Journal of Animal & Plant Sciences, 34(4): 2024, Page: 832-852
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2024.4.0769
REVIEW ARTICLE

RESEARCH PROGRESS ON MAJOR DISEASES OF PIGS AND YAKS ON THE QINGHAI-TIBET PLATEAU: A COMPREHENSIVE REVIEW FROM 1990 TO 2023

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ABSTRACT

The increased prevalence of diseases in Tibetan pigs and yaks has significantly hampered the cultivation industry, leading to substantial socioeconomic losses and adversely affecting both Tibetan pig production and the livelihoods of surrounding nomads. To conduct a comprehensive analysis, relevant articles on epidemics affecting Tibetan pigs and yaks from 1990 to 2023 were collected from five databases: CNKI, Google, PubMed, Science Direct, and Web of Science. The study findings, covering the period 1990 to 2023, revealed that Tibetan pigs faced primarily challenges from the porcine epidemic diarrhea virus (PEDV), Swine flu, *Cysticercus tenuicollis*, diarrheagenic *Escherichia coli* (DEC) and Enterococci. Zoonotic diseases such as Trichinosis, Swine flu, Hepatitis E virus (HEV), *Toxoplasma gondii*, Cystic echinococcosis (CE), and Japanese encephalitis virus were prevalent in the Tibetan pig area. Meanwhile, the yaks experienced severe outbreaks caused by bovine coronavirus (BCoV), bovine rotavirus A (BRVA), *Echinococcus granulosus*, Neosporosis IgM, *Theileria* spp. and *Anaplasma* spp., significantly impacting their quality of life. Primary risk factors for diseases in Tibetan pigs and yaks included age, housing conditions, frequency of deworming and vaccinations, and environmental factors on the plateaus. This review aims to improve regional breeding practices for Tibetan pigs and yaks by addressing these risk factors, thus reducing the prevalence of various diseases in the future. Achieving these objectives will not only elevate the local socioeconomic status, but also establish the Tibetan pig and yak industry as an independent and flourishing sector.

Keywords: Tibetan pigs; Yaks; Epidemics; Zoonotic diseases; Risk factors

Published first online June 22, 2024 Published final August 25, 2024

INTRODUCTION

The Tibetan pig is the exclusive plateau pig breed under conservation in China, with the distinction of being the sole plateau pig species worldwide. Generally, its habitat spans the plateau located between Qinghai and Tibet. Tibetan pig thrives in semiarid and semipastoral alpine regions, flourishing at elevations ranging from 2900 to 4100 meters within forests and valleys (Li *et al.*, 2013; Qi *et al.*, 2021)(Figure. 1).

Among the estimated 300,000 Tibetan pigs, approximately 4,000 purebred animals are distributed in the provinces of Sichuan, Yunnan, Tibet, and Qinghai (Qiu *et al.*, 2019; Qi *et al.*, 2021). The Qinghai-Tibetan plateau is home to more than 14 million yaks, representing more than 90% of the global yak population. Yaks and Tibetan pigs demonstrate resilience in harsh environments characterized by extreme cold, low oxygen levels, intense UV radiation, and limited forage availability. In high-altitude regions, Tibetan nomads, relying on Tibetan pigs and yaks, meet their economic needs, which includes meat and milk for food, hides for leather production, and dung as a fuel source (Bai *et al.*, 2013).

Tibetan pigs, due to their petite stature and moderate concentrations of amino acids in their muscles, are frequently employed as animal models in medical and genetic research. The rearing of Tibetan pigs involves three primary methods: confinement in pens, pastureing in grasslands, or keeping them in proximity to residences (Qi *et al.*, 2021; Zhu *et al.*, 2022). However, the prevention and treatment of certain diseases prove challenging due to the exposure of animals to contaminated food and water in the wild.

Fig. 1: Main distribution of Tibetan pigs in China.

For Tibetan nomads, the raising of Tibetan pigs and yaks serves as a crucial source of income. The central government, through the Fifth Tibetan Labor Symposium in 2010, focused on developing strategic support industries with local characteristics and advantages, progressively advancing agriculture and animal husbandry. This concerted effort has placed the industry as a key area of development in the region. The breeding process for humans can benefit significantly from Tibetan pigs and yaks. However, the emergence of diseases can affect the morbidity, mortality, and productivity of these animals, subsequently affecting the local population. Various factors such as age, housing environment, free range raising practices, types of additional food, frequency of deworming and immunization, weather conditions, and the high-altitude plateau environment contribute to the susceptibility of Tibetan pigs and yaks to illness (Wang *et al*., 2018b; Qi *et al*., 2021; Tang *et al*., 2021). Highly contagious pathogens, such as the porcine epidemic diarrhea virus and the porcine coronavirus, cause severe diarrhea and vomiting, often with a high fatality rate, in breastfeeding piglets and Tibetan pigs. Some diseases, such as swine flu, can reach a prevalence rate of 100% (Liu *et al*., 2014; Qi *et al*., 2021). These not only significantly impact the profitability of the cultivation industry, but also pose a serious threat to public health, particularly in regions where pigs and yaks are raised in Tibet. Zoonotic diseases, with the expansion of the cultivation industry, pose a substantial threat to public safety, and the prevalence of respiratory illnesses has become more widespread and complex in their etiology. The economy and the welfare of animals depend on effective management of diseases. Quick preventive measures are required in the presence of zoonotic diseases to mitigate pathogen hazards both for food safety and public health. This study aims to improve our understanding of the diseases that affect Tibetan pigs and yaks, providing valuable information for disease prevention, scientific reproduction, breeding conservation, and improving disease incidence. Drawing from searches in the databases CNKI, Google, PubMed, Science Direct, and Web of Science, this is the first analysis of the prevalence of major diseases in Tibetan pigs and yaks (1990–2023). The literature search and selection heavily depend on the marking of journal sources to eliminate low-quality literature. Thorough screening uses quantitative metrics such as downloads and citations to gauge the quality of the literature. Relevant material is identified using database filters and keyword search approaches such as "Tibetan pig and diseases," "Yak and diseases" and "Epidemics." The publication year filter is then applied to include works published between 1999 and 2023. Finally, a combination of machine and human screening is used to select pertinent references aligned with research objectives.

Tibetan porcine and yak virus infection

Porcine deltacoronavirus (PDCov): The novel porcine enteropathogenic coronavirus, known as the porcine delta coronavirus (PDCoV), causes severe diarrhoea, vomiting, and respiratory failure in breastfeeding piglets. It belongs to the *Coronaviridae* family, characterized by a single-stranded positive-stranded RNA virus with a capsid(He *et al*., 2020). M. Wang and colleagues conducted the first investigation on Tibetan pigs of the Tibetan Plateau to identify the presence of PDCoV, and it was detected. In 2016, a total of 98 diarrheal samples were collected from Gansu, Qinghai, and Sichuan, followed by an additional 91 samples in 2017. Molecular reverse transcription polymerase chain reaction (RT-PCR) was utilized to identify PDCoV in Tibetan pigs. The study revealed that the prevalence of PDCoV in Tibetan pigs was 3.70%, 27.51% for PEDV and 1.59% for PDCoV and PEDV co-infection (Wang *et al*., 2018b). Studies on the Tibetan plateau should not ignore environmental considerations because arid and chilly conditions can alter pathogen transmission and infection. Furthermore, all the Tibetan pigs infected were piglets under a month old, indicating that PDCoV is also age related. Phylogenetic research shows that the PDCoV found in Tibetan pigs is closely related to the CHN-AH-2004 strain discovered in Anhui Province, China. However, these strains are different, demonstrating that PDCoV evolves and adapts to the host in particular field circumstances (Wang *et al*., 2018b). As a result, those involved in Tibetan pig breeding areas should organize regular and effective vaccination against PDCoV for Tibetan pigs to reduce herd losses caused by the disease and increase Tibetan pig resistance to the disease.

