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RESEARCH ARTICLE

Gastrointestinal Parasites in Asian and African Elephants: A Systematic Review

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ABSTRACT

Gastrointestinal parasites (GIPs) in elephants have been reported in several studies over the last decades. Nonetheless, comprehensive data on clinicopathology of elephant GIPs, parasite burden threshold value, and the effectiveness of conventional anthelmintic drugs are still lacking. Herein, we have systematically reviewed the available knowledge on elephant GIPs identified among different parts of the world based on their prevalence, epidemiology, pathology, diagnosis, treatment, and control. Two electronic databases were searched for publications that met the inclusion criteria. About19 English journal articles published between year of 2011- 2021 were included. The main GIPs reported in elephants were Cyathostomidae (at least 14 species), Ancylostomidae, *Haemonchus contortus*, *Trichostrongylus colubriformis*, *Oesophagostomum columbianum*, *Oesophagostomum aceleatum*, Ascarids, Trichurids, Strongyloides, Anophlocephalidae, flukes, and *Coccidia* across different parts of the world, including Malaysia, Indonesia, Thailand, Myanmar, Sri Lanka, India, Kenya, Nigeria, and South Africa. Most elephants show no clinical signs until the equilibrium between parasite and host is disturbed. The common diagnostic methods for GIPs are traditional direct smear, faecal floatation, sedimentation, and McMaster egg counting technique, all involving morphological identification. However, some articles described the use of molecular detection to characterise common GIPs of elephants. Although benzimidazoles and macrocyclic lactones group of anthelmintic are the most conventional GIPs treatment and control for captive and semi-captive elephants, there is limited data on the threshold value of faecal egg count as the baseline for treatment decision. Over the last decades, various studies regarding elephant GIPs have been conducted. However, more focused and systematic studies are required to enhance our knowledge in multiple aspects of elephant parasitology to find effective solutions and improve elephant health.

Keywords: Gastrointestinal parasites; endoparasites; elephants; Asian elephants; African elephant.

INTRODUCTION

Elephants are the largest land mammal and among the earliest animals domesticated by humans thousands of years ago due to their being the largest and mightiest vertebrate on land. The earliest evidence of elephants in captivity was documented about 4,500 years ago, with the finding of images on soapstone seals represented by the Harappan culture of the Indus Valley (Csuti, 2006). Elephants are categorised into two genera: *Elephas* and *Loxodonta*. *Elephas* is represented by the Asian elephants, including the Sri Lankan subspecies (*Elephas maximus maximus*), Mainland subspecies (*E. maximus indicus*), Sumatran subspecies (*E. maximus sumatranus*), and Bornean subspecies (*E. maximus borneensis*; Fernando *et al*., 2003). Meanwhile, *Loxodonta* is represented by the African elephants, comprising Bush or Savanna species (*Loxodonta africana*) and Forest species (*Loxodonta* cyclotis; Shoshani, 2006).

The *E. maximus* and *L. africana* are listed as endangered, while *L. cyclotis* is recognised as critically endangered by the International Union for Conservation of Nature (IUCN), with an estimated 50,000 Asian and 415,000 African elephants left in the wild (Williams *et al*., 2020; Gobush *et al*., 2021). As several causes have already threatened the elephant population, e.g., poaching, habitat loss, and habitat fragmentation (Riddle *et al*., 2010), gastrointestinal parasites (GIPs) are an added threat that could potentially become a serious worldwide concern.

GIPs are parasitic worms and protozoa that reside and infect the intestinal tract of vertebrates. GIPs reported in this systematic review consist of nematodes strongyles (Cyathostomidae and

Ancylostomidae; Thurber *et al*., 2011; Mc Lean *et al*., 2012) and Strongyloididae (Mbaya *et al*., 2013), cestode Anoplocephalidae (Abhijith *et al*., 2018), and trematode and protozoan (*Entamoeba* and *Coccidia*; Abeysekara *et al*., 2018). These parasites are associated with clinical illnesses like emaciation, colic, and diarrhoea (Hing *et al*., 2013), dependent oedema (Caple *et al*., 1978), and reduced appetite and weight loss (Tripathy *et al*., 1991). Although Asian and African elephants can harbour similar genera of parasites, the parasite species are commonly different (Fowler & Mikota, 2006). The prevalence of GIPs in the elephant population varies worldwide, considering the impact of various epidemiological factors, treatment and control that could contribute to the parasitic load.

Most of the time, parasites rarely cause fatality and could live in the host for a long time (Albery *et al*., 2018). However, GIPs could compromise the immune system of the host (Maizels *et al*., 2012), reduce reproduction (Irvine, 2006), and affect the growth rate of the elephants (Sepalage & Rajakaruna, 2020). In cases of severely infected elephants, death could be indicated. Fatality is commonly associated with severe cestodes infestation (Perera *et al*., 2017) and partially associated with nematodes in cases where concurrent disease or poor nutrition could also contribute to death (Condy, 1974; Obanda *et al*., 2011).

GIPs need to be crucially monitored as part of health screening and disease prevention, especially in captive elephants, as various factors such as husbandry practices, disease prophylaxis, and treatment are believed to influence the occurrence of parasites in them (Fowler & Mikota, 2006). Moreover, there are limited studies on GIPs in elephants, both in the wild and in captivity (Woodroffe, 1999).

The main objective of this study is to provide a systematic overview of the prevalence, epidemiology, pathology, diagnosis, and treatment of elephant GIPs from 2011-2021 (the recent decade).

MATERIALS AND METHODS

The systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page *et al*., 2020). All inclusion and exclusion criteria were clarified regarding the pertinence of the references to accomplish the objectives of this systematic review.

