Heliyon 10 (2024) e31955

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

A systematic review and meta-analysis on prevalence of gastrointestinal helminthic infections in rodents of Iran: An emphasis on zoonotic aspects

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ARTICLE INFO

Keywords:
Prevalence
Gastrointestinal helminths
Rodents
Iran
Meta-analysis
Systematic review

ABSTRACT

Rodents are the largest group of mammals that adapt to different ecosystems and may act as the potential reservoirs of significant pathogens including gastrointestinal (GI) helminths. Rodent-borne parasitic pathogens have been and remain a great concern for animal and human health. The aim of this systematic review and meta-analysis is thus to clarify and better understand the pooled prevalence of GI helminthic infections and the associated risk factors in rodents in Iran. Multiple databases (PubMed, Scopus, Web of Science, Google Scholar, SID, Magiran and Irandoc) were searched for relevant literature published up to March 2022. A random-effects meta-analysis model was applied to estimate the pooled prevalence with 95 % confidence interval. Moreover, heterogeneity among studies was evaluated using the Cochran's *Q* test and the I^2-statistic. Out of the 5438 publications searched, 28 articles (30 datasets) were ultimately eligible for inclusion in the study. Thus, 3649 captured rodents belonging to 6 families, 20 genera, and 35 species were examined for GI helminths in Iran. Then, 54 helminth species were identified in the present research, including 33 nematodes, 16 cestodes, 4 trematods, and 1 acanthocephalan. The prevalence rate of GI parasitic infections was 56 % (95 % CI: 50–63 %). *Hymenolepis diminuta*, *Syphacia obvelata* and *Rodentolepis nana* were the most common helminthic infections (13 %, 9 %, and 8 %, respectively). Moreover, 11 potential zoonotic helminths were found. There was no significant difference in pooled prevalence between male and female rodents (P = 0.40). Considering geographical areas, northern and eastern provinces had the highest prevalence of GI helminthic infections among rodents. The prevalence of GI worms in Iranian rodents was as high as 56 % with 11 zoonotic helminths. Therefore, it is suggested to observe the health of the environment, destroy the biological nests of rodents, avoid half-finished constructions, repair and improve streams and sidewalks, organize and collect garbage, and carry out biological and chemical

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https://doi.org/10.1016/j.heliyon.2024.e31955
Received 28 September 2023; Received in revised form 24 May 2024; Accepted 24 May 2024
Available online 25 May 2024

control to handle the population of rodents. Increasing the awareness of local people about the harmful effects of rodents and the ways of transmission and prevention of rodent-borne intestinal worms transmitted to humans should be prioritized in health decisions.

1. Introduction

The order of rodents includes more than 2552 species and 34 families [1]. They are one of the main links in the natural food chain. Rodents are an essential food source for many carnivores, such as foxes, mongooses, otters, and predatory birds [2]. Among the benefits of rodents, one can mention the digging activities of underground species that lead to the aeration of the soil, moving mineral nutrients into the upper layer of soil, and controlling the insect population of some species [3]. Nevertheless, rodents are considered as agricultural pests that reduce the yield of agricultural farms and spoil stored food. Furthermore, Invasive species are a major threat to biodiversity and can cause irreversible damage to nature [4]. Perhaps, the main importance of these mammals is their potential of transmitting some serious pathogenic agents to human [5]. They can act as reservoirs and definitive, intermediate, or paratenic hosts of various infectious diseases [6,7]. Rodents transfer more than 60 known diseases to humans, and the list is still growing [6]. Zoonotic diseases transmitted by rodents may be directly transmitted to humans; in other words, the infectious agent infects the environment and as a result, humans may become infected directly due to contamination of hands, food, water, or indirectly through an arthropod vector previously contaminated with the infectious agent directly [8,9].

One of the most common types of infectious diseases is gastrointestinal (GI) helminthic infection. The helminths are divided into three main groups of Acanthocephala (thorny-headed worms), Nematodes (roundworms), and Platyhelminthes (flatworms). The latter group includes Trematodes (flukes) and Cestodes (tapeworms) [10]. GI worm infections are prevalent throughout the world and may cause malnutrition, vague abdominal pains, diarrhea, nausea, vomiting, weight loss, and anemia in humans, especially in children and the elderly or immunocompromised people. In some cases, they may cause serious complications such as intestinal obstruction, myocarditis, cholecystitis, and appendicitis [11]. They also have important effects on the biological communities and ecosystems [12].

Iran is located at a latitude of 25–39° south of the northern hemisphere's temperate zone and a longitude of 44–63° east. This geographical location, along with the distance from the large seas, especially the air currents, has contributed to a dry climate. However, due to its large size and the presence of various natural factors, such as high altitudes in the north and west, vast lowlands such as the central plains inside the plateau, and the vicinity of the Caspian Sea, the Persian Gulf, and the Indian Ocean, Iran has a diverse climate classified into four sections, including temperate and humid (southern coast of the Caspian Sea), hot and dry (central plateau), cold and mountainous (western mountains), and hot and humid (southern coast) [13].

Seventy-six rodent species in 8 families have been identified in Iran [14]. This wide variety of rodents in the country can be a significant risk factor for the transmission of rodent-borne parasites to humans [8,15]. Significant efforts have already been made to control and reduce the burden of parasitic infections; however, GI parasitic infections remain a concern for healthcare services [16]. Over the last few decades, because of high prevalence, and also the large number of rodent-related parasites in Iran, many studies have been conducted on the parasitic fauna of rodents. Our country is one of the leading countries in the field of rodent-borne pathogens research. However, there is no comprehensive study of the prevalence of GI worms in Iranian rodents. Given the diversity of climate and environmental conditions (humidity, rainfall, temperature, vegetation cover) in Iran, it is necessary to evaluate the fauna of parasites based on the published data from different regions to identify the distribution of different parasites and contribute to the development and advancement of the parasitological knowledge. Therefore, the current systematic review and meta-analysis was designed to address the pooled prevalence of GI helminths in Iranian rodents and its determinants.

2. Materials and methods

A systematic review and meta-analysis was conducted based on the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [17] (see PRISMA checklist in Additional file 1: Table S1).

2.1. Data bases and search strategy

The literature on the prevalence of GI helminths in rodents in Iran published up to March 31, 2022 was searched by two authors (AB and HJ) in the MEDLINE (via PubMed), Web of Science, Google Scholar, Scopus and Magiran, and Scientific Information Database (SID). Additionally, the database of IranDoc was searched to get unpublished dissertations relevant to the topic. The resulting articles from the searched databases were imported into the EndNote X9 software library for de-duplicating, and title and abstract screening. The reference lists of the included studies were manually searched to find additional relevant articles. Terms used for search were GI parasites, helminths, endoparasite, rodent, epidemiology, and prevalence, Iran.

2.2. Inclusion and exclusion criteria

Observational studies investigating the prevalence of GI helminths in rodents in Iran based on parasitological methods that were published up to March 30, 2022 were included in the study. Case reports, meeting reports, case series, reviews, studies without original data, studies on laboratory rodents in the animal house, articles in languages other than English and Persian, articles with inaccessible full-texts, those with confusing/unclear analysis, and the articles that did not report the prevalence of GI helminthic infection were excluded. Two reviewers (HJ and SK) independently and manually assessed the studies based on the inclusion and exclusion criteria. Any probable disagreement was resolved through discussions between the two reviewers or by consulting with a third researcher.

2.3. Study quality assessment

The quality of the studies with accessible full-texts was assessed using the Joanna Briggs Institute (JBI) checklist [18]. This checklist contains 9 items with 'Yes = 1', 'No = 0', and 'Unclear or Not applicable = 0' options that evaluated the sampling process, data analysis process and statistical methods, study settings, measurement tools and response rate. Based on the obtained score, the authors decided to include studies that scored 4–9 points as moderate-high quality and exclude the publications that scored ≤3 points. Quality assessment was independently done by two reviewers (YH, AD). Any disagreement between assessors was resolved through consulting with AB.

