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Calf Mortality in the Tropics: Multidimensional Challenges and Implications for Sustainable Dairy Development

Md. Emran Hossain[1], Shilpi Islam[2,*]

Abstract

Calf mortality remains a significant challenge in tropical dairy farming, posing threats to productivity and sustainability. This review explores the multifactorial factors contributing to calf mortality in the tropics, including environmental stress, infectious diseases, nutritional deficiencies, management practices, genetic factors, and social dynamics. Tropical climates, characterized by extreme temperature variations, humidity, and poor shelter, exacerbate stress and compromise calf health. Infectious diseases, such as bacterial, viral, and parasitic infections, coupled with inadequate veterinary care, further elevate mortality risks. Nutritional deficiencies, particularly in essential vitamins and minerals, contribute to weakened immune systems, while imbalanced feeding practices, such as poor-quality forage and excessive concentrate feeding, hinder optimal growth and health. Management-related issues, such as failure in colostrum feeding, inadequate hygiene, and improper handling, also contribute to high mortality rates. Additionally, genetic factors, including inbreeding and hereditary disorders, increase vulnerability to disease and environmental stress. This review highlights the need for integrated approaches to improve calf management, focusing on enhancing immunity through better nutrition and vaccination, reducing environmental stressors, and implementing effective disease control strategies. By addressing these challenges, sustainable dairy development in the tropics can be promoted, ensuring the proper health and welfare of calves.

Keywords: Calf mortality, disease management, dairy farming, environmental stress, genetic factors, immune function, infectious diseases, nutrition, tropical climate

INTRODUCTION

Calf mortality is a significant concern in tropical dairy farming systems, where environmental, nutritional, and management-related factors contribute to high mortality rates. The tropical climate, characterized by extreme temperatures, humidity, and variable rainfall, exacerbates the challenges faced by calves in their early life stages [1]. In these regions, calves are more susceptible to stress, infections, and diseases, which not only impact their survival but also affect the productivity and economic viability of dairy farms [2]. Addressing the root causes of calf mortality is critical to ensuring the sustainability of dairy production in the tropics and improving the overall welfare of the animals.

***Author for Correspondence**
Shilpi Islam
E-mail: shilpi@gau.edu.bd

[1]Professor, Department of Animal Science and Nutrition, Chattogram Veterinary and Animal Sciences University, Khulshi, Chattogram, Bangladesh, India
[2]Professor, Department of Animal Science and Nutrition, Gazipur Agricultural University, Salna, Gazipur-1706, Bangladesh

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The primary factors contributing to calf mortality include environmental stressors, such as heat and cold stress, inadequate shelter, and poor ventilation, as well as infectious diseases like bacterial, viral, and parasitic infections [3]. Nutritional deficiencies, particularly in the early stages of life, further compromise calf health, leaving them vulnerable to infections and impairing their growth

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[4]. Additionally, poor management practices, including failure to provide adequate colostrum, improper feeding, and lack of timely veterinary care, significantly increase mortality rates [5]. Despite various efforts to address these issues, calf mortality rates remain alarmingly high in many tropical regions, highlighting the need for more targeted and comprehensive strategies.

This study introduces a multidimensional approach to understanding calf mortality in the tropics, with a focus on integrating environmental, nutritional, and management-related factors. By analyzing the complex interplay of these factors, the study aims to provide practical recommendations for improving calf survival rates in tropical dairy farming. The novelty of this study lies in its holistic perspective, combining a detailed review of current research with on-the-ground insights from tropical dairy farms. This approach not only enhances the understanding of the underlying causes of calf mortality but also contributes to the development of evidence-based strategies that can be implemented to ensure more sustainable dairy development in the tropics.

NUTRITIONAL DEFICIENCIES

Vitamin A Deficiency

Vitamin A deficiency results in poor growth, weak immune responses, and increased susceptibility to infections in calves [6]. In tropical climates where forages are often deficient in vitamin A, supplementation is crucial for calf health. Ensuring access to quality forage or using vitamin A supplements can prevent deficiency-related mortality, supporting long-term health and sustainability in dairy farming systems.

Vitamin D Deficiency

Vitamin D deficiency in calves leads to improper bone development, growth retardation, and immune suppression [7]. In tropical regions with limited sunlight exposure or poor-quality feed, supplementation with vitamin D is essential for proper calcium absorption and skeletal health [8]. Preventing deficiency through dietary management and supplementation is vital for reducing mortality and enhancing dairy farm sustainability in tropical areas.

Vitamin E Deficiency

Vitamin E deficiency in calves can lead to muscular dystrophy, weakened immunity, and increased risk of infections, contributing to higher mortality rates [9]. In tropical environments, vitamin E intake is often insufficient, particularly when calves are raised on poor-quality or stored feed [10]. Supplementing the diet with vitamin E can prevent these deficiencies, promoting calf health and survival for sustainable dairy farming.

