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Meat Borne Parasites in Iran: A Review

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ABSTRACT

Public health and the economy are seriously affected by diseases transmitted by meat and its products, including Zoonotic diseases. Several factors contribute to carcass condemnation in slaughterhouses, such as parasitic infections that can be extremely harmful to human societies. Parasites transmitted from red meat and its products can induce disorders in humans. These parasites include helminths such as *Taenia* spp. (intestinal disorders), liver flukes (hepatic disorders), and *Trichinella* spp. (intestinal and muscular disorders), as well as protozoans such as *Toxoplasma gondii* (neurological and reproductive disorders) and *Sarcocystis* spp. (gastrointestinal, respiratory, and muscle disorders) and *Cryptosporidium* spp. (intestinal disorders and severe diarrhea). Generally, there is little knowledge about meat-borne parasitic diseases. Global food trade, population growth, unprincipled cooking methods, and lack of improvement in monitoring and diagnostic procedures are among the increasing factors of diagnostic cases of parasitic diseases caused by meat and meat products around the world, including Iran. Despite the decrease in meat consumption per capita in recent years, there is a significant prevalence of meat-borne parasitic diseases among Iranian population, which requires attention towards preventive and monitoring methods. Iran's northern provinces, including Gilan and Mazandaran, have the highest documented incidence of parasite infections in meat, especially in rural areas with humid climates where cattle are raised. Recent studies have estimated the prevalence of human infections in Iran. The studied diseases included taeniasis (0.25%-0 5%), trichinellosis (2.6% in high-risk group), fascioliasis (0.7% in Jolfa county), dicrocoeliasis (2.2% in Meshkinshahr city), toxoplasmosis (39.3% of the whole Iranian population), sarcocystosis (0.16%-0.1%, only found in eight cases), cryptosporidiosis (2.9% of healthy population and 1.3% of patients suffering from gastroenteritis). Therefore, this study aimed to evaluate the essential parasitic diseases transmitted through meat and meat products in the geographical area of Iran and their effects on both human and animal health.

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Introduction

Food-borne disease is a significant public health issue that directly impacts the affected people's health, resulting in disruption of social and economic development at the regional and national levels [1]. Approximately 2.23 million people get sick from parasites in food each year, and 45,927 people die as a result. Based on the WHO's 2010 estimate, this results in about 64.6 million DALYs (Disability Adjusted Life Years) [2]. Meat, as the most available source of animal protein, can lead to numerous infectious diseases, as well as direct or indirect transmission of various parasitic ones. Although the incidence of meat-borne parasitic diseases is low, their impact on the health of human societies can be much more severe. Underestimating meat-borne zoonotic parasitic infections, along with inefficiency in their prevention, diagnosis, and monitoring methods, have increased the occurrence of these diseases in different regions of the world [3, 4]. While meat inspections generally have low sensitivity, they are considered the primary method of diagnosing meat-borne parasites. However, many carcasses may not be inspected in developing countries, such as Iran, because of the traditional slaughter outside abattoirs, and the only method of preventing their transmission to humans fails at this point [4, 5]. Iran is located in the Middle East, with a population of

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approximately 88.5 million in 2022 and an area of 1,648,195 km^2, in the center of which mountains surround desert areas. The climate can be anything from dry and semi-arid to subtropical, from the northern woodlands and the Caspian coast to the rest of Iran [6]. In this country, beef, mutton, and poultry are the three most common meat sources. Although consumption of pork is forbidden under Islamic laws, wild boars are hunted and consumed by religious minorities. According to the reports of the Iran Statistics Center (2023), 598 thousand tons of red meat were produced and sold in the country's official slaughterhouses, and the imported meat reached 48.5 thousand tons in that year. The Iranian Center for Strategic Research reported in 2018 that beef and mutton production reached 501 thousand tons, and more than 40% of the country's need for red meat was fulfilled through imports that year. The amount of red meat produced unofficially is also estimated to be 60 to 180 thousand tons in 2023. The per capita consumption of red meat in 2023 was estimated to be between 8.225 and 9.630kg annually in Iran, while this value was 26kg in 2017 [7].

Food safety and public health concerns are raised by rising populations, higher protein demands, and the relative ease of processing meat in developing countries compared to industrialized countries. As a result, there is a pressing need to address the issue of meat-borne parasites. Therefore, more research is required to prevent, diagnose, and treat diseases caused by meat and meat products, particularly parasitic meat-borne diseases. The main parasites that can infect humans through eating raw or undercooked meat or meat products infected with parasite cyst stages include *Toxoplasma gondii, Sarcocystis spp., Taenia spp., and Trichinella spp.* [4]. Humans can experience a wide range of symptoms caused by the parasites mentioned above, including gastrointestinal, muscular, neurological, and reproductive problems. The purpose of this study was to present our current understanding of these zoonotic parasites that infect meat, including their life cycles, epidemiological data, transmission methods, potential risk factors, disease characteristics, and prevention strategies, and assess the current status of these parasites in Iran. This study provides an updated and comprehensive review of Iran's epidemiology, pathogenesis, and challenges associated with meat-borne and meat product-transmitted parasitic diseases.