2.4. Data extraction

The following data were extracted and tabulated: first author's name, publication year, county of study, rodent species, gender, sample size, region, detected parasite species, and number of positive cases. Three researchers (H.B., M.R.S., and H.J.) extracted all the data from the included studies, and a fourth researcher (AD) rechecked these data for accuracy before data-analysis. Any the

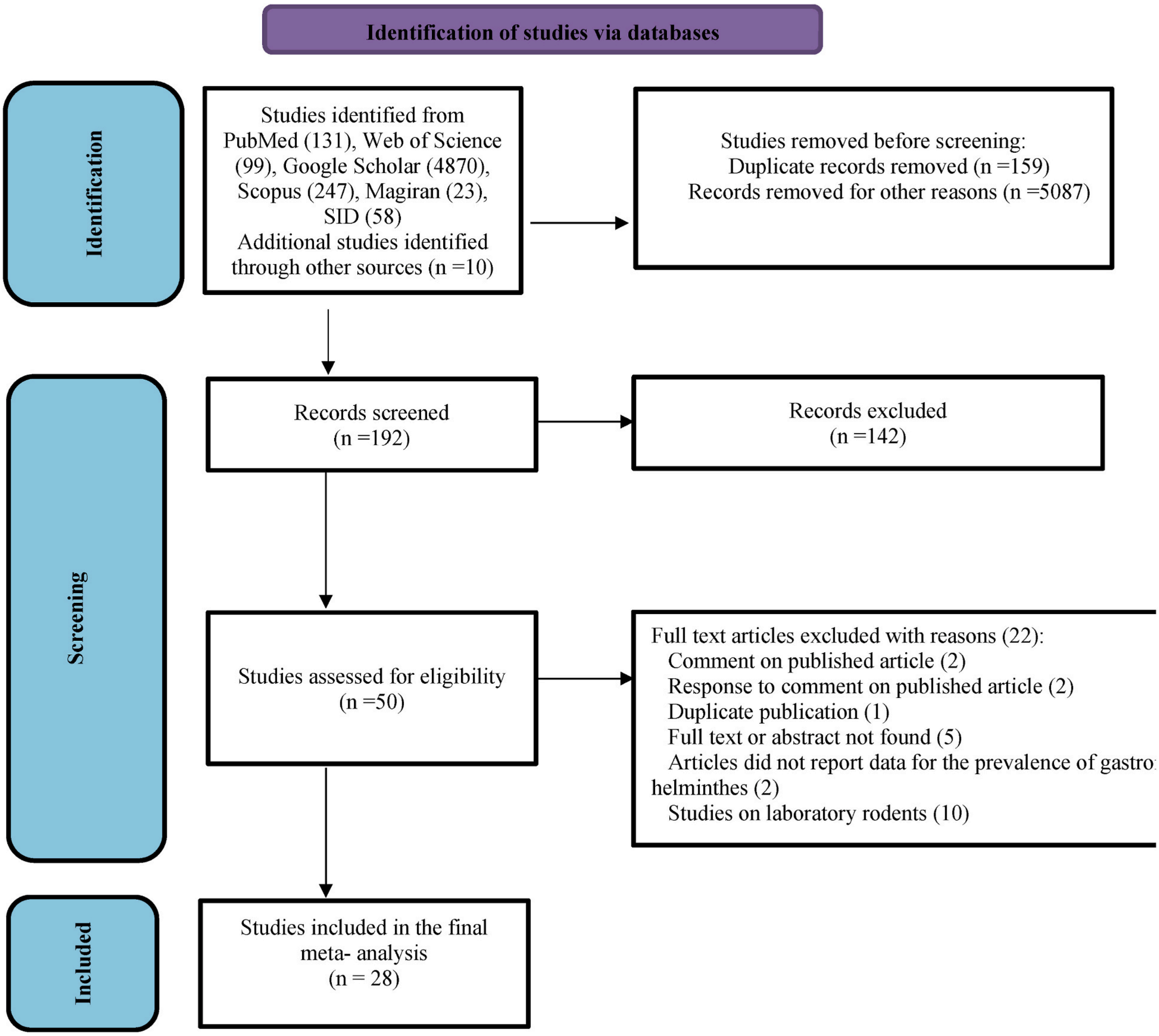

Fig. 1. PRISMA flow diagram describing included/excluded studies.

Table 1
Baseline characteristics of included studies.

no		Province	County/area	Sample size	Number infected	Rodent details	Rodent helminths
1	Khajeh et al., 2018 [20]	Hormozgan, Sistan& Baluchestan, Kerman	The Jaz Murian depression	146	49	*Mus musculus, Tatera indica, Acomys dimidiatus, Gerbillus nanus, Meriones libycus, Nesokia indica, Jaculus blanfordi, Calomyscus hotsoni, Apodemus witherbyi, Rattus rattus, Golunda ellioti, Microtus mystacinus, Cricetulus migratorius*	*Trichuris muris, Syphacia obvelata, Labiostomum* spp.*, Labiostomum naimi, Mastrophorus muris, Aspicularis tetraptera, Heligmosomoides skrjabini, Physaloptera* spp.*, Choanotaenia* spp.*, Raillietina* spp.*, Hymenolepis diminuta*
2	Pakdel et al., 2013 [22]	Kermanshah	Kermanshah	138	58	*Mus musculus, Rattus norvegicus, Rattus rattus*	*Trichuris muris, Syphacia obvelata, Syphacia muris, Aspicularis tetrapetra, Heterakis spumosa, Capillaria hepatica* (egg)*, Hyminolepis diminuta, Taenia taeniaeformis* larva/ *Cysticercus fasciolaris*
3	Fattahi et al., 2021 [23]	Eeast Azerbaijan	Tabriz	100	68	*Rattus* spp.	*Trichuris muris, Syphacia obvelata, Strongyloides ratti, Gongylonema* spp.*, Physaloptera, Nippostrongylus* spp.*, Rodentolepis nana, Hymenolepis diminuta, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Moniliformis moniliformis*
4	Hasanpor et al., 2013 [24]	Khuzestan	Dezfoul, Andimeshk	108	38	*Rattus rattus, Rattus norvegicus*	*Nippostrongylus brasiliensis, Rictolaria ratti, Trichosomoides crassicauda, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Hymenolepis diminuta, Rodentolepis nana, Moniliformis moniliformis*
5	Ebrahimi et al., 2016 [25]	West Azerbaijan	Piranshahr	156	43	*Mus Musculus*	*Syphacia obvelata, Syphacia muris, Aspicularis tetraptera, Hymenolepis diminuta, Rodentolepis nana*
6	Mohammadi et al., 2022 [26]	Kurdistan	Sarvabad, Marivan, Sanandaj	208	67	*Apodemus witherbyi, Apodemus ponticus, Apodemus mystacinus, Apodemus* sp.*, Microtus qazvinensis, Microtus socialis, Meriones vinogradovi, Meriones libycus, Meriones tristrami, Meriones persicus, Mus macedonicus, Mus musculus domesticus, Dryomys nitedula, Cricetulus migratorius, Sciurus anomalus*	*Syphacia muris, Streptophagus* spp.*, Mastophorus muris, Skrjabinema* spp.*, Trichostrongylus* spp.*, Trichuris muris, Rodentolepis nana, Hymenolepis dimimuta, Heligmosomoide* sp.
7	Allymehr et al., 2012 [27]	West Azerbaijan	–	77	43	*Mus musculus*	*Syphacia obvelata, Syphacia muris, Aspiculuris tetraptera, Taenia taeniaeformis* larva/ *Cysticercus fasciolaris, Hymenolepis diminuta*
8	Kia et al., 2010 [28]	Ardabil	Germi	177	131	*Meriones persicus, Microtus socialis*	*Trichuris* spp.*, Capillaria hepatica* (egg)*, Moniliformis moniliformis, Aspiculuris tetraptera, Syphacia obvelata, Taenia endothoracic* larva*, Physaloptera* spp.*, Dentostomella translucida, Heligmosomum mixtum, Taenia taeniaeformis* larva/*Cysticercus*

