et al. [19] reported that *O. bacoti* mite species are detected infrequently in Malaysian rats despite their worldwide spread and cause pruritic dermatitis in humans. This mite species bites humans and contributes to the transmission of filariasis as an intermediary host for filarial worms [7]. The first documented case of dermatitis caused by *O. bacoti* dates back to 1974 [19]. For *L. deliense, the* parasite species of the chigger group is recognized as the main vector of scrub typhus [14,26,29,54]. Scrub typhus remains a significant public health concern, with an estimated annual attack incidence of 18.5%. Therefore, the existence of this vector species suggests that individuals bitten by chiggers may be at risk of contracting scrub typhus [26]. Thus far, no cases of scrub typhus disease have been reported in Malaysia.

Endoparasites infection in rodents inhabiting Malaysia

Endoparasites, also known as intestinal parasites, reside within their hosts in the gut, body cavity, lungs, blood, or other tissues. They include helminths, which are multicellular organisms, and protozoa, unicellular organisms [31]. Helminthic parasites are further classified into trematodes (flatworms), cestodes (tapeworms), and nematodes (roundworms). Both helminthic and protozoan parasites can infect various tissues and organs within the host's body. Helminths are typically found in the intestines, muscles, liver, and urinary bladder, while protozoa predominantly circulate in the blood [15].

In Malaysia, 27 available published studies on endoparasites in rodents have been conducted using various methods and techniques for parasite detection [4,13,15,19,20,22,23,27,32-50]. In contrast to ectoparasite reports in Malaysia, most endoparasite studies were conducted with a larger sample size of hosts over 80 individuals. Only eleven (11) out of 27 studies examined a small sample size (< 80 individuals) for the host [13,17,22,31,34,35,37,39,41,49,50]. Briefly, the findings of previous endoparasites studies suggested that endoparasites infecting rodents inhabiting Malaysia can be categorized into five groups: nematode, cestode, trematode, acanthocephalan, and protozoa (further classified into intestinal protozoa and blood protozoa).

Endoparasites in rodents associated with zoonotic implications

Among the above-mentioned endoparasites, the following are endoparasite species associated with zoonotic implications: *Capillaria hepatica* (nematode); *Hymenolepis diminuta, Hymenolepis nana, Taenia taeniaformis, Raillietina* sp. (cestodes); and *Entamoeba histolytica, Toxoplasma gondii, Blastocystis* sp. (intestinal protozoa). In rodents, infections of *C. hepatica* are common and widely reported worldwide, contributing to a zoonotic disease called hepatic

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capillariasis [38,60-62]. Although this parasite species occasionally infects humans, *C. hepatica* is accountable for hepatic capillariasis, possibly spurious. Globally, 163 human cases have been reported, including 72 cases of hepatic capillariasis, 13 serologically confirmed infections, and 78 cases of spurious infections [63,64]. No cases of hepatic capillariasis disease in humans in Malaysia have been reported.

In addition to *C. hepatica* infections, more than 175 million individuals worldwide have been reported to be infected by two species of *Hymenolepis: H. diminuta* and *H. nana* [65-67]. These parasites can cause hymenolepiasis in humans, characterized by symptoms such as restlessness, irritability, diarrhea, and abdominal pain [21]. According to Muehlenbachs et al. [11], infections with *H. nana* and *H. diminuta* can be fatal in severe cases, particularly in immune-compromised individuals. Sinniah et al. [68] reported infections of *H. diminuta* and *H. nana* in oil palm estate workers in Malaysia, suggesting the transmission of these parasites from rodents to human hosts.

Rodents also serve as intermediate hosts for the zoonotic helminth, *T. taeniaformis*, which can potentially transmit to humans [15,69]. Despite occasional human infections with *T. taeniaformis* earlier recorded in Argentina, the Czech Republic, Slovakia, Denmark, and Taiwan [70,71], it remains a public health threat necessitating efficient prevention and control methods, as reported by Tijjani et al. [40]. The zoonotic parasite *Raillietina* sp. is a medium-sized tapeworm that primarily parasitizes birds but has also been known to infect humans [72]. This parasite requires two intermediate insect hosts to complete its life cycle, e.g., beetles, ants, and cockroaches. Human cases have also been recorded in Indian Ocean countries, China, Japan, and Thailand in the Asia region [73]. Ingesting cysticercoid-contaminated intermediate hosts can infect humans on rare occasions. On the other hand, individuals infected with this cestode lacked associated symptoms [72]. In this genus of *Raillietina*, three zoonotic species are primarily found in rodents, namely, *R. celebensis, R. siriraji*, and *R. demerariensis. R. celebensis* and *R. siriraji* are commonly found in peridomestic rats and other Southeast Asian murid rodents. In contrast, *R. demerariensis* has been discovered in various Neotropical rodents and occasionally in monkeys [74]. Thus far, no *T. taeniaeformis* and *Raillietina* spp. infections have been reported among Malaysians.

