**Prevalence and Detection of Zoonotic Cestodes in Contaminated Meat Sold in Local Markets in India and its Health Impact: A Comprehensive Review**

**Abstract**

Zoonotic cestodes, including *Taenia* and *Echinococcus* species, represent a significant but often neglected public health burden in India, primarily transmitted through meat consumed from local markets. The resulting diseases, neurocysticercosis (NCC) and cystic echinococcosis (hydatidosis), impose severe health and economic consequences. This comprehensive review aims to synthesize the current evidence on the prevalence of zoonotic cestode larvae in meat sold in Indian markets, critically evaluate the efficacy of detection methods, and delineate the associated public health and economic impact. A review of relevant research articles was conducted and data focusing on prevalence studies in livestock meat, diagnostic evaluations (conventional and modern), and assessments of the health and economic impact specific to the Indian context was assessed. The review identifies significant geographical hotspots for *T. solium* and *Echinococcus* infections, linked to specific animal husbandry and sanitation practices. A major finding is the critical inadequacy of conventional post-mortem meat inspection, which has low sensitivity and allows contaminated meat to enter the food chain. In contrast, modern serological (ELISA) and molecular (PCR, LAMP) diagnostics demonstrate high accuracy but face significant implementation gaps in local abattoirs due to cost and infrastructure constraints. The public health burden is severe, with NCC being a leading cause of adult-onset epilepsy and hydatidosis imposing a substantial surgical load and economic losses from carcass condemnation and healthcare costs. The presence of zoonotic cestodes within the Indian meat supply chain constitutes a significant, albeit insufficiently addressed, public health concern. An integrated strategy that consolidates veterinary, medical, and environmental sectors is essential. Future initiatives should focus on the deployment of economically viable diagnostic tools, the augmentation of public awareness, and the advancement of research pertaining to vaccines for livestock in order to effectively address this complex challenge.

**Keywords:** Zoonotic cestodes, cysticercosis, hydatidosis, meat inspection

**1. Introduction**

Zoonotic illnesses, which are naturally transferred between vertebrates and humans, threaten worldwide public health, animal welfare, and economic stability. With over 60% of human infections and 75% of new infectious diseases being zoonotic, the importance of the animal-human health interface is underscored (Samad, 2024; Taylor et al., 2001). In low- and middle-income nations like India, where agriculture is a primary industry, the close and frequent contact between humans and domestic animals facilitates easy disease transmission (Samad, 2024). Among these, foodborne parasites, particularly cestodes spread through meat, constitute a major but frequently overlooked public health issue (Divyashri et al., 2024). This paper discusses the three major zoonotic cestodes affecting public health in India: *Taenia solium* (pork tapeworm), *Taenia saginata* (beef tapeworm), and *Echinococcus granulosus* (hydatid worm or dog tapeworm).

The complex life cycles of these parasites intersect with cattle production, environmental sanitation, and human health. By consuming undercooked pork or beef containing larval cysts (cysticerci), humans become the definitive host for *T. solium* and *T. saginata*, leading to intestinal taeniasis (Balodhi et al., 2023). Critically, fecal-oral contamination with *T. solium* eggs can result in cysticercosis, where larvae encyst in human tissues. When these cysts form in the central nervous system, they cause NCC, a prominent cause of adult-onset epilepsy in developing nations such as India (Singh et al., 2013). T. solium infection is prevalent in various parts of the world (Khan et al., 2023) such as Latin American rural communities (Hernández-Chea R et al., 2023), Sub-Saharan Africa, (Barac et al., 2022), Asia (Rajshekhar et al., 2003), and North America and Europe (Laranjo-González et al., 2017)

For *Echinococcus granulosus*, humans act as accidental intermediate hosts by ingesting eggs shed by canid definitive hosts, primarily dogs (Ahmed et al., 2021). This infection leads to cystic echinococcosis (hydatid disease), a condition characterized by large, space-occupying cysts in the liver and lungs that often necessitates complex surgery (Farooque Hassan et al., 2023; Singh et al., 2013). Cystic echinococcosis (CE) is prevalent in India due to environmental factors suitable for the spread of cestodes in both humans and livestock which varies annually from 1-200/100,000 persons (Parija, 2004).