Calcium Deficiency

Calcium deficiency, or milk fever, is a common metabolic disorder in dairy cattle, affecting both calves and adult cows. This condition can lead to weak bones, poor muscle function, and, in severe cases, paralysis [11]. Ensuring proper calcium intake during the early stages of calf development, through quality forages and mineral supplements, can help prevent milk fever and reduce calf mortality rates.

Phosphorus Deficiency

Phosphorus deficiency in calves leads to poor bone development, low growth rates, and reduced immunity, increasing susceptibility to disease [12]. In tropical regions, where phosphorus content in pasture and feed may be low, supplementing with phosphorus is critical for maintaining healthy bone structure and promoting overall calf health [10]. Ensuring adequate phosphorus intake is vital to reducing the risk of mortality in tropical dairy systems.

Magnesium Deficiency

Magnesium deficiency, or grass tetany, affects calves and is typically associated with inadequate magnesium intake from pasture. Symptoms include muscle tremors, convulsions, and in severe cases,

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sudden death [13]. Managing magnesium levels in calf diets, particularly in areas with magnesium-poor soils or pastures, is essential to prevent deficiencies and minimize the risk of mortality in tropical dairy herds.

Energy Deficiency

Energy deficiency in calves, often resulting from malnutrition or underfeeding, leads to stunted growth, weakened immune systems, and increased susceptibility to infections. In tropical regions where feed quality may fluctuate, ensuring calves receive adequate energy from a balanced diet is essential. Proper energy intake is critical for reducing mortality and promoting healthy growth, ultimately supporting sustainable dairy development.

Malnutrition

Malnutrition or underfeeding is a significant contributor to calf mortality, especially in regions where feed resources are limited. Inadequate nutrition impairs growth, weakens the immune system, and increases vulnerability to diseases [14]. Ensuring a consistent and nutritionally balanced diet for calves is key to preventing underfeeding and improving survival rates, contributing to sustainable dairy farming practices in tropical environments.

Protein Deficiency

Protein deficiency in calves leads to poor muscle development, stunted growth, and weak immune responses, increasing the risk of disease and mortality. In tropical regions where feed quality can be variable, ensuring adequate protein intake through high-quality forage and supplements is essential for calf health [15]. Protein-rich diets are crucial for optimal growth, survival, and productivity in sustainable dairy farming systems.

Imbalanced Diet

An imbalanced diet, characterized by an improper ratio of nutrients, can significantly impact calf health, leading to metabolic disorders and growth problems. In tropical dairy farming, feeding calves excessive concentrates or poor-quality forage can lead to nutrient imbalances, impairing health and increasing mortality risk [16]. Ensuring a well-balanced, nutrient-rich diet tailored to the specific needs of calves is essential for promoting healthy development and sustainability in dairy farming.

Excessive Concentrate Feeding

Excessive concentration feeding in calves can lead to digestive disorders, including acidosis and diarrhea, which increase mortality risks [17]. In tropical regions, where forage quality may be low, over-reliance on concentrates as a protein source can disrupt the digestive system [18]. Balancing concentration and forage intake and gradually introducing high-quality feeds is essential to ensure proper digestion and reduce mortality in tropical dairy systems.

Poor-Quality Forage

Poor-quality forage, which is often low in essential nutrients, is a significant factor in calf mortality in tropical regions. Inadequate fiber, vitamins, and minerals in poor-quality forage led to malnutrition, stunted growth, and weakened immune systems in calves [19]. Improving forage quality through better pasture management, fertilization, and supplementation is crucial for enhancing calf health, growth, and survival in tropical dairy farming systems.

MANAGEMENT PRACTICES

Failure to Colostrum Feed

Colostrum feeding is essential in the first few hours of life for providing calves with vital antibodies. Failure to ensure adequate colostrum intake leads to immune system deficiencies, increasing susceptibility to infections and diseases [20]. Ensuring that all calves receive an appropriate quantity of high-quality colostrum promptly after birth is crucial for promoting immunity, growth, and survival in tropical dairy farming.

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Inadequate Milk Replacers

Inadequate milk replacers can result in malnutrition and poor growth in calves, leading to higher mortality rates. When natural milk is unavailable or insufficient, selecting quality milk replacers that meet nutritional needs is essential for calf health [21]. Providing milk replacers with adequate protein, fat, and essential nutrients helps to prevent malnutrition, improve growth rates, and reduce mortality risks in tropical dairy farming systems.

Poor Weaning Practices

Weaning calves too early or abruptly can lead to stress, nutritional deficiencies, and digestive problems, increasing mortality risks. Gradual and proper weaning practices that ensure adequate nutrition and minimize stress are critical for the health and growth of calves [22]. Implementing effective weaning strategies supports the transition to solid feed and reduces the likelihood of complications during this vulnerable stage of development.

Contaminated Water or Feed

Contaminated water or feed is a primary cause of gastrointestinal infections and diarrhea in calves, leading to dehydration and death [23]. In tropical climates, poor storage and handling practices can introduce pathogens such as bacteria and parasites. Providing clean water, safe feed storage, and regular testing of water sources are crucial measures for preventing contamination and ensuring healthy, thriving calves in dairy systems.