Porcine epidemic diarrhea virus (PEDV): The genus *Coronavirus* and the Coronaviridae family contain the Porcine Epidemic Diarrhea Virus (PEDV). Porcine epidemic diarrhea, as is known, is caused by the virus and results in vomiting, watery diarrhea, and a high mortality rate in piglets (Sun *et al*., 2016). According to a 2018 study, PEDV poses a significant health hazard for Tibetan pigs, with detection rates for Tibetan piglets substantially higher than previously reported. In Ganzi Tibetan Autonomous Prefecture, Sichuan Province, located on the southern tip of the Tibetan Plateau, Qin *et al*. collected 193 feces samples from Tibetan piglets aged 10 to 40 days from 13 farms in four distinct localities. Piglets were raised outdoors and were not immunized against porcine rotavirus (PoRV), porcine embryovirus (PEDV), or porcine delta coronavirus (PDCoV). The 193 collected samples included 129 from piglets with severe diarrhea and 64 from clinically healthy piglets. The results of RT-PCR showed a detection rate of 38.34% for PEDV, and 74 of 193 samples tested positive. In contrast to the 29.69% detection rate in clinically healthy animals, PEDV was discovered in 42.64% of the 129 diarrheal samples. While TGEV and PDCoV were absent from the samples, PoRV was present in 55.96% of them. The samples also exhibited a 35.25% rate of co-infection with PEDV-PoRV. The 13 farms' samples tested positive for PEDV, confirming that PEDV is a leading infection in the area causing diarrhea in Tibetan pigs (Qin *et al*., 2019a). It is possible that the risk of disease is higher in free-ranging Tibetan pigs because they may be more likely to have access to naturally occurring sources of infection. The fact that the feces came from free-ranging Tibetan pigs that had not received a PEDV vaccination suggests that vaccination is crucial for disease prevention. Recent years have seen rapid proliferation and accelerated mutation of PEDV in Tibetan pigs due to frequent travel and trading of Tibetan pigs between the Tibetan Plateau and other regions of China. Through phylogenetic analysis of 10 partial S1 genes from four farms, nine new S genes were discovered in Tibetan pig PEDV as part of a genomic characterization study of PEDV strains. This finding suggests that new PEDV subtypes have circulated and spread in Tibetan pigs, and the harsh environments of these animals may be factors that accelerate microbial evolution and mutation (Qin *et al*., 2019a).

Swine influenza A virus (SIV): Influenza A virus in pigs (SIV) is a zoonotic pathogen, and swine influenza (SF) is the most prevalent infectious disease caused by SIV in pigs. The virus induces symptoms such as fever, coughing, sneezing, lethargy, respiratory problems, and appetite loss, with a low mortality rate but a high morbidity rate (Pyo *et al*., 2015). In addition to posing a serious threat to public health in modern civilization, the swine influenza A virus (SIV) also imposes a significant economic burden on the agricultural sector. In Tibet, China, between April and December 2010, Liu *et al*. (2014) collected 421 blood samples from Tibetan pigs. After centrifugation, all serum samples were examined using commercially available ELISA kits to detect the presence of anti-H1N1 and anti-H3N3 antibodies. The results revealed that 37 samples tested positive for both H1N1 and H3N2, with a positivity rate of 8.8%. Furthermore, 71 samples were tested positive for H3N2, with a prevalence rate of 16.9%, and 219 samples were screened positive for H1N1, with a positivity rate of 52%. Among various species of pigs, piglets (66.7%), slaughter pigs (66.4%), breeding pigs (50%), and breeding pigs

(100%) exhibited the highest H1N1 seropositivity. Pigs raised for breeding had the highest seropositivity for H3N2, followed by pigs raised for slaughter (23.6%), fattening pigs (20.2%) and piglets (13%). Pigs raised for breeding also had the highest seropositivity for H1N1 and H3N2, followed by piglets (11.6%), slaughter pigs (10.9%) and fattening pigs (9.6%). H1N1 is more likely than H3N2 to infect Tibetan pigs, and both positive rates are sufficient to conclude the prevalence of swine influenza. Despite the high prevalence of SIV, sows frequently receive SIV vaccinations, which can prevent pigs from being infected (Li and Robertson, 2021b).

Hepatitis E virus (HEV): A zoonotic pathogen, the Hepatitis E virus (HEV) is a single-stranded RNA virus that most frequently spreads from animal hosts to humans through interspecies contact (Sayed *et al*., 2022). There is a significant risk of zoonotic transmission of HEV between humans and Tibetan pigs when HEV is present, highly associated with diarrhea in Tibetan pigs.

Between July 2014 and August 2015, Zhang *et al*. (2017b) collected serum samples from 600 community volunteers and 453 Tibetan pigs, conducting an enzyme-linked immunosorbent test to detect the presence of HEV IgG antibodies in all samples (ELISA). According to the inquiry study, both local HEV infection and hepatitis E were present in the Tibetan community. The HEV IgG antibody was found in 39.33% (236/600) of the local population and 42.38% (192/453) of the Tibetan pig population. This study, for the first time, describes the high prevalence of Hepatitis E in native Tibetan populations and Tibetan pigs, suggesting that porcine HEV can infect humans, other animals, and the environment. It also implies that various factors and appropriate preventive measures should be taken to reduce the disease epidemic. Zhang *et al*. (2018) obtained 253 samples of Tibetan pig bile from several slaughterhouses during 2017 and 2018, using RT-nPCR to find HEV RNA. The results showed that HEV-4 can infect humans and animals in 11 of 253 samples (4.35%), and is endemic in the Tibetan region. HEV infection in Tibetan pig herds is becoming a public health concern. In Ganzi Tibetan Autonomous Prefecture, Sichuan Province, on the southern border of the Tibetan Plateau, Zhou *et al*. (2019b) collected 229 fecal samples from Tibetan pigs (age, 4 months), 145 from Tibetan piglets with severe diarrhea and 84 from clinically healthy piglets. 38 out of 229 fecal samples (16.59%) tested positive for HEV RNA using RT-nPCR. HEV was found in 24.14% (35/145) of diarrheal samples and 3.57% (3/84) of clinically healthy Tibetan pigs, suggesting a possible association between HEV and diarrhea in Tibetan pigs.

To detect HEV IgM and IgG antibodies and conduct a HEV RNA experiment, Wang *et al*. (Wang, 2018d) collected serum from Tibetan pigs in five locations in Tibet, China. The findings show differences in HEV prevalence trends in each of the five regions, with pig samples positive for anti-HEV IgM antibodies up to 7.6%, anti-HEV IgG antibodies up to 1.8%, and HEV RNA up to 7.6%. The reverse transcription set polymerase chain reaction (RT-nPCR) was used in 2018–2019. Boars may have a higher incidence than piglets, and vice versa. It is possible for HEV to spread when Tibetan pigs come into contact with contaminated food and water due to structural flaws in housing or enclosures and the high prevalence of HEV positivity in Tibetan pigs (Zhang *et al*., 2018). Furthermore, studies have indicated that raw contaminated pork products can increase the risk of contracting HEV and that the preference of certain locals for eating raw meat can enhance the transmission between species of HEV from pigs to people (Zhang *et al*., 2017b).