The Indian setting offers a variety of risk factors that help these cestode infections to be persistent and spread in the vast majority of population (Jyothimol & Ravindran, 2015). Many people eat meat, most of which comes from nearby, often uncontrolled markets and slaughterhouses where meat inspection standards may be poor or nonexistent (Prasad et al., 2007). Conventional post-mortem inspection techniques rely on visual identification, which has low sensitivity and usually misses mildly contaminated carcasses, so failing to stop contaminated meat from getting into the food chain (Borkataki et al., 2012; Divyashri et al., 2024). Moreover, socio-cultural behaviors like free-range pig farming in areas with inadequate sanitation directly support the T. solium life cycle (Prasad et al., 2007). Notwithstanding the significant health and financial load—including neurological morbidity, surgical costs, and economic losses resulting from cattle carcass condemnation—a thorough picture of the state of affairs in India is still scattered among several regional studies.

The purpose of this thorough investigation is to compile the present knowledge on the frequency of zoonotic cestodes in meat sold on Indian markets. It will also show their significant effects on public health and the economy as well as assess how well both new and old approaches identify these parasites in humans and animals. This paper will argue for an integrated approach to surveillance and control by spotting important knowledge gaps and high-risk areas, so offering a vital resource for public health authorities, legislators, and researchers.

**2. Major Zoonotic Cestodes Transmitted Through Meat in India**

The most significant zoonotic cestodes found in meat produced in the Indian market include *Taenia solium*, *Taenia saginata*, and *Echinococcus granulosus*. Each species has its own unique life history and distinct health implications by the diseases they cause.

**2.1. *Taenia solium***

*Taenia solium* or the pork tapeworm, parasitize both pigs and men. Humans, upon ingesting raw or undercooked pork containing larval cysts (cysticerci) serve as the definitive host for the adult worm, leading to intestinal taeniasis. A more serious condition called cysticercosis occurs when humans ingest eggs of *T. solium* by fecal-oral contamination from a human tapeworm carrier (Balodhi et al., 2023; Borkataki et al., 2012). These larvae form cysts (bladderworm) (Rabiela, 2000) in the central nervous systems, causing NCC, which is considered the foremost cause of preventable adult-onset epilepsy in India and other endemic regions (Chalipat et al., 2022; Singh et al., 2013). The reason for the transmission of this cestode can be attributed to the strong relationship between free-range pig farming, whose pigs are intermediate hosts, and populations lacking hygiene.

**2.2. *Taenia saginata* (Beef Tapeworm)**

*Taenia saginata* or beef tapeworm, is a digenic cestode where man is the definitive host and cattle and buffalo are the intermediate hosts. It causes intestinal infection (taeniasis) when people consume cysticerci through raw or improperly cooked beef but does not cause cysticercosis (Balodhi et al., 2023). Hence its health impact is less severe compared to *T. solium* (Borkataki et al., 2012).

**2.3. *Echinococcus granulosus* (Hydatid Tapeworm)**

The hydatid tapeworm, *Echinococcus granulosus*, presents a different zoonotic pathway where canids (primarily domestic dogs) are the definitive hosts. Livestock such as sheep, goats, and cattle serve as the principal intermediate hosts (Farooque Hassan et al., 2023). Humans become accidental intermediate hosts by ingesting parasite eggs shed in the feces of infected dogs, not by consuming meat. However, the meat may get contaminated with parasite eggs in the unregulated and unhygienic conditions of the local meat market which is flooded with stray dogs. Consumption of this meat may lead to cystic echinococcosis, also referred to as hydatid disease, which is caused by *Echinococcus granulosus* eggs that hatch in the colon and release larvae. This condition is characterized by the slow, silent growth of large, fluid-filled hydatid cysts in vital organs, most commonly the liver and lungs, which can cause severe organ dysfunction and often require complex surgical intervention (Farooque Hassan et al., 2023; Singh et al., 2013). The major *E. granulosus* genotypes found in India include G1 strain found in sheep and G3 strain found in buffalo (Sharma et al., 2013).