Dirty Bedding or Environment

Dirty bedding and unsanitary living conditions contribute to the spread of infectious diseases, respiratory problems, and stress in calves. Inadequate ventilation, wet bedding, and overcrowding exacerbate these issues [24]. Maintaining a clean, dry, and well-ventilated environment is essential to reduce disease transmission and stress, promoting healthy growth and reducing calf mortality in tropical dairy systems.

Trauma from Rough Handling

Rough handling of calves can lead to physical injuries, such as fractures or internal damage, which may result in death [25]. Stress from improper handling, including being dropped or restrained incorrectly, can also lead to weakened immune systems. Ensuring that all personnel are trained in humane handling practices and prioritizing calf welfare helps reduce injury risks and supports healthier, more resilient calves in dairy systems.

Accidental Injuries

Accidental injuries, including falls, kicks from other animals, or equipment-related injuries, contribute to calf mortality. Inadequate facilities, improper handling, and high-stress environments increase the likelihood of accidents. Implementing safe infrastructure, providing sufficient space, and ensuring proper personnel training are crucial to minimizing accidents and ensuring the safety of calves, ultimately improving survival rates and sustainability in tropical dairy farming.

Delayed Treatment of Illnesses

Delayed treatment of illnesses, such as respiratory or gastrointestinal diseases, increases the likelihood of calf mortality [26]. In tropical environments, where diseases can spread rapidly, immediate medical intervention is necessary to manage symptoms and prevent complications. Implementing early disease detection systems and ensuring access to veterinary care are essential practices for minimizing calf mortality and supporting sustainable dairy farming systems.

Improper Vaccination

Failure to administer proper vaccines or follow vaccination schedules results in calves being unprotected against common infectious diseases, leading to higher mortality rates [27]. Ensuring that all calves receive appropriate vaccines at the correct times, according to veterinary guidelines, is crucial

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for building immunity and preventing outbreaks of diseases like FMD and BVD. Effective vaccination practices support calf health and long-term sustainability in dairy farming.

Lack of Health Monitoring

The absence of regular health monitoring significantly increases the risk of undiagnosed diseases, leading to higher calf mortality rates. In tropical dairy systems, frequent changes in environmental conditions can exacerbate health issues. Routine health checks, including growth assessments and disease screenings, are essential to detect early signs of illness and implement preventative measures. Consistent monitoring enhances calf survival and contributes to sustainable dairy development.

PREVENTIVE MEASURES

Calf Diarrhea

Calf diarrhea, or scours, is a leading cause of mortality in young calves, often caused by bacterial, viral, or protozoal infections. Scours can lead to dehydration, malnutrition, and death if not managed promptly [28]. Preventative measures, such as good hygiene, proper colostrum feeding, and timely vaccination, are essential for reducing the incidence of scours and improving calf survival rates in tropical dairy systems.

Bacterial

Bacterial infections, such as *Escherichia coli*, are a common cause of calf diarrhea and other gastrointestinal issues. *E. coli* can lead to severe dehydration, sepsis, and death [23]. Implementing strict biosecurity measures, providing clean drinking water, and ensuring proper sanitation are key practices in preventing bacterial infections like *E. coli*. Early diagnosis and antibiotic treatment are essential for controlling bacterial outbreaks in tropical dairy herds.

Viral

Viral infections, including rotavirus and coronavirus, contribute significantly to calf mortality, often through diarrhea and respiratory distress. These viruses weaken the calf's immune system, increasing susceptibility to secondary infections [29]. Vaccination programs, good colostrum management, and minimizing stress during calving can reduce viral transmission, thereby improving calf health and survival in tropical environments.

Protozoal

Protozoal infections, particularly cryptosporidiosis, are another significant cause of diarrhea and dehydration in calves. This parasitic disease affects the intestines and can cause severe malnutrition and death if untreated [29]. Good hygiene practices, such as cleaning feed and water sources, and the use of specific anticryptosporidial treatments, help prevent the spread of protozoal infections and ensure healthier calves in tropical dairy farming systems.

Respiratory Diseases

Respiratory diseases, including pneumonia, are a major cause of calf mortality in tropical dairy systems. These diseases often result from bacterial or viral infections, stress, and poor ventilation [30]. Adequate housing that minimizes stress, proper ventilation, and prompt treatment of respiratory symptoms are essential management practices that help reduce the incidence of respiratory diseases and improve calf survival rates.

Pneumonia

Pneumonia caused by bacterial and viral infections is a leading cause of death in calves, often exacerbated by environmental factors such as overcrowding and poor ventilation [31]. Pneumonia can lead to severe lung damage, respiratory failure, and death. Early detection, proper housing conditions, and the administration of vaccines and antibiotics are essential strategies to reduce pneumonia incidence and ensure calf survival in tropical dairy systems [30].