Porcine reproductive and respiratory syndrome virus (PRRS): The Porcine Reproductive and Respiratory Syndrome virus (PRRSV), a single-strand positive-strand RNA virus with a capsid, impacts the reproductive systems of pigs and causes respiratory symptoms. It belongs to the *Arteriviridae* family. Compared to the earlier Porcine Reproductive and Respiratory Syndrome (PRRS), the Highly Pathogenic Porcine Reproductive and Respiratory Syndrome Virus (HP-PRRSV) causes more severe clinical symptoms, including anorexia, lethargy, respiratory distress, and diarrhea. This infection significantly impacts the global agriculture industry (Han *et al*., 2014). To assess host susceptibility among three pig breeds: Tibetan pigs, Tibetan plum pigs, and large white pigs (with Tibetan plum pigs being a registered breed resulting from a cross between Tibetan pigs and Meishan pigs). Kang *et al*. (2016) conducted experiments using HP-PRRSV. Although Tibetan pigs did not exhibit typical clinical signs such as coughing, diarrhea, and fever, they showed significant hypo and brief viremia. Histological analysis of lung sections showed mild to moderate interstitial pneumonia between 7 and 14 days after infection. Tibetan pigs were less affected by the virus compared to the other two breeds. This suggests that Tibetan pigs may possess specific resistance or tolerance characteristics of the disease, as well as mechanisms to prevent virus replication. Such insights can aid researchers in developing more effective plans to prevent and manage porcine blue ear disease in various breeds of pigs.

In 2016, Fan *et al*. (Fan *et al*., 2016) demonstrated that Tibetan pigs are highly susceptible to HP-PRRSV strains. The HP-PRRSV BB0907 strain caused high mortality and severe lung pathological lesions in Tibetan pigs, and a severe cytokine-release syndrome also appeared in Tibetan pigs infected with HP-PRRSV. The results highlight the significant morbidity and mortality rate of HP-PRRSV in Tibetan pig herds, highlighting the importance of studying and controlling PRRSV infection in highland environments. Although there is currently no better alternative in the case of a PRRSV pandemic and more comprehensive preventive measures are needed to avoid HPRSV, the use of the PRRSV vaccine remains problematic and clinically inefficient or insignificant (Guo *et al*., 2018 ; Zhou and Yang, 2010).

Porcine Circumvirus (PCV):The genus *Circovirus* and the family *Circoviridae* encompass the porcine circovirus (PCV), one of the smallest known animal viruses. Pigs have been observed to develop PCV3 (type 3 porcine circulcovirus) and it is found in pigs with digestive or respiratory disorders (Sun *et al*., 2018). Between June 2018 and December 2019, Pan *et al*. (Pan *et al*., 2022) used 316 diarrheal Tibetan pigs and 182 clinically healthy Tibetan pigs randomly selected from 56 farms in three separate provinces (Gansu, Sichuan, and Qinghai) on the Tibetan plateau. The pigs were all between 4 and 12 weeks of age. The prevalence of PCV3 was 23.42% at the sample level, 27.59% at the farm level, and 7.69% at the farm level in Tibetan pigs with diarrhea. The results indicated that the prevalence of PCV3 was significantly higher in samples from pigs with diarrhea compared to those without, and the incidence of PCV3 positive was notably higher in Gansu Province than in Sichuan and Qinghai Provinces. The incidence of PCV2 in different populations of pigs across the country was approximately 53%, and other breeds had a higher prevalence of PCV2. Tibetan pigs exhibit a higher incidence of PCV3 but a lower prevalence of PCV2. This may be attributed to the fact that Tibetan pigs are tolerant of the climate of the plateau and engage in free-range activities. Furthermore, there is no cross-immunity protection between PCV-2 and PCV-3, and the PCV-2 vaccine proves ineffective in preventing PCV-3 infection (Woźniak *et al*., 2019). Therefore, Tibetan breeders should implement early disease prevention and adopt an integrated approach to disease prevention and management.

Pseudo-rabies virus (PRV): The genus Porcine Herpesvirus and the Herpesviridae family encompass the pseudorabies virus (PRV), which causes acute infectious pig disease known as pseudorabies (PRV). Clinical symptoms include evident neurological symptoms in affected pigs, vomiting, diarrhea, and aborted or stillborn/mummified neonates in pregnant sows, depending on the virus's virulence and the severity of the infection (Pomeranz *et al*., 2005). This disease, classified as a Category II animal sickness in China, is widespread and common, resulting in significant financial losses for the agriculture industry. In 2015, Wu *et al*. (Wu *et al*., 2018a) collected 368 blood samples from unvaccinated Tibetan pigs (214 from large farms and 154 from free-range Tibetan pigs). The sera were separated for the detection of porcine pseudorabies virus IgG antibodies using ELISA kits. The results indicated an overall positive detection rate for PRV in Tibetan pigs of 15.76% in large farms. Specifically, there was an overall positive detection rate of 15.76% for pseudorabies virus in Tibetan pigs, a 16.36% positive rate for pseudorabies antibody, and a 14.94% positive rate for pseudorabies virus in serum. The investigation supported the impact of the pseudorabies virus on Tibetan pigs. In contrast, the detection rate of PRV positive pigs in semi-pastoral and semi-agricultural alpine regions such as Tibet and Qinghai ranged from 10.1% to 20%; Tibetan pigs exhibit a higher PRV infection rate. Factors such as the feeding schedule, season, breed of the pig, and grazing behaviors can contribute to the high prevalence of PRV despite improved husbandry, management and comprehensive vaccination. The prevalence of the disease is significantly reduced by routine immunization, pen sanitation, and other preventive and control measures (Tan *et al*., 2021). The data presented in Table 1 unequivocally demonstrate that the Tibetan Chinese pig herd is currently at risk of viral infection. Relevant personnel should perform routine quarantine work, prioritize the prevention and management of Tibetan pig disease, and administer vaccinations promptly to avert any epidemic risks.

Other viruses: Several reports of epidemics have been documented in Tibetan pigs, in addition to the viruses mentioned above (see Table 1). Furthermore, Table 2 provides an overview of the prevalence of common viral infections in yaks, including bovine rotavirus A (BRVA) and bovine viral diarrhea virus (BVDV).

Japanese B encephalitis, caused by the B encephalitis virus, is one such viral infection. This virus, which belongs to the *Flaviviridae* family, is a single-strand positive RNA virus mainly transmitted through zoonotic interactions between water fowl, pigs, and mosquitoes (Misra and Kalita, 2010). In 2009, Li *et al*. (Li *et al*., 2011) detected Japanese encephalitis by PCR in 22 (33.3%) of the 66 serum samples collected from Tibetan piglets. A PCR investigation conducted by Zhang *et al*. in 2017 (Zhang *et al*., 2017a) in 102 samples of pig serum from Tibetan regions revealed a seropositivity rate of 6.86% for Japanese encephalitis in Tibetan pigs overall.

Classical Swine fever (CSF), classified as a class I animal disease, is characterized by severe contact infection and fever, caused by the Classical Swine fever virus in pigs (Paton and Greiser-Wilke, 2003). Between 2014 and 2015, Li *et al*. (Li *et al*., 2018a) collected 454 cerebral fluid samples from Tibetan pigs in the Linzhi district of Tibet, 241 (53.1% of them) confirmed positive by ELISA. The course of swine fever has recently changed from acute to chronic, with a substantially lower incidence (Zhou *et al*., 2019a). In the microvirus family, PARV4, a single-stranded DNA virus that can infect humans (Matthews *et al*., 2014), is noteworthy. In the

Chinese regions of Gansu and Qinghai, Pan *et al*. (Pan *et al*., 2019) used PCR to obtain blood samples from 281 domestic pigs and 181 Tibetan pigs. The findings revealed that P-PARV4 was prevalent in both domestic pigs and Tibetan pigs, with prevalence rates of 15.59% and 9.38%, respectively. Among Tibetan pigs, the prevalence was 9.38%, 14.28% in Gansu province and 4.44% in Qinghai province.

Foot and mouth disease (FMD), an extremely contagious and acute disease, affects more than 70 species of animals, mainly affecting large domestic animals such as pigs, cattle, sheep, and other even-hoofed domestic and wild animals. FMD has long-term negative effects on animal production and health due to its contagious nature and its ability to cause persistent infection (Knowles and Samuel, 2003). Compared to long-white pigs, Tibetan pigs exhibit a higher count of immune cells and a higher level of humoral immune response. Moreover, in recent years, there has been a growing interest in numerous newly emerging viral diseases, due to extensive research and investigation efforts. Chen successfully identified a previously unknown Astrovirus (AstV) strain associated with diarrhea in yaks. Elevated levels of AstV were notably observed exclusively in samples collected from yaks experiencing diarrhea, in contrast to those obtained from healthy counterparts. This finding strongly suggests a potential link between AstV and the clinical manifestation of yak diarrhea (Chen *et al*., 2015).