Material & Methods

Published references, including original articles, reviews, short communications, books, and certified online references, were collected from English language electronic databases (Google Scholar, ScienceDirect, Scopus, and PubMed) and national electronic databases (SID, IranDoc, Magiran, and IranMedex), during March and April 2024. A number of keywords were used in conjunction to complete the search. Information was gathered regarding the frequency and distribution of various parasitic diseases in meat in Iran, including Taeniosis/Cysticercosis, Trichinellosis, Liver flukes (Fascioliasis and Dicrocoeliasis), Toxoplasmosis, Sarcocystosis, and Cryptosporidiosis, as well as other human and animal populations. Two researchers (I.S. and A.A.) first assessed the abstracts and/or titles of the retrieved publications separately after deleting the duplicate papers. Consequently, all of the full-text publications that met our criteria were downloaded and carefully reviewed. An Excel file was used to record the collected data.

Meat-borne Cestode infections

Taeniosis and Cysticercosis

The human *taeniasis*-causing adult tapeworms belong to one of three species: the beef tapeworm, the pork tapeworm, or the Asian tapeworm, the only species whose worms are found in humans [8]. Iran has a lengthy history of human tapeworm infections. Tapeworm eggs of the genus *Taenia* were identified in a study of natural human mummies belonging to the third century BC, which were found in the Cheharabad salt mine in the northwest of Iran [9]. *Taenia solium* is more common in non-Muslim countries because the laws of Islam strictly forbid the consumption of pork. Accordingly, taeniosis caused by *Taenia solium* is almost non-existent in Iran. However, the wild hunter is allowed only for Armenians, Jews, and Zoroastrians in this country [8, 10].

As neglected tropical illnesses with a global distribution, the World Health Organization has introduced taeniosis and cysticercosis. Infectious T. saginata affects 45–60 million people globally, with comparatively high prevalence (more than 20% of the population) in East Africa, Bali (an Indonesian island), and parts of Tibet. According

to some sources, this parasite is also common in Europe, the Americas, and the Middle East [8].
There are two distinct phases to the life cycle of *T. saginata*. The adult tapeworm matures in the human host's intestine and either lays eggs directly in the stool or in proglottids containing eggs. The metacestode stage is created when the oncosphere migrates through the bloodstream to the striated muscles, where the intermediate host, typically cattle, becomes infected after ingesting water or food contaminated with human feces. The larval stage, known as *Cysticercus bovis*, is formed in the host's body. Infected humans can contract cysticercus by eating raw, partially cooked, or unfrozen beef (Figure 1) [8, 11]. Parasites can lay thousands of eggs in human feces—about 150,000 eggs every day—if an infected person is not careful [12].

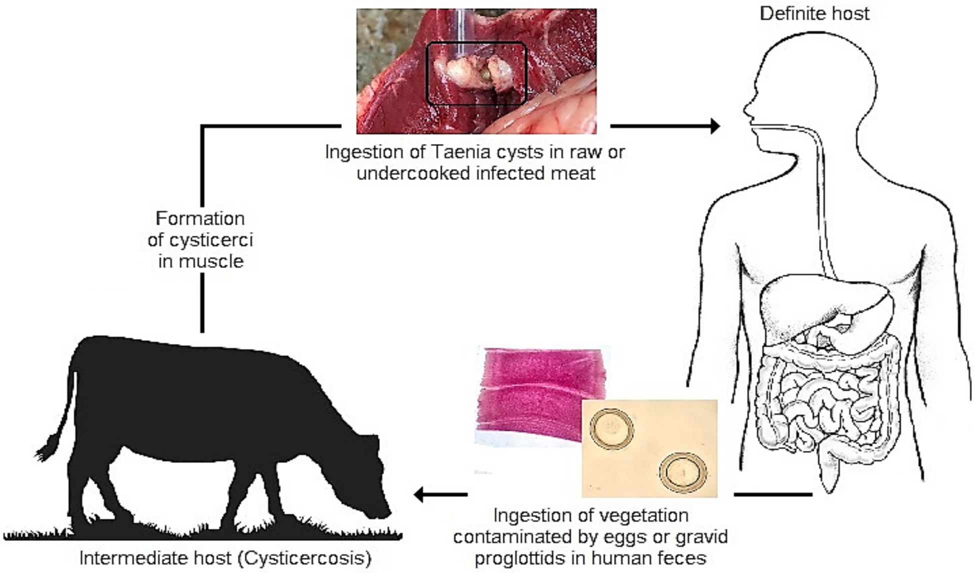

Figure 1. Life cycle of *Taenia saginata*.

T. saginata often only causes minor eosinophilia, fever, anal pruritus, and gastrointestinal problems in humans, and the side effects are frequently accompanied by other less severe symptoms [10, 11]. The worldwide burden of disease caused by *T. saginata* is vanishingly small, with hardly any fatalities and extremely low disability weights, in spite of its prevalence in several low-income countries [11]. While appendicular taeniosis is not common, there have been reports of cases. Multiple writers have recorded case reports in Iran regarding this matter [8]. The expense of diagnosing and treating human diseases has minimal direct economic impact [11].
Since bovine cysticercosis rarely causes noticeable symptoms in cattle, postmortem exams are the gold standard for confirming a diagnosis [12]. The highest prevalence of parasites in beef has been found in spring, summer, and autumn in slaughterhouse studies in Iran. Perhaps the difference in prevalence in different seasons can be considered a result of climatic differences in Iran. In addition, studies have shown that the contamination is more in the masseter, heart, diaphragm, tongue, shoulder, and triceps brachii muscles (due to higher oxygenation). The transmission of *T. saginata* cysticercosis is minimal in areas without dew, rain, or irrigation, as studies have shown that bovine cysticercosis is caused by the ingestion of tapeworm eggs, which are typically transmitted through plants contaminated with human feces. Tapeworm egg outbreaks in grassland are possible after the first spring rains. Consequently, in late spring, *T. saginata* cysticercosis in cattle may be more common [13].
According to Nasiri et al. (2009), the prevalence of *T. saginata* among 13,915 individuals from Karaj, Alborz region, Iran, was 0.028% in fecal samples of randomly selected individuals. Kia et al. (2005) reported *T. saginata* as much as 0.5% in 417 people after the administration of antiparasitic agents. Kia et al. (2004) also revealed that the prevalence of appendicitis caused by *T. saginata* in 2379 appendectomy