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Table 1 (*continued*)

no		Province	County/area	Sample size	Number infected	Rodent details	Rodent helminths
							fasciolaris, Mesocestoides larva/*tetrathyridium, Hymenolepis diminuta, Rodentolepis nana*
9	Meshkekar et al., 2014 [29]	Teheran	Tehran	120	75	*Rattus rattus, Rattus norvegicus*	*Capillaria annulosa, Heterakis spumosa, Hymenolepis diminuta, Rodentolepis nana*
10	Yousefi et al., 2014 [30]	Hamadan	Hamadan	132	54	*Apodemus sylvaticus, Mus musculus*	*Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Syphacia fredrici, Syphacia ohtarom, Syphacia stroma, Syphacia obvelata,* Anoplocephalidae, *Skrjabinotaenia lobata, Plagiorchis muris, Rodentolepis nana, Hymenolepis diminuta, Rodentolepis crassa*
11	Zarei et al., 2016 [31]	Ardabil	Meshkin-Shahr	205	97	*Meriones persicus, Mus musculus, Cricetulus migratorius*	*Trichuris* spp., *Trichuris rhombomidis, Capillaria hepatica* (egg), *Syphacia frederici, Aspicularis tetraptera, Heligmosomom* spp., *Streptopharagus kuntzi,* Spiruridae, *Rodentolepis nana, Hymenolepis diminuta, Mesocestoides* larva/*tetrathyridium, Paranoplocephala* spp., *Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Taenia endothoracica* larva, *Moniliformis moniliformis*
12	Ranjbar et al., 2017 [32]	Kohgiluyeh and Boyer-Ahmad	Boyer-Ahmad	52	38	*Meriones persicus, Calomyscus bailwardi, Arvicola terresterris, Rattus rattus, Rattus norvegicus, Apodemus sylvaticus*	*Trichuris muris, Aspiculuris tetraptera, Syphacia* sp., *Rictularia* spp., *Trichostrongylus* spp., *Gongylonema* spp, *Hymenolepis diminuta, Rodentolepis nana, Skrjabinotaenia* spp., Anoplocephalidae, *Taenia taeniaeformis* larva/*Cysticercus fasciolaris,*
13	Kamranrashani et al., 2013 [33]	Golestan	Maraveh Tappeh	77	63	*Rhombomys opimus*	*Trichuris rhombomidis, Trichuris muris, Trichuris* spp., *Syphacia muris, Dipetalonema vitae (Acanthocheilonema viteae)*[a], *Skrjabinotaenia lobata, Rodentolepis nana, Taenia endothoracica* larva
14	Fasihi Harandi et al., 2016 [34]	Kerman	Kerman, Rafsanjan, Anar, Baghin, Zangiabad, Kouhpaye, Mahan, Rabor, Rayen, Ravar, Bam	51	23	*Meriones persicus, Meriones libycus, Tatera indica, Dryomys nitedula, Mus musculus, Paraechinus hypomelas*[b], *Lepus europeus*[b]	*Trichuris muris, Mastophorus muris, Moniliformis moniliformis, Hymenolepis diminuta, Rodentolepis nana*
15	Mohtasebi et al., 2020 [35]	Alborz	Taleqan	62	30	*Mus musculus, Meriones persicus, Meriones libycus, Apodemus witherbyi, Dryomys nitedula*	*Syphacia obvelata, Heligmosomoides polygyrus, Rodentolepis nana, Hymenolepis diminuta, Trichuris muris,* Capillariid nematodes
16	Arzamani et al., 2017 [36]	North Khorasan	Raz and Jargalan, Maneh and Samalqan, Garmeh, Jajarm, Bojnord, Esfarayen, Faruj, Shirvan	113	58	*Mus musculus, Apodemus witherbyi, Meriones persicus, Meriones libycus, Nesokia indica, Microtuss paradoxus, Dryomys nitedula,*	*Aspiculuris tetraptera, Hymenolepis diminuta, Nippostrongylus brasiliensis, Protospirura numidica, Rictolaria ratti, Skrjabinotaenia lobata, Streptopharagus kuntzi, Syphacia obvelata, Trichuris*

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Table 1 (*continued*)

no		Province	County/area	Sample size	Number infected	Rodent details	Rodent helminths
						Allactaga elater, Calomyscus elburzensis, Calomyscus mystax, Rhombomys opimus, Ellobius fuscocapillus, Cricetulus migratorius	*muris, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Acanthocephala* spp.*, Trichuris* spp.
17	Shahabi et al., 2019 [37]	Fars	Shiraz	10	6	*Calomyscus bailwardi*	*Syphacia obvelata*
18	Mazhari et al. [1]. 2019 [38]	Gilan	–	54	40	*Rattus* spp.	*Rodentolepis nana, Hymenolepis diminuta, Heterakis spumosa, Capillaria annulosa, Syphacia obvelata, Syphacia muris, Aspiculuris tetraptera, Trichuris muris, Streptopharagus kuntzi, Skerjabinotaenia abnormalis*
19	Mazhari et al. [2]. 2019 [38]	Mazandaran	–	36	23	*Rattus* spp.	*Rodentolepis nana, Hymenolepis diminuta, Heterakis spumosa, Syphacia obvelata, Euparyphium murinum*
20	Mazhari et al. [3]. 2019 [38]	Golestan	–	42	20	*Rattus* spp.	*Rodentolepis nana, Hymenolepis diminuta, Heterakis spumosa, Syphacia obvelata, Syphacia muris, Streptopharagus kuntzi, Skerjabinotaenia abnormalis*
21	Moradpour et al., 2018 [21]	Golestan, Khorasan Razavi, South Khorasan, North Khorasan, Koh-giluyeh & Boyer Ahmad, Semnam, Chaharmahal & Bakhtiari, Fars, Zanjan and Sistan & Baluchistan. Khuzestan	Gorgan, Ali Abad-e Katoul, Cheshme Hesar, Zoshk, Kakhk, Darekesh, Bojnord, Yasouj, Shahmirzad, Shahr-e Kord, Shiraz, Zanjan, Sistan & Baluchistan, Ahvaz	253	109	*Mus musculus, Microtus, Apodemus witherbyi, Calomyscus elburzensis, Meriones libycus, Tatera indica, Alactaga elater, Arvicola amphibius*	*Syphacia obvelata, Aspicularis tetraptera, Trichuris muris, Capillaria* spp.*, Physaloptera* spp.*, Gongylonema* spp.*, Nippostrongylus brasiliensis, Heligmosomoides polygyrus, Hymenolepis diminuta, Rodentolepis nana, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Mesocestoides* spp.*, Moniliformis moniliformis, Notocotylus noyeri*
22	Gholami et al., 2002 [39]	Mazandaran	Sari, Amol, Nur, Ramsar, Tonekabon, Mahmudabad, Juybar, Behshahr, Gaemshahr	371	175	*Rattus rattus, Rattus norvegicus, Mus musculus, Nesokia indica, Apodemus sylvaticus, Glis persicus, Arvicola terrestris*	*Echinostoma ilocanum, Syphacia obvelata, Trichuris muris, Nippostrongylus* spp.*, Hymenolepis diminuta, Heterakis spumosa, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Mateotaenia*
23	Rashidi Gheshlagh et al., 2017 [40]	Kurdistan	Saqqez	138	80	*Ellobius lutescens, Microtus socialis, Mus musculus, Rattus norvegicus, Rattus rattus, Meriones libycus*	*Syphacia obvelata, Aspicularis tetraptera, Syphacia muris, Nippostrongylus brasiliensis, Rodentolepis nana, Syphacia mesocricetus, Hymenolepis diminuta, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Protospirura muricola, Catenotaenia pusilla*
24	Moradi et al., 2015 [41]	Hamadan	Hamadan	100	62	*Rattus norvegicus*	*Strongyloides* spp.*, Heterakis spumosa, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Hymenolepis diminuta, Rodentolepis nana, Trichuris muris*
25	Rasti et al., 2002 [42]	Isfahan	Kashan	120	68	*Meriones libycus, Mus musculus, Rattus rattus, Rhombomis opimus, Gerbillus nanus, Jaculus blanfordi*	*Syphacia obvelata, Gongylonema* spp. *Rodentolepis nana, Hymenolepis diminuta, Trichuris muris, Aspicularis tetraptera, Capillaria annulosa, Trichosomoides crassicauda,*

