Veterinary Medicine: Research and Reports

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REVIEW

Eukaryotic Infections in Dairy Calves: Impacts, Diagnosis, and Strategies for Prevention and Control

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Abstract: Eukaryotic infections are common among dairy calves and can have significant impacts on their health and growth rates. Fungal infections caused by *Aspergillus fumigatus, Trichophyton verrucosum*, and *Candida albicans* can cause respiratory diseases, dermatophytosis, and diarrhea, respectively. Protozoan parasites, including *Cryptosporidium parvum, Giardia duodenalis*, and *Eimeria spp*., are also common in dairy calves. *C. parvum* is highly contagious and can cause severe diarrhea and dehydration, while *Giardia duodenalis* can lead to poor growth and is transmissible to humans through contaminated food or water. *Eimeria spp*. can cause coccidiosis and lead to reduced growth rates, poor feed conversion, and death. The common helminthic infections in dairy calves include *Ostertagia ostertagi, Cooperia spp., Fasciola hepatica*, and *Strongyloides papillosus*. These parasitic infections significantly impact calf health, growth, and dairy industry productivity. Diagnosis of these infections can be made through fecal samples using microscopy or molecular methods. However, diagnosis of the infections can be challenging and requires a combination of clinical signs and laboratory tests such as culture and PCR. Preventing and controlling eukaryotic infections in dairy calves requires several measures. Good hygiene and sanitation practices, proper management strategies, and timely treatment of affected animals are important. It is also necessary to avoid overcrowding and consider vaccination against ringworm. Further research is needed to better understand the epidemiology and characterization of eukaryotic infections in dairy calves, which will help in the development of more effective prevention and control strategies. In general, good hygiene practices, appropriate management strategies, and timely treatment of affected animals are crucial in preventing and controlling the infections, ensuring the health and well-being of dairy calves.

Keywords: protozoa, fungus, helminths, diagnosis methods, prevention strategies, dairy calves

Introduction

Dairy farming is an important sector of agriculture industry, providing a significant source of food and income worldwide. However, infectious diseases pose a major threat to the health and productivity of dairy calves.[1,2] Eukaryotic infections caused by protozoan parasites, helminths, and fungi are common problems among dairy calves. The term "eukaryotic infections" encompasses a wide array of pathogens that belong to the domain Eukarya, including protozoa, fungi, and helminths.[3] Unlike bacteria or viruses, these microorganisms possess complex cellular structures with membrane-bound organelles, reflecting a higher level of biological organization.[4] These pathogens can affect different parts of the body, including the digestive system, respiratory system, and urogenital system. Therefore, it is crucial to understand the nature of infections and their management strategies to ensure the welfare of dairy calves and the profitability of dairy farming.[5,6]

Protozoan and fungal infections are significant concerns in the health of dairy calves, representing major eukaryotic health problems. These infections can lead to substantial economic losses attributed to decreased milk production, treatment costs, and mortality.[3,7] Moreover, some of these infections can also be transmitted to humans, posing a public

Received: 27 September 2023
Accepted: 27 November 2023
Published: 1 December 2023

health concern.[8] In addition to protozoa and fungi, helminthic infections, such as roundworms and tapeworms, have also been identified as critical contributors to the health burden of dairy calves.[9] These parasites can lead to gastrointestinal disturbances, decreased nutrient absorption, and anemia, thereby impeding calf growth and performance.[10,11] Several studies have reported the prevalence of the infections in dairy calves worldwide. A study conducted by[12] and[3] in Ethiopia reported a prevalence of 20.1% for coccidiosis and 13.8% for cryptosporidiosis, respectively, in dairy calves. Similarly, a study by[13] in Bangladesh reported a prevalence of 55.6% for cryptosporidiosis in dairy calves.

The diagnosis of eukaryotic infections in dairy calves poses unique challenges due to the diversity of pathogens and their varied clinical presentations. Traditional diagnostic methods, such as microscopic examination of fecal samples and other, are often labor-intensive and lack sensitivity and specificity.[4] However, advancements in molecular techniques, such as polymerase chain reaction (PCR) and next-generation sequencing (NGS), have revolutionized the identification and characterization of eukaryotic pathogens. These methods enable precise detection, differentiation, and quantification of various pathogens, enhancing our ability to diagnose infections accurately.[14,15]

Effective management of eukaryotic infections in dairy calves involves a combination of preventive measures, early diagnosis, and appropriate treatment.[16,17] Preventive measures include maintaining good hygiene and sanitation practices, such as using clean and dry bedding, and implementing biosecurity measures. Early diagnosis can be achieved through regular monitoring and diagnostic testing, while appropriate treatment may involve the use of antiparasitic drugs or antifungal agents.[18] Therefore, the aim of this review is to provide an overview of the common eukaryotic infections affecting dairy calves, their effects on the animals, and the current strategies used for their management. We also highlight recent advancements in the diagnosis and treatment of the infections, as well as areas for future research. Understanding these pathogens and employing management strategies is essential to prevent and control the diseases in dairy calves.