In humans and animals, amoebic dysentery or amoebiasis disease is caused by intestinal protozoa known as *Entamoeba histolytica.* Globally, this disease affects approximately 50 million individuals annually, resulting in 40,000 to 100,000 fatalities [7]. Transmission occurs through the consumption of contaminated food or water. Infection of this disease might appear with no symptoms, mild symptoms, or severe symptoms, such as stomach pain, diarrhea, and dysentery [7]. Aboriginal communities in Malaysia frequently experience *E. histolytica* infections [75]. *E. histolytica* and *Toxoplasma gondii* are zoonotic intestinal protozoa found in rodents that cause toxoplasmosis in humans [10]. Dubey and Beattie [10] reported that humans contract toxoplasmosis by ingesting sporulated oocysts in contaminated food or drink or by consuming undercooked meat containing tissue cysts. This parasite infection can potentially induce a life-threatening opportunistic infection in immunocompromised people and developing fetuses. Nissapatorn et al. [76,77] stated that toxoplasmosis disease is common among Malaysians and people in Southeast Asia.

Blastocystis sp., a zoonotic intestinal protozoan documented in rodents, inhabits the intestines of various animals, including reptiles, birds, fish, amphibians, and humans [78]. Despite its widespread occurrence in humans, the clinical importance of *Blastocystis* sp. is debatable, and effective treatment remains challenging. Infected individuals often exhibit asymptomatic infections, but clinical manifestations of symptomatic patients include vomiting, diarrhea, and other gastrointestinal symptoms [46,79]. Anuar et al. [80] reported that 102 out of 500 individuals in Orang Asli communities in peninsular Malaysia tested positive for *Blastocystis* infection. The prevalence of positive cases was highest among individuals under 15 years of age, with a decrease in the number of cases with increasing age. The findings suggested *Blastocystis* infections are frequent in Orang Asli communities in Malaysia.

Molecular technique for parasite detection and identification

The identification of parasite species morphologically or microscopically is typically successful only at the genus level, particularly for endoparasites. This limitation arises because some parasites of the same genus pose identical similarities in terms of morphological characteristics that hinder their differentiation at the species level. For example, distinguishing intestinal parasites from the genus *Entamoeba* (i.e., *E. histolytica* and *E. dispar*) is challenging because of their identical morphology [45,81]. Tijjani et al. [40] encountered similar difficulties distinguishing between these two species of *Entamoeba*. On the other hand, differentiation from the non-pathogenic *E. muris* species was feasible by comparing the number of nuclei and cyst sizes. Mature cysts of *Entamoeba histolytica* typically contain four nuclei, while immature cysts may have one or two nuclei, with the cyst size for this species ranging from 10 to 15 µm. In contrast, *E. muris* contains up to eight nuclei with size ranges between 9 and 20 µm [81,82].

Achieving morphological identification of parasites at the species level is often challenging because of the loss or damage of critical morphological characteristics such as legs, mouthpieces, and others during the collection process. Furthermore, some of the identification keys of parasite species are scarce in the literature, particularly for endoparasites. Nevertheless, few studies could morphologically identify parasites of the same genus at the species level. The molecular approach was suggested as an alternative method to identify morphologically indistinguishable parasite species.

In Malaysia, parasite studies on species determination by the molecular approach are still lacking, with only 10 published studies on rodents over the past two decades [27,28,30,34,42,43,45,46,49,50]. Utilizing molecular techniques, researchers successfully identified parasites at the species level by extracting DNA from the positive samples and targeting various sites for amplification. For example, a study that differentiated *E. histolytica* and *E. dispar* among wild rats in Kuala Lumpur was conducted using a molecular technique [45]. In this study, the species-specific primers targeting the small subunit ribosomal RNA (ssu rRNA) gene were used in the polymerase chain reaction process to detect the species. Consequently, these findings successfully documented infections of *E. histolytica, E. dispar,* and mixed infections of both parasites in the wild rat population.

Tan et al. [43] detected the zoonotic *Cryptosporidium* and *Giardia* species for the first time in urban rodents in Malaysia through a molecular approach. The study discovered the rare occurrence of *Cryptosporidium meleagridis* in rodents, *Cryptosporidium muris*, *Cryptosporidium parvum,* and *Giardia duodenalis* genotype B. The presence of *C. meleagridis* in humans has been documented globally, including Malaysia, where its infection was detected in two out of 122 (1.6%) HIV patients. For *C. muris*, however, although it is not a prominent cause of human cryptosporidiosis in Malaysia, it has been implicated in several symptomatic and asymptomatic cases in neighboring countries such as Thailand and Indonesia. For *C. parvum*

https://doi.org/10.4142/jvs.24098

species, the findings showed that IiaA15G2R1 [accession numbers KY696272-KY696274] was the most prevalent genotype among these urban rats, which is commonly associated with infections in HIV patients in Malaysia. In addition, the study recorded *G. duodenalis*, another protozoan parasite responsible for a zoonotic disease called human giardiasis. This disease was prevalent in indigenous peoples in Malaysia and is caused by *G. duodenalis* genotype B [43].