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Infectious Bovine Rhinotracheitis

Infectious bovine rhinotracheitis (IBR) is a viral infection that affects the respiratory tract of calves, leading to coughing, nasal discharge, and pneumonia. IBR weakens the calf's immune system, making it more susceptible to secondary infections [32]. Vaccination programs, isolating infected calves, and improving overall herd management practices help control IBR outbreaks, enhancing calf health and reducing mortality risks.

Shipping Fever Complex

Shipping fever complex, also known as bovine respiratory disease complex (BRDC), occurs in calves subjected to stress such as transportation or sudden environmental changes [33]. Stress weakens the immune system, making calves more susceptible to infections like pneumonia. Minimizing transportation stress, providing proper nutrition, and ensuring adequate veterinary care can help prevent shipping fever, improving calf survival and health in tropical dairy farms.

Navel Infections

Navel infections, or omphalitis, occur when bacteria infect the umbilical cord, leading to systemic illness and potential death in calves. This infection is common in calves born in unsanitary environments [34]. Proper cleaning and disinfection of the navel at birth, along with maintaining clean calving areas, are essential practices to prevent omphalitis and improve calf health and survival rates in tropical dairy systems.

Bacterial Contamination of the Umbilical Cord

Bacterial contamination of the umbilical cord is a significant cause of navel infections in calves, leading to septicemia and death. Inadequate sanitation during calving increases the risk of bacterial entry through the navel [35]. Ensuring proper hygiene during the birthing process, disinfecting the navel, and monitoring for signs of infection help reduce the risk of umbilical cord contamination and improve overall calf health and survival.

GENETIC FACTORS

Congenital Heart Defects

Congenital heart defects are among the genetic conditions that can lead to premature calf death. These defects often result in inadequate blood flow, oxygen deprivation, and heart failure. Regular screening and genetic testing for heart defects in breeding programs can help identify at-risk calves, allowing for better management practices and selective breeding to reduce the incidence of such conditions in tropical dairy herds.

Bovine Leukocyte Adhesion Deficiency

Bovine leukocyte adhesion deficiency (BLAD) is a genetic disorder that impairs immune function in calves, making them highly susceptible to infections. Calves with BLAD suffer from recurrent bacterial infections and often have a shortened lifespan [36]. Selective breeding programs aimed at eliminating this genetic defect from herds can significantly reduce BLAD incidence and improve overall calf health and survival in tropical dairy systems.

Brachygnathism

Brachygnathism, or underbite, is a genetic condition where the lower jaw is shorter than the upper jaw, affecting the calf's ability to feed properly. This condition leads to malnutrition, poor growth, and a higher risk of infections. Identifying and culling calves with brachygnathism through genetic testing and breeding for improved jaw alignment is essential to prevent the negative impacts on calf survival and promote herd health.

Inbreeding

Inbreeding reduces genetic diversity within a herd, making calves more vulnerable to genetic disorders and environmental stress. It increases the risk of recessive genetic conditions, leading to

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higher mortality rates and decreased overall herd productivity [37]. To avoid the detrimental effects of inbreeding, dairy farmers must implement genetic management practices, such as introducing new bloodlines and utilizing advanced breeding technologies, to maintain genetic diversity and calf health.

Reduced Genetic Diversity Leading to Vulnerability

Reduced genetic diversity in a herd makes calves more susceptible to diseases, environmental stresses, and genetic disorders, ultimately leading to higher mortality rates [38]. In tropical dairy systems, where external conditions, such as climate and disease pressure, can be severe, maintaining genetic diversity through careful breeding programs and genetic testing is essential to ensure the long-term health and resilience of the herd, reducing calf mortality and promoting sustainable dairy development.

PARTURITION-RELATED FACTORS

Dystocia

Dystocia, or difficult birth, is a major contributor to calf mortality, often resulting from oversized calves, incorrect positioning, or inadequate calving management. Dystocia can cause trauma to both the calf and the dam, leading to injury, asphyxiation, or infection [39]. Proper monitoring during calving, timely intervention, and the use of assisted delivery methods can reduce the occurrence of dystocia, improving calf survival rates.

Oversized Calf

An oversized calf, also known as fetal macrosomia, increases the risk of dystocia during delivery [40]. Calves that are too large for the dam's birth canal are more likely to experience difficult births, leading to traumatic injuries or asphyxiation. Managing maternal nutrition and breeding practices, as well as aiding during calving, can mitigate the risk of oversized calves and ensure safer deliveries for both the dam and calf.

Incorrect Positioning

Incorrect positioning of the calf during birth, such as a breech or malpositioned calf, can lead to complications like obstructed labor, reduced oxygen supply, and injury to both the calf and the mother [41]. Early detection and timely intervention by skilled personnel can correct these positions, prevent injury and improve the chances of a successful delivery, which in turn reduces calf mortality rates.