Eukaryotic Infections in Dairy Calves

Fungal Infections

Aspergillus fumigatus (*A. fumigatus*) is a ubiquitous fungus found in soil, decaying vegetation, and other organic matter.[19] It is also known to colonize the respiratory tract of animals, including dairy calves. Infection with *A. fumigatus* in dairy calves can result in a variety of clinical signs, including coughing, fever, and decreased appetite. In severe cases, it can lead to pneumonia, respiratory distress, and death.[5]

The transmission of *A. fumigatus* to dairy calves occurs through contaminated feed or bedding material, and environmental conditions such as high humidity and poor ventilation can facilitate its growth and spread.[20] Calves that are immune compromised or stressed due to factors such as transport or weaning may be more susceptible to infection. In dairy calves, *A. fumigatus* can cause a range of respiratory diseases, including pneumonia, bronchopneumonia, and aspergillosis. Clinical signs of *Aspergillus*-related respiratory disease in calves include coughing, labored breathing, and fever.[21] In severe cases, the disease can progress rapidly and lead to death.

A study conducted by[22] investigated the prevalence of *A. fumigatus* in the lungs of dairy calves with respiratory distress. The study found that the infection was the most frequently isolated fungus from the lungs of affected calves. Moreover, the study identified an association between the presence of *A. fumigatus* and the severity of respiratory distress in the calves. Another study by[23] investigated the pathogenicity of *A. fumigatus* in dairy calves. The study found that *A. fumigatus* was capable of causing severe lung lesions and mortality in experimentally infected calves. The study also identified several virulence factors that were involved in its pathogenicity, including the production of toxins and proteases.

Diagnosis of *A. fumigatus* infection in dairy calves can be challenging as clinical signs may be non-specific and other pathogens may also cause similar symptoms. However, a combination of clinical signs, radiographic findings, and laboratory tests such as culture and PCR help to confirm the presence of *A. fumigatus*.[24] Treatment of infection in dairy calves typically involves the use of antifungal medications such as itraconazole or voriconazole (Table 1). However, prevention and control measures such as improving ventilation, reducing humidity, timely treatment of affected animals and avoiding contaminated feed and bedding material can reduce the risk of infections in dairy calves.[21,25,26]

Table 1 Fungal Types and Their Management, Effects, Diagnostic Samples, and Methods

Fungus	Type	Management	Effects	Samples	Diagnostic Methods
Aspergillus fumigatus	Mold	Improve ventilation, remove moldy bedding	Respiratory distress, pneumonia	Nasal swabs, lung washes	Culture, PCR
Trichophyton verrucosum	Mold	Sanitation, topical antifungal treatment	Ringworm lesions, hair loss, itching	Skin scrapings, hair samples	Culture, microscopic examination
Candida albicans	Yeast	Oral/topical antifungal medication, improved hygiene	Thrush, diarrhea, reduced feed intake	Fecal samples, oral swabs	Culture, PCR
Cryptococcus neoformans	Yeast	Antifungal medication, improve hygiene	Nasal discharge, respiratory distress, neurological symptoms	Nasal swabs, cerebrospinal fluid	Culture, PCR
Fusarium spp.	Mold	Improve ventilation, remove moldy bedding	Diarrhea, reduced feed intake, immune suppression	Fecal samples, nasal swabs	Culture, PCR

Trichophyton verrucosum (*T. verrucosum*) is a dermatophyte fungus that commonly infects dairy calves, causing a skin disease known as bovine dermatophytosis or ringworm. This fungal infection is highly contagious and can spread rapidly between calves, leading to significant economic losses in the dairy industry. It is a zoonotic pathogen that can also infect humans who come in contact with infected animals or contaminated surfaces.[27–29] *T. verrucosum* is primarily found in humid and cold environments, making it more prevalent in northern regions. Calves between 1–6 months of age are most susceptible to infection, as their immune systems are not fully developed. The fungus can be transmitted through direct contact with infected animals or through contaminated environments, such as bedding or equipment.[29–31]

The clinical signs of bovine dermatophytosis include circular patches of hair loss, scab formation, and crusty lesions on the skin of affected calves. The lesions occur on any part of the body but are most commonly seen on the head, neck, and shoulders. Infected calves may also experience itching and discomfort, leading to reduced feed intake and weight loss.[32,33] According to a study by[34] and,[35] *T. verrucosum* was identified as the most common dermatophyte isolated from dairy calves with ringworm infections in Brazil and Italy, respectively. The study also found that the prevalence of ringworm infection was higher in calves that were not treated with fungicides and in farms with poor hygienic practices. This suggests that proper management practices and regular treatment with fungicides can help prevent and control *T. verrucosum* infections in dairy calves.