samples was 0.08%. Moazeni et al. (2018) found that the prevalence of human taeniosis (*T. saginata*) among the investigated participants in Iran ranged from 0.025% to 0.5%. Studies in other parts of the world, particularly those that produce a lot of cattle, have demonstrated far greater rates of human taeniosis due to *T. saginata* infection. As an illustration, the reported prevalence of human taeniasis in endemic areas ranges from 0% to 13.9% in Africa, from 0.24% to 17.25% in Latin America, and from 0% to 3.02% in Asia. The variety in eating habits might explain this difference. In Iran, eating raw meat is uncommon or rare, and consuming raw or partially cooked meat is a common preference in other continents [8].

T. saginata infections in rural Iran are a result of lax meat inspection systems, inadequate human training, and, on occasion, peculiar dietary practices. Therefore, limiting the consumption of raw beef, conducting practical meat inspections, improving sewage management, and using restrooms properly can prevent the infection and spread of taeniosis among humans. Arfaa (2010) concluded that *T. saginata* is prevalent across Iran, while the majority of studies on human taeniosis have focused on northern regions. The author mentioned that the parasite is more prevalent in rural areas of Mazandaran province, where animal husbandry is prevalent. Researchers in the north of Iran who focus on taeniasis (a disease caused by *T. saginata*) and meat-borne infections may find this to be an explanation, at least in part [8]. In one report, the leading cause of contamination in feedlot cattle was attributed to immigrant workers employed on farms [14]. The immigrant workers consume undercooked meat as part of their diet, and they can easily sustain the parasite life cycle because they are in contact with cattle.

Meat-borne Trematode and Nematode infections

Trichinellosis

The zoonotic parasite disease known as trichinellosis (previously trichinosis) [15, 16] is caused by the species Trichinella. Humans can contract this disease by consuming raw or undercooked meat, as well as meat products contaminated with the nematode's larvae [17]. The parasite is most commonly seen in omnivores like pigs and wild boars (Sus scrofa). Eating pork is considered highly forbidden in Iran due to Islamic beliefs. The only religious groups allowed to shoot wild boar in the nation are the Armenians, Jews, and Zoroastrians. Nonetheless, some religious minorities, including Muslims, may be at risk of contracting trichinellosis due to their unlawful hunting and ingestion of wild boar meat. The estimated global prevalence of this parasite disease, however, is close to 11 million [16]. The annual incidence rate of trichinellosis worldwide was estimated to be between 469.2 and 985.3 cases per billion people. On a global scale, the condition caused 523 disability-adjusted life years (DALYs) and 0.3 to 0.8 per billion people per year in death [15].

Fransen et al. (2017) indicated that wild boars had a 4100-fold greater frequency of Trichinella than pigs and that 55% of the simulated instances of trichinellosis in humans were caused by eating wild boar meat. There are four of the nine species of the genus Trichinella [16]: *T. britovi, T. spiralis, T. murrelli*, and *T. nelson* in Iranian biodiversity in several provinces, such as Gilan, Mazandaran, Golestan, Isfahan, Ardabil, Khuzestan, Razavi Khorasan, and Hormozgan. The regions of the globe where pig is extensively consumed have the highest concentration of T. spiralis [8]. *T. spiralis* is the most common species in the parts of the world that widely use pork [17]. *T. britovi* is the most prevalent in wild animals (carnivores and ruminants) in Iran following the sylvatic cycle [15].

Two stages of gastrointestinal and skeletal muscle involvement characterize human trichinellosis [16]. Infected meat causes the stomach to release larvae, which then undergo four molting phases before maturing into adult parasites in the intestines. Copulation results in the death of the male, while pregnant females lay their eggs in the intestinal mucosa [17]. Diarrhea and stomachaches may occur during this phase of the intestines [16]. Thus, the larvae move and settle in various organs and structures, including striated muscles, the central nervous system (brain), and the heart and lungs. The brain encases itself in a characteristic lemon-shaped cyst after reaching the fully formed first-stage larva (L1) stage [17]. In this phase, clinical manifestations include fever, myalgia, periorbital edema, allergic skin reactions, myocarditis, and encephalitis [16].

There were two reports of *Trichinella sp*. in 4950 wild boar carcasses in the Iranian regions of Mazandaran and Gilan between 1961 and 1967

[18]. Trichinella infection in wild boars has a pooled seroprevalence of about 6%. Nonetheless, estimates put the rates at 9% in North America, 7% in Europe, 3% in Asia, and 3% in Oceania [19]. Trichinella was initially reported in humans in 1966 in northern Iran. The patient had specific symptoms, tested positive for the parasite, and had a history of eating wild boar. Two members of a family in Tehran who had eaten pig meat from Gilan province, northern Iran, were verified to have contracted the disease in 2007, about 50 years later [20]. According to Rostami et al. (2018), eight men (2.2%) tested positive for anti-Trichinella IgG out of 364 high-risk individuals who ate wild boar meat at least thrice a year. The results showed a strong correlation between this infection and hunting as a profession and eating wild boar meat more than seven times a year [21]. Koohsar et al. (2021) stated that five individuals (2.6%) out of 189 individuals in Golestan province, northern Iran, were found to have anti-Trichinella IgG antibodies [16].