**3. Prevalence in Livestock and Meat from Local Markets/Abattoirs**

The prevalence of zoonotic cestode larvae in livestock and meat sold in India varies significantly, influenced by geographical location, local dietary customs, animal husbandry practices, and the efficacy of meat inspection services. The data from local markets and abattoirs, though fragmented, reveals critical public health insights. The prevalence of zoonotic cestodes, their hosts, mode of infection, disease caused, and their health impacts are discussed in Table 1 below.

**Table 1: Prevalence of zoonotic cestodes, hosts, disease, and their health impact**

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | ***Taenia solium*** (Balodhi et al., 2023) | ***Taenia saginata*** (Balodhi et al., 2023) | ***Echinococcus granulosus*** (Farooque Hassan et al., 2023; Gayathri et al., 2023) |
| **% Prevalence in India** | 11.06% (cysticercosis/taeniasis) | 4.7% (taeniasis) | 15% in cattle; 13% in buffalo; 17% in dogs |
| **Definitive Host** | Human | Human | Dog (domestic); wild canids (feral) |
| **Intermediate Host** | Pig | Cattle | Sheep, cattle, goats, pigs, camels, yaks |
| **Mode of Infection** | Ingestion of undercooked pork or eggs (fecal–oral route) | Ingestion of undercooked beef | Ingestion of eggs from dog feces (contaminated food/water); eating infected offal |
| **Disease Caused** | Taeniasis, Neurocysticercosis | Taeniasis | Cystic Echinococcosis (CE) |
| **Identification Techniques** | MRI, CT scan, serological tests (EITB, ELISA), LAMP test | Stool examination, imaging when symptomatic | Imaging (ultrasound, CT, MRI), serology, postmortem, coproantigen ELISA in dogs |
| **Impact on Human Health** | Seizures, epilepsy, hydrocephalus, headaches; major neurological burden | Mild GI symptoms, weight loss, proglottid passage | Chronic disease with cysts in liver, lungs; can affect brain, bones; surgery often needed |
| **Endemic Regions** | Bihar, Assam, Tamil Nadu, West Bengal | Northern and central India | North East (Assam, Meghalaya, Mizoram), Rajasthan, Bihar |
| **Strategies for Prevention and Control** | Health education, meat inspection, improved sanitation, pig control | Proper cooking of beef, sanitary disposal of human waste | Deworming dogs, hygiene, meat inspection, restricting dog access to offal, vaccination in livestock |
| **Challenges** | Cultural practices, lack of hygiene, poor meat inspection, free-roaming pigs | Low symptom profile, misdiagnosis | Complex dog-livestock-human cycle, underreporting, poor hygiene, lack of surveillance |

**3.1. Porcine Cysticercosis (*Cysticercus cellulosae*)**

The prevalence of *Cysticercus cellulosae* in pork is a direct indicator of the risk of human taeniasis and neurocysticercosis. Certain regions in India, particularly those with substantial pork consumption and traditional free-range pig rearing, are well-documented endemic zones. In northern India, particularly in states such as Uttar Pradesh, community-based studies have shown a significant presence of cysticercosis among both humans and pig populations (26%). Similar studies in and around Chandigarh showed 8-10% of pigs were infected with cysticercus (Prasad et al., 2007). In the North-Eastern states like Assam, where pork is a common part of the diet, there is a notable occurrence of porcine cysticercosis (9.5%) (Borkataki et al., 2012), which poses a considerable public health challenge (Barua et al., 2018; Divyashri et al., 2024). A thorough meta-analysis that brought together data from various regions of the country found that the overall prevalence of *T. solium*-related taeniasis/cysticercosis in India stands at a notable 11.06% (Balodhi et al., 2023).