Premature Birth

Premature birth in calves results in underdeveloped organs and systems, leading to weak calves that are more susceptible to infections, malnutrition, and failure to thrive. Causes of premature birth include maternal stress, poor nutrition, and infections. Improving maternal care, managing stress, and ensuring optimal nutrition during pregnancy can reduce the incidence of premature births and enhance calf survival rates in tropical dairy farming systems.

Retained Placenta

Retained placenta, a condition where the placenta fails to expel after birth, can cause infection, uterine complications, and a delay in the calf's ability to nurse, which can ultimately result in calf mortality. This condition is often associated with poor calving management, nutritional deficiencies, or infections. Timely veterinary intervention, proper calving management, and adequate nutrition can help prevent retained placenta and improve both maternal and calf health.

Inadequate Birth Weight

Calves born with inadequate birth weight are at a higher risk of health issues such as hypothermia, malnutrition, and difficulty suckling [42]. Low birth weight can be caused by poor maternal nutrition, stress, or infections. Ensuring that the dam receives proper nutrition throughout pregnancy, managing stress, and monitoring for signs of poor fetal development can reduce the occurrence of low-birth-weight calves and improve overall survival rates.

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ENVIRONMENTAL FACTORS

Heat Stress

Heat stress significantly impacts calf health in tropical regions, contributing to dehydration, reduced feed intake, and weakened immune systems [43]. Prolonged exposure to high temperatures exacerbates the risk of disease and increases mortality rates. Effective cooling strategies, such as shade provision and proper hydration, are critical to mitigating heat stress and ensuring calf survival for sustainable dairy production.

Cold Stress

Although it is less common in tropical climates, cold stress can still pose a threat to calves in cooler highland areas. Prolonged exposure to low temperatures impairs immune function and increases the risk of respiratory diseases [44]. Adequate shelter and temperature management practices are necessary to maintain calf health, particularly during unseasonal cold spells, contributing to sustainable dairy farming.

Flooding

Flooding, often a consequence of seasonal rains or tropical storms, leads to poor environmental conditions that exacerbate calf mortality. Floodwater can contaminate drinking water, promoting the spread of waterborne diseases. The loss of shelter and grazing areas further stresses calves, reducing growth and survival rates. Managing flood risks is crucial to protect calves and ensure sustainable dairy operations.

Drought

Droughts in tropical regions severely impact the availability of water and forage, crucial resources for calf health and growth. Reduced feed availability leads to malnutrition and increased vulnerability to disease [45]. Calves may suffer from dehydration, weakened immune systems, and lower birth rates. Long-term drought management strategies are essential to ensuring calf survival and sustainable dairy development in these areas.

Poor Shelter

Poor shelter contributes to calf mortality by exposing animals to harsh environmental conditions such as extreme heat, rain, and wind. Inadequate protection from the elements increases the risk of dehydration, infection, and stress. Constructing well-ventilated, temperature-controlled shelters is essential for promoting calf health and reducing mortality, ensuring the sustainability of dairy farming in tropical climates.

Inadequate Ventilation

Inadequate ventilation in calf housing leads to the accumulation of harmful gases, such as ammonia, which negatively affects respiratory health. Poor air quality can predispose calves to respiratory diseases, reducing their chances of survival [46]. Proper ventilation systems in calf housing are essential for maintaining air quality, supporting immune function, and promoting growth, ensuring sustainable dairy farming in tropical environments.

Extreme Temperature Variations

Extreme temperature variations, common in tropical regions, pose significant risks to calf health. Sudden temperature shifts can stress calves, impair immune function, and increase susceptibility to diseases [47]. Consistent and controlled environmental conditions, including shade provision and ventilation, help mitigate the effects of temperature fluctuations, promoting calf survival and ensuring a stable foundation for sustainable dairy production in the tropics.

Overcrowding

Overcrowding in calf housing increases the risk of disease transmission, stress, and inadequate nutrition. Calves in cramped conditions are more likely to experience poor health, leading to higher

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mortality rates [48]. Proper housing design, adequate space, and good management practices are essential for maintaining calf health. Addressing overcrowding is key to ensuring sustainable dairy farming and minimizing calf mortality in tropical climates.

Pollution

Pollution, including air and water contamination, poses significant health risks to calves, leading to respiratory problems, infections, and compromised immune function. Airborne pollutants, such as dust, ammonia, and fumes from nearby industrial activities, can cause lung irritation and stress [49]. Effective management of farm locations, proper waste disposal, and maintaining clean environments can reduce pollution exposure and improve calf health, leading to lower mortality rates.

Airborne Pollutants

Airborne pollutants, such as ammonia, particulate matter, and gases from manure or nearby industrial activities, can cause respiratory distress in calves, leading to pneumonia and other health complications [49]. Prolonged exposure weakens the immune system, increasing susceptibility to diseases. Ensuring proper ventilation, maintaining clean housing, and minimizing pollution sources are key strategies to protect calves from the harmful effects of airborne pollutants and reduce mortality risks.