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Table 1 (*continued*)

no		Province	County/area	Sample size	Number infected	Rodent details	Rodent helminths
							Meggitina, Mateotaenia cimertica
26	Jadidoleslami et al., 2014 [43]	Kerman	Kerman	100	36	*Mus musculus*	*Trichiuris* spp, *Syphacia obvelata, Heterakis spumosa, Hymenolepis diminuta, Rodentolepis nana, Physaloptera* spp, *Aspicularis tetraptera, Taenia taeniaeformis* larva/*Cysticercus fasciolaris*
27	Homayoni et al., 2000 [44]	Khuzestan	Ahvaz	70	41	*Mus musculus, Rattus rattus, Rattus norvegicus*	*Syphacia muris, Streptopharagus kuntzi, Trichosomoides crassicauda, Strongyloides* spp. *Rictularia* spp, *Hymenolepis diminuta, Rodentolepis nana, Taenia taeniaeformis larva/Cysticercus fasciolaris, Gongylonema* spp., *Physocephalus sexalatus*
28	Najari et al., 1993 [45]	Ardabil	Dasht e Moghan	320	295	*Microtus socialis, Meriones libycus*	*Paranoplocephala brevis, Mastophorus muris, Skrjabinotaenia lobata, Rodentolepis nana, Hymenolepis diminuta, Heligmosomum* spp., *Syphacia* spp., *Trichuris* spp.
29	Molavi et al., 1992 [46]	Tehran	Tehran	80	63	*Rattus* spp.	*Syphacia muris, Aspicularis tetrapetra, Trichosomoides crassicauda, Hymenolepis diminuta, Rodentolepis nana, Taenia taeniaeformis* larva/ *Cysticercus fasciolaris, Gongylonema* spp., *Heterakis spumosa, Capillaria annulosa, Capillaria hepatica* (egg), *Moniliformis moniliformis, Mastophorus muris, Plagiorchis muris*
30	Shahrokhi Sabzevar et al., 2019 [47]	Razavi Khorasan	Sarakhs	33	30	*Allactaga elater*	*Heligmosomoides polygyrus, Aspicularis tetraptera, Trichiuris* spp., *Syphacia obvelata, Taenia taeniaeformis* larva/*Cysticercus fasciolaris, Hymenolepis diminuta, Rodentolepis nana*

Note Some species such as *Taenia taeniaeformis* larva, *Mesocestoides* larva and *Capillaria hepatica* egg are usually isolated extra-intestinally in rodents. Due to the report of these species as gastrointestinal parasites in published articles and the lack of reporting of their prevalence separately in some studies, therefore in this report, we considered them as gastrointestinal parasites.

[a] *Acanthocheilonema viteae* (*Dipetalonema viteae*) is also a filarial nematode.

[b] It is not a rodent.

discrepancy and inconsistency were settled by discussion, and, if not resolved, a third researcher (AB) was consulted.

2.5. Statistical analysis

A meta-analysis was performed using the Stata software version 14 (Stata Corp, College Station, TX, USA). A random-effects model was used to estimate overall effects. Heterogeneity was evaluated using I^2 and Cochrane Q tests. The egger's regression asymmetry test was applied to detect publication bias [19]. Moreover, subgroup analysis was used to compare the prevalence of GI helminths in rodents in Iran according to rodent gender, rodent species, and region. Meta-regression analysis was used to assess the relationship between the prevalence of GI helminthic infections with year of publication, and sample size. The statistical significance level was set at 0.05.

3. Results

3.1. Literature search and eligible studies

The procedure for the selection of eligible studies is presented in Fig. 1 and Supplementary Table 2. Then, of 5428 studies identified, 10 were retrieved through searching the dissertations database and the reference list of the eligible articles. One hundred and fifty nine studies were excluded because of duplication. The titles and abstracts of 192 publications were screened of which 146 were excluded. Moreover, the full-texts of the remaining 46 studies were assessed of which 18 were excluded. Finally, 28 studies were used for quantitative synthesis (4 studies in Persian, 5 theses, 19 studies in English).

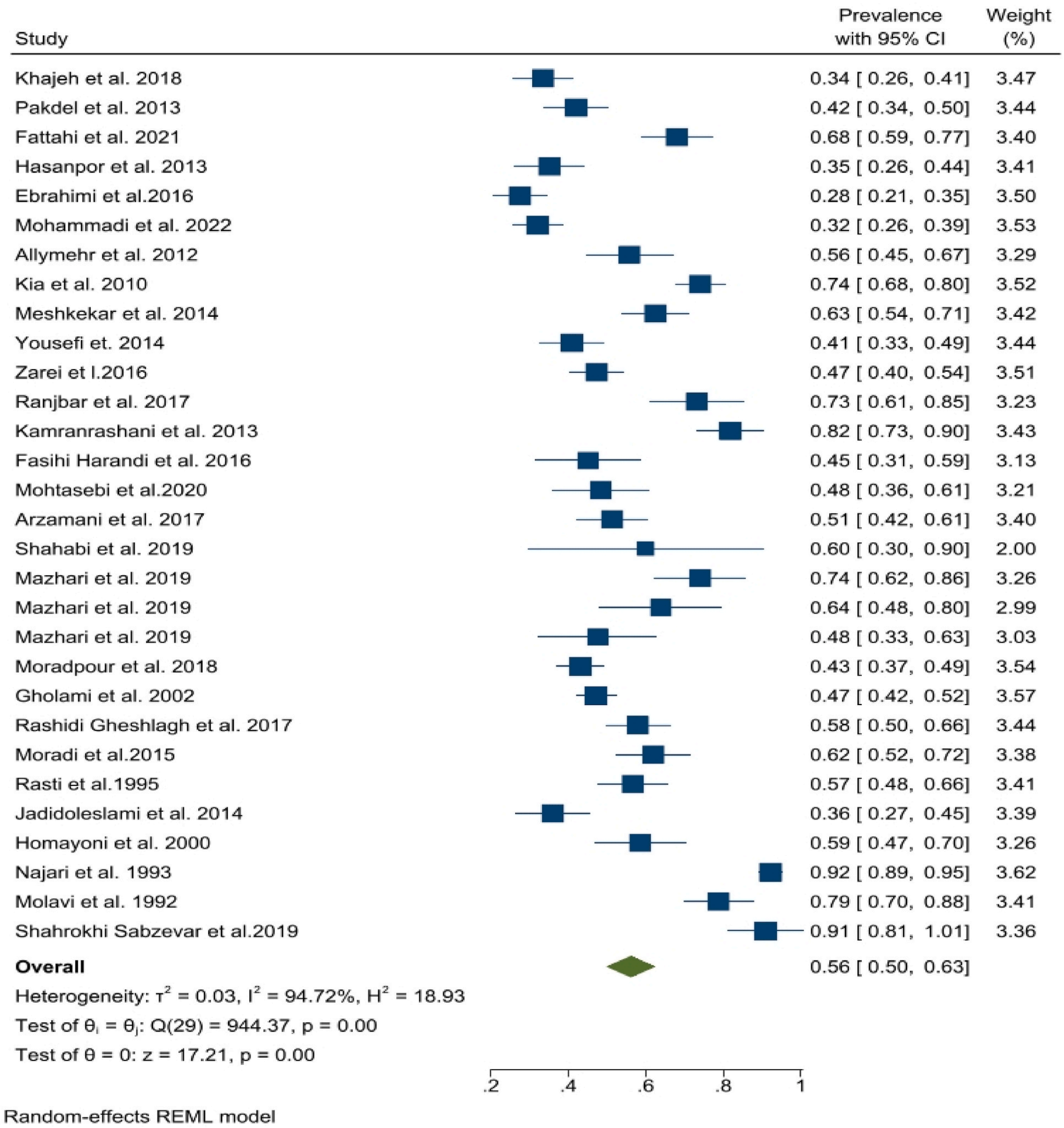

Fig. 2. The forest plot of prevalence of GI helminthic infections among rodents in Iran based on the published studies up to March 30, 2022.