The diagnosis of bovine dermatophytosis is usually based on clinical signs and confirmed by fungal culture or microscopic examination of skin scrapings.[31] Diagnosis of the disease in dairy calves can be done through a combination of clinical signs, fungal culture, and microscopic examination.[34] Fungal culture can confirm the presence of etiological agent of the disease, while microscopic examination can identify the fungal structure and aid in species identification.[27,29]

Treatment options for the disease include topical antifungal agents such as miconazole or clotrimazole, as well as other systemic antifungal drugs. Implementing good hygienic practices and avoiding overcrowding of calves are the key prevention measures of the disease.[36,37] Vaccination against ringworm is also available in some countries and can be a useful preventive measure.[28] Prevention of *T. verrucosum* infection in dairy calves is essential to control the spread of the disease (Table 1).

Candida albicans (*C. albicans*) is a fungal pathogen that can cause infections in various animal species, including dairy calves. In dairy farming, *C. albicans* infections in calves have been associated with a range of clinical signs, including diarrhea, reduced appetite, and poor growth rates.[38,39] *C. albicans* is a type of yeast that commonly colonizes the mucosal surfaces of mammals, including dairy calves. In healthy animals, *C. albicans* is typically present in low numbers and does not cause disease. However, in certain circumstances, when the animal's immune system is compromised, *C. albicans* can cause a range of infections, including oral thrush, skin infections, and systemic infections.[40,41] The pathogenesis of the *C. albicans* infection in dairy calves involves colonization of gastrointestinal tracts particularly the rumen and abomasum even if not fully understood. Then it causes inflammation and tissue damage.

In some cases, it can also spread to other organs, such as the liver and lungs, causing systemic infections in dairy calves.[38]

Several risk factors have been identified for *C. albicans* infections in dairy calves, including poor hygiene, inadequate nutrition, and stress.[38] Furthermore, the infections can be more common in calves that are housed in crowded or unsanitary conditions. Diagnosis of the infection in dairy calves can be challenging, as it requires the identification of the organism in clinical samples such as feces, oral swabs, or blood cultures (Table 1). Diagnosis can be done through culture and PCR testing.[42] Treatment of *C. albicans* infections in calves typically involves the use of antifungal drugs, such as fluconazole and nystatin.[42] Prevention of the infections in dairy calves involves good management practices, providing adequate nutrition and hydration, and minimizing stress.[43,44]

Cryptococcus neoformans (*C. neoformans*) is a fungal pathogen that can cause serious disease in both humans and animals. *C. neoformans* is a yeast-like fungus that is found worldwide in soil, bird droppings, and other organic matter.[45,46] This pathogen can cause disease in immune compromised hosts. In dairy calves, the fungus can cause cryptococcosis, which is characterized by respiratory symptoms, neurological problems, and other clinical signs.[47] The exact mode of transmission of *C. neoformans* in dairy calves is not fully understood, but it is thought to occur via inhalation of fungal spores from contaminated feed or bedding. Furthermore, immunocompromised calves are at higher risk of developing cryptococcosis, as their weakened immune systems make them more susceptible to infection.[48,49]

Clinical signs of cryptococcosis in dairy calves can vary, but commonly include respiratory symptoms such as coughing and dyspnea, as well as neurological symptoms like ataxia and seizures.[50] In some cases, the disease can also cause skin lesions and ophthalmic problems. Diagnosis of cryptococcosis in dairy calves is typically made through a combination of clinical signs, laboratory testing, and imaging studies.[47] The diagnosis of the disease in dairy calves is challenging since clinical signs are often non-specific and overlap with other diseases. Therefore, A combination of clinical examination, laboratory tests and histopathological analysis are required for definitive diagnosis.[45]

Treatment of *C. neoformans* in dairy calves usually involves a combination of antifungal drugs and supportive care. Fluconazole is the most commonly used antifungal medication, and has been shown to be effective in treating cryptococcosis in calves.[18] However, successful treatment also depends on early diagnosis and prompt initiation of therapy. Prevention of *C. neoformans* in dairy calves involves maintaining good hygiene practices, including regular cleaning and disinfection of feed and bedding areas (Table 1). Furthermore, it is important to monitor calf health and implement appropriate measures to manage immunocompromised individuals.[17,26]

Fusarium is of filamentous fungi commonly found in soil and plant debris. The genus *Fusarium fungus* contains economically important species that cause a wide range of health problems in calves, including respiratory and gastrointestinal disease.[51] The fungus has been identified as major cause of mycotoxicosis in dairy calves which leads to reduce growth rate, feed intake and diarrhea. In severe cases, mycotoxicosis can even lead to death.[52] The mycotoxins produced by *Fusarium* are trichothecenes, zearalenone, and fumonisins. These toxins can contaminate feed and forage, leading to ingestion by dairy calves.[53,54] The toxins damage the intestinal lining leading to inflammation and reduced nutrient absorption following ingestion of toxins. Furthermore, the toxins disrupt the immune system, leaving the calf vulnerable to other infections.[55,56]