Formulation of the research questions (RQ)

Research questions for this systematic review were formulated by applying the mnemonics of PICO, i.e., P for Population or Problem, I for Interest, and Co for Context (Lockwood *et al*., 2015). According to this concept, the elephants worldwide represent the population; GIPS represents the interest; and existing knowledge of the prevalence, epidemiology, pathology, diagnostic methods, and treatments represent the Context. Based on the selected criteria, the main research question for this study is: "What are the prevalence, epidemiology, pathology, diagnostic tools, and treatments for GIPs in elephants?"

Literature search

Identification

A systematic search was conducted using Scopus and PubMed web databases from 2011 to 2021 to identify reports from various publications documenting GIPs in elephants. Multiple keywords used in the search string (Shaffril *et al*., 2021) of the articles are tabulated (Table 1). The search from Scopus and PubMed resulted in 129 articles.

Screening

From the 129 selected articles during the identification process, 22 were duplicated and therefore excluded. All the remaining articles were screened by setting up the inclusion criteria (Mohammed Shaffril *et al*., 2020) automatically based on the available sorting function in the database. The inclusion criteria were based on Year (2011-2021), Document type (Article), Source type (Journal), and Language (English). Throughout this process, 60 articles were excluded based on inclusion criteria. The remaining 47 articles were used for the next process, i.e., eligibility.

Eligibility

The titles and abstracts were reviewed manually for inclusion suitability in the current work to determine if all 47 articles from the previous screening process fulfilled the criteria to be included in the systematic review (Bilotta *et al*., 2014). From the manual review, 24 articles were left for the final process, the appraisal of quality.

Appraisal of quality

The quality of the 24 eligible articles was appraised by the authors to ensure that the articles included for the review were bias-free and articles with poorly described methodology excluded (Littlewood *et al*., 2012). The quality appraisal was based on the guidelines proposed by Kitchenman and Charters (2007), covering objective, interest and usefulness, methodology, concepts of the approach, comparison with other studies, and limitations of the study. The scoring system used to evaluate each guideline was based on Yes = 1, Partially = 0.5 and No = 0 (Kitchenham & Charters, 2007). From 24 articles, 19 articles are included to be reviewed systematically. The flow diagram from the identification process to screening, eligibility, and quality appraisal is illustrated (Figure 1).

Data extraction and analysis

Upon finalising the articles to be included in the systematic review, data extraction was performed (Shaffril *et al*., 2021) from the selected studies that fit the objectives using the research questions as a guideline. The extracted data were placed systematically in a table to ease the data analysis (Okoli, 2015). Three types of qualitative data are commonly used to analyse a study; qualitative synthesis of qualitative studies, qualitative analysis of quantitative studies, and qualitative analysis of mixed research designs comprising qualitative and quantitative studies (Okoli, 2015). In this review, the author used the third method of qualitative data analysis.

Table 1. Multiple keywords used in search string

Database	Search string
Scopus	Title-abs-key ((“gastrointestinal parasites” OR “gastrointestinal helminths” OR “gastrointestinal protozoan” OR “intestinal parasites” OR “endoparasites” OR “cestodes” OR “nematodes” OR “strongyles” OR “strongyloides”) AND (“elephants” OR “elephant” OR “elephas maximus” OR “Loxodonta Africana” OR “African elephants” OR “Asian elephants” OR “Sumatran elephants” OR “Bornean elephants”))
PubMed	((“gastrointestinal parasites” OR “gastrointestinal helminths” OR “gastrointestinal protozoan” OR “intestinal parasites” OR “endoparasites” OR “cestodes” OR “nematodes” OR “strongyles” OR “strongyloides”) AND (“elephants” OR “elephant” OR “elephas maximus” OR “Loxodonta Africana” OR “African elephants” OR “Asian elephants” OR “Sumatran elephants” OR “Bornean elephants”))