In their groundbreaking study, Z. Guo and colleagues successfully detected Noroviruses (NeVs) in yaks for the first time and characterized an exceptional NeVs strain by analyzing its entire genome. The VP1 protein of the strains YAK / NRG-17 / 17 / CH and YAK / HY1-2 / 18 / CH exhibited a new genotype of VP, specifically genotype 3, as previously reported (Guo *et al*., 2019). On the Qinghai-Tibetan plateau, He *et al*. (He *et al*., 2017) made a significant finding by identifying a previously unknown enterovirus (EV) strain in a yak exhibiting severe diarrhea, subsequently designated SWUN-AB001. Furthermore, a plausible association was established between EV and the manifestation of diarrhea in yaks. He *et al*. (He *et al*., 2019) examined samples from yaks experiencing diarrhea and identified several genetic variations in strain YAK/HY24/CH/2017. Specifically, a total of seven distinct amino acid variations (N359Y, A380T, G384R, G400R, C938S, F1032I, and V1100D) and three unique amino acid variations (P501A, T540I, and T544A) were detected in the S gene of this strain. In particular, these variations may play a crucial role in facilitating the adaptation of bovine coronavirus (BcoV) to infect yaks as potential hosts.

Parasitic infection in Tibetan pigs and yaks

Echinococcus granulosus (E. granulosus): Dogs serve as the final host for the zoonotic disease echinococcosis, parasitizing the small intestine. Afflicted animals exhibit complex clinical signs, including appetite reduction, weight loss, and wasting (Ito *et al*., 2003). From December 2014 to February 2015, Li *et al*. (2017b) collected 454 sera from Tibetan pigs in the Linzhi area and tested them using ELISA kits. They achieved a detection rate of 7.27% for *Echinococcus granulosus* in 33 of the 454 sera examined. Phylogenetic and sequencing analyzes by Li *et al*. in 2014–2015 identified the genotypes of 373 Tibetan pigs (Li *et al*., 2017c). Of these, 9.9% were positive for *Echinococcus granulosus*, with the prevalence of Tibetan pigs in 2014 and 2015 being 7.9% and 13.0%, respectively. The prevalence of *Echinococcus granulosus* infection in Tibetan pigs ranged from 5.8% to 12.3% according to season. The results showed that 4.4% to 15.9% of Tibetan pigs in various growth stages had parasitic infections. Tibetan pigs exhibited a higher prevalence of fine-grained *Echinococcus* tapeworm, potentially influenced by the area's climate characterized by lower temperatures and more precipitation.

The open grazing practices of Tibetan pig herds on the plateau increase the probability that dog feces come into contact with herds, thus increasing the risk of parasite infection, a factor closely associated with Tibetan pig grazing practices (Li *et al*., 2017b).

Cysticercus tenuicollis: Adult worms reside in the small intestine of dogs, while Hydatigera taeniaformis larvae, commonly known as 'water bells', or *Cysticercus tenuicollis*, can cause wasting and reduced appetite in large numbers. In 2014, Luo *et al*. (2017) conducted a study collecting 112 samples from Tibetan pigs at various slaughterhouses in the Tibetan region. The following year, they gathered 86 samples from the same locations. Overall, a positive rate of 43.93% for *Cysticercus tenuicollis* was discovered in Tibetan pigs, with detection rates of 42.86% in 2014 and 45.35% in 2015. The percentages of male and female pigs were 44.56% and 43.93%, respectively. Parasitization rates ranged from 30.20% to 63.79% in different stages of development of Tibetan pigs. The high prevalence of *Cysticercus tenuicollis* in Tibetan pigs underscores the importance of regular deworming treatments and avoiding feeding Tibetan pig offal to dogs. The elevated prevalence of cysticercosis in Tibetan pigs may be associated with the varying degrees of expertise of the breeders, the ecological environment, the free-range model, and the presence of wild canines. Two key factors contribute to the high prevalence of parasitic disorders: the unique free-range model exposing animals to more microorganisms in the external environment and some breeders not employing antiparasitic drugs in a scientifically and logically sound manner (Luo *et al*., 2017).

Table 1: Number and percentage of samples tested positive for different viruses in Tibetan pigs..

Virus	Breeds	No. Samples	Regions	Methods	Years	Positive rate, %	References
Porcine deltacoronavirus(PDCov)	Tibetan pig	189	Gansu, Qinghai and Sichuan Provinces, China	RT-PCR	2016-2017	3.7	(Wang *et al*., 2018b)
Porcine epidemic diarrhea virus (PEDV)	Tibetan pig	193	Sichuan Province, China	RT-PCR	2018	38.34(74/129)	(Qin *et al*., 2019a)
Swine influenza A virus (SIV) H1	Tibetan pig	421	Tibet, China	ELISA	2010	52(219/421)	(Liu *et al*., 2014)
Swine influenza A virus (SIV) H3	Tibetan pig	421	Tibet, China	ELISA	2010	16.9(71/421)	(Liu *et al*., 2014)
Hepatitis E virus (HEV)	Tibetan pig	146	Sichuan Province, China	ELISA	2018-2019	10.58	(Zhou *et al*., 2021)
	Tibetan pig	453	Tibet, China	Double antibody sandwich ELISA	2014-2015	42.38(192/453)	(Zhang *et al*., 2017b)
	Tibetan pig	253	Tibet, China	RT-PCR	2017-2018	4.35(11/253)	(Zhang *et al*., 2018)
	Tibetan pig	229	Sichuan Province, China	RT-PCR	2018	16.59(38/229)	(Zhou *et al*., 2019b)
	Tibetan pig	340	Tibet, China	RT-PCR	2018	7.6(26/340)	(Wang, 2018d)
Porcine Reproductive and Respiratory Syndrome (PRRS).	Tibetan pig	-	Sichuan Province, China	Toxic attack test	2016	-	(Kang *et al*., 2016)
	Tibetan pig	15	Qinghai Province, China	Toxic attack test	2016	-	(Fan *et al*., 2016)
Porcine circovirus (PCV) Ⅲ.	Tibetan pig	498	Gansu, Qinghai and Sichuan Provinces, China	PCR	2018-2019	17.68(88/498)	(Pan *et al*., 2022)
Pseudorabies virus (PRV)	Tibetan pig	368	Tibet, China	ELISA	2015	15.76	(Wu *et al*., 2018a)
Japanese encephalitis virus (JEV)	Tibetan pig	66	Tibet, China	PCR	2009	33.3(22/66)	(Li *et al*., 2011)
	Tibetan pig	102	Tibet, China	PCR	2017	6.86	(Zhang *et al*., 2017a)
Classical Swine fever virus (CSFV)	Tibetan pig	454	Tibet, China	ELISA	2014-2015	53.1(242/454)	(Li *et al*., 2018a)
PARV4	Tibetan pig	181	Gansu and Qinghai Provinces, China	PCR	2016-2017	9.38	(Pan *et al*., 2019)

Table 2: Number and percent of samples tested positive for various viruses in Yaks.