**3.2. Bovine Cysticercosis (*Cysticercus bovis*)**

Information regarding the occurrence of *Cysticercus bovis* in beef and buffalo meat is relatively limited, indicating that this condition might be overlooked or could actually be less common than porcine cysticercosis. Nevertheless, its presence in Indian livestock is confirmed. Abattoir-based surveillance, while limited, provides concrete evidence of its circulation. For example, a study conducted at a major abattoir in Mumbai documented the presence of *C. bovis* in slaughtered cattle, highlighting the potential risk to beef consumers even in large metropolitan areas (Bengale, 2013). The national meta-analysis estimated the pooled prevalence of *T. saginata*-associated taeniasis at 4.7%, indicating a widespread, if less intensely studied, public health issue (Balodhi et al., 2023).

**3.3. Hydatid Cysts in Intermediate Hosts**

Hydatidosis, caused by *Echinococcus granulosus*, is a widespread zoonosis in India, with prevalence data primarily derived from abattoir surveys of intermediate hosts like sheep, goats, cattle, and buffalo. These studies are crucial as they quantify the parasite reservoir that poses a risk to humans via contamination by dog feces. A key survey in Punjab documented the prevalence of hydatid cysts in various food animals, finding the highest rates in buffaloes, followed by cattle, sheep, and goats (Singh et al., 2013). The high prevalence in these livestock species underscores the considerable economic losses incurred due to organ condemnation at slaughter and points to an active transmission cycle involving domestic dogs. High incidence is described from Tamil Nadu, Andhra Pradesh, Kashmir and many parts of Central India (Akther et al., 2011; Nepalia et al., 2006).

**3.4. Geographical Hotspots and Risk Factors**

The literature clearly delineates specific geographical hotspots for different cestode infections. For *T. solium* cysticercosis, Uttar Pradesh and the North-Eastern states are prominent endemic regions (Divyashri et al., 2024; Prasad et al., 2007). For hydatidosis, pastoral regions with large populations of sheep, goats, and associated canids, such as Punjab, are significant risk areas (Singh et al., 2013). Key risk factors underpinning this prevalence include: husbandry practices (free-range pig rearing), sanitation (poor community sanitation and open defecation), slaughter practices: (lack of stringent, standardized meat inspection), dietary habits (consumption of raw or undercooked pork or beef), host proximity (the close association between domestic dogs and livestock).

**4. Detection Methods for Cestode Larvae in Meat**

The accurate detection of cestode larvae in meat is the cornerstone of preventing human infection. The methods employed in India range from traditional, low-tech inspection to sophisticated laboratory-based assays, with a significant gap between their respective efficacies.

**4.1. Conventional Methods: Ante-mortem and Post-mortem Meat Inspection**

In most local abattoirs across India, the standard practice for detecting cysticercosis relies on conventional ante-mortem and post-mortem inspection. Ante-mortem methods include tongue palpation in live pigs to feel for cysts of *Taenia solium*. Post-mortem inspection involves visual examination and making multiple incisions into key muscle groups, such as the masseters, heart, and diaphragm, to look for visible cysticerci (Borkataki et al., 2012).

However, the primary and most critical limitation of these conventional methods is their notoriously low sensitivity and specificity. For example, in the case of *E. granulosus,* the ELISA technique gives sensitivity from 51.4% to 62.7% and specificities from 95.8% to 99.5%; for EITB, sensitivity ranges between 90% and 97.5% and specificity was at 100%. For nested PCR, the specificity was 100%. By conventional methods, the failure rate for *T. saginata* was as low as 27% and as high as 85% (Alemu et al., 2015). Visual inspection can only detect heavily infected carcasses and frequently misses light infections where cysts are sparse, small, or located deep within the muscle tissue. Consequently, meat that appears safe can still harbor viable larvae, allowing contaminated products to enter the food chain and posing a direct risk to consumers (Borkataki et al., 2012).