Serological studies have shown the presence of this parasite in wild boar in Iran is almost equal to that of other countries. However, Muslim beliefs and the ban on eating pig or boar meat are mostly to blame for the low seropositivity or nearly non-existent human cases in Iran. Nevertheless, these findings could be influenced by the absence of comprehensive research [15]. In addition, there is a substantial risk of *Trichinella* due to the fast growth of wild boar populations in Iran [16] and the consumption of their game meat [8, 15]. Training programs for hunters, farmers, and consumers, particularly in remote areas where people may not be aware of the link between consuming pork and Trichinella and prohibiting the illegal hunting of wild animals are recommended measures to prevent and control the disease, given the lack of pig breeding in Iran and the rarity of human cases [15].

Liver flukes

Fascioliasis

The flatworms *Fasciola hepatica* and *Fasciola gigantica*, which are members of the Digenea subclass and the Trematode class, are the infectious agents responsible for fascioliasis. Their impact on human and animal health is well-documented, and they are responsible for substantial economic losses in many parts of the world. Humans are considered accidental hosts, while farmed herbivores such as sheep and cattle serve as definitive hosts and reservoirs. *Fascioliasis* can be more or less common depending on people's diets and the number of snails serving as ultimate hosts [22].

The life cycle of *Fasciola* spp. includes egg, miracidium, cercaria, metacercaria and adult fluke. Freshwater snails from the genus *Lymnaea* are intermediate hosts, which can transmit the infection to humans or animals [23]. Adult *Fasciola* lives in large bile ducts and causes swelling of these ducts and the liver. *Fasciola* worm causes separation of the epithelium covering the bile ducts by inducing secondary adenomatous hyperplasia. Plasma cells, lymphocytes, and eosinophils in the tissue surrounding the duct and port spaces are replaced by a fibrotic reaction. As a result, the thickness of the wall of the bile ducts increases, and its lumen becomes narrow [22].

Metacercariae can infect humans through a variety of routes, including raw or undercooked sheep's liver, unboiled water, and contaminated food. Patients may have a variety of symptoms, including fever, abdominal pain, headache, itching, urticaria, weight loss, and eosinophilia during the acute phase of an *F. hepatica* infection, which is associated with the larval stage's migration from the gut. Intermittent cholangitis is one of the most notable subclinical symptoms during the chronic phase [24].

More than 180 million individuals are at risk of getting fascioliasis, and 25 million people in 61 countries have been infected, with a disproportionate number of cases in Bolivia, Peru, Egypt, Iran, Portugal, and France. According to the WHO report, Iran is among the six countries with serious fascioliasis problems [24, 25]. Studies have indicated that the economic losses caused by fascioliasis in Iran's animal husbandry are estimated at thousands of dollars annually [26].

The prevalence of human fascioliasis is very high in many parts of Iran, and in some years, nearly 10,000 cases have been recorded. Few cases have been documented from other regions of Iran, including the western provinces of Kermanshah, Yasuj, and Lorestan; this illness is primarily observed in the humid regions of Gilan province. Zeinali et al. (2024) reported 0.7% seropositivity in 600 Jolfa County habitats in the northwest of Iran [27]. A total of 19 lymnaeid snails (0.09%) and six lymnaeid snails (0.03%) infected with *Filariasis* were discovered among two thousand specimens acquired from four provinces in Iran's northwest (West Azerbaijan, East Azerbaijan, Ardabil, and Zanjan) by Galavani et al. (2024) [28]. Heydarian et al. showed that fascioliasis is widespread in many parts of Iran, including Lorestan, Mazandaran, Ardabil, and Tehran [29]. The Meshkin Shahr central laboratory in Northwest Iran collected 460 fecal samples (0.2%) from patients, of which one specimen tested positive for *Fasciola spp.* (or 0.2% of the total) [30]. Fascioliasis can be transmitted from humans and cattle in regions with abundant rainfall and moderate temperatures all year round. These places also have a high population of lymnaeid freshwater snails, acting as intermediate hosts, and vast pastures for ruminants [1]. Therefore, consumption of vegetables grown near ponds and rivers is a significant risk for fascioliasis in rural areas.

Dicrocoeliasis

The bile ducts and gall bladders of the hosts can become infected by one of three species of *Dicrocoelium*, which cause food-borne dicrocoeliasis (*D. dendriticum, D. hospes*, or *D. chinensis*). There are two intermediate hosts and one final host in the life cycle of the *Dicrocoelium* parasite. *Helicella* and *Zebrina* snails are the first intermediate hosts, followed by *Formica* ants and mammals [31].

Domestic animals such as sheep and cattle are directly affected by dicrocoeliasis, which causes damage to their livers. This damage, in turn, causes the loss of valuable protein substances from the human diet when infected livers are removed from the slaughterhouse. Investigations from 2005 to 2008 have shown that the economic damages caused by confiscation of the liver due to fascioliasis and dicrocoeliasis in cattle and sheep slaughtered in the Tehran slaughterhouse were $227,216. In addition, the economic damage caused by the confiscation of the liver due to dicrocoeliasis in the Arak slaughterhouse was estimated at $30,479 in 2013-2016 [32].