Virus	Breeds	No. Samples	Regions	Methods	Years	Positive rate, %	References
Bovine viral diarrhea virus (BVDV)	Yaks	549	Qinghai and Tibet, China	ELISA	2011	60.84	(Gao *et al*., 2013)
	Yaks	1584	Gansu province, China	ELISA	2013-2014	37.56	(Ma *et al*., 2016)
Neboviruses (NeVs)	Yaks	354	Qinghai-Tibet Plateau, China	RT–PCR	2018	22	(Guo *et al*., 2019)
Bovine Herpesvirus 1 (BoHV-1)	Yaks	1840	Qinghai-Tibetan Plateau, China	ELISA	2011-2012	37.93	(Han *et al*., 2016)
Enterovirus (EV)	Yaks	235	Qinghai-Tibetan Plateau, China	RT-PCR	2014	31.05	(He *et al*., 2017)
Bovine coronavirus (BCoV)	Yaks	336	Qinghai-Tibet Plateau, China	RT-PCR	2015-2017	69.05	(He *et al*., 2019)
The bluetongue (BT)	Yaks	736	Tibet and Hongyuan area of Sichuan Province, China	ELISA	2012-2013	3.53	(Li *et al*., 2015)
	Yaks	1584	Qinghai-Tibet Plateau, China	ELISA	2013-2014	13.3	(Ma *et al*., 2017b)
Bovine ephemeral fever virus (BEFV)	Yaks	1123	Qinghai-Tibet Plateau, China	ELISA	2012-2015	40.4	(Liu *et al*., 2017a)
Chuzan Virus	Yaks	208	Qinghai and Gansu province, China	RT-PCR	2016-2017	2.4	(Wang *et al*., 2018a)
Bovine Rotavirus A (BRVA)	Yaks	541	Qinghai-Tibet Plateau, China	RT-PCR	2015-2018	73.6	(Yan *et al*., 2020)

Enterocytozoon bieneusi: There are currently five genera of eukaryotic organisms known as microsporidia that affect humans. These microsporidia belong to the phylum *Microsporum* and the order *Microsporidia*. *Enterocytozoon bieneusi* (*E. bieneusi*), a common intestinal protozoan that infects humans and various animals, typically presents with diarrhoea as the most prevalent clinical symptom. In a study conducted from June to October 2017, Luo *et al*. (2019) collected 266 fresh fecal samples from Tibetan pigs in Ya'an, Sichuan Province. PCR analysis revealed a positive result of 36.73% (83/266) for *E. bieneusi,* with a prevalence rate of 17.7% for male Tibetan pigs and 13.5% for females. Zou *et al*. (2019) collected 345 fecal samples from three counties in the Tibetan region in February and March 2017, detecting a prevalence rate of 11.88% (41/345) of *E. bieneusi* through PCR analysis. In 2021, Chen *et al*. (2022) collected 60 fecal samples from Tibetan pigs on the Tibetan plateau, finding a 56.7% positive rate for *E. bieneusi* by PCR. Furthermore, there is a lack of research on risk factors associated with *E. bieneusi* infection and transmission, contributing to the high infection rate (Wang *et al*., 2018c). *Enterocytozoon bieneusi* appears to be rare in Tibetan pigs, likely due to environmental variables associated with highland climates. The age and condition of the host animal, geoecological circumstances, feeding/herd density, herd management, sample size, and other factors can also influence infection levels (Luo *et al*., 2019).

Giardia duodenalis: A zoonotic parasite called *Giardia duodenalis* poses health risks to both humans and animals, causing financial losses in the animal husbandry industry. Zou *et al*. (2019) discovered Giardia duodenalis in 0.58% (2/345) of fecal specimens collected in February and March 2017 from three counties in the Tibetan region. This flagellated parasite is a common intestinal pathogenic protozoan that can be transmitted by fecal oral contamination, leading to infections with clinical symptoms such as diarrhea, weight loss, and malabsorption (Adam, 2021). *Giardia duodenalis* infection appears to be less common in Tibetan pigs, potentially influenced by variables such as species, feeding regimen, animal husbandry methods, and geographic ecology. The identification of zoonotic genotypes of *Enterocytozoon bieneusi* and *Giardia duodenalis* in Tibetan pigs raises concerns about potential environmental contamination, emphasizing the need for efficient pathogen prevention efforts in the Tibetan region.

Toxoplasma gondii: *Toxoplasma gondii*, an intracellular parasite, spreads through the bloodstream by residing within cells and utilizes intermediate hosts such as humans and end hosts such as cats for its life cycle. Strong acute inflammatory reactions caused by invasion of *Toxoplasma gondii* organs pose a significant threat to pig health, making pigs a major source of infection among farm animals in China (Dubey *et al*., 2020). Wu *et al*. (2012) found a prevalence of 22.72% (97/427) of *Toxoplasma gondii* infection in Tibet, China, after analyzing 427 fecal samples. Research indicates that *Toxoplasma gondii* can survive longer in warm, humid environments and is more prevalent in Tibetan pigs (Dubey, 1998). Despite the low annual average temperature in the Linzhi region, Tibetan pigs are typically raised outdoors, exposing them to cats and rodents, increasing their risk of contracting pathogens. Free-ranging Tibetan pigs are also more likely to consume contaminated food or water, contributing to the higher prevalence of toxoplasmosis (Wu *et al*., 2012).

***Cryptosporidium* spp.** *Cryptosporidium* spp., a parasitic coccidian belonging to the *Cryptosporidaceae* family, undergoes five developmental stages, including trophozoite, schizonts, gametophyte, conidia, and oocyst - the latter being the infective stage. Diarrhea, induced by this zoonotic protozoan, is the most common clinical symptom (Feng and Xiao, 2017). Zheng *et al*. (2019) conducted microscopy and PCR testing on 614 fecal samples collected in Tibet between March and June 2016, revealing a *Cryptosporidium* detection rate of 0.49% (3/614) in Tibetan pigs, with the infected pigs aged between one and two months. Chen *et al*. (2022) collected 60 fecal samples from Tibetan pigs on the Tibetan plateau in 2021, detecting *Cryptosporidium* by PCR with an prevalence of 18.3%.

Pigs are more susceptible to the *Cryptosporidium* porcine genotype II than piglets and may serve as a source of zoonotic *Cryptosporidium* water contamination. To prevent possible public health problems, improving pig feeding procedures, effluent outflow, manure disposal, and field worker protection is essential (Yin *et al*., 2013). Tibetan pigs exhibit a considerably lower rate of *Cryptosporidium* infection due to their environment, since oocysts have a higher survival rate in warm, humid conditions and a lower survival rate in cold, dry environments. Furthermore, although microscopic examination is cost-effective, it is less sensitive and can misidentify parasite oocysts as other microorganisms (Wang *et al*., 2021a).

Trichinella spiralis: Trichinosis, a zoonotic disease caused by *Trichinella spiralis* larvae that infect muscle fibers, is primarily spread through food consumption (Taratuto and Venturiello, 1997). Li *et al*. (2021a) conducted an ELISA analysis on 41 serum samples from wild Tibetan pigs in Gansu in 2021, revealing a positive detection rate of 43.9% (18/41) for *T. spiralis.* The study indicates that *Trichinella* infection is prevalent in Tibetan pigs, often transmitted through litter (eg, feeding pigs with slop containing raw pork residues). Pigs in rural and mountainous areas of central and southern China, especially those reared on small farms near cities, are susceptible to infection due to exposure to rats and wildlife, feeding on raw animal excrement or carcasses, and inadequate deworming efforts. Unique free-ranging methods used by Tibetan pigs may increase the likelihood of *Trichinella* contraction, driven by factors such as inadequate deworming, increased exposure to parasites, and higher infection risk due to the numerous intermediate hosts (Murrell, 2016).

Other parasites: The parasitic infections of Tibetan pigs are detailed in Table 3. In addition to the parasitic infections mentioned above, *Oesophagostomum* spp., commonly known as nodular worms, are zoonotic nematodes, and recent studies by Li *et al*. (2017a) revealed a high prevalence of these parasites, particularly *O. dentatum*, in Tibetan pigs. The prevalence reached approximately 66.04%, and *O. dentatum* infection reached 81.13%, affecting both public health and the Tibetan pig industry.