**4.2. Modern Laboratory-Based Techniques**

Serological assays offer a powerful ante-mortem tool for screening livestock. Techniques like the enzyme-linked immunosorbent assay (ELISA) can detect either the host's antibody response to the parasite or circulating parasite antigens in the blood. Antigen-detection ELISAs are particularly valuable as they indicate an active, viable infection (Kirmani et al., 2016). The above tests aid in identifying cestode-infested animals in advance as they arrive at the slaughterhouse. This helps in better-quality management and preventing contaminated meat from entering into the food supply chain.

Techniques involving molecular tools are a better option for positive diagnosis as they offer greater accuracy. The most common methods that are used, including PCR, real-time PCR, and LAMP, concentrate on identifying the DNA of the cestode in tissue samples (Bilal & Musa, 2021; Ito & Craig, 2003; Raoul et al., 2013). Studies have shown that the sensitivity of swab-PCR for detecting Taenia (n=68) was 89.8% (95% CI, 77.7–96.6) and 89.5% (66.9–98.7) using methods A and B, respectively (method A: DNA was extracted using alkaline lysis coupled with a commercial DNA isolation kit; method B: alkaline lysis alone). The sensitivity of the swab-LAMP assay was 83.7% (70.3–92.7) using method A and 89.5% (66.9–98.7) with method B (Muchaamba et al., 2021).

Comparative evaluation of the above techniques for cysticercosis revealed that they are excellent diagnostic tools. However, LAMP is a better option since it doesn't require advanced thermal cyclers, making it a cheaper and more adaptable choice for those areas that are short of resources. This technique utilizes multiple primer pairs for specific binding in presence of a DNA polymerase with high strand displacement capability. LAMP has proven its superiority over PCR by specific amplification of target DNA even in the co-presence of non-target sequences while eliminating the need for multiple temperature cycles, lengthy reaction times and sophisticated laboratory settings which are responsible for amplification errors and longer turn-over times (Garg et al., 2022; Notomi et al., 2000; Raoul et al., 2013).

**4.3. Bridging the Gap between Abattoir Actuality and Prospective Diagnostic Tools**

There is a tremendous variation between the diagnostic potential presented in research and actuality, as seen in many local Indian markets. Conventional meat inspection methods are fast and cheaper, but lack sensitivity and specificity, making them inadequate for protecting public health, while modern serological and molecular diagnostic facilities provide the accuracy needed for proper monitoring of meat. However, their broader use in abattoirs is restricted due to heavy expenditure, the need for trained staff, and required laboratory facilities.

This implementation gap highlights the urgent need for developing and validating cost-effective, rapid, and field-deployable diagnostic tests, such as LAMP, to bridge the divide and improve food safety at the local level (Borkataki et al., 2012; Garg et al., 2022; Raoul et al., 2013)

**5. Public Health and Economic Impact in India**

The presence of zoonotic cestodes in the meat supply chain in India translates into a dual burden, inflicting substantial public health consequences and significant economic losses. This impact is felt across the human health, veterinary, and agricultural sectors.

**5.1. Human Taeniasis and Neurocysticercosis**

The most devastating public health impact stems from *Taenia solium*. While intestinal taeniasis acquired from consuming undercooked pork is a concern, the ingestion of *T. solium* eggs leading to NCC is a major cause of preventable adult-onset epilepsy in India and many other developing nations (Balodhi et al., 2023; Singh et al., 2013).

The effect of NCC encompasses not only the affected person and their families but also includes significant medical expenses such as costly diagnostics (neuroimaging), ongoing antiepileptic medication, occasional neurosurgery, loss of income, reduced productivity, and considerable social stigma (Prasad et al., 2007; Singh et al., 2013).

**5.2. Human Cystic Echinococcosis (Hydatidosis)**

Hydatidosis (also known as Cysticechinocosis) is a disease that involves the slow and gradual development of large hydatid cysts. It is a major public health problem that affects important organs, specifically the liver and the lungs. Its occurrence is due to the ingestion of *E. granulosus* eggs, often from dog feces.