3.2. Characteristics of eligible studies

The characteristics of 28 articles (30 datasets) included in this systematic review and meta-analysis was summarized in Table 1. A total of 3649 captured rodents are examined for GI helminthes in Iranian. The included rodents belonged to 6 families, 20 genera and 35 species. Studies were conducted between 1990 and 2019 and published between 1992 and 2022. The studies covered eighteen provinces in Iran, which includes Kurdistan, Kermanshah, Hamadan, Isfahan, Ardabil, Fars, Khuzestan, Gilan, Golestan, Mazandaran, Kerman, Kohgiluyeh & Boyer-Ahmad, North Khorasan, Razavi Khorasan, Teheran, Alborz, West Azerbaijan and East Azerbaijan. In two studies, the rodents were collected from different regions of the country, while the prevalence of GI worms in each province was unknown [20,21].

In all studies, the GI tract was scraped with a scalpel and the contents were examined for the presence of worms in a Petri dish

Table 2
Prevalence of intestinal helminthic infection among rodents by parasites species*.

Helminth species	Prevalence % (95 % CI)
Nematoda	
Trichuris muris	3 (2–4)
Trichuris rhomboids	0.7 (0.5–1)
Trichuris spp.	5 (4–6)
Syphacia obvelata	9 (8–10)
Syphacia muris	1 (1–1)
Syphacia syphacia	<0.5
Syphacia frederici	1 (0.9–1)
Syphacia mesocricetus	<0.5
Syphacia stroma	<0.5
Syphacia ohtarom	<0.5
Syphacia spp.	0.6 (0.5–0.7)
Aspiculuris tetraptera	4 (3–5)
Dentostomella translucida	<0.5
Heligmosomum spp.	1 (1–2)
Nippostrongylus spp.	2 (1–2)
Trichosomoides crassicauda	1 (0.8–1)
Trichostrongylus spp.	<0.5
Gongylonema sp.	0.5 (0.2–0.7)
Heterakis spumosa	0.5 (4, 5)
Strongyloides sp.	1 (1–2)
Capillariid nematodea	<0.5
Capillaria sp.	<0.5
Capillaria annulosa	<0.5
Capillaria hepatica (egg)s	1 (1–2)
Streptopharagus kuntzi	<0.5
Spiruridae	<0.5
Physocephalus sexalatus	<0.5
Mastophorus muris	0.7 (0.5–1)
Protospirura numidica	<0.5
Physaloptera sp.	<0.5
Rictularia sp.	4 (2–6)
Dipetalonema viteae	0.8 (0.5–1)
Platyhelminthes (Cestoda)	
Hymenolepis diminuta	13 (12–14)
Rodentolepis nana	8 [8–9]
Rodentolepis crassa	<0.5
Paranoplocephala brevis	0.5 (0.3–0.8)
Taenia endothoracicus larva	<0.5
Paranoplocephala sp.	<0.5
Mesocestoides larva/tetrathyridium	<0.5
Taenia taeniaeformis larva/*Cysticercus fasciolaris*	2 (2–3)
Skrjabinotaenia lobata	
Skrjabinema spp.	1 (1–1)
Anoplocephalidae	<0.5
Meggitina gerbilli	<0.5
Mateotaenia cimertica	0.5 (0.2–0.7)
Catenotaenia sp.	<0.5
Platyhelminthes (Trematoda)	
Plagiorchis muris	<0.5
Notocotylus noyeri	<0.5
Euparyphium murinum	<0.5
Echinostoma ilocanum	<0.5
Acanthocephala	
Moniliformis moniliformis	1 (1–2)

containing PBS or distilled water. The scraped material was examined with a stereo microscope to isolate the worms. After clarification or staining, the worms were identified based on systematic keys. The quality of the studies included in this review was generally acceptable with 28 medium-quality studies. Therefore, all studies were considered eligible for final meta-analysis.

3.3. Prevalence of GI helminthic infections in rodents in Iran

The overall pooled prevalence of GI helminthic infections in rodents was estimated 56 % (95 % CI: 50–63 %) ($I^2 = 94$ %, $P < 0.0001$) (Fig. 2). Supplementary Table 3 shows the distribution of GI worms of rodents based on rodent species.

Fifty four helminthic species were identified in the present study, including 33 nematodes, 16 cestodes, 4 trematodes, and 1 acanthocephalan. Moreover, 25 articles (27 datasets) including data on the frequency of GI helminthic infections based on helminth species in rodents showed that *Hymenolepis diminuta* (13 %, 95 % CI: 12–14 %), *Syphacia obvelata* (9 %, 95 % CI: 8–10 %) and *Rodentolepis nana* (8 %, 95 % CI: 8–9%) had the highest prevalence. Table 2 presents prevalence of GI helminthic infection among rodents by parasites species.

Among 35 rodent species (3649 individuals), 11 potential zoonotic helminths were found. *H. diminuta* had the highest prevalence (13 %, 95 % CI: 12–14 %) followed by *S. obvelata* (9 %, 95 % CI: 8–10 %), *R. nana* (8 %, 95 % CI: 8–9%), and *Moniliformis moniliformis* (1 %, 95 % CI: 1–2%). Other zoonotic helminths had a prevalence of less than 0.5 %, including *Plagiorchis muris*, *Echinostoma ilocanum*, *Gongylonema* spp, *Capillaria hepatica* (egg), *Mesocestoides* larva/tetrathyridium, *Physaloptera* spp, and *Euparyphium murinum*.

Table 3
Subgroup analysis for comparison of prevalence of GI helminthic infections according to family and kind of rodent species.

Family[a]	Rodent species[b]	References	Pooled prevalence 95 % CI			Heterogeneity	
			No. of captured rodents	Positives	prevalence 95 % CI	I^2 (%)	P value
Muridae	*Rattus(R. Rattus, R. norvegicus)*	[20,23,24,38,40–42,44,46]	672	419	63 (54–71)	79.75	0 < 001
	Mus musculus	[20,21,25,27,30,31,34–36,40,42–44]	684	295	50 (36–64)	96.89	0 < 001
	Nesokia indica	[20,34,36]	38	11	20 (13–53)	94.67	0 < 001
	Meriones (M. persicus, M. libycus)	[20,21,28,31,34–36,40,42,45]	557	405	59 (43–75)	95.23	0 < 001
	Rhombomys opimus	[33,36,42]	119	79	54 (24–84)	89.89	0 < 001
	Tatera indica	[20,21,34]	50	33	53 (7–99)	93.43	0 < 001
	Gerbilus nanus	[20,42]	15	1	12 (30–55)	50	0.16
	Apodemus (A. witherbyi, A. Sylvaticus)	[20,21,30,35,36]	134	49	27 (8–45)	90.54	0 < 001
	Acomys dimidiatus	[20]	21	14	67 (47–87)	–	–
	Golunda ellioti	[20]	2	0	0 (0–0)		0 < 001
Total			**2292**	**1306**	**57(49–64)**	**93.87**	**0 < 001**
Cricetidae	*Cricetulus migratorius*	[20,31,36]	27	17	36 (10–82)	94.08	0 < 001
	Microtus (M. mystacinus, M. socialis, M. paradoxus)	[20,21,28,36,40,45]	316	250	48 (15–82)	99.98	0 < 001
	Ellobius (E. lutescens, E. fuscocapillus)	[36,40]	11	8	89 (60–100)	76.67	0.04
	Arvicola amphibius	[21]	1	1	100 (98–100)	–	–
Total			**355**	**276**	**56(31–81)**	**99.19**	**0 < 001**
Calomyscidae	*Calomyscus (C. elburzensis, C. bailwardi, C. mistax, C. hotsoni)*	[20,21,36,37]	44	17	34 (5–63)	88.87	0 < 001
Total			**44**	**17**	**34(5–63)**	**88.87**	**0 < 001**
Gliridae	*Dryomys nitedula*	[34–36]	6	2	67 (1–100)	99.98	0 < 001
Total			**6**	**2**	**67(1–100)**	**99.98**	**0 < 001**
Dipodidae	*Jaculus balanfordis*	[20,42]	8	1	1 (6–8)		0.28
	Allactaga elater	[21,36,47]	52	39	58 (16–100)	91.35	0 < 001
Total			**60**	**40**	**37(2–72)**	**97.58**	**0 < 001**

[a] There was no significant difference between the prevalence of GI helminthic infection and family of rodents ($P > 0.5$).
[b] There was a significant relationship between the prevalence of GI helminthic infection and kind of rodents ($P < 001$).