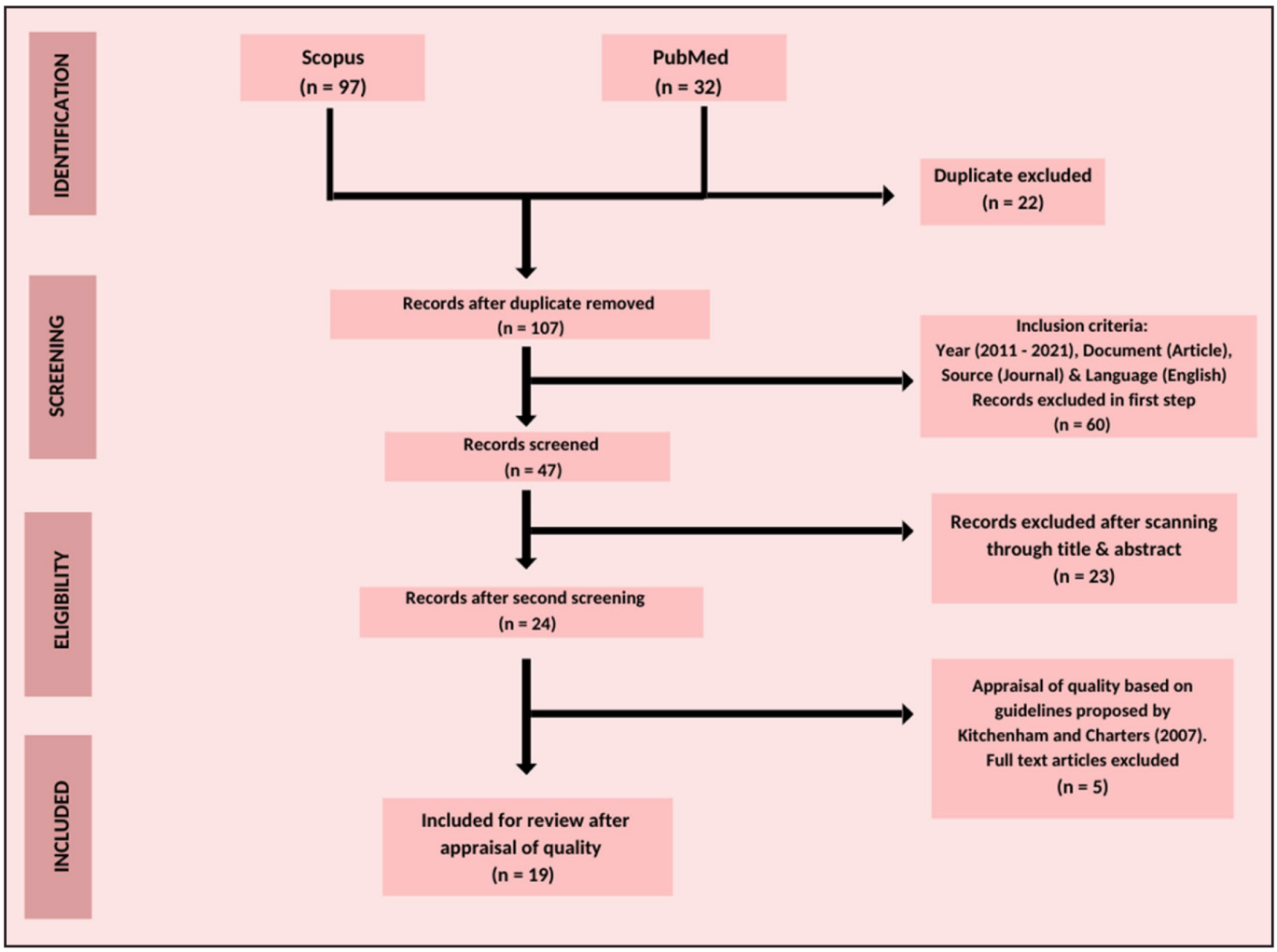

Figure 1. An overview of the assessment and the selection criteria applied to include articles for this systematic literature review.

RESULTS

Prevalence and distribution

At least 25 species of nematodes have been reported across different parts of the world, with 14 species of the Cyathosthomidae family: *Murshidia* sp. (*Murshidia falcifera*, *Murshidia indica*, *Murshidia neveulemairei*, *Murshidia dawoodi*, *Murshidia longicaudata*, *Murshidia africana*, and *Murshidia linstowi*), *Quilonia* sp. *(Quilonia renniei*, *Quilonia travancra*, *Quilonia apiensis*, *Quilonia africana*, and *Quilonia magna*), and *Khalilia* sp. (*Khalilia sameera*; Mc Lean *et al*., 2012; King'ori *et al*., 2020); two species of Anyclostomidae family: *Ancylostoma* sp. and *Grammocephalus clathratus* (Obanda *et al*., 2011; Abhijith *et al*., 2018); four species of other strongyles: *H. contortus*, *T. colubriformis*, *O. columbianum*, and *O. aceleatum* (Mbaya *et al*., 2013; Phuphisut *et al*., 2015); five species of non-strongylid nematodes: Ascaridae (*Ascaris* sp., *Oxyuris* sp., and *Toxocara* sp.); Enoplida (*Trichuris* sp.); and Strongyloididae (*Strongyloides* sp. and *Strongyloides papillosus*; Mbaya *et al*., 2013; Vimalraj & Jayathangaraj, 2013; Phuphisut *et al*., 2015; Rizwar *et al*., 2017; Abhijith *et al*., 2018).

In addition, two species of cestodes represented by Anoplocephalidae (*Anoplocephala* sp. and *Anoplocephala manubriata*) were also observed (Hing *et al*., 2013; Vimalraj & Jayathangaraj, 2013; Perera *et al*., 2017; Abhijith *et al*., 2018). Five species of trematodes reported include *Fasciola* sp., *Protofasciola robusta*, *Brumptia bicaudata*, *Pseudodiscus hawkesii*, and *Paramphistomum* sp. (Hing *et al*., 2013; Baines *et al*., 2015; Abeysekara *et al*., 2018; King'ori *et al*., 2020). Meanwhile, the protozoan comprises two species, *Entamoeba* and *Coccidia* (Mbaya *et al*., 2013; Baines *et al*., 2015; Abeysekara *et al*., 2018).

Among the elephant populations in this study, the nematodes are prevalent (78%, n = 15/19 articles), mainly Cyathosthomidae. *Murshidia* sp. and *Quilonia* sp. have been identified more persistently (prevalence 100%, n = 27/27 and 96.3%, n = 234/243) in elephants than other species (Mc Lean *et al*., 2012; King'ori *et al*., 2020).

The distribution of the GIPs infecting elephants varies between different parts of the gastrointestinal tracts (GIT). *G. clathratus* is commonly found in bile ducts (Obanda *et al*., 2011; Parker *et al*., 2020), as with *Fasciola* sp. (Rizwar *et al*., 2017). A previous study also reported that a trematode, *P. robusta*, was isolated from the duodenum (Obanda *et al*., 2011).

While most strongyles mainly reside in the intestine (Parker *et al*., 2020), *M. linstowi* was found in the stomach together with *P. hawkesii* (Hota *et al*., 2020). In 2015, a study recorded that *Oesophagotomum* sp. was identified from the small and large intestine (Phuphisut *et al*., 2015), while *Anoplocephala* sp. was isolated from the small intestine, mainly in the jejunum and ileum (Perera *et al*., 2017).

Data of GIPs infecting elephants and location(s) of isolates are tabulated in Table 2.