One of the most common *Fusarium* species in dairy calves is *Fusarium verticillioides*. This fungus produces fumonisin mycotoxins, which can cause a range of health problems, including neurological disorders, liver and kidney damage, and reduced growth rates.[57] Another *Fusarium* species that can infect dairy calves is *Fusarium graminearum*, which produces deoxynivalenol (DON) mycotoxins. It is a potent inhibitor of protein synthesis and can cause feed refusal, vomiting, and diarrhea in dairy calves. DON can cause vomiting, diarrhea, and reduced feed intake in calves.[58,59] In addition to causing mycotoxicosis, *Fusarium* spp. can also cause systemic infections in dairy calves. *Fusarium solani* is known to cause pneumonia in calves. *Fusarium oxysporum* can cause disseminated infections in calves with compromised immune systems.[55]

Preventing *Fusarium* infection in dairy calves can be challenging, as the fungi are ubiquitous in the environment.[60] However, several strategies can be employed to reduce the risk of infection. These include ensuring proper ventilation and hygiene in calf housing facilities, using clean and high-quality feed, and avoiding the use of contaminated bedding (Table 1). Moreover, proper storage and handling of feed can help to minimize mycotoxin exposure.[38] To prevent

Fusarium-related mycotoxicosis in dairy calves, it is important to implement measures such as proper feed storage and handling, routine mycotoxin testing of feed, and the use of mycotoxin binders in feed. These strategies can help reduce the risk of *Fusarium* contamination and minimize the negative impact on calf health.[13]

Protozoa Infections

Protozoa are single-celled organisms that cause various health problems in humans and animals. *Cryptosporidium parvum, Giardia duodenalis*, and *Eimeria species* are major types of protozoa parasites (Table 2).

Cryptosporidium parvum (*C. parvum*) is a protozoan parasite that commonly infects dairy calves, causing diarrhea and other gastrointestinal symptoms.[61] The *C. parvum* is highly contagious and transmitted through direct contact with infected animals, as well as through contaminated water and feed.[62,63] Several studies have investigated the prevalence and impact of *C. parvum* in dairy calves. The prevalence of *C. parvum* was range from 6.3% to 39.7%[64] with infection rates highest in calves between one and three weeks of age. Another study by[65] found that *C. parvum* infection in dairy calves was associated with reduced weight gain and increased mortality.

C. parvum is ubiquitous in the environment and can survive for long periods in moist and cool conditions. The main source of infection for dairy calves is contaminated water, feed, or bedding material.[66] The parasite has a complex life cycle, with both asexual and sexual stages occurring in the host's intestinal tract. Infected cows can shed millions of oocysts (the infective stage of the parasite) in their feces, which can contaminate the environment and spread the infection to susceptible calves.[63] Once ingested, *C. parvum* oocysts release sporozoites that invade the intestinal epithelium, causing damage and inflammation. This leads to malabsorption, maldigestion, and osmotic diarrhea, which can result in severe dehydration and electrolyte imbalances.[67,68] The severity of the disease depends on various factors, such as the calf's age, immune status, nutritional status, and concurrent infections.[69]

Clinical signs of *C. parvum* infection in dairy calves include watery diarrhea, dehydration, weight loss, and lethargy. In severe cases, infection can result in death.[63] The diagnosis of cryptosporidiosis in dairy calves can be challenging, as the clinical signs can be similar to those of other gastrointestinal diseases. However, several diagnostic methods are available, including fecal examination, antigen detection assays, and molecular techniques, as described in a review by[70] and.[68]

The treatment of the infection in dairy calves involves rehydration, electrolyte therapy, and supportive care. Antimicrobial agents, such as halofuginone and nitazoxanide, are also effective in reducing the severity and duration of diarrhea.[71] However, the emergence of drug-resistant strains of *C. parvum* has limited the efficacy of the drugs in some cases. Prevention and control of the infection in dairy calves involve proper hygiene and sanitation, good management practices, and vaccination.[72,73] Vaccination against *C. parvum* can reduce the severity and incidence of the disease and has been shown to be effective in field trials.[74,75]

Giardia duodenalis (*G. duodenalis*), also known as *Giardia intestinalis* or *Giardia lamblia*, is a protozoan parasite that infects the small intestine of various animals, including dairy calves. It is a significant cause of diarrhea and poor growth in young calves, leading to economic losses in the dairy industry.[76] In addition to causing disease in dairy calves, *G. duodenalis* can also be transmitted to humans through contaminated food or water. This zoonotic potential highlights the importance of effective control measures to prevent transmission of the parasite between animals and humans.[77]