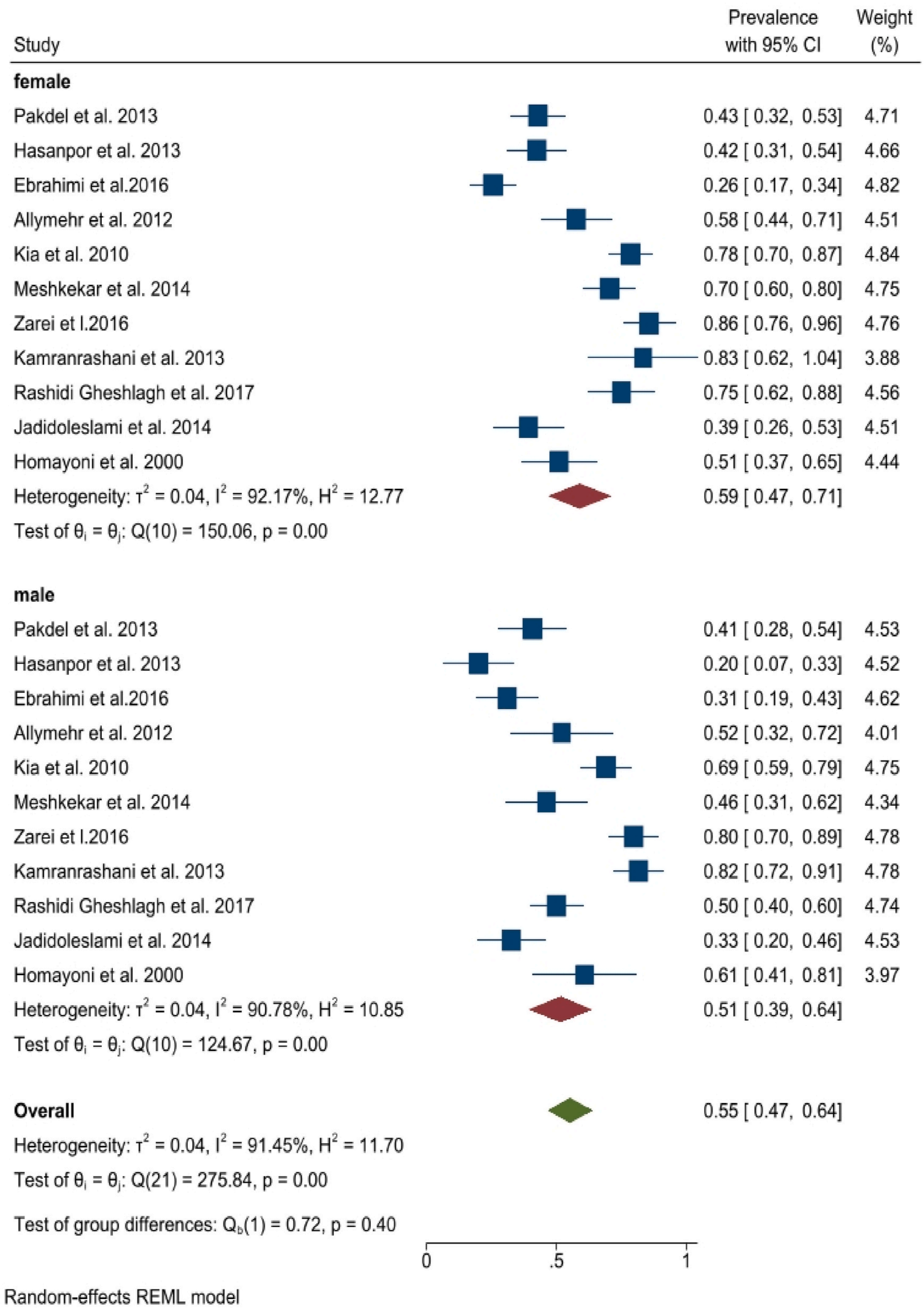

Fig. 3. The forest plot of prevalence of GI helminthic infections in rodents according to gender.

3.4. Subgroup analysis of infections in the rodents based on region, species, and gender

As for rodent species, the highest prevalence of GI helminthic infections was reported among *Arvicola amphibious* (100 %), and *Ellobius* spp. (89 %) and the lowest was reported among *Golunda ellioti* with zero prevalence (Table 3).

Eleven studies provided data on the gender of the rodents (644 male and 735 female). The prevalence of GI helminthic infections was 59 % (95 % CI: 47–71 %) in the female and 51 % (95 % CI: 39–64 %) in the male rodents. There was no significant difference between the two groups (P = 0.40) (Fig. 3).

As for the geographical location, the northern (69 %, 95 % CI: 58–80 %) and eastern area (71 %, 95 % CI: 32–100 %) had the highest pooled prevalence of GI helminthic infections among rodents followed by central (62 %, 95 % CI: 50–74 %), southern (48 %, 95 % CI: 33–64 %) and western (45 %, 95 % CI: 37–54 %) area (Table 4). There was a significant relationship between the prevalence of GI helminthic infection and geographical zone (P = 0.001). The highest prevalence of GI helminthic infections in rodents was reported from Ardabil (74 %), Gilan (74 %), and Razavi Khorasan Provinces (91 %) and the lowest was reported from West Azerbaijan Province (36 %) (Fig. 4). Supplementary Table 4 shows the diversity of GI worms of rodents based on different geographical regions.

Our analysis revealed that sample size did not affect the prevalence of GI helminthic infections in rodents (P =0.096; Fig. 5A). Furthermore, the results of a meta-regression analysis showed that the prevalence of GI helminthic infections in rodents decreased significantly in recent years (P = 0.017, Fig. 5B). Furthermore, funnel plot demonstrated a mild asymmetry. However, egger's test was observed to be P > 0.05, implicating no or undetected publication bias (Fig. 6).

4. Discussion

The rodents have high public health significance as they may contribute to the establishment of new zoonotic parasites or amplifying existing zoonotic threats [7]. In recent years, the increasing frequency of zoonotic pathogens highlights the need for applied research to prevent and control rodent-borne diseases. In some area of developing countries, poor infrastructure and lack of sanitation positively affect the rodents frequency and increase the rate of indiscriminate contact. Therefore, people living in slums or rural area are at greater risk of contracting rodents-borne infections; moreover, among them, drug users, immunocompromised subjects, and homeless people are the most vulnerable [48]. In the present study, the overall prevalence of GI helminths in different rodents was 56 % (95 % CI: 50–63 %). Some of reported helminthic species were of medical and/or veterinary importance. Therefore, it is suggested to improve awareness and possible diagnosis of rodent-borne diseases among public health and veterinary professionals and educate communities about rodent-borne diseases in order to improve preventive behaviors.

This study also showed that nematodes were the most diverse parasite with 33 species followed by cestodes with 16 species and trematodes with 4 species. In rodents, only one acanthocephalan (*M. moniliformis*) was reported. Diversity in rodent parasites refers to their adaptability and the host's ability to support them. The high diversity and prevalence of GI worms transmitted by rodents in Iran is not surprising. Because of geographical and climatic conditions, Iran is a suitable area for the growth and distribution of most parasites.