From this review, the main GIPs infecting elephants with high prevalence are nematodes compared to other parasites (cestodes, trematodes, and protozoans). A previous work reported higher prevalence in nematodes (96.3%, n = 234/243) compared to trematodes (39.1%, n = 95/243; King'ori *et al*., 2020). Nematodes are most likely the most intense and abundant in number, besides

Table 2. Data of GIPs infecting elephants. (Studies from 2011–2021)

GIPs	Location (S)	Prevalence (%)		Elephant	Reference
Nematode					
Murshidia dawoodi	Kenya (Tsavo East National Park, Laikipia-Samburu, Maasai Mara National Reserve & Amboseli National Park)	96.3a	n = 234/243	African	King'ori *et al*., 2020
Murshidia longicaudata	Kenya (Amboseli Ecosystem)	100[a]	n = 27/27	African	Mc Lean *et al*., 2012
Murshidia africana	Kenya (Amboseli Ecosystem)	100[a]	n = 27/27	African	Mc Lean *et al*., 2012
Murshidia linstowi	Kenya (Amboseli Ecosystem)	100[a]	n = 27/27	African	Mc Lean *et al*., 2012
Quilonia africana	Kenya (Amboseli Ecosystem)	19	n = 5/27	African	Mc Lean *et al*., 2012
	Kenya (Amboseli National Park)	96.3[a]	n = 234/243	African	King'ori *et al*., 2020
Quilonia apiensis	Kenya (Amboseli National Park)	96.3[a]	n = 234/243	African	King'ori *et al*., 2020
Quilonia magna	Kenya (Amboseli National Park)	96.3[a]	n = 234/243	African	King'ori *et al*., 2020
Khalilia sameera	Kenya (Amboseli National Park)	4	n = 1/27	African	Mc Lean *et al*., 2012
Haemonchus contortus	Nigeria (Chad Basin National Park)	28.8[a]	n = 79/274	African	Mbaya *et al*., 2013
Trichostrongylus colubriformis	Nigeria (Chad Basin National Park)	28.8[a]	n = 79/274	African	Mbaya *et al*., 2013
Oesophagostomum columbianum	Nigeria (Chad Basin National Park)	28.8[a]	n = 79/274	African	Mbaya *et al*., 2013
Oesophagostomum aculeatum	Thailand (Salakpra Wildlife Sanctuary)	93[a]	n = 42/45	Asian	Phuphisut *et al*., 2015
Ancylostoma sp.	India (Wayanand Forest Division, Kerala)	1.82	n = 1/55	Asian	Abhijith *et al*., 2018
Ascaris sp.	Thailand (Salakpra Wildlife Sanctuary)	2.3	n = 1/45	Asian	Phuphisut *et al*., 2015
Trichuris sp.	Thailand (Salakpra Wildlife Sanctuary)	2.3	n = 1/45	Asian	Phuphisut *et al*., 2015
Strongyloides sp.	India (Wayanand Forest Division, Kerala)	52.73	n = 29/55	Asian	Abhijith *et al*., 2018
	India (Anamalai Wildlife Sanctuary)	14	n = 7/50	Asian	Vimalraj & Jayathangaraj, 2013
	India (Mudumalai Wildlife Sanctuary)	16	n = 8/50	Asian	Vimalraj & Jayathangaraj, 2013
Strongyloides papillosus	Nigeria (Chad Basin National Park)	4	n = 11/274	African	Mbaya *et al*., 2013
Cestode					
Anoplocephala sp.	Sabah (Lower Kinabatangan Wildlife Sanctuary & Tabin Wildlife Reserve)	50	n = 52/104	Bornean	Hing *et al*., 2013
	India (Anamalai Wildlife Sanctuary)	46	n = 23/50	Asian	Vimalraj & Jayathangaraj, 2013
	India (Wayanand Forest Division, Kerala)	1.82	n = 1/55	Asian	Abhijith *et al*., 2018
Trematode					
Fasciola sp.	Sabah (Lower Kinabatangan Wildlife Sanctuary & Tabin Wildlife Reserve)	70.2	n = 73/104	Bornean	Hing *et al*., 2013
Protofasciola robusta	South Africa (Okovango, Botswana)	24[b]	n = 110/458	African	Baines *et al*., 2015
	Kenya (Tsavo East National Park, Laikipia-Samburu, Maasai Mara National Reserve & Amboseli National Park)	39.1[b]	n =95/243	African	King'ori *et al*., 2020
Brumptia bicaudata	Kenya (Tsavo East National Park, Laikipia-Samburu, Maasai Mara National Reserve & Amboseli National Park)	39.1[b]	n =95/243	African	King'ori *et al*., 2020
Protozoan					
Coccidia	South Africa (Okovango, Botswana)	51	n = 234/458	African	Baines *et al*., 2015
	Nigeria (Chad Basin National Park)	4.74	n = 13/274	African	Mbaya *et al*., 2013

[a] Prevalence with other strongylid nematodes reported in the study.
[b] Prevalence with other trematodes reported in the study.

the simplicity of the direct life cycle compared to other helminths. Trematodes of the *Fasciolidae* family require snails (*Lymnae trunculata*) as the intermediate host to complete the life cycle, while larvae of strongyles (nematodes) do not require an intermediate host to develop into the infective stage (L3; Fowler & Mikota, 2006). Furthermore, the transmission of *Fasciola* is facilitated by water (King'ori *et al*., 2020), as the eggs require access to water to mature to the ciliated miracidia stage before developing to sporocyst, redia, cercaria, and finally, metacercaria, which is the infective stage. In addition, cestodes such as *A. manubriata* require Oribatid mites as the intermediate host (Michael McAloon, 2004; Athapattu, 2018) to mature into cysticercoids (Fowler & Mikota, 2006).

Epidemiology and predisposing factors

Host factors

GIPs infection could be affected significantly by host factors, including age, gender, and social integration. Few studies have reported that young calves are generally more susceptible to higher parasitic loads of nematode infection than adult elephants (Abhijith *et al*., 2018; Lynsdale *et al*., 2020; Parker *et al*., 2020). Previous work showed that 5-year-old calves had the highest faecal egg count (FEC) while 45-year-old adults had the lowest FEC (Lynsdale *et al*., 2020). Gender is most likely not a risk factor in nematode infection, since contradictory findings revealed that male elephants showed slightly higher prevalence than females (Mbaya *et al*., 2013), while another work reported that males had 29.6% lesser strongylid burden than females (Parker *et al*., 2020).