Table 2 Protozoa Types and Their Management, Effects, Diagnostic Samples, and Methods

Protozoa	Type	Management	Effects	Samples	Diagnostic Methods
Cryptosporidium parvum	Coccidian	Hygiene, disinfection, supportive care	Diarrhea, dehydration, weight loss, decreased growth rates	Fecal samples	Microscopy, ELISA, PCR
Giardia duodenalis	Flagellate	Hygiene, disinfection, supportive care	Diarrhea, weight loss, decreased growth rates	Fecal samples	Microscopy, ELISA, PCR
Eimeria spp.	Coccidian	Hygiene, disinfection, supportive care	Diarrhea, dehydration, weight loss, decreased growth rates	Fecal samples	Microscopy, ELISA, PCR

The transmission of *G. duodenalis* in dairy calves occurs through the ingestion of cysts, which are the parasite's infective stage, shed in the feces of infected animals. The transmission of *G. duodenalis* in dairy calves occurs through the ingestion of cysts, which are the parasite's infective stage, and are shed in the feces of infected animals. The cysts can survive for prolonged periods in the environment, particularly in damp and cool conditions, making it challenging to control the spread of infection.[78] Once ingested, the cysts release trophozoites, the active form of the parasite, which attach to the intestinal wall, causing damage to the intestinal villi and reducing nutrient absorption. This results in diarrhea, weight loss, and decreased feed efficiency, ultimately leading to decreased milk production and potential mortality in severe cases.[76] The infection can also cause damage to the intestinal lining, leading to malabsorption of nutrients and impaired growth in dairy calve.[77]

Several diagnostic methods are available to detect *G. duodenalis* infection in dairy calves, including fecal flotation, ELISA, and PCR. Diagnosis of *Giardia* infections in dairy calves can be challenging, as the parasite is not always detectable in fecal samples and may require multiple sampling and testing methods.[79] According to a study by,[80] microscopy and immunological assays are the most commonly used diagnostic methods, although PCR-based techniques are becoming increasingly popular due to their high sensitivity and specificity in calve.

Treatment of the infections in dairy calves typically involves the use of antiparasitic drugs such as metronidazole or fenbendazole, although resistance to these drugs has been reported in some regions (Siwila, 2017). Prevention of the infections in dairy calves requires good hygiene practices, such as regular cleaning and disinfection of feeding and watering equipment, as well as minimizing contact with contaminated environments and infected animals.[77,81]

The genus *Eimeria* is protozoan parasites that can cause coccidiosis in dairy calves. Coccidiosis is a common disease in young calves that can lead to reduced growth rates, poor feed conversion, and even death in severe cases.[82,83] *Eimeria* are ubiquitous in the environment, and infection typically occurs through ingestion of oocysts shed in the feces of infected animals.[84]

There are several species of *Eimeria* that can infect dairy calves, including *Eimeria (E. bovis), Eimeria (E. zuernii), Eimeria (E. auburnensis), and Eimeria) E. ellipsoidalis)*.[13] These parasites can be found in the environment and are typically transmitted through fecal-oral contamination. Once ingested, *Eimeria* oocysts release sporozoites that invade the cells lining the intestinal wall in dairy calves. The parasites then reproduce asexually, causing damage to the intestinal lining and leading to diarrhea, dehydration, and weight loss.[85] Clinical signs of coccidiosis in dairy calves include diarrhea, anorexia, lethargy, and dehydration. Each species has a unique pathogenesis and clinical presentation.[86] *E. bovis*, for example, is associated with severe diarrhea and weight loss, while *E. zuernii* causes less severe clinical signs but can lead to more chronic infections.[87] *Eimeria spp* infections are particularly common in young calves, as their immune systems are not yet fully developed, making them more susceptible to infection.[13]

Diagnosis of *Eimeria spp* infection in dairy calves can be challenging, as the clinical signs are nonspecific and can be caused by other gastrointestinal pathogens. However, fecal flotation and microscopic examination can reveal the presence of oocysts, which are the infective stage of the parasite. It is important to note that not all infected calves will shed oocysts in their feces, so a negative fecal test does not necessarily rule out infection. Diagnosis is typically made through more advanced diagnostic techniques such as PCR and ELISA.[23]

Preventing and controlling *Eimeria spp* infections in dairy calves is critical to maintaining calf health and reducing economic losses. Management practices, such as proper sanitation and hygiene, can help reduce the risk of *Eimeria* infection. Moreover, anticoccidial drugs can be used to treat and prevent *Eimeria* infections in dairy calves. However, the overuse of these drugs can lead to the development of drug-resistant strains of *Eimeria*, making it important to use them judiciously.[59] Additionally, some producers may choose to use medicated feed or oral medications to help control the parasites.[13]