Contaminated Water Sources

Contaminated water sources, such as those containing harmful pathogens, chemicals, or heavy metals, can lead to diarrhea, dehydration, and infections in calves. Poor water quality is a significant contributor to calf mortality, as it can lead to compromised gut health and weakened immune systems [50]. Regular testing of water sources, proper sanitation, and ensuring access to clean, safe water are essential to prevent contamination-related health issues in calves.

TRANSPORT-RELATED ISSUES

Stress During Transportation

Transportation stress significantly contributes to calf mortality, as it can weaken the immune system and make calves more susceptible to diseases. Factors, such as long travel times, overcrowding, and poor ventilation, exacerbate stress [51]. Minimizing transport duration, ensuring adequate space, and providing comfort can reduce stress and improve calf health, enhancing survival rates during and after transportation in tropical dairy systems.

Trauma During Transport

Trauma during transportation, such as injuries from rough handling or accidents, can lead to severe physical harm or even death. The confined spaces and sudden movements during transport increase the risk of calves sustaining injuries [52]. Ensuring safe loading and unloading practices, providing appropriate vehicles, and handling calves gently can reduce the incidence of transport-related trauma and promote calf well-being during movement.

Dehydration

Dehydration is a common issue during transport, particularly when calves are not provided with adequate access to water or are exposed to high temperatures. Dehydration can lead to a decline in calf health, resulting in weakness, organ failure, or death [53]. Ensuring regular hydration, minimizing transport time, and maintaining a cool environment during travel are key strategies to prevent dehydration and improve calf survival during transportation.

SOCIAL AND BEHAVIORAL FACTORS

Social Stress

Social stress occurs when calves experience aggression or dominance challenges from other animals, leading to fear, anxiety, and weakened immune function. Such stress can increase susceptibility to disease and injury, impacting calf survival [54]. Managing social interactions, ensuring proper group composition, and providing adequate space can reduce social stress, promote healthier calf development and minimize mortality risks.

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Aggressive Interactions with Other Animals

Aggressive interactions, particularly in overcrowded environments, can cause physical injury and stress, leading to weakened health and increased vulnerability to disease. Calves subjected to frequent aggression may experience trauma or nutritional deficiencies due to disrupted feeding [55]. Proper group management, maintaining adequate space, and introducing animals gradually can reduce aggressive behavior and improve calf well-being, thus reducing mortality rates.

Isolation Stress

Isolation stress occurs when calves are separated from their mothers or familiar groups, leading to behavioral disturbances and physiological stress responses. Such stress can impair growth, immune function, and overall health [56]. To alleviate isolation stress, it is essential to ensure that calves remain in familiar, supportive environments or with companions, thereby improving their chances of survival and health during the early stages of life.

Separation From the Dam

Separation from the dam at an early age can cause significant stress for the calf, resulting in poor growth, nutritional deficiencies, and higher susceptibility to diseases. This stress can also impact the bonding process, which is crucial for the calf's emotional and physical development [57]. Minimizing separation, or ensuring gradual and supportive weaning practices, can help reduce stress and enhance calf survival and welfare.

TOXICITY AND POISONING

Plant Toxicity

Plant toxicity, caused by the ingestion of toxic plants, such as Lantana and Jimsonweed, is a significant cause of calf mortality. These plants contain harmful compounds that affect the digestive system, liver, or nervous system, often leading to death if not identified and treated promptly [58]. Proper pasture management, regular monitoring of toxic plants, and providing safe feeding practices can help prevent plant toxicity in calves.

Toxic Plants

Toxic plants, like Lantana and Jimsonweed, pose a major risk to calf health in tropical dairy systems. These plants contain toxins that can cause severe poisoning, leading to symptoms such as vomiting, lethargy, liver damage, or death [58]. Preventing access to these plants through pasture management, early identification, and educating farmers about the risks can significantly reduce the incidence of poisoning in calves.

Mycotoxins in Feed

Mycotoxins, toxic compounds produced by molds in feed, can lead to various health issues in calves, including digestive disturbances, immune suppression, and organ damage. In severe cases, mycotoxin exposure can result in mortality [59, 60]. Ensuring proper feed storage, inspecting mold growth and using mycotoxin binders in feed are effective strategies to mitigate the risks posed by these toxins and enhance calf health.

Chemical Contamination

Chemical contamination from improper handling of farm chemicals, such as pesticides and herbicides, can lead to poisoning in calves, with symptoms ranging from lethargy to death [61]. Ensuring that chemicals are stored and applied correctly, using safe chemicals, and preventing calves' exposure to contaminated feed, water, or environment are critical in reducing the risk of chemical toxicity and promoting calf survival.

Pesticides

Pesticides used in agriculture or animal husbandry can be toxic to calves if consumed in contaminated feed or water. These chemicals can cause a range of health problems, including neurological disorders,

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respiratory distress, and death [62]. Safe application practices, proper chemical handling, and regular monitoring for pesticide residues in feed and water are essential measures to protect calves from poisoning and reduce mortality risks.