As a neglected parasite illness, human cases of dicrocoeliasis are sporadic. On the other hand, raw or undercooked liver can lead to human cases of false dicrocoeliasis [33, 34]. Constipation, diarrhea, abdominal pain, nausea, itching, an enlarged liver, blocked bile ducts, and elevated eosinophils in the blood are all signs of this condition [31]. The reports of cases of human infection from the center of Iran, Isfahan province, and the north of the country, Gilan province, have indicated the severe role of this parasite in the public health of the country [34]. Asadi et al. (2024) reported that *D. dendriticum* was present in 2.2% of 460 fecal samples from people referring to the Central Laboratory of Meshkin Shahr County, Ardabil province. According to the authors, their results were caused by consuming liver from contaminated livestock [30]. Therefore, snail activity also increases in highly humid areas, increasing the likelihood of infection in ruminants. At this moment, the consumption of raw liver, based on a wrong belief in some rural and urban areas, can lead to the occurrence of dicrocoeliasis in humans. Furthermore, some dietary habits tend to consume undercooked liver, which increases the chance of this disease in humans.

Meat-borne protozoal infections

Toxoplasmosis

The obligatory intracellular parasite Toxoplasma gondii is the causative agent of the prevalent zoonotic illness toxoplasmosis. A North African mouse (*Ctenodactylus gondii*) in 1908 was the first host for this protozoan, which is a member of the Apicomplexa branch [14, 35]. Humans and a wide variety of warm-blooded species, including agricultural animals, are intermediate hosts, while felines, especially domestic cats, are the final hosts [36]. Three infectious phases make up the life cycle of Toxoplasmosis caused by Toxoplasma gondii. The first stage is the oocyst, which is excreted by cats and their feces. As the disease progresses, tachyzoites form, which is the active form of the disease. The third stage is the tissue cyst that can be found inside muscles and the central nervous system (Figure 2) [14].

There are multiple basic methods by which *Toxoplasma gondii* can enter a host's body, including vertical transmission (from mother to fetus), contaminated food and water, organ transplants, raw or semi-cooked meat, and goods containing live tissue cysts. The life cycle of Toxoplasma gondii is mainly supported by poultry, particularly free-ranging chickens, which can infect humans and cats when their meat is not fully cooked. Another potential vector for illness transmission is drinking raw milk from sick goats and cows [36].

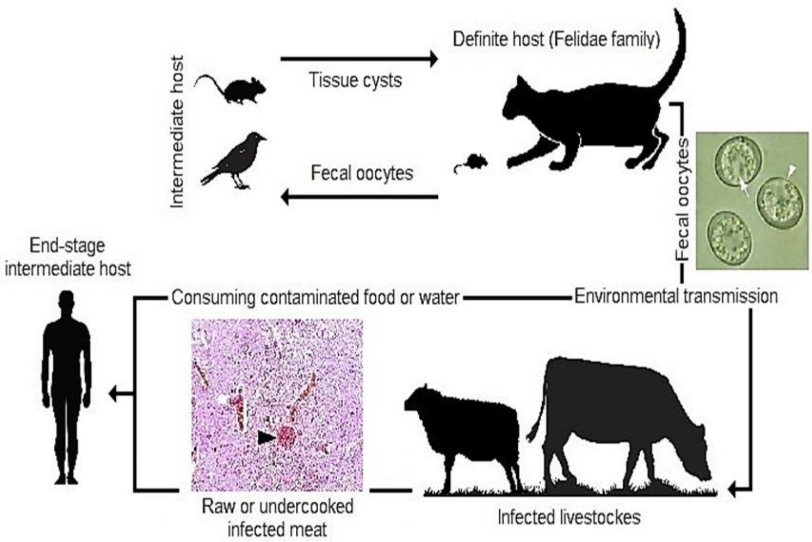

Figure 2. Life cycle of *Toxoplasma gondii*.

As parasite cysts cannot be seen with the naked eye, they go undetected when meat is inspected. Domestic animals, mainly sheep and goats, are a significant reservoir for the infection, which reaches humans through their raw or undercooked meat and liver [35]. A significant risk factor for toxoplasmosis in Iran is the consumption of liver, raw meat, and its byproducts, and traditional beliefs suggest pregnant women and anemic patients should avoid [14, 35]. One study found that those who eat more raw meat or vegetables had a higher seropositivity rate. Almost every variety of Iranian food relies heavily on meat. *T. gondii* is mainly transmitted through eating raw or undercooked meat. In another method the disease might be transmitted is through the consumption of pork products, namely sausages, because of the special way they are prepared. Economic losses in farm animals can occur as a result of reproductive and fertility abnormalities such as stillbirth, miscarriage, or mummification, even though toxoplasmosis typically causes asymptomatic humans [36]. Pregnant women and people with immune deficiency (cancer patients, organ transplants, and AIDS) are two risk groups for toxoplasmosis. Toxoplasmosis may lead to flu-like symptoms in the first few weeks. The opportunistic parasite's preference for the eyes and brain makes for a bad prognosis and the possibility of consequences such as chorioretinitis, glaucoma, retinal detachment, brain abscess, and encephalitis in both acute and chronic infections. In addition, pathological severe complications such as microcephaly, hydrocephaly, deafness, blindness, mental retardation, and death of the fetus may occur as a result of vertical transmission to the fetus, depending on the gestational age. Further evidence suggests a strong correlation between cerebral toxoplasmosis and neurodegenerative diseases, including bipolar disorder, epilepsy, and schizophrenia. There is a high correlation between autoimmune disorders and chronic toxoplasmosis [37].