Helminthic Infections

Helminthic infections are a prevalent health concern in dairy calves, impacting growth, productivity, and overall herd management (Table 3). These infections are primarily caused by parasitic worms, including nematodes, trematodes and cestodes.[88] Ostertagiasis is a gastrointestinal parasitic infection that predominantly affects young ruminants, including dairy calves. Ostertagiasis is caused by the nematode *Ostertagia ostertagi*, commonly affecting dairy calves.[89] This

Table 3 Common Helminthic and Their Management, Effects, Diagnostic Samples, and Methods

Helminthic type	Management	Effects	Diagnostic Samples	Methods of Control
Ostertagia ostertagi	Pasture management, Strategic deworming programs, good nutrition	Reduced growth rates, Decreased milk yield, Diarrhea	Fecal egg count, Clinical signs, Post-mortem examination	Culture, PCR
Dictyocaulus viviparus	Avoid overgrazing, Deworming during dry season, Housing during wet periods	Coughing, Respiratory distress, Reduced weight gain	Baermann technique (lungworm larvae in feces), Clinical signs	Culture, PCR
Fasciola hepatica	Pasture management, Anthelmintic treatment	Reduced growth, Liver damage, Anemia	Fecal egg count, Blood tests (enzyme levels), Liver inspection post-mortem	Culture, PCR
Cooperia spp.	Rotational grazing, Anthelmintic treatment	Diarrhea, Poor growth	Fecal samples	Fecal egg count
Strongyloides papillosus	Clean environment, Deworming, Good nutrition	Diarrhea, Weight loss, Dehydration	Fecal examination, Clinical signs	Anthelmintic treatment, Hygiene improvement

disease poses significant challenges to the dairy industry due to its impact on calf health, growth, and overall productivity.[90] Understanding the epidemiology, clinical signs, diagnosis, and management of Ostertagiasis is crucial for effective control and prevention.[91]

The disease is prevalent in temperate regions with humid climates, where the larvae of *O. ostertagi* can survive on pasture. Calves grazing on contaminated pastures are at high risk of infection.[92] Calves raised in confinement systems may experience lower exposure compared to those on pasture. High stocking densities and poor manure management contribute to increased contamination of grazing areas.[93] Ostertagia nematodes have a complex life cycle involving both direct and indirect transmission.[94] Cattle become infected by ingesting infective larvae from contaminated pastures. Once ingested, these larvae penetrate the gastric glands, leading to the development of L4 larvae, which emerge into the abomasum, causing tissue damage and clinical symptoms.[95] Clinical manifestations of Ostertagiasis in dairy calves include poor growth rates, weight loss, diarrhea, and suboptimal feed conversion efficiency. These signs are primarily attributed to the damage caused by the parasite's larval migration and the subsequent inflammatory response in the abomasal lining.[96]

Accurate diagnosis of Ostertagiasis involves a combination of clinical signs, fecal examination, and laboratory techniques. Fecal egg count (FEC) is a commonly used diagnostic method to quantify parasite burden.[97] Furthermore, the use of serological assays and polymerase chain reaction (PCR) techniques can enhance diagnostic accuracy.[82,95,98] The management and control of the disease require a multi-faceted approach. Implementing strategic deworming protocols based on calf age, grazing history, and FEC results can help reduce parasite load.[91] Pasture management practices such as rotational grazing, maintaining hygiene, and minimizing overcrowding can also mitigate the risk of infection. Furthermore, promoting calf immunity through proper nutrition and vaccination can aid in reducing the impact of the disease.[99,100]

The genus *Cooperia* are a group of small intestinal nematodes belonging to the family Trichostrongylidae. They are recognized as major contributors to the gastrointestinal parasite burden in dairy calves.[101] The detrimental effects of *Cooperia* infections on calf health and productivity have made them a subject of intense research and management efforts.[102] The infection has a direct lifecycle involving both free-living and parasitic stages. The infective third-stage larvae (L3) are ingested by calves while grazing, eventually migrating to the abomasum and small intestine.[95] The larvae develop into adults that attach to the intestinal mucosa, leading to nutrient depletion, inflammation, and potential tissue damage. These physiological disruptions contribute to diarrhea, weight loss, and decreased growth rates in infected calves.[103]

Clinical signs of *Cooperia* infections vary in severity and can include diarrhea, dehydration, anemia, and poor body condition. Diagnostic methods encompass fecal egg counts (FEC), which quantify the parasite burden, as well as fecal culture and larval differentiation techniques to identify the specific *Cooperia spp*.[97] Molecular methods, such as polymerase chain reaction (PCR), aid in species identification and differentiation.[104,105] *Cooperia* infections are influenced by various factors, including geographical location, climate, management practices, and host immunity.[106] Calves in group housing systems are particularly susceptible due to higher exposure levels. Environmental conditions, such as humidity and temperature, also play a crucial role in larval survival and infectivity. Accurate diagnosis is essential for effective management.[107]