Herbicides

Herbicides, commonly used for weed control, can cause poisoning in calves when residues contaminate their feed or water. Symptoms of herbicide poisoning may include gastrointestinal distress, lethargy, and even death. Preventing exposure involves careful management of herbicide application, ensuring adequate time between treatment and grazing, and testing feed for residues to safeguard calf health and minimizing risks associated with chemical toxicity.

POOR IMMUNE FUNCTION

Immunosuppression

Immunosuppression in calves, often induced by environmental stressors, such as heat, transport, or overcrowding, weakens the calf's ability to fight off infections. This condition increases susceptibility to diseases, leading to higher mortality rates [29]. Managing stress, improving housing conditions, and ensuring optimal nutrition can help enhance immune function and reduce the risk of immunosuppression, promoting better calf health.

Stress-Related Immunosuppression

Stress-related immunosuppression occurs when calves experience prolonged stress, which reduces the efficiency of their immune systems. Factors, like transportation, environmental conditions, or poor nutrition, can trigger this response [63]. Minimizing stress by providing a calm environment, proper nutrition, and care can improve immune resilience, reducing the likelihood of infections and diseases that lead to calf mortality.

Maternal Immunoglobulin Failure

Failure of maternal immunoglobulin transfer (failure of passive transfer) results in calves being born with insufficient immunity, leaving them vulnerable to infections. If calves do not receive adequate colostrum within the first few hours of life, their ability to fight disease is compromised [64]. Ensuring prompt and sufficient colostrum feeding is critical to protecting calves from infection and enhancing their survival rates.

Immunodeficiencies

Immunodeficiencies in calves, whether inherited or caused by environmental factors, result in an impaired immune response, making them highly susceptible to infections [65]. These deficiencies can be congenital or develop later in life due to poor nutrition or disease exposure. Early detection, appropriate vaccination, and ensuring proper care can help mitigate the effects of immunodeficiencies and improve calf survival outcomes.

Congenital Immunodeficiencies

Congenital immunodeficiencies are inherited conditions that impair the calf's immune system from birth, making them more prone to infections. Such calves often exhibit repeated illness and higher mortality rates [66]. Genetic screening, selective breeding, and early veterinary intervention can help identify and manage these deficiencies, reducing the impact of congenital immunodeficiencies on calf survival and improving herd health.

INFECTIOUS DISEASES

E. coli Infection

E. coli infections are a major cause of mortality in young calves, especially in tropical regions where unsanitary conditions prevail. These infections often cause severe diarrhea, dehydration, and systemic infections, leading to high mortality rates [67]. Ensuring clean living environments and promoting early intervention with antibiotics and rehydration therapy are essential for preventing calf deaths due to *E. coli*.

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Salmonella Infection

Salmonella infections in calves lead to gastrointestinal disorders, fever, and systemic infection, significantly affecting calf health [68]. In the tropics, where sanitation issues are common, Salmonella thrives, spreading quickly in contaminated feed and water. Implementing stringent biosecurity measures, proper sanitation, and timely vaccination can significantly reduce the incidence of Salmonella and its impact on calf mortality.

Clostridium Perfringens

Clostridium perfringens causes enterotoxemia, a rapid and fatal infection that affects calves, especially in tropical regions where poor feeding practices and environmental stress are prevalent [69]. Symptoms include abdominal pain, diarrhea, and sudden death. Vaccination against *C. perfringens* and improved management practices are key strategies for controlling this deadly disease and reducing calf mortality in tropical dairy systems.

Leptospirosis

Leptospirosis, caused by the Leptospira bacteria, is a zoonotic disease affecting calves in tropical regions. Transmission occurs through contaminated water, soil, or animal urine. This disease can lead to abortion, stillbirth, and calf mortality [70]. Control measures, such as vaccination, controlling rodent populations, and improving water quality, are essential to reduce the prevalence of leptospirosis and ensure calf health and survival.

Tuberculosis

Bovine tuberculosis, caused by *Mycobacterium bovis*, is a slow-developing disease that can lead to chronic wasting, respiratory issues, and eventual death in calves [71]. While less common, its prevalence in certain tropical regions remains a threat to livestock. Early detection, quarantine of infected animals, and proper management practices, including testing and culling, help mitigate the risks of tuberculosis in dairy herds.

Rinderpest

Rinderpest, a highly contagious viral disease, causes severe gastrointestinal symptoms and high mortality in calves. The virus spreads rapidly in areas with poor biosecurity and limited veterinary services [72]. While rinderpest has been eradicated globally, it remains a risk in some regions. Ongoing surveillance and rapid response to any re-emergence are essential to maintaining the progress made in rinderpest eradication.

Foot and Mouth Disease

FMD is a viral infection that causes fever, blisters, and lameness in affected calves, leading to reduced productivity and increased mortality [73]. It spreads quickly in crowded conditions, making it a significant risk in tropical dairy farming. Effective vaccination campaigns, movement restrictions, and quarantine measures are necessary to control FMD outbreaks and protect calves from this devastating disease.