Blastocystis sp., an anaerobic intestinal parasite that affects humans and various animal species, can be transmitted through a fecaloral pathway, as demonstrated by Chen *et al*. (2022), who found an 18.3% positivity rate in Tibetan pigs on the Tibetan plateau in 2021. Our findings in Table 3 highlight the prevalence of gastrointestinal parasites in Tibetan pigs in Tibetan regions, highlighting their susceptibility to parasites during breeding. Most Tibetan pigs are raised in challenging conditions, contributing to a high parasite load. Regular infections checks, proper cleaning and disinfection, deworming, and improved management of pig feed are crucial to reducing parasite infection rates and preventing financial losses.

For the parasitic infection of yaks, Li and Jiang *et al*. (2018b) utilized high-throughput sequencing to examine parasitic diversity in three groups of yaks in the Gannan Tibetan Autonomous Prefecture. The study revealed changes in parasitic diversity among healthy adult yaks, adult yaks with diarrhea, and diarrhea-affected yak calves. The prevalence rates of various parasitic infections in yaks were documented by Li *et al*. (2018c), including *Eimeria* (48.02%), *Babesia* (13.06%), *Theileria* (36.11%), *Hypodermosis* (59.85%), Cystic echinococcosis (16.93%), Alveolar echinococcosis (0.99%), *Toxoplasma gondii* (20.50%), *Neospora caninum* (5.14%), *Cryptosporidium* (10.00%), *Giardia duodenalis* (3.68%), *Enterocytozoon bieneusi* (4.07%), *Toxocara vitulorum* (22.23%), and Fascioliasis (28.7%). Qin *et al*. (2019b) detected seasonal variations in parasitic infections in yaks, with *Strongylidae*, *Trichuris* spp., and *Eimeria* spp. consistently present throughout the year. Strongyloides papillosus was identified only during fall and summer, *Nematodirus* spp. in both fall and spring, and *Fasciola* spp. exclusively during spring. Yaks also exhibit a high prevalence of Neosporosis and *Echinococcus granulosus*, as observed in their study. In addition to the parasitic infections mentioned above in yaks, other parasitic diseases in yaks are listed in Table 4.

Bacterial infections in Tibetan pigs and yaks

Escherichia coli: Gibberella *enterotoxigenic Escherichia coli* (ETEC), a gram-negative member of the *Enterobacteriaceae* family, has the ability to produce enterotoxins that cause fluid release and adhesions that facilitate adherence to specific enterocyte receptors for intestinal colonization (Dubreuil *et al*., 2016). In pigs, *E. coli* can induce diarrhea, with yellow and white diarrhea in piglets being the most common manifestations. This acute, highly pathogenic intestinal infectious disease presents as severe yellow or yellow-white watery diarrhea, often resulting in substantial morbidity and mortality (Kim *et al*., 2022). Ruminants, particularly cattle, are significant reservoirs for *Escherichia coli* (STEC) that produces Shiga toxin. The prevalence of STEC in beef cattle varies widely, with reported ranges of 0.2% to 27.8% for O157 STEC and 2.1% to 70.1% for non-O157 STEC (Bai *et al*., 2013). In a study aiming to evaluate the impact of enterotoxin-producing *E. coli* on intestinal development of Tibetan piglets and identify the dominant phylum and family of bacteria in Tibetan piglets, Qi *et al*. collected 18 samples of piglet diarrhea of various ages in 2021. Pathological alterations induced by *E. coli* in the intestines of piglets with yellow diarrhea include intestinal epithelial cell destruction, inflammatory cell infiltration, interstitial red blood cell presence, intestinal villus hemorrhage, and necrosis (Qi *et al*., 2021). Li *et al*. (2014b) collected 232 fecal samples from Tibetan pigs aged 6 to 12 months between June and October 2012, revealing a 55.6% isolation rate of 129 *E. coli* bacteria. Effective diarrhea treatment in pigs involves preventing the growth of harmful bacteria in the digestive tract. Tibetan pigs, due to factors such as advanced age or high levels of lactic acid bacteria, exhibit a higher prevalence of *E. coli* compared to other breeds.

Enterococci: Gram-positive parthenogenic anaerobic bacteria exhibiting a spherical shape are collectively known as *Enterococcus* spp. (Radhouani *et al*., 2014). Among *enterococci*, *Enterococcus faecium* and *Enterococcus faecalis* are the primary pathogenic species. *Enterococcus faecalis* accounts for 85~90% of enterococcal infections, while *Enterococcus faecium* contributes to 5~10% (Shiadeh *et al*., 2019). In a study conducted by Li *et al*. (2014b), 232 fecal samples were collected from Tibetan pigs aged 6 to 12 months between June and October. With a 36.2% isolation rate, they identified 84 different *strains of Enterococcus.* Among these, 53.6% (45/84) were *Enterococcus faecium* and 36.9% (31/84) were *Enterococcus faecalis. Enterococcus faecium* and *Enterococcus faecalis* are highly prevalent in Tibetan pigs. Unlike animals from other intensive farms, Tibetan pigs have a free-range lifestyle, which may have

Table 3: Positive test rates for different species of parasites in Tibetan pigs.

Parasites	Breeds	No. Samples	Positive rate, %	Methods	Regions	Years	References
Echinococcus granulosus (E. granulosus)	Tibetan pig	454	7.27(33/454)	ELISA	Linzhi, China	2014-2015	(Li *et al.*, 2017b)
	Tibetan pig	373	9.9	Sequence and phylogenetic analysis	Tibet, China	2014-2015	(Li *et al.*, 2017c)
Cysticercus tenuicollis	Tibetan pig	198	43.93	PCR	Tibet, China	2014-2015	(Luo *et al.*, 2017)
Enterocytozoon bieneusi	Tibetan pig	266	36.73 (83/266)	PCR	Sichuan Province, China	2017	(Luo *et al.*, 2019)
	Tibetan pig	345	11.88 (41/345)	PCR	Tibet, China	2017	(Zou *et al.*, 2019)
Giardia duodenalis	Tibetan pig	345	0.58 (2/345)	PCR	Tibet, China	2017	(Zou *et al.*, 2019)
Toxoplasma gondii	Tibetan pig	427	22.72(97/427)	MAT	Linzhi, China	2010	(Wu *et al.*, 2012)
Cryptosporidium spp.	Tibetan pig	614	0.49 (3/614)	Microscopic methods and PCR	Tibet, China	2016	(Zheng *et al.*, 2019)
	Tibetan pig	41	43.9 (18/41)	ELISA	Gansu Province, China	2021	(Li *et al.*, 2021a)
Oesophagostomum spp.	Tibetan pig	-	Over 66.04	Marker Gene	Qinghai-Tibetan Plateau, China	2017	(Li *et al.*, 2017a)

Table 4: Positive test rates for different species of parasites in Yaks.