Age plays an important role in GIPs occurrence and prevalence in elephants, as young animals lack a well-developed immune system, whereas the elderly tend to succumb to infection due to immunosenescence (Albery *et al*., 2018). Meanwhile, the inclination of males to infestation might be a result of their behaviour. Since adult males are solitary, the males tend to move from one matriarch group to another during mating season in search of on-heat females. In order to find out whether the female is ready to mate, matured bull elephants will wet their trunks using females' urine on the ground and insert it into their mouths for Jacobson's organ to detect the pheromones. This habit most likely contaminates their trunks with GIPs eggs or, worse, the larvae infective stage (Poole, 1989). However, males are exposed to fewer strongylids because they spend little time in greatly contaminated places with faeces and more time in distinct locations (referred to as bull areas; Condy, 1974) as they gradually begin to disperse from the social group at the age of 5 to 18 years (Wittemyer *et al*., 2013).

Social integration plays an important role in acquiring GIPs infection (Parker *et al*., 2020). Elephants who were constantly a recipient of aggression from other elephants in the group exhibited lesser infestation given that they mostly isolate themselves at the periphery of social groups, away from dung boluses (Goldenberg & Wittemyer, 2018), thereby minimising their exposure to infective larvae. Since a social group comprises more individuals, including a matriarch, some close female relatives, and calves, they are often in close contact with each other. As a result, such elephants have a greater tendency to contaminate forage with faeces and be exposed to GIPs infection, which is associated with a greater nematode burden (Thurber *et al*., 2011). Higher population density will exacerbate faecal-oral transmission, thus becoming a key contributor to the prevalence, burden, and diversity of nematodes (Wiergertjes & Flik, 2004; Lebarbenchon *et al*., 2006). Higher strongyles prevalence observed in Bornean elephants might be due to the greater density of elephant populations (Hing *et al*., 2013).

Environmental factors

Several environmental factors that could influence the occurrence of GIPs infecting elephant populations are seasons, management (captive, semi-captive, or free-ranging), and nutritional components (Hing *et al*., 2013; Chichilichi *et al*., 2018). A study reported a higher occurrence of GIPs at the peak of rainfall and a lesser occurrence during the drought season in Nigeria (Mbaya *et al*., 2013). The GIPs nematode infection was generally low in the winter season in India (Chichilichi *et al*., 2018). Meanwhile, regarding elephant management, strongyles infection in wild elephants had the highest intensity than in captive and semi-captive elephants (Abeysekara *et al*., 2018; Chichilichi *et al*., 2018). Poor diet is another risk factor for GIT parasitism, as observed in African elephants in Laikipia-Samburu, Kenya, resulting in mass mortalities (Obanda *et al*., 2011).

The high and low occurrence of GIPs during rainfall and the dry months are similarly reported in sheep and goats, where temperature and rainfall affect the prevalence and development of *H. contortus* in the open pasture (Soulsby, 1982; Chiejina, 1986). Prolonged dry months and increased ambient temperature from 40°C to 45°C in Nigeria contribute to less incidence of GIPs due to the degree of pasture sterilisation to some extent (Nwosu, 1995; Mbaya *et al*., 2006). The low incidence of GIPs infection during the winter season is due to the unfavourable temperature and humidity in the environment to the parasites, causing less egg shedding in the faeces (Chichilichi *et al*., 2018). The fluctuating temperature might affect the prolific rates of the parasites, hatching and survival of the eggs, adult life span, feeding rate, and their activities (Vidya & Sukumar, 2002). Moreover, elephants in the wild have a higher prevalence of GIPs than captive and semi-captive elephants because elephants in captivity are scheduled for regular deworming (Abeysekara *et al*., 2018). In addition, strict biosecurity implemented for elephants in captivity could contribute to much lower infestation rates (Chichilichi *et al*., 2018).

Diet is associated with parasitism due to the synergistic effect between diet levels, GIPs burdens, and intensity of infection. When animals suffer from nutritional stress due to limited food (mainly protein and energy; Chapman *et al*., 2006), available nutrients will be used to survive parasitic infection instead of for production. For instance, the available nutrients are used to synthesise immune cells (macrophages and granulocytes) and immunoglobulins, and repair damaged GIT tissues (Pathak, 2017).

Presently, the prevalence studies are mainly specific to certain localities and involved either Asian or African elephants. No information is available in the literature regarding the geographical factors affecting the parasite diversity/density/distribution. Hence, geographical factors would be crucial factors to be studied and explored by future researchers.

Pathology

Three studies have reported the post-mortem of elephants. The first study reported a case of an elephant that succumbed to fasciolosis with an average of 98,800 eggs/100 g/individual. The elephant appeared sick and emaciated with watery dark-coloured faeces (Rizwar *et al*., 2017). In another study, elephants with a severe parasitic infestation of cestode, *A. manubriata*, had haemorrhagic enteritis generally in the jejunum and ileum as major pathological lesions. The intestinal mucosa was thickened and hyperaemic with multifocal ulcerative sites and the presence of necrotised membranes covering the elevated nodular lesions (Perera *et al*., 2017). In a study where 11 fresh elephant carcasses were necropsied, petechial haemorrhage and erosion of the bile duct were observed, with the most likely diagnosis due to hookworm, *G. clathratus*, infestation (Obanda *et al*., 2017).