Anthelmintic resistance has become a concern in *Cooperia spp* control. Rotation of different anthelmintic classes and the use of combination therapies are recommended to mitigate resistance development.[105,108] Strategic deworming protocols, based on calf age, infection risk, and anthelmintic efficacy, are crucial for successful treatment. Integrated parasite management (IPM) strategies are essential to control *Cooperia spp* infections. These strategies involve a combination of measures, including strategic deworming, pasture management, nutrition optimization, and genetic selection for resistance.[109,110] However, indiscriminate use of anthelmintics may lead to the development of drug-resistant strains, underscoring the need for judicious and targeted treatment.[105,111] Recent research has shed light on various aspects of *Cooperia spp* infections, including host immunity, genetic resistance, and alternative control methods such as biological agents and plant-based treatments.[112] Developing a deeper understanding of the host-parasite interaction and identifying novel control strategies are crucial for sustainable management of the infections in dairy calves.[109]

Dictyocaulus viviparus (*D. viviparous*), commonly known as the lungworm, is a parasitic nematode that affects cattle, particularly dairy calves. Lungworm infections impose substantial economic burdens on dairy producers due to reduced calf growth rates, increased veterinary costs, and decreased milk production in affected animals. Implementing effective control measures can mitigate these losses and improve overall herd health.[113]

The life cycle of *D. viviparus* involves both direct and indirect transmission.[114] The primary host is the bovine, where the adult lungworms reside in the bronchi and bronchioles of the lungs. Female lungworms produce eggs that are coughed up by the host and excreted in the feces. These eggs hatch into first-stage larvae (L1) within the feces and develop into infective third-stage larvae (L3) over a period of several days.[115,116] These L3 larvae of are then ingested by grazing calves during feeding, completing the indirect life cycle. Upon ingestion, L3 larvae penetrate the intestinal wall and migrate through the bloodstream to the lungs. This migration can cause a localized inflammatory response, leading to coughing, respiratory distress, and reduced feed intake. The presence of adult lungworms in the bronchi can further exacerbate the clinical signs and cause chronic respiratory issues.[114]

Lungworm infections commonly occur in grazing systems where calves are exposed to contaminated pastures. The infective third-stage larvae (L3) are ingested during grazing and migrate to the lungs, causing damage to the respiratory tract.[82] Climate, management techniques, and herd immunity factors all influence the seasonal and geographical prevalence of *D. viviparus* infections. The infection in dairy calves can have various detrimental effects, including reduced weight gain and poor feed conversion efficiency.[117] Calves with compromised lung function are also more susceptible to secondary infections, such as bacterial pneumonia, which can significantly impact calf mortality rates. Moreover, respiratory issues in infected calves can result in long-term lung damage, affecting overall health and productivity even after the infection is cleared.[114]

Accurate diagnosis of *D. viviparus* infection involves analyzing fecal samples for the presence of lungworm eggs. Techniques like the Baermann technique or fecal flotation are commonly used to detect these eggs. Early diagnosis is crucial for effective management and intervention.[98,118] Maintaining clean and hygienic living conditions, rotational grazing to reduce exposure to contaminated pastures, and strategic deworming protocols are prevention and control strategies for lungworm infestation in dairy calves. These protocols may involve the use of anthelmintic drugs administered at appropriate intervals to target both adult lungworms and larvae.[109] Anthelmintic medications may be used in these procedures at appropriate intervals to target both adult lungworms and larvae.

Fasciola hepatica (*F. hepatica*) is a digenetic trematode that infests the liver of numerous mammalian species, including dairy calves. *Fasciola hepatica* infections impose substantial economic losses on dairy calf producers due to

decreased growth rates, impaired feed efficiency, veterinary expenses, and potential mortality. Furthermore, the infections may lead to trade restrictions for livestock and animal products.[119,120]

The complex life cycle of *F. hepatica* starts with the release of eggs through bovine feces. Upon reaching aquatic environments, miracidia hatch from eggs and infect specific freshwater snail species. Within the snail, miracidia undergo a series of developmental stages, eventually leading to the emergence of cercariae. Cercariae are released into water bodies and can directly infect cattle by penetrating their skin or being ingested with contaminated herbage.[121] *F. hepatica* larvae migrate through liver tissue, causing inflammation, fibrosis, and tissue damage. This can lead to clinical signs such as anorexia, decreased milk production, and weight loss. Moreover, migrating larvae can cause mechanical damage to bile ducts, obstructing bile flow and inducing cholangitis. Severe infections may result in hepatic necrosis, impaired liver function, and even death.[122]