Names	Breeds	No. Samples	Regions	Methods	Years	Positive rate, %	References
Enterocytozoon bieneusi	Yaks	353	Tianzhu Tibetan Autonomous County, Gansu Province, China	PCR	2013-2016	1.13	(Ma *et al.*, 2017a)
Sarcosporidiosis	Yaks	2549	Qinghai-Tibet Plateau, China	ELISA	2011-2017	0.9	(Li *et al.*, 2019)
Giardia duodenalis	Yaks	605	Qinghai Province, China	PCR	2013-2016	10.4	(Jin *et al.*, 2017)
	Yaks	208	Tianzhu Tibetan Autonomous County, Gansu Province, China	PCR	2013-2014	1.92	(Song *et al.*, 2016)
	Yaks	297	Qinghai Province, China	Light microscopic analysis、IFT and PCR	2015	5.5	(Wang *et al.*, 2017)
Echinococcus granulosus	Yaks	184	Xinjiang, Sichuan, Qinghai, China	PCR	2016-2020	15.2	(Hua *et al.*, 2022)
	Yaks	1371	Qinghai-Tibet Plateau, China	ELISA	2014-2016	6.49	(Li *et al.*, 2017b)
	Yaks	1641	Qinghai-Tibet Plateau, China	IAT	2012-2013	24.98	(Li *et al.*, 2014a)
	Yaks	752	Qinghai-Tibet Plateau, China	ELISA	2021-2022	25.27	(Qi *et al.*, 2022a)
Toxoplasma gondii (T. gondii)	Yaks	974	Tianzhu Tibetan Autonomous County (TTAC), Gansu province, China	MAT	2013-2014	15.91	(Qin *et al.*, 2015b)
	Yaks	2784	Qinghai-Tibet Plateau, China	ELISA	2018-2019	9.38	(Sun *et al.*, 2021)
	Yaks	1603	Qinghai Province, China	IHAT	2009-2010	8.3	(Wang *et al.*, 2012)
Toxocara vitulorum	Yaks	891	Qinghai-Tibet Plateau, China	PCR	2015	19.42	(Li *et al.*, 2016a)
	Yaks	554	Qinghai Province, China	PCR	2013-2015	28.5	(Li *et al.*, 2016b)
Cryptosporidium spp.	Yaks	76	Tianzhu Tibetan Autonomous County, Gansu province, China	PCR	2013	5.26	(Qin *et al.*, 2014)
Babesia	Yaks	409	Tianzhu Tibetan Autonomous County, China	PCR	2015	3.91	(Liu *et al.*, 2017b)
Neosporosis IgG	Yaks	792	Qinghai-Tibet Plateau, China	Indirect ELISA tests	2021-2022	0.5	(Qi *et al.*, 2022b)
Neosporosis IgM	Yaks	792	Qinghai-Tibet Plateau, China	Indirect ELISA tests	2021-2022	46.8	(Qi *et al.*, 2022b)
Echinococcus canadensis	Yaks	129	Gansu Province, China	PCR	2016	25.6	(Wu *et al.*, 2018b)

significantly reduced the occurrence of antibiotic resistance. (Li *et al*., 2014b).

Haemophilus parasuis *Haemophilus parasuis*, also known as Glässers' disease, is a commensal organism in the upper respiratory tract of conventional pigs that can cause severe systemic disease characterized by fibrous polypoiditis, arthritis, and meningitis under certain conditions (Oliveira and Pijoan, 2004). In the Linzhi district of Tibet, Zhang *et al*. (2014) obtained 423 sera from Tibetan pigs between April and December 2010 for independent testing of *Haemophilus parasuis* antibodies. Of 423 sera, 147 were tested positive for *Haemophilus parasuis*, with detection rates of 34.75% and prevalence rates of 19.72% in all age groups. Breeding pigs had the highest prevalence, with infection rates of 45.04% and 30% in males and females, respectively. Tibetan pigs were tested more frequently positive for *Haemophilus parasuis*. Seroprevalence can be influenced by diagnostic techniques, the immune system, feeding conditions, socioeconomic factors, and animal welfare, or it may be due to challenging feeding conditions that expose Tibetan pigs to infection more than intensively fed pigs (Zhang *et al*., 2014).

Bacterial infections severely affect the health of Tibetan pig herds, with *E. coli* disease being the most common bacterial infection. The prevalence of lactic acid bacteria, the type of intestinal flora and the age of Tibetan pigs may all be contributing factors to this infection (Qi *et al*., 2021). Our findings in Table 5 highlight the prevalence of bacterium in Tibetan pigs in Tibetan regions. In addition, factors such as the introduction of breeding stock, topography, and local pig farm feeding management can also play a role. Given the significant impact of these bacterial diseases on the health of Tibetan pigs, and considering that some are zoonotic (eg *E. coli*), effective disease prevention becomes critical for both animal and public health.

The bacterial diseases that infect yaks on the Tibetan plateau are listed in Table 6. *Theileria* spp. and *Borrelia burgdorferi* have the highest infection rates among the numerous bacterial diseases indicated in the table. In 2020, there was a maximum positivity rate of 75.53% for yak *Borrelia burgdorferi*. In 2019, 25.7% of the samples tested positive for *Theileria* spp. Yak had a 24.19% infection rate with *Anaplasma* spp. in 2010. These three diseases have become relatively common in recent years, raising concerns for the yak breeding industry. As part of the next round of disease control, special attention should be paid to preventing these three diseases, in addition to other comprehensive measures to reduce the incidence of bacterial diseases in yaks.

***Mycoplasma hyopneumoniae* infection in Tibetan pigs and yaks:** *Mycoplasma hyopneumoniae* can cause swine epidemic pneumonia during the acute phase of infection, characterized by clinical signs such as coughing and shortness of breath. Within 3~4 days, the dry cough may transition to a wet cough. The most common type of infection, tracheobronchitis, presents as a cough (Parrott *et al*., 2016). For pathological examinations of lung lesions and serum ELISA tests, Qiu *et al*. (2017) collected lung tissue and 454 blood samples from 155 randomly chosen Tibetan pigs in November and December 2014. The results revealed inflammatory cell infiltration in the samples, with 29 solid lung lesions (18.71%) and 93 (20.48%) of the 454 sera positive for *Mycoplasma hyopneumoniae*. From September to December 2016, Qiu *et al*. (2018) tested 450 Tibetan pigs from three intensive farms in Tibet for *M. hyopneumoniae*. They found that 82 (18.2%) of the 450 Tibetan pigs tested positive for *Mycoplasma hyopneumoniae* alone and the majority (85.1%) had pneumonia-related symptoms. Sera from 423 Tibetan pigs of various breeds collected in Tibet in 2010 by Zhang *et al*. (2013b) were subjected to ELISA, and 249 (58.86%) of the sera were positive for *Mycoplasma hyopneumoniae*, showing seropositivity rates ranging from 25% to 75% at both locations. The findings of these studies showed that Tibetan pigs are highly susceptible to *M. hyopneumoniae*. There was a significant difference in prevalence among animals at different developmental stages. Piglets and breeding sows had the highest levels of *M. hyopneumoniae* in their serum. Apart from the Tibetan Plateau, Tibetan pigs are extensively cultivated in other Chinese provinces. Given its high susceptibility to *M. hyopneumoniae,* it is imperative to implement comprehensive preventive measures to contain the outbreak.

Furthermore, with the rapid development of the yak industry, the high rate of *M. bovis* infection in yaks may be attributed to frequent trading and the absence of strict quarantine measures. Niu *et al*. (2021) reported a high prevalence of *M. bovis* infection in yaks on the Qinghai-Tibet Plateau (Table 7). The effectiveness of vaccination in reducing clinical symptoms, lung lesions, and drug use varied based on vaccination strategies, including timing, vaccination in conjunction with antimicrobial treatments, and vaccination strategies tailored to herd type (Maes *et al*., 2008). Therefore, it is crucial to pay more attention to thoroughly assessing the impact of *M. bovis* infection.

Seroprevalence of Chlamydia in Tibetan pigs and yaks: *Chlamydia* consists mainly of specialized intracellular pathogens such as *Chlamydia trachomatis*, *Chlamydia pneumoniae*, and *Chlamydia psittaci* (Ansari and Mande, 2018). In pigs, *Chlamydia* infections have been associated with various pathologies, including conjunctivitis, pneumonia, pericarditis, polyarthritis, polycythemia vera, pseudomembranous or necrotizing enteritis, abortion, mummification, delivery of weak piglets, higher neonatal mortality, poor semen quality,

Table 5: **Positive test rates for different species of bacteria in Tibetan pigs**

Names	Breeds	No. Samples	Regions	Methods	Positive rate, %	Years	References
Escherichia coli	Tibetan pig	18	Tibet, China	PCR	-	-	(Qi *et al*., 2021)
	Tibetan pig	232	Linzhi, China	PCR	55.6(129/232)	2012	(Li *et al*., 2014b)
Enterococcus faecalis	Tibetan pig	84	Linzhi, China	PCR	36.9(31/84)	2012	(Li *et al*., 2014b)
Enterococcus faecium	Tibetan pig	84	Linzhi, China	PCR	53.6(45/84)	2012	(Li *et al*., 2014b)
Haemophilus parasuis	Tibetan pig	423	Linzhi, China	ELISA	34.75	2010	(Zhang *et al*., 2014)

Table 6: Positive test rates of different bacterial species in yaks.