Information on the clinicopathology of elephant GIPs is scarce. Most of the time, a healthy elephant infected with GIPs shows no obvious clinical signs. This is termed sub-clinical unless in conditions where the equilibrium between GIPs and the host is destabilised by other factors that might lead to stress (Hota *et al*., 2020). The sick and emaciated elephant with fascioliasis most likely led to the lesion in the liver parenchyma, which compromised the metabolism of carbohydrates, proteins, and fats (Rizwar *et al*., 2017). Subsequently,

the elephant will lose weight, have reduced growth, and eventually die. In chronic cases, cholestasis could manifest as a result of flukes obstructing the cholangio hepatic, causing hepatic fibrosis and increasing intrahepatic blood pressure. Moreover, the blood-sucking activity of adult *Fasciola* might lead to intrabiliary haemorrhage, which then progresses to anaemia (Fowler & Mikota, 2006). In tapeworm, haemorrhagic enteritis from *Anoplocephala* infection results from necrotised mucosal lining caused by the strong pressure of the tapeworm's muscular suckers once they are tightly attached to the intestinal mucosa (Perera *et al*., 2017). Adult *G. clathratus* are bloodsuckers (Fowler & Mikota, 2006) and, most of the time, can lead to haemorrhagic anaemia, with signs of hepatic insufficiency if the elephants are severely infected. Moreover, a severe infestation may cause death if they obstruct bile flow (Evans, 1910).

Diagnosis

Freshly voided faecal samples must be processed in less than 48 hours to obtain accurate results because, for strongyles, egg hatching will occur in 1 to 2 days and become larvae (Fowler & Mikota, 2006). This can lead to inaccurate representation of the GIPs, as samples must be properly collected, preserved, and processed to detect infections. The direct wet mount requires little faecal sample; however, it is less sensitive since the parasites are not concentrated. A relatively higher number of *Anoplocephala*, Strongyle, *Strongyloides*, and *Ancylostoma* eggs were reported in the floatation technique than in the sedimentation technique, proving that the floatation technique enhanced the detection (Abhijith *et al*., 2018). However, the finding contradicts another finding stating that it is usually difficult to identify eggs of cestode in the faeces, and ELISA is an option for *Anoplocephala* detection (Fowler & Mikota, 2006). Identification of GIPs up to the species level using only morphological description is insufficient in most cases. Molecular detection is used to complement morphological and morphometrical detection as it can characterise the sequence of genomic DNA (Ahmed *et al*., 2011) and compare it with sequences provided in the genbank (Phuphisut *et al*., 2015). Species identification is important as potential zoonotic risk might be present, although very limited information is available regarding this matter. Nevertheless, *O. aculeatum* was discovered in the Asian wild elephant in Kanchanaburi, Thailand, through molecular detection (Phuphisut *et al*., 2015), similar to the *O. aculeatum* reported infecting Japanese macaques. (Arizono *et al*., 2012; Ghai *et al*., 2014). The infection of Japanese macaques also proved that this nematode has potential zoonotic transmission.

Most elephants might harbour GIPs subclinically and most likely did not show any obvious clinical signs (Hota *et al*., 2020). Common approaches to diagnose the GIPs infection in elephants include the fresh sampling of elephant faeces and processing using techniques such as direct wet mount, floatation, McMaster, and sedimentation (Abeysekara *et al*., 2018; King'ori *et al*., 2020). The floatation technique is generally used to qualitatively assess nematode and cestode eggs, while the sedimentation technique isolates larger and denser eggs of trematodes (Abhijith *et al*., 2018). The quantitative analysis, which enables the calculation of the infection intensity, was a modified McMaster technique and recorded as the number of oocysts/cysts/eggs per gram (OPG/CPG/EPG; Abeysekara *et al*., 2018).

Morphological and morphometry identifications were suggested to specifically determine the species of GIT helminths using the light microscope and scanning electron microscope (SEM; Prahardani *et al*., 2019). The identification of nematode species is possible by observing the mouth, leaf crown, collar, buccal capsule, papilla, oesophagus, vulva, anus, tail, speculum, and bursa copulatrix (Chel *et al*., 2020). The morphometric data for *Murshidia* and *Quilonia* species previously reported are tabulated in Table 3. In addition, molecular detection via polymerase chain reaction (PCR) and sequencing for species identification was also used in recent works (Figure 2 and 3; McLean *et al*., 2012; Phuphisut *et al*., 2015; Perera *et al*., 2017; Chel *et al*., 2020; Hota *et al*., 2020). Molecular identifications were used to investigate the evolutionary lineage of the parasite, the lack of availability of sequences in GeneBank for further molecular analysis, and simply to observe the genetic relationship between species under the same genus (Phuphisut *et al*., 2015; Perera *et al*., 2017; Chel *et al*., 2020). Among the Murshidia species in Asian and African elephants, *M. indica* and *M. africana* demonstrated different morphological characteristics but were closely related in terms of phylogenetic analysis of the COI gene (Chel *et al*., 2020). Another reason for performing molecular identification of the parasite is the similarity in egg morphology as observed in the strongylida group for identification up to the species level (Phuphisut *et al*., 2016).

Treatment and control

Two groups of drugs were reported to be beneficial in treating or controlling GIPs infection, i.e., benzimidazole and macrocyclic lactone groups. The treatment options for elephants infected with GIPs nematodes are ivermectin or albendazole, which could be administered via oral or subcutaneous. The dosage for administering the drugs subcutaneously is 1 mL/100 kg, while via oral, different dosages are recommended, i.e., 10 mg/100 kg for ivermectin and 750 mg/100 kg for albendazole. In addition, treatment was deemed successful with the decline in strongylid loads within 90 days of administration (Lynsdale *et al*., 2020). Another study suggested a single dose of 5 mg/kg of fenbendazole, which is effective against *Murshidia* sp. infection in elephants (Nei & Kumar, 2020). In Sri Lanka, elephants raised in captivity and semi-captivity are administered with febantel and mebendazole as control measures (Abeysekara *et al*., 2018).