The symptoms of infection appear late, usually after many years, when the cysts have enlarged, causing noticeable problems, or are found by chance, and costly surgical operation remains the only treatment options

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**5.3. Financial Damage**

The financial burdens caused by zoonotic tapeworms are intricate and diverse. In the animal husbandry sector, direct losses occur when infected meat carcasses and organs are rejected at slaughterhouses, while indirect damage is due to a decrease in their meat and milk production (Borkataki et al., 2012; Singh et al., 2013). In relation to human health, treating epilepsy over a lifetime, along with the surgery cost for hydatidosis, causes a substantial monetary burden on families and the public health system. This further accelerates in places that are short of resources.

**6. Areas for Future Research and Interventions**

Even though zoonotic cestodes pose a notable public health and economic challenge in India, there are still considerable gaps in our understanding and efforts to manage them. The scattered nature of current data, which depends on localized studies, highlights the pressing need for a cohesive, nationwide approach to monitoring, utilizing consistent diagnostic methods. Monitoring like this is crucial for pinpointing areas where diseases are most common and for grasping the real rates of prevalence (Balodhi et al., 2023).

A unified and integrated framework is essential for controlling diseases caused by zoonotic cestodes as a result of complex intermingling of humans and animals with the environment (Farooque Hassan et al., 2023; Samad, 2024).

It includes disruption of the transmission cycles of parasites (*Taenia* and *Echinococcus*) by bringing about cooperation between medical, veterinary, and environmental health sectors. This change can be brought about by focusing on practical ideas that improve meat inspection and hygiene in slaughterhouses. Conventional inspection methods must be replaced with modern diagnostic tools to improve consumer health (Borkataki et al., 2012). Public health education campaigns to teach the masses regarding the dangers of eating undercooked meat, poor sanitation, and unsafe animal husbandry practices can help them make better decisions regarding their own health and safety (Prasad et al., 2007).

Further research is needed that primarily focuses on creating and using affordable and quick diagnostic tools that are easy to use in the field. LAMP holds great potential for application in resource-limited environments (Raoul et al., 2013). Developing a vaccine against these parasites is the best way to break the life cycle at its source, thus preventing its transmission.

At present, the use of the TSOL18 vaccine for porcine cysticercosis represents a game-changing tool for breaking the *Taenia solium* life cycle (Lightowlers et al., 2016). Regular deworming of domestic and stray dogs, along with education on proper disposal of animal viscera and other wastes, plays an important role in controlling *E. granulosus* to a large extent. An integrated approach that pools together community behavior in relation to sanitation, modern meat testing methods, cutting-edge diagnostic tools, and targeted intervention in life the cycle of parasites can significantly decrease the economic burden of these zoonotic cestodes.

**7. Conclusions**

This review brings together a wealth of evidence showing that zoonotic cestodes, which are spread through meat available in local Indian markets, represent a serious and often overlooked public health concern. The presence of *T. solium*, *T. saginata*, and *Echinococcus granulosus* in livestock poses a continuous risk, leading to serious health issues in humans like neurocysticercosis and hydatidosis. There is a significant disconnect between the clear shortcomings of traditional meat inspection and the promising capabilities of contemporary serological and molecular techniques, which are still not widely adopted in slaughterhouses. This issue enables contaminated meat to repeatedly find its way into our food supply, continuing the cycle of parasites and their harmful effects on health and the economy. To tackle this challenge, we need to urgently embrace a unified approach that brings together comprehensive nationwide monitoring and enhanced hygiene practices in slaughterhouses. Additionally, it's essential that future initiatives focus on creating and implementing affordable diagnostic tools while also emphasizing the importance of public education and a solid political commitment to effective control measures. By embracing a collaborative and multi-faceted approach, India can truly work towards easing the challenges posed by these overlooked zoonotic diseases.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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