Peste Des Petits Ruminants

Peste des Petits Ruminants (PPR) primarily affects goats but can also impact calves in some cases. The virus leads to fever, nasal discharge, and pneumonia, with high mortality rates [74]. In tropical regions, where mixed farming systems are common, PPR can spread rapidly. Vaccination of cattle and goats, along with improved management practices, is essential for controlling this disease.

Bovine Viral Diarrhea

Bovine Viral Diarrhea (BVD) is a viral infection that affects the digestive and immune systems of calves, often leading to diarrhea, fever, and immunosuppression. BVD can cause significant economic loss due to calf mortality and long-term health issues [75]. Vaccination, biosecurity measures, and testing for infected animals are vital components of managing BVD and ensuring calf survival in tropical dairy systems.

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Protozoa

Coccidiosis, caused by protozoa, leads to severe diarrhea, dehydration, and weight loss in calves. In tropical regions with high humidity and poor hygiene, coccidia thrive, increasing the risk of infection [76]. Preventative measures, including proper sanitation, rotation of grazing areas, and anticoccidial treatments, are essential for controlling this parasitic infection and reducing its impact on calf mortality.

Helminthiasis

Helminthiasis, caused by intestinal worms, is a widespread issue in tropical regions where cattle often graze on contaminated pasture. These parasitic worms lead to malnutrition, anemia, and poor growth, increasing the risk of death in affected calves [77]. Regular deworming programs and improved pasture management are key strategies for controlling helminthiasis and improving calf survival in tropical dairy systems.

Tick-Borne Diseases

Tick-borne diseases, such as babesiosis and anaplasmosis, pose a significant threat to calf health in tropical regions. Ticks transmit protozoal and bacterial infections that cause fever, anemia, and weakness in calves [78]. Implementing tick control programs, including acaricides and pasture management, alongside regular veterinary care, is essential to mitigate the impact of these diseases on calf mortality.

Fungal Infections

Fungal infections, such as ringworm, affect the skin and hair of calves, causing lesions and secondary infections. While less fatal, they can lead to significant health problems, including reduced growth and compromised immune function [79]. Fungal control involves improving hygiene, managing overcrowding, and using antifungal treatments to prevent the spread of infection and protect calf health in tropical dairy systems.

OTHER FACTORS

Age-Related Factors

Young calves are more vulnerable to infections and environmental stressors due to their immature immune systems and physical development [80]. This makes them highly susceptible to diseases like diarrhea, pneumonia, and malnutrition. Ensuring proper nutrition, minimizing stress, and providing timely vaccinations and medical care can help support calf health and survival during the critical early stages of life.

Natural Disasters

Natural disasters, such as earthquakes, wildfires, and floods, can cause widespread devastation, leading to significant calf mortality. These events disrupt food and water sources, damage infrastructure, and create dangerous environmental conditions [81]. Effective disaster preparedness, including contingency plans for evacuation, shelter, and resource distribution, is crucial for mitigating the impact of natural disasters on calf health and minimizing losses.

Lack of Veterinary Access

Limited access to veterinary resources or trained professionals can hinder timely diagnosis and treatment of illnesses in calves, leading to higher mortality rates [82]. This is particularly problematic in remote or underserved regions. Providing better access to veterinary care, offering training to farmers, and establishing mobile veterinary units can help improve calf health management and reduce preventable deaths.

CONCLUSIONS

Calf mortality in the tropics is a complex issue influenced by environmental stress, nutritional deficiencies, infectious diseases, and poor management practices. Addressing these factors through targeted interventions, such as improved nutrition, better disease management, and climate-adapted

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housing, is crucial for reducing mortality rates and ensuring the sustainability of dairy farming in tropical regions. The findings from this study emphasize the need for a holistic approach that integrates these diverse elements to promote calf health and productivity. By focusing on practical, evidence-based solutions tailored to the unique challenges of tropical environments, it is possible to enhance calf survival rates, thereby contributing to the long-term success and welfare of dairy farming in the tropics.

Future Direction

Future research should focus on developing and implementing climate-smart strategies for managing environmental stress, such as heat and humidity, in tropical dairy systems. This includes exploring innovative cooling techniques, shelter designs, and modifications to farming practices that can mitigate temperature extremes. Additionally, more studies are needed to investigate the impact of local feed resources on calf health, with an emphasis on enhancing nutritional interventions to address vitamin and mineral deficiencies. Research on vaccine development and better management of infectious diseases specific to tropical regions is essential to reduce calf mortality. Furthermore, improving the accessibility and quality of veterinary care, along with training farmers in best management practices, will be crucial. Long-term studies evaluating the genetic diversity of dairy herds and their relation to calf survival can also provide valuable insights into breeding strategies that enhance resilience. These combined efforts will promote sustainable dairy development and improve calf health outcomes in tropical regions.

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