The six main families within order of rodents in Iran are Sciuridae, Hystricidae, Dipodidae, Muscardinidae, Muridae, and Cricetidae [16]. In the present systematic review study, the highest prevalence of GI helminthic infection was reported among the families of Gliridae (67 %), Muridae (57 %), Cricetidae (56 %). The family Muridae plays a significant role in the transmission and spread of many zoonotic diseases, because they live very close to humans in rural and urban areas. The family Cricetidae is also important for disease transmission, but the number of diseases transmitted by them is less than those from the family Muridae [49]. On the other hand, the families Sciuridae, Hystricidae, and Muscardinidae live far from human habitation thus reducing human-rodent contact and the subsequent potential risks to human health [16].

This study indicated the heterogeneity in the distribution of rodent parasitic worms in Iran. The prevalence of GI worms in rodents was higher in the north and east of the country and lower in the west and central regions. The northern provinces are located between the highlands of Alborz and the Caspian Sea and the mutual influence of these two geographical phenomena on each other and its effects on the climatic conditions of the provinces has caused the emergence of special climatic conditions characterized by rainfall, moderate temperature, and dense vegetation, which can justify the higher prevalence of rodent-borne GI worms [50]. On the other hand, the distribution of rodent species and their richness, sampling season, animal population behaviors, the age of the host, the presence of reservoir and intermediate hosts, the endemicity of parasites, and the difference in the number of studies conducted in each

Table 4
The pooled prevalence of GI helminthic infections among rodents based on different geographical areas.

Region[a]	Number of data sets	Sample size	Number infected	Pooled prevalence (95 % CI)	Heterogeneity		Test for Subgroup differences
					I^2	t^2	
North	9	1315	874	67 (56–78)	95.54 %	0.03	0.001
South	4	213	103	48 (33–64)	87.98 %	0.03	
Center	4	382	236	62 (50–74)	85.11 %	0.01	
West	9	1227	554	45 (37–54)	88.88 %	0.01	
East	2	113	58	71 (32–100)	96.99	0.08	

[a] For two studies, rodent samples were collected from different geographical areas and the sample size and positive cases of each area were not separable, therefore, they were not included in the meta-analysis.

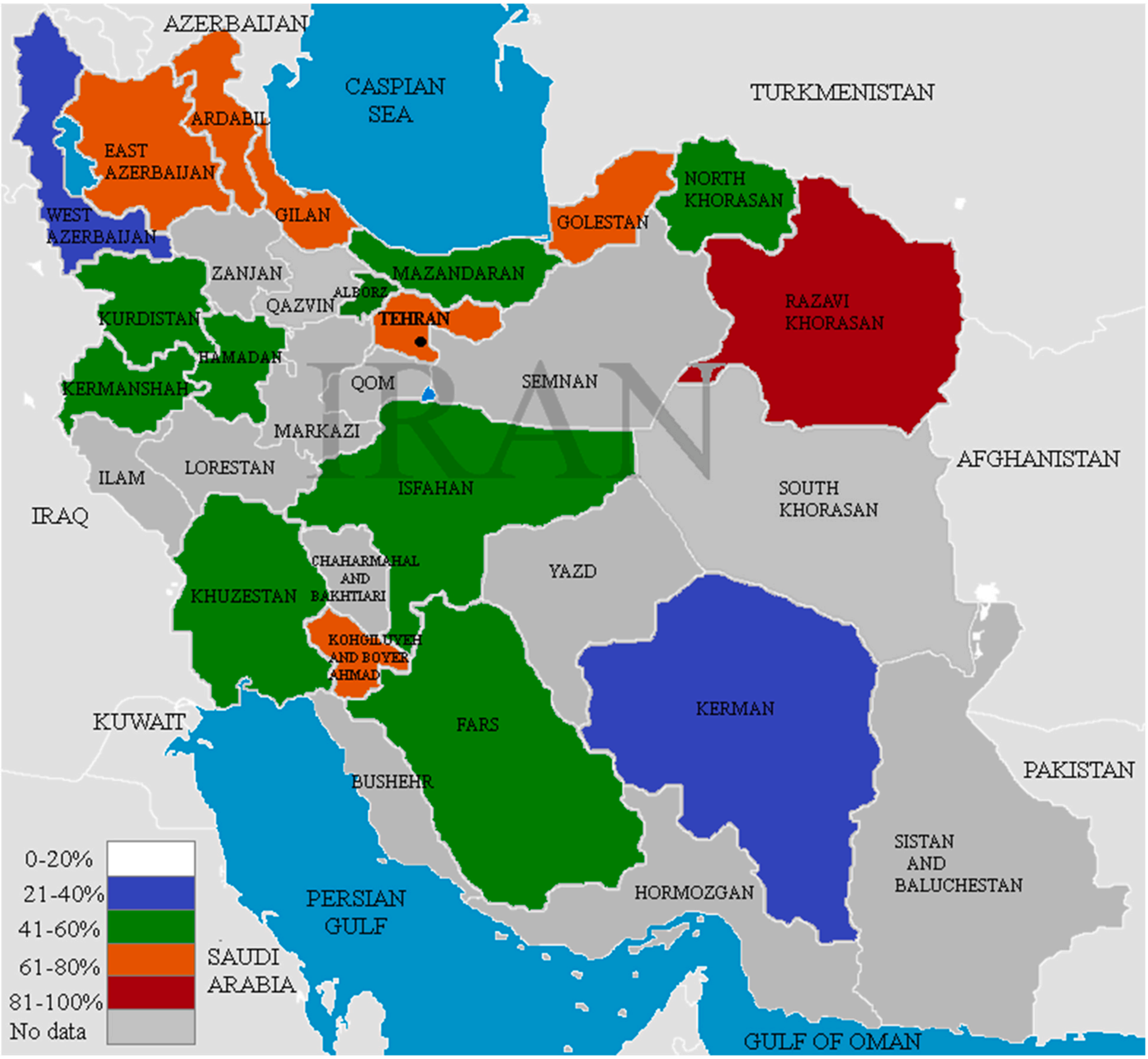

Fig. 4. Prevalence rate of GI helminthic infections among rodents in different provinces of Iran.

region can contribute to the variations across regions [51].

Although, due to the lack of information on the prevalence of GI worms by season, subgroup analysis of seasons was not performed in our study, climate changes in the seasons may affect the frequency and geographical distribution of worms transmitted by rodents directly (dispersion of eggs and larvae in the environment) or indirectly (the larvae living in an intermediate host of invertebrates, mainly insects and mollusks) [52,53]. In general, high humidity in the wet season increases the growth and survival rates of the parasite eggs and larvae in the environment, and the infective stages of the parasite in the wet seasons are probably more frequent and active compared to dry seasons [50].

In this study, only four genera of trematodes, including *Echinostoma*, *Plagiorchis*, *Euparyphium* and *Notocotylus* were reported. The frequency of trematode species in Iranian rodents was less than nematodes and cestodes. Digenetic trematodes have a complex life cycle and many fresh water snails act as their first intermediate hosts whose presence depends on environmental characteristics [7]. Desert areas indicate lack of surface water in some southern, central, and eastern provinces such as Sistan-and-Baluchestan, Kerman, and South Khorasan, which can lead to the reduction or absence of some aquatic snails or amphibians as intermediate hosts of trematodes. More research is suggested to find rodent-borne trematodes in Iranian provinces.

In the included studies, several species of the enteric parasites investigated had a possible or even definite zoonotic transmission risk including *S. obvelata*, *H. diminuta*, *R. nana*, *P. muris*, *E. ilocanum*, *Gongylonema* sp, *C. hepatica* (egg), *Mesocestoides* larva/tetrathyridium, *Physaloptera* sp, and *E. murinum*. Future work should combine genetic identification with morphology to elucidate zoonotic

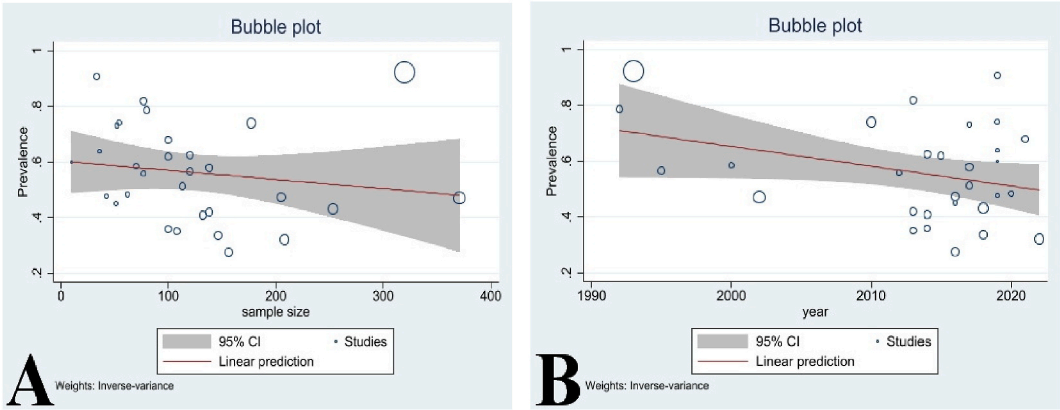

Fig. 5. Meta-regression plot for prevalence of gastrointestinal helminthic infections among rodents in Iran based on the study sample size (A), and based on year of publication (B).