Table 3. Morphometrical data of Murshidia and Quilonia species reported by Chel *et al*. (2020)

Morphometry differences	GIPs								
	M. falcifera		*M. neuvelemairei*		*M. indica*	*Q. renniei*		*Q. travancra*	
	M	F	M	F	M	M	F	M	F
Body length (mm)	24	29.6-32	17-23	25-28.8	15.7	15-17.2	19.7-26.4	16.6-19	25.8
Body width (mm)	0.7	1.0-1.3	0.6-0.8	0.9-1.1	0.54	0.6-0.7	0.8-1.1	0.7	0.9
Esophagus length (ʮm)	792	956-1058	698-776	724-880	517	611-667	668-812	746-790	956
Buccal capsule diameter (ʮm)	131	111-136	53-64	55-65	64	44-79	50-104	53-85	136
No. of leaf crown	~80	~80	~40	~40	~40	12-18	16-18	8-10	8-10

*M, male; *F, female.

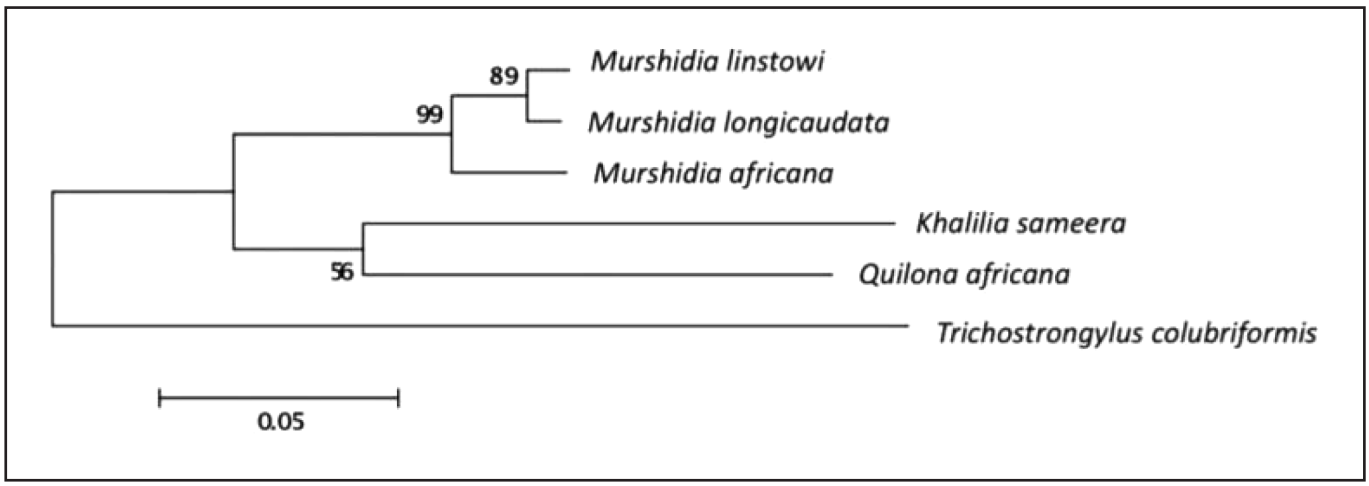

Figure 2. Genetic analysis of five species of strongyle nematodes in *Loxodonta africana. Trichostrongylus colubriforis* is used as an outgroup (McLean *et al*., 2012).