The most common food-borne infection that results in hospitalization worldwide is toxoplasmosis [14]. The prevalence of *T. gondii* in different regions of the world varies from 0 to 100% and is associated with severe consequences such as treatment costs, morbidity, and mortality in vulnerable groups [35]. According to Pal et al. (2014), an estimated 39.3% of the Iranian population has varying antibody titers against *Toxoplasma gondii*. This proportion is at least one-third worldwide. Latin America, Southeast Asia, Central and Eastern Europe, and Latin America have the highest seroprevalences of Toxoplasma gondii infection (75–85%), whereas North America and Northern Europe have the lowest. Estimates for the seroprevalence rates of this virus in surrounding countries are 29.8% in Qatar and 29.45% in Pakistan [35, 38].

A meta-analysis conducted by Foroutan et al. (2024) revealed a moderate rate of T. gondii exposure among 8226 blood donors from Iran in terms of specific IgG (32.9%), IgM (1.4%), and both IgG/IgM (1.7%) antibodies. The study found five potential risk factors for T. gondii seropositivity: gender, interaction with cats, soil contact, eating unwashed veggies and/or undercooked meat, and contact with soil [39]. A prior study found a seroprevalence of T. gondii of 24.6% in women with an abortion history and 21.5% in women with a normal delivery. In addition, an estimated 24.3% of Araki women had a T. gondii infection [40]. Anti-*T. gondii* IgG was detected in 29.7% of pregnant women. In contrast, anti-IgM was positive in 0.6% of cases, according to a recent study by Bashour et al. (2024) on 340 pregnant women admitted to a hospital in the capital of West Azerbaijan Province, located in northwest Iran [41]. Furthermore, 381 (31.7%) and 41 (3.4%) of 1200 pregnant women tested positive for IgG and IgM anti-*T. gondii* antibodies, respectively, according to Barzgar et al. (2024) [42]. Arbabi and Taheri (2002) and Mohammadi et al. (2015) have indicated a strong correlation between the presence of T. gondii-IgG antibodies in human blood and the ingestion of liver, hamburger, and undercooked meat [40, 43]. Contact with soil contaminated by the feces of an infected cat is one of the leading causes of human infection with this parasite. Additionally, untreated drinking water, undercooked meat, liver, hamburgers, or unknown meat that has not been adequately frozen may transmit *T. gondii* to humans consuming unwashed vegetables contaminated with soil. Recently, the trend of keeping indoor-outdoor cats, especially in urban and rural communities in Iran, has increased, which may explain the high seroprevalence of this parasite among people. Patients with immunodeficiencies in Iran have a 50% seroprevalence of infection, which is higher among those undergoing organ transplants, living with HIV/AIDS, or battling cancer. This high rate of infection can have devastating effects on these individuals [37].

Sheep had the most significant prevalence among Iran's common food animals (31%), followed by goats (27%) and cattle (18.1%). There was a 31.01% and 17.11% seroprevalence of Toxoplasma gondii in sheep and goats in Egypt, 26.2% and 42.8% in Pakistan, and 33% and 27% in Ghana. In the provinces of Qazvin, Gilan, Mazandaran, Kashan, Kerman, and Khuzestan, the seroprevalence of Toxoplasma gondii in sheep and goats was 33.62% and 36.41%, respectively. In comparison, in the center of Iran, the seroprevalence of Toxoplasma gondii was 36.22% and 44.49%. In the southeast, the seroprevalence was 3.33% and 1.74%, and there was a seroprevalence of 13.13 % and 10.6 % in the southwest [35]. Since sheep and goat farming relies on pastures in Iran, there is a higher chance of these animals coming into contact with soil and forage contaminated by the feces of infected cats. In Gharekhani and Yakhchali (2019), the serum prevalence of *T. gondii* in cows of Hamedan (western Iran) was estimated to be 13%. Additionally, the presence of these infected cats in industrial farms can lead to water and feed contamination and subsequent transmission of the parasite to cattle. In general, the seroprevalence of *T. gondii* in cattle in Iran is reported to be 18.1%, which is 0% in Australia, Canada, Italy, and Indonesia and 100% in the USA [18].

The environment is a major factor in the spread of toxoplasmosis; districts along the coast of the Caspian Sea, which have a humid environment and get between 390 and 700 mm of rainfall per year, have the highest incidence of *T. gondii* [35]. In Gilan province, Pour et al. (2024) studied 208 soil samples from 16 cities and revealed that *T. gondii* oocytes were present in 14.9% of samples, ranging from 10.9% in rural areas to 16.3% in urban areas [44]. On the other hand, high and cold provinces such as Ardabil province and warm regions such as Sistan and Baluchestan province have lower seroprevalence [37].

Sarcocystosis

A zoonotic disease called sarcocystosis is caused by almost 100 species of *Sarcocystis protozoa*, which infect most mammals, reptiles, and birds [45, 46]. This intracellular parasite mainly infects skeletal and cardiac muscles and produces a toxin called sarcocystin [47].