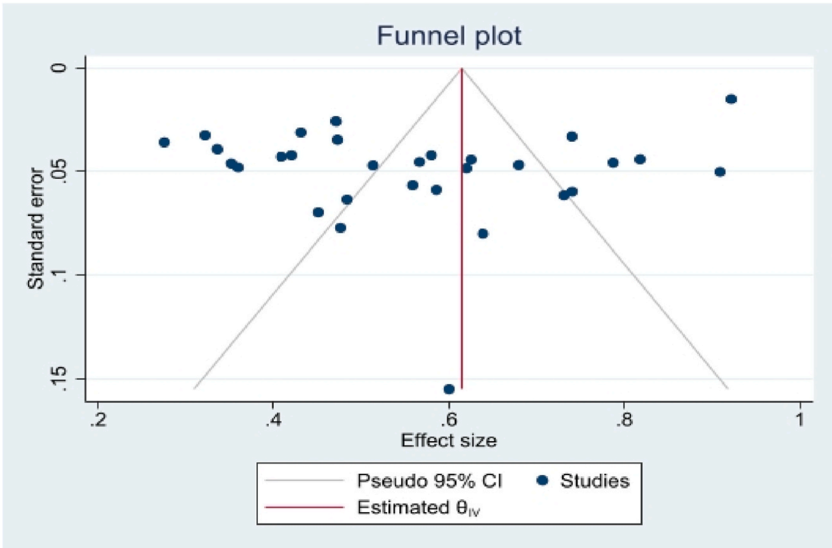

Fig. 6. Bias assessment plot from egger's for the global prevalence of gastrointestinal helminthic infections in examined rodents in Iran.

potential in addition to precise identification of parasite species.

Hymenolepiasis is a common intestinal infection in humans caused by cestodes of the *Hymenolepis* and *Rodentolepis* genus, including *R. nana* and *H. diminuta*. Infection is more common in children and in areas with poor economic and health conditions with close contact between rodents and humans [54]. In fact, *H. diminuta* needs an arthropod (as an intermediate host) such as a moth, grain beetle, flea, millipede, or centipede to complete its life cycle, while *R. nana* is directly transmitted through oral-fecal contact [55]. The overall prevalence of human *R. nana* is estimated at 1.2 % in Iran [56], while cases of infection with *H. diminuta* have been rarely and sporadically reported [56,57]. It should be noted that with the exception of *R. nana* and *H. diminuta*, other identified zoonotic helminth infections have less health importance and human infections by them have rarely been reported. So that less than five Iranian cases of human infection with *M. moniliformis* are known [58,59]. Molavi et al. reported the first known case of human infection with *Gongylonema* in Iran, in a female who complained of a creeping sensation, in her neck and upper digestive tract [60]. Furthermore, *Syphacia obvelata* has very rarely been reported infecting humans [61,62]. Parasites of the genus *Syphacia* cause asymptomatic infection in their host due to low pathogenicity or a high degree of adaptation of the host to the parasite [63,64]. Due to the agility of rodents and the close relationship of some of them with human habitations, the use of kitchen waste and sewage, they may act as reservoirs or carriers of various pathogens. Therefore, hygiene education, clean environment, good eating habits, and prevention of direct or indirect food contamination with feces and carcasses of rodents and carrier species are recommended.

Some studies have reported higher rates of intestinal worms in male rodents [25,44], while others have found that females are more sensitive to parasitic infections [22,24,33]. Various factors can influence the prevalence of rodent-borne intestinal worms, such as sex hormones, which affect the host's immune response directly or indirectly. Size difference serves as an example. Greater (generally male) rodents consume more energy, which leads to a decrease in the immune system function; therefore, they are more sensitive to parasitic infections. Moreover, gender-specific behavior such as feeding or mating results in differential exposure to parasitic infections [65]. The present study found no significant difference in the prevalence of GI worms between male and female rodents ($P = 0.40$). However, only 11 out of 29 studies determined the prevalence of GI parasites based on the host's gender, which is a relatively small sample size. Therefore, the results of the present study should be interpreted within its limitations. Additionally, to confirm or reject the results of the present studies, larger studies, even in a global scale, are suggested.

The results of meta-regression analysis showed that the prevalence of GI worms in rodents decreased with an increase in the sample size. On the other hand, the prevalence of GI helminthic infections in rodents decreased significantly based on recently-published studies. In recent years, some climatic changes have occurred in Iran, especially a decrease in the average annual rainfall and an increase in the average annual temperature [66]. However, it seems that these changes are not an important factor in reducing the GI helminthic infections transmitted by rodents in Iran.

A high degree of heterogeneity was found in the present study, which can significantly affect the results. The heterogeneity among studies may be due to differences in the geographic area, publication year, number and sample size of the studies conducted in each region, and the species and gender of the host. In addition, other indicators that were not evaluated in this study, such as sampling method, rodent's age, and sampling season, may have affected the results. Therefore, the results of the present study should be interpreted with caution.

5. Limitations

There are a few limitations of the present meta-analysis. The prevalence data were reported from a number of provinces in the country. Therefore, the distribution of studies was uneven in different geographical areas. In addition, there were insufficient data on some risk factors such as the seasonal prevalence of helminthic infections and rodent age.

6. Conclusion

The current systematic review spans more than 30 years of GI helminthic infections reports in rodents from Iran. The prevalence of GI rodent worms was as high as 56 %. Regarding the climatic diversity in Iran and the frequency of different species of domestic and wild rodents, it is necessary to study the parasitic fauna of rodents to monitor the possible potentials for transmission of zoonotic helminths to humans and livestock. Although the present study was relatively small in terms of the number of the included studies and sample size, it showed the potential of rodents to infect humans with zoonotic parasites. Therefore, it is suggested to observe the health of the environment, destroy the biological nests of rodents, avoid half-finished constructions, repair and improve streams and sidewalks, organize and collect garbage, and carry out biological and chemical control to handle the population of rodents.

Funding

This study was supported by a grant from the Vice Chancellery for Research and Technology, Kermanshah University of Medical Sciences (grant number: 4010245).

Institutional review board statement

The protocol was approved by the Ethics Committee of Kermanshah University of Medical Sciences (IR.KUMS.MED.REC.1401.046).

Informed consent statement

Not applicable.

Data availability statement

The datasets used during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Yazdan Hamzavi: Writing – review & editing, Supervision, Conceptualization. **Mohammad Taghi Khodayari:** Software, Formal analysis. **Afshin Davari:** Data curation. **Mohammad Reza Shiee:** Data curation. **Seyed Ahmad Karamati:** Data curation. **Saber Raeghi:** Writing – original draft, Data curation. **Hadis Jabarmanesh:** Data curation. **Helia Bashiri:** Data curation. **Arezoo Bozorgomid:** Writing – original draft, Supervision, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

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

Acknowledgements

We also like to acknowledge the cooperation of Vice Chancellor for Research of Kermanshah University of Medical Sciences. This article was part of a MD dissertation (by Hadis Jabarmanesh) supported by Kermanshah University of Medical Sciences (KUMS), Kermanshah, Iran.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31955.

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