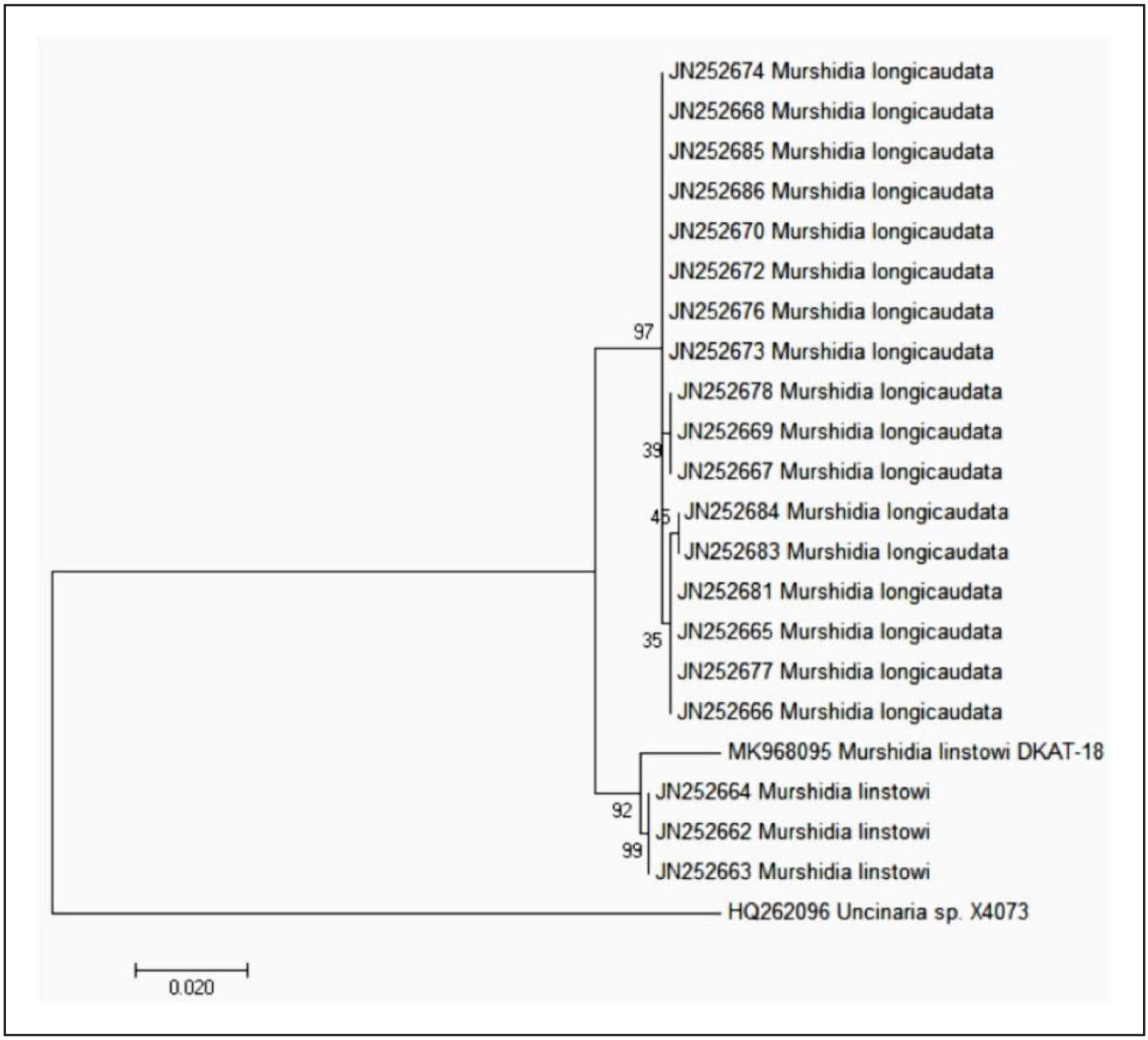

Figure 3. Evolutionary genetic analysis of *Murshidia linstowi* by using 16S rDNA sequencing (Hota *et al*., 2020).

Table 4. Anthelmintics used for elephant management, reference from Fowler (2006) and Tiwari & Rao (1996)

Anthelminthics	Dosage & Administration route	Affected GIP Parasites
Macrocylic lactones		
Ivermectin	0.1mg/kg, PO	Ascarids, strongyles
Benzimidazoles		
Albendazole	2.5mg/kg, PO	Cestodes, nematodes, strongyles
Fenbantel	5–10mg/kg, PO	Roundworms, hookworms, whipworm, ascarids & tapeworms
Mebendazole	2.5–4mg/kg, PO	Strongyles, trematodes
Thiabendazole	20mg/kg, PO	Strongyles
Oxfenbendazole	2.5mg/kg, po	Ascarids, strongyles
Imidazothiazole		
Levamisole HCL	2.5–3mg/kg, PO	Strongyles, hookworms
Tetrahydropyrimidines		
Morantel tartrate	2–4mg/kg, PO	Strongyles
Isoquinolenes		
Praziquantel	2.5–4mg/kg, PO	Cestodes, trematodes

*PO, per os (orally).

Several antiparasitic drugs are used in elephant management (Table 4). Antiparasitic drugs classified under the benzimidazoles group (fenbendazole, mebendazole, albendazole, and febantel) are broad-spectrum anthelmintics that act by binding to tubulin, which is part of the cellular cytoskeleton, damaging them and preventing the formation of microtubules and disrupting the intracellular microtubular transport systems. As a result, helminths will be starved as their energy metabolism pathway is disturbed. In comparison, ivermectin will paralyse the parasites, leading to death, as ivermectin increases the secretion of gamma-amino butyric acid (GABA) at presynaptic neurons, inhibiting neurotransmitters and causing a blockage at postsynaptic regions of adjacent neurons in nematodes (Plumb, 2008). Even though it is important to estimate the GIPs burden to address a proper treatment regimen and management (Abeysekara *et al*., 2018), there is limited information on the threshold value of faecal egg count as a baseline for treatment decisions; thus, more studies are required. Since elephants have a long life span, especially captive elephants, which can exceed 70 years (Sukumar *et al*., 1997), intensive use of anthelmintic long-term in captive elephants might give negative results (Stringer & Linklater, 2014) due to resistance to the drugs (Gasbarre *et al*., 2009). For coccidia infection, decoquinate, a coccidiostat, has been recorded to prevent further development of sporozoites once they penetrate the intestinal cell of the host (Mikota & Plumb, 2003).

Avoiding close contact with captive animals that are in close proximity to wildlife could control parasitic diseases (Abhijith *et al*., 2018). Providing the best quality nutrients in ideal proportions through daily feed intake is beneficial because well-nourished animals tend to tolerate GIP infestation far better than those fed with a low-quality diet (Pathak, 2017). In addition, it would be favourable if GIP infections were controlled based on natural immunity by strengthening their immune system via appropriate nutrition, biosecurity, reducing stress, and doing a regular faecal test to treat elephants with the above 'normal' parasite burden (Abeysinghe *et al*., 2017).

One of the limitations of this study is the inclusion of only the articles published online in SCOPUS and PubMed and not the printed ones as those were inaccessible on the website.

CONCLUSION

In conclusion, the present review shows that nematodes have the highest prevalence among the discovered GIPs. The prevalence of GIPs significantly correlates with a few predisposing factors listed in the studies. However, findings on clinicopathology and threshold of parasite burden that should be used as a baseline for treatment decisions are still limited, and GIPs remain a major health concern in elephants worldwide as some cases could lead to mortality. Moreover, accurate diagnosis of GIPs infecting elephants is important for parasite surveillance, treatment, and control programmes.

More extensive studies should be conducted to determine the prevalence of each GIP species, if possible, in various geographical regions, and genetic analysis for species identification to discover other unknown GIP species. This could be achieved by sampling more captive and semi-captive elephants, and elephants in the wild, for both Asian and African elephants. In addition, this research is crucial for parasitic surveillance to study any potential zoonotic disease or inter-species infection, enhancing the efficacy of control and management of parasitic diseases.

Conflict of interest

All authors have no conflict of interest concerning the work reported in this paper.

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