Parasites like these go through both sexual and asexual life cycles. The carnivores' intestinal wall undergoes gametogony and sporogony during the sexual stage, whereas other intermediate hosts' tissues and muscles undergo schizogony and cyst development during the asexual extraintestinal phase. Cattle S. hominis serve as intermediate hosts, and when they consume sporocysts, the sporozoites are released. Sporozoites undergo schizogony upon entering the endothelial cells of blood arteries, resulting in the development of first-generation schizonts. Merozoites, which infiltrate blood vessels in the first generation, develop into schizonts in the second generation. The second generation of merozoites attacks muscle cells and transforms into sarcocysts with bradyzoites—the final stage of infection for the host. Bradyzoites invading the intestinal epithelium undergo a process of differentiation into macrogametocytes and microgametocytes after being discharged from small intestine cyst ruptures. The oocysts are formed when gametes fuse, which are then sporulated in the intestinal epithelium and expelled from the host's stool (Figure 3) [47, 48].

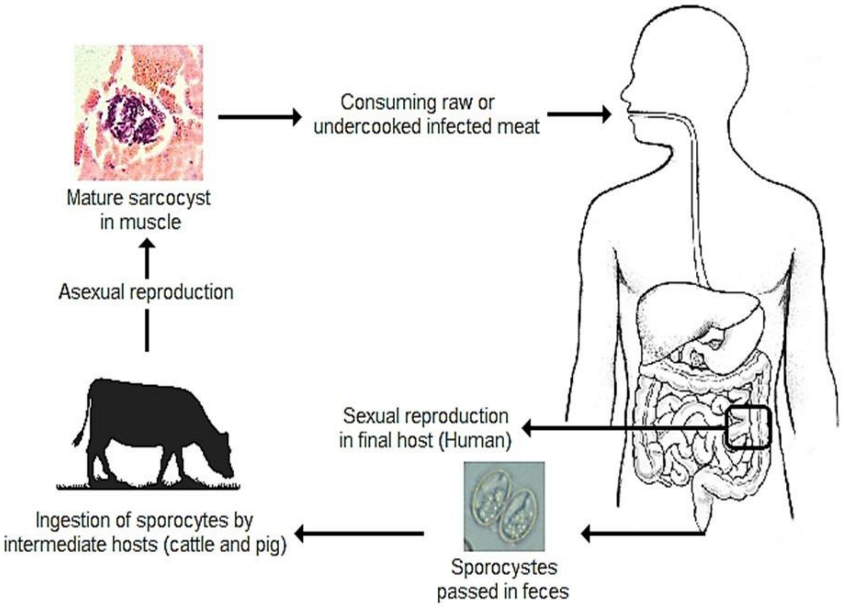

Figure 3. Life cycle of *Sarcocystis* spp.

Sarcocystis leads to severe infection of some intermediate hosts, such as cattle and sheep, and can lead to disease and, as a result, emaciation, loss of appetite, fever, anemia, muscle weakness, reduction of milk production, and abortion in cattle and sheep. As an essential source of meat and meat products for humans, cattle are affected by at least three *Sarcocystis* types, including *S. hominis, S. cruzi*, and *S. hirsute* [49, 50]. The *S. hominis* species is shared between humans and cattle. As the primary host of this parasite, humans are infected by eating infected beef and raw or semi-cooked products. Symptoms of the disease in humans include abdominal pain, bloating, anorexia, vomiting, diarrhea, respiratory problems, and tachycardia. Most people will start to experience gastrointestinal problems after 24 to 48 hours of consuming tainted meat [47, 50].

Different studies in Iran have considered raw meat and hamburgers the most contaminated food sources with *Sarcocystis.* The heart of ruminants is consumed as a protein source among Iranians. Hooshyar et al. (2024) found *Sarcocystis* cysts in 72 (75%) out of 96 ruminant heart samples from the slaughterhouse of Kashan, the center of Iran. A 100%, 97.2%, and 25.8% prevalence of *Sarcocystis* infection was found in cattle, sheep, and camel [51]. Najafian et al. (2008) reported 99% contamination of slaughtered cattle carcasses in Shahryar, Iran [50]. Moreover, Nourollahi Fard et al. (2009) estimated that the contamination of cattle carcasses in Kerman, Iran, was 100% [52]. Shekarforoush et al. (2004) reported the prevalence of *Sarcocystis* contamination in cattle carcasses to be 94.8% in the Isfahan slaughterhouse. The results of these studies showed that *Sarcocystis* contamination is abundantly visible in raw beef [50]. Humans might be useless hosts for non-human *Sarcocystis* species when they get infected by accident. Consumption of infected and undercooked meat or contaminated water with animal feces can cause this infection. In this case, muscle cysts develop as myalgia and muscle weakness. To date, this type of sarcocystosis has not been reported by humans in Iran, and there are few reports (eight cases) regarding the intestinal and gallbladder type [47, 48]. Sarcocystis are typically overlooked since they are tiny and uncommon in stool. Misdiagnosis of Sarcocystis infections is possible due to inadequate microscopic examination of stool smears, which appropriate hygiene control measures in abattoirs might explain. Since these cysts are easily recognizable in muscle carcasses, disposal of infected meat can prevent human disease transmission [53].

Regarding contamination of meat products, Jafari et al. (2022) showed that 25% of traditional beef hamburgers and 38% of industrial beef hamburgers in Hamedan province were infected with *Sarcocystis* [54]. Further, HajiMohammadi et al. (2014) revealed that 77.9% of 190 samples of traditional and industrial hamburgers in Yazd province were infected with *Sarcocystis* [55]. Moreover, Faghiri et al. (2019) reported 87.9% *Sarcocystis* contamination of traditional hamburgers, which was significantly higher than the contamination of industrial hamburgers (67.8%) [56]. Additionally, 56% and 47.9% infection with this parasite was reported in the hamburgers of Ahvaz and Tehran, respectively [50]. *Sarcocystis* contamination in hot dogs and sausages as other widely consumed meat products in Rahdar and Salehi (2011) was reported as 20% and 8%, respectively [57]. Although meat products are highly infected in Iran, Iranians do not usually eat raw or undercooked hamburgers. Thus, there is little concern regarding transmission when the products are properly cooked.