Names	Breeds	No. Samples	Regions	Methods	Years	Positive rate, %	References
Shiga toxin (Stx)-producing *Escherichia coli* (STEC)	Yaks	728	Qinghai-Tibetan plateau, China	TaqMan real-time PCR	2012	11.68	(Bai *et al*., 2013)
Salmonella spp.	Yaks	162	Aba Tibetan Autonomous Prefecture, China	Isolation	2019	19.75	(Fu *et al*., 2021)
Mycobacterium bovis	Yaks	1244	Tibet and Qinghai plateau, China	ELISA	2011	2.17	(Han *et al*., 2013)
Theileria spp.	Yaks	144	Sichuan province, China	PCR	2019	25.7	(Hao *et al*., 2020)
	Yaks	194	Qinghai-Tibetan plateau, China	PCR	2018	10.3	(Li *et al*., 2020)
	Yaks	425	Qinghai Province, China	PCR	2021	5.9	(He *et al*., 2021)
***Rickettsia* spp.**	Yaks	222	Qinghai-Tibetan plateau, China	PCR	2018	11.3	(Jian *et al*., 2020)
	Yaks	194	Qinghai-Tibetan plateau, China	PCR	2018	82	(Li *et al*., 2020)
Piroplasmosis	Yaks	350	Gansu province, China	PCR	2015	38.3	(Li *et al*., 2017d)
	Yaks	140	Hongyuan County of Ngawa, China	PCR	2021	45.71	(Lu *et al*., 2022)
Anaplasma spp.	Yaks	214	Qinghai province, China	PCR	2020	75.23	(Wang *et al*., 2021b)
	Yaks	332	Tianzhu Tibetan Autonomous County, Gansu province, China	PCR	2015	10.9	(Yang *et al*., 2016)
	Yaks	792	Qinghai-Tibetan plateau, China	Indirect ELISA	2021-2022	6.5	(Zhang *et al*., 2022)
Borrelia burgdorferi	Yaks	186	Gannan Tibetan Autonomous Prefecture of Gansu Province, China	PCR	2010	24.19	(Fu *et al*., 2012)
E. chaffeensis	Yaks	214	Qinghai province, China	PCR	2020	0.5	(Wang *et al*., 2021b)

Table 7: Positive test rates for *Mycoplasma hyopneumoniae and Chlamydia* in Yaks.

Names	Breeds	No. Samples	Regions	Method	Years	Positive rate, %	References
Chlamydia abortus (C. abortus).	Yaks	938	Gansu and Qinghai province, China	ELISA	2019	11.1	(Liang *et al*., 2021)
	Yaks	974	Tianzhu Tibetan Autonomous County, Gansu province, China	IHA	2013-2014	16.22	(Qin *et al*., 2015a)
Mycoplasma bovis	Yaks	959	Qinghai-Tibet Plateau, China	ELISA	2019-2020	48.7	(Niu *et al*., 2021)

orchitis, epididymitis, and urethritis (Schautteet and Vanrompay, 2011). Between April and December 2010, Zhang *et al*. (Zhang *et al*., 2013a) collected 427 serum samples in Tibet and examined them using indirect hemoglutination. The results revealed a 16.63% positivity rate for Chlamydiaceae antibodies, with growing pigs showing the highest detection rate (20.61%). Infection was identified in 12.72% of male Tibetan pigs and 17.61% of female Tibetan pigs. This study is the first to highlight the prevalence of *chlamydia* in Tibetan pigs, indicating its widespread presence among all populations of Tibetan pigs. Tibetan pigs had a lower prevalence of *Chlamydia* compared to pigs raised in intensive farming systems. This difference may be attributed to the higher resistance of Tibetan pigs to the disease and the reduced incidence of transmission due to inbreeding among Tibetan pigs (Zhang *et al*., 2013a).

Regarding the case of yak *chlamydia* infection, Qin *et al*. (Qin *et al*., 2015a) conducted the first survey on the seroprevalence of C. abortus, expanding the host range of C. abortus in Chinese white yaks. Liang *et al*. (Liang *et al*., 2021) collected 938 serum samples from yaks in Tibet, China and used an enzyme-linked immunosorbent assay (ELISA) to detect specific antibodies against C. abortus. The results, as shown in Table 7, revealed an overall seroprevalence of C. abortus in yaks at 11.1% (104/938) with a 95% confidence interval of 9.1~13.1%. There was generally no discernible gender difference in the prevalence of M. bovis. However, *M. bovis* was more common in females in Gansu and Sichuan than in males. This difference may be the result of inadequate resistance, particularly during pregnancy and delivery. Furthermore, due to vertical transmission, intense stress response, and insufficient resistance, calves had the highest prevalence.

Conclusions: This paper outlines the prominent pandemic diseases that have affected Tibetan pigs and yaks from 1990 to 2023. The primary objective of this study is to improve our understanding of the epidemics that affect Tibetan pigs and yaks, laying the foundation for mitigating their high incidence. Tibetan pigs and yaks have significant economic importance for Tibetans and nomadic herders in high-altitude regions. The existence of substantial public health and safety concerns not only jeopardizes the well-being of pig and yak herds, but also poses a threat to humans, especially those residing in areas with a high risk of transmission of zoonotic diseases, such as the Hepatitis E virus (HEV) between humans and Tibetan pigs. Therefore, investigating the epidemiological trends of the major infectious diseases recently observed in Tibetan yaks and pigs is imperative. Currently, statistics on the epidemiology of Tibetan yaks and pigs in recent years are not available. Relevant research and studies must be conducted to establish a scientific foundation for animal husbandry's welfare and enhance our understanding of and ability to prevent major infectious diseases affecting these two animals. The socioeconomic and public health impacts of the epidemics that affect Tibetan pigs and yaks are increasingly gaining attention to health concerns. Tibetan pigs and yaks are susceptible to various zoonotic diseases, including swine influenza A virus, hepatitis E virus, echinococcosis, toxoplasmosis, trichinosis, Japanese B encephalitis, and numerous newly identified virus subtypes currently observed in these animals. In addition, enterococcal infections are prevalent.

Outbreaks caused by bovine coronavirus (BCoV), bovine rotavirus A (BRVA), *Echinococcus granulosus*, Neosporosis IgM, *Theileria* spp. and *Anaplasma* spp. severely impact the well-being of yaks. Regions involved in the rearing of Tibetan yaks and pigs should improve early detection and monitoring of diseases that affect these animals. Establishing an optimal monitoring network and real-time epidemic surveillance is essential for quickly diagnosing and controlling outbreaks, preventing their spread. Gleichzeitig, comprehensive prevention and control plans should be developed, incorporating strategies such as immunization, biosecurity measures, feeding management, and others. These measures aim to reduce the frequency and fatality rate of outbreaks, ensuring steady progress in animal husbandry. Future research efforts should focus on understanding the dynamics of pathogens that affect Tibetan pigs and yaks in plateau environments. The emphasis should be placed on scientific research and innovation, enhancing the research and development of vaccines and medicines.

Strengthening veterinary practice training is crucial to elevate their expertise and awareness of epidemic prevention, providing robust technical support for the animal husbandry industry.

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

Funding: This work was supported by the national key research and development program (2022YFD1600904), the central-led local projects "Research and demonstration of integrated control technology for various diarrhea diseases in Tibetan pigs and yaks (ZYYD2024000081)" and the main science and technology projects of the autonomous region of Tibet (XZ202101ZD0005N).

Authors' Contributions: All authors contributed to the conception and design of the study. The first draft of the manuscript was written by Peipei Tian and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability: Data sharing was not applicable to this article as no datasets were generated or analyzed during the current study.

Ethics approval: As no animals were experimented on in the study, approval by an ethics committee was not required.

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