Comprehension and molecular reports on zoonotic parasites are significant because these parasites threaten public and veterinary health. Identifying and documenting zoonotic parasites at the species level are essential for comprehending their life cycle, effects, and associated diseases. On the other hand, from previous research efforts, a notable gap exists in information concerning the primers for zoonotic parasites, particularly ectoparasite species.

Histopathological examination for intestinal parasite detection

In addition to the molecular approach, histopathological examination was suggested as an alternative approach with high sensitivity in detecting intestinal parasites. Generally, organs undergo gross examination before histological processing using Hematoxylin and Eosin staining. In Malaysia, the histopathological study of parasites in rodents remains scarce, with only six available studies over the past two decades [38-41,47,49].

Kamaruzaman et al. [49] investigated the prevalence of leptospirosis and ectoparasites in an urban rat population in wet markets in Kelantan. On the other hand, the study accidentally recorded the presence of Trypanosomes through the blood smear technique, which was also recorded recently in Klang Valley, Malaysia [13]. The histopathology findings revealed abundant epimastigotes in kidney tubules. Despite this, the kidneys exhibited no signs of inflammatory or degenerative tissue alterations, and other organs appeared normal [49]. These findings coincide with Alias et al. [48], who reported the presence of *T. lewisi* in the urban rodent population in Peninsular Malaysia.

In Serdang, Selangor, the detection of the rodent-borne parasitic pathogens of wild rats in student colleges also used a histopathological examination as one of the detection methods [40]. As an outcome, this study documented parasite infection-related inflammation using a histopathology technique as follows: *Taenia taeniaformis* cyst (*Cysticercus fasciolaris*) and *Capillaria hepatica* eggs were observed in the liver; the larvae of *Angiostrongylus cantonensis* were recorded in brain and lungs tissues; *Toxoplasma gondii* and *Sarcocystis* spp. were examined in the brain and skeletal muscle. A gross examination of the liver revealed lesions, including fibrosis associated with *C. hepatica* egg and cysts, which appeared creamy, white, and round and were recognized as *T. taeniaformis* cysts. The lesions of *C. hepatica* reported in this study were consistent with other studies [38,39,41].

Organs examined in all six previous pathological studies include the brain, heart, lung, liver, spleen, kidney, intestine, and muscle. On the other hand, information on pathological findings encompassing both gross and histological lesions observed in organs exhibited by parasites in rodents is still lacking, with a predominant focus on examinations of the liver and kidney. Therefore, future research is suggested to describe gross and histological lesions caused by parasites, particularly zoonotic parasites, for future reference.

DISCUSSION

The recent findings in this review highlight several significant parasitology-related topics. The contributions of this review include a list of parasites infecting rodents in Malaysia. This information will assist local researchers in identifying parasite species more effectively as the range of species infecting rodents in Malaysia has been refined. In addition, this review discusses information on previous molecular works and pathological findings in each infected organ in rodents with parasites, offering baseline information for researchers, especially local researchers.

Despite numerous parasite studies in rodents conducted in Malaysia, this review emphasized some limitations and gaps in previous studies. For example, most parasite studies in rodents were conducted with small sample sizes of less than 80 samples for the host of parasites, affecting the accuracy of the research outcome. A sufficient sample size is necessary to help understand the distribution of parasites infesting and infecting rodents in Malaysia. Regarding blood parasite, molecular, and histopathological studies, this information is lacking in Malaysia, where most studies used conventional methods in detecting parasites in rodents. Therefore, it identifies critical gaps in understanding information related to blood parasites, species-specific primers for parasites, and gross and histological observations of parasites infecting rodents in Malaysia. Further studies should address these knowledge gaps to enhance the understanding of parasites in rodents in Malaysian regions.

Considering earlier discussions, rodents play a significant role as hosts for zoonotic parasites, serving as reservoirs that facilitate the transmission of various diseases to humans. Their close proximity to human populations amplifies the risk of zoonotic disease outbreaks. Therefore, preventive measures should be implemented by individuals and authorities to minimize rodent exposure, which could reduce the transmission of zoonotic parasites. For example, installing rat traps regularly to reduce the population of rodents, improving waste management procedures, such as disposing of the waste in covered garbage containers to prevent rat infestation, ensuring the stored food is secure to avoid contamination with rodents' excreta, and wearing PPE, such as gloves and rubber boot, while handling garbage.

ACKNOWLEDGMENTS

The authors are thankful to the staff of Veterinary Parasitology Laboratory, Faculty of Veterinary Medicine, Universiti Putra Malaysia, who helped in the project, particularly Mrs. Maizatul Akmal and Mr. Abd Rashid. We expressed our gratitude to the Exiang for granting us permission to use the Malaysia map (**Fig. 1**).

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