Cryptosporidiosis

Cryptosporidiosis is an infection caused by a protozoan coccidian intestinal parasite called *Cryptosporidium*, which manifests as diarrhea. This infection was first mentioned in 1976 as a potential cause of diarrhea in humans [58] and causes about eight million episodes of food-borne illness every year, making it a significant concern for public health in both industrialized and developing nations [59]. The estimated prevalence of Cryptosporidium spp infections among Iranians is 3.6% in children, 2.9% in healthy adults, 1.3% in gastroenteritis patients, and 4.5% in immunocompromised individuals [58].

Cryptosporidium is an infectious disease, which can affect both animals and humans. Of these, *Cryptosporidium* parvum and *Cryptosporidium* hominis cause cryptosporidiosis in people more often than any other species. Oocytes, released through the feces of an infected host, are potentially infective, and their outer layer protects them from harsh environmental conditions like many common disinfectants, such as chlorine-based disinfectants. Eggs hatch inside the body and change forms several times after swallowing contaminated food or water. Consequently, they multiply asexually and then reproduce sexually, producing two types of eggs: thin-walled and thick-walled. Thick-walled eggs are excreted in feces and can infect new hosts, but thin-walled eggs can cause autoinfection in the present host [58, 59].

In most cases, the oral-fecal routes spread *cryptosporidium* through eating or drinking tainted food or water, touching infected raw fruits and vegetables, or coming into touch with an infected person or animal. Clinical signs in animals include reduced appetite and emaciation, mild to moderate and self-limiting diarrhea, yellow or pale and occasionally mucoid feces, severe dehydration, and death in acute cases [60].

Moreover, consuming infected meat and sausage can lead to infection due to their higher prevalence and widespread distribution. There have been reports of *Cryptosporidium spp.* being found in cattle at the same time as they are in close contact with humans, which could indicate a zoonotic transmission of the parasite [58]. Furthermore, there have been incidents of raw meat being contaminated with animal excrement in slaughterhouses, which can lead to human cryptosporidiosis and severe, long-lasting diarrhea [5, 58]. Nevertheless, a number of reports of respiratory illnesses have been made. Moreover, the transmission of *Cryptosporidium* through consuming contaminated raw meat has been reported in Arab countries. Therefore, beef and its products may potentially harbor and transmit *C. parvum* due to fecal contamination of the carcass during slaughter [5]. In this case, there is a high risk of transmitting this parasite to humans. There has never been any research on cryptosporidiosis contamination of meat products, despite the high prevalence of the disease in Iran.

Conclusion

There is a growing demand for red meat and meat products in developing countries, but the per capita consumption of red meat in Iran has significantly declined in recent years. However, red meat is the main ingredient of most Iranian traditional dishes. Moreover, the internal organs of cattle and sheep, such as the liver and heart, are routinely consumed in Iran, and the diseases caused by their consumption are also significant. Additionally, much red meat is produced in unofficial slaughterhouses without health and quality inspections. However, meat inspection is sometimes overlooked even in official slaughterhouses. In addition, Iran has a new trend for producing handmade meat products such as sausages and hamburgers. Healthcare systems need to be monitored more closely for their products. Boars, for example, are abundant in the country's northern areas, and religious minorities there occasionally engage in lawful hunting—though Muslims do so infrequently and illegally. Many people do not know enough about zoonotic diseases to make an informed decision about eating meat from hunted animals.

Preventative measures are crucial in light of the current state of meat production and consumption in Iran, the high incidence of food-borne parasitic diseases, and the negative effects on public health and economic losses caused by meat-prevalent parasites, such as Sarcocystis spp., *Toxoplasma gondii*, and *Taenia Saginata*. A number of critical steps can be taken to prevent meat-borne parasites, such as implementing safety assurance systems, inspecting meat, using laboratory diagnostic procedures, and educating the public about the proper temperature for cooking meat.

A combination of fluctuations in the meat price in Iran compared to neighboring countries, lack of oversight by regulatory organizations, and legal issues have contributed to the increased smuggling of livestock and meat into neighboring countries. As a result, parasites can spread over a wider geographic area. Additionally, reports have indicated the smuggling of livestock and meat from neighboring countries such as Pakistan into Iran, which could increase the risk of the spread of meat-borne parasitic diseases in bordering cities. National official data and statistics regarding human infections and the contamination of meat and meat products infected with transmissible parasites are unavailable.

Human clinical and laboratory data regarding parasitic infections should be collected from hospitals, as well as more animal studies.

Declarations

Conflicts of Interest

The authors declare no competing interests.

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Authors' Contributions

Conceptualization: Peyman Dehghan Rahimabadi; Methodology: Peyman Dehghan Rahimabadi, Iliya Sharifipanah and Amirhossein Azarakhsh; Writing - original draft: Iliya Sharifipanah, Amirhossein Azarakhsh and Javad Abbasi; Writing - review and editing: Peyman Dehghan Rahimabadi and Mohammad Hashemi. All authors read and approved the final manuscript.

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