The distribution of *F. hepatica* is influenced by climatic conditions, grazing practices, and management strategies. The infection prevalence varies seasonally and geographically, with regions characterized by high humidity and abundant vegetation favoring transmission.[121] Accurate diagnosis of *F. hepatica* infection is crucial for effective management. Techniques include fecal examination for eggs using sedimentation or flotation methods, and serological tests like ELISA for detection of specific antibodies. Advanced imaging techniques like ultrasound can aid in identifying liver damage caused by migrating larvae.[123–125]

Anthelmintic drugs, such as triclabendazole, are the primary approach to treating *F. hepatica* infections. However, drug resistance has been reported, requiring monitoring and judicious use of the drugs. Integrated control strategies involve pasture management, grazing rotation, and strategic deworming to reduce transmission risk.[119,126] Preventing the infection involves minimizing exposure to contaminated water and pasture. Proper snail control measures, such as habitat modification and molluscicides, can reduce snail populations.[127] Vaccination against *F. hepatica* has also shown promise in some studies, offering a novel approach to disease prevention.[128]

Strongyloides papillosus (*S. papillosus*) is a nematode parasite that primarily affects young ruminants, especially dairy calves. *S. papillosus* infections contribute to significant economic losses in the dairy industry. Reduced growth rates, increased veterinary costs, and decreased milk production all contribute to the financial burden on producers.[129]

The life cycle of *S. papillosus* involves direct transmission through the fecal-oral route. Infective third-stage larvae (L3) develop in the environment from eggs passed in the feces of infected animals.[130] The infective L3 larvae can penetrate the skin of calves, leading to internal migration through the body of host. This unique feature sets the infection apart from other gastrointestinal parasites, contributing to its persistence and ability to cause chronic infections.[131]

Strongyloides papillosus infection can result in a range of clinical symptoms in dairy calves. These include diarrhea, weight loss, decreased feed efficiency, and reduced growth rates.[132] Furthermore, the migration of larvae in the body of host can cause tissue damage, leading to inflammation and secondary infections. The severity of clinical signs can vary based on factors such as age of the calf, nutritional status, and overall health.[129] Several factors contribute to the prevalence of *S. papillosus* infection in dairy calves, including management practices, environmental conditions, and host susceptibility.[132]

Accurate diagnosis of *S. papillosus* infection is crucial for effective management. Various diagnostic methods are available, including fecal egg counts, larval culture, and serological tests.[98] Differentiating *S. papillosus* eggs from those of other gastrointestinal parasites can be challenging due to their morphological similarity. Molecular techniques, such as polymerase chain reaction (PCR), offer promising avenues for improving diagnostic accuracy.

Implementing effective management strategies is essential to mitigate the impact of the infections in dairy calves. These strategies encompass both preventive and therapeutic measures. Pasture management, rotational grazing, and maintaining proper hygiene in calf housing facilities can help reduce environmental contamination and larval exposure.[109,129] Anthelmintic treatment, based on veterinary recommendations and targeted at the appropriate stage of the parasite's life cycle, remains a cornerstone of control efforts.[100]

Conclusion

Fungal, protozoal, and helminthic infections pose significant health risks for dairy calves. Among the most common pathogens affecting these animals are *Aspergillus fumigatus, Trichophyton verrucosum, Candida albicans,*

Cryptosporidium parvum, Giardia duodenalis, and *Eimeria spp*. Common helminthic infections in dairy calves, caused by parasitic worms including *Ostertagia ostertagi, Cooperia spp., Fasciola hepatica*, and *Strongyloides papillosus*, present significant challenges to the dairy industry. They can cause respiratory diseases, dermatophytosis, diarrhea, weight loss, and decreased growth rates, leading to economic losses and the potential transmission to humans. Preventive measures such as good hygiene and sanitation practices, timely treatment of affected animals, and proper ventilation can help reduce the risk of these infections. Vaccination against ringworm and *C. parvum* is also available and can be useful in preventing these infections. Early and accurate diagnosis of the infections is critical to initiate appropriate treatment with antifungal medications and antiparasitic drugs, as well as provide supportive care and electrolyte therapy. Implementing effective control measures on dairy farms is crucial in preventing the transmission of eukaryotic infections. This not only safeguards the health and welfare of both animals and humans but also minimizes economic losses in the dairy industry. Moreover, further research is needed to better comprehend the epidemiology and characterization of eukaryotic infections in dairy calves.

Acknowledgments

I want to convey our genuine appreciation to the Ethiopian Institute of Agricultural Research (EIAR) for their invaluable aid in this review. Their proficiency and aid have played a crucial role in upholding the precision and excellence of my work. Moreover, I wish to express my sincere gratitude to all the people and entities who have contributed to this review. Their assistance, whether in providing data, perspectives, or comments, has been vital in helping me meet my review objectives.

Disclosure

The authors report no conflicts of interest in this work.

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