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Impact of climate change on ruminant health and Emerging Diseases in Egypt

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ABSTRACT

Climate change is one of the biggest risks to animal health. Although extensive livestock production was one of the major contributing causes of this change. Egypt's climate has unique factors that are influenced by its geographic position. The average temperature throughout the year, relative humidity and heat waves in Egypt were escalating, especially in Upper Egypt. There is a direct and indirect link between climate change and animal diseases, which present as a serious health threat. Ruminants are stressed by meteorological changes, which lower their immunity and make them more susceptible to infections. In ruminant animals, climate change can lead to higher temperatures and humidity levels that facilitate the reproduction, survival, and transmission of certain bacteria, viruses, and parasites that cause diseases. In livestock production, heat stress (HS) is a major stressor as it acts as a severe climate shock. Multiple weather variables contribute to the adverse effects of HS, such as high ambient temperatures, humidity, solar radiation, and wind speeds, which negatively impact animal welfare and productivity. The aim of this review article is to summarize the current state of knowledge regarding the influence of climate and climate change on the health of food-producing cattle and sheep as well as explore its potential relationship with increased incidence of ill bleeding, jaundice and feverish cases in slaughtered animals.

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INTRODUCTION

Climate change represents a significant factor adversely affecting livestock production. The environmental alterations linked to the rising occurrence of heat waves and humidity levels detrimentally impact livestock productivity **(Hussein *et al.*, 2024).**

These climatic shifts may modify various biological processes, potentially leading to behavioural adaptations in animals as they respond to stress. The cellular and molecular transformations are crucial for enabling livestock to endure extreme environmental conditions **(Moss *et al.*, 2000).** The inability of livestock to manage elevated temperatures can lead to detrimental pathological changes in essential organs, observable at both macroscopic and histological levels. Therefore, identifying these cellular alterations is essential for comprehending the mechanisms that facilitate livestock adaptation to HS **(Assumaidaee *et al.*, 2010).** It is particularly important to investigate these changes across various organs, including the heart, lungs, liver, kidneys, lymph nodes, and gastrointestinal tract (GIT), as this assessment is vital for evaluating climate resilience in livestock **(Rebez *et al.*, 2023).**

Examining pathological changes at the cellular level will enhance our understanding of the connection between climate change and animal diseases. This encompasses both the direct and indirect impacts on disease vectors, hosts, and pathogens, along with the complex ecological interactions involved **(Dublin and Ogutu, 2015).** The purpose of this article is to illustrate how climatic fluctuations induce significant histological alterations in various organs of livestock and their implications for ruminant diseases in Egypt.

Egypt's Current Climatic Zone

Egypt, renowned for its rich historical heritage and varied topography, is encountering a multitude of challenges because of climate change. Its distinctive geographical position, which stretches from the Mediterranean Sea in the north to the Red Sea in the east, along with extensive desert regions and the Nile River, renders it particularly susceptible to climatic shifts **(Hamed *et al.*, 2022).** These changes pose serious threats to several sectors, notably agriculture and livestock, which are vital to Egypt's economy and essential for ensuring food security. The increasing temperatures, modified precipitation patterns, and heightened climate variability are fostering conditions that facilitate the emergence and proliferation of various diseases affecting cattle and sheep **(Mohammed, 2023).**

The implications of these climatic changes extend beyond immediate effects on agricultural productivity through higher temperatures may be more immediately detrimental, increasing the heat stress on crops and water loss by evaporation **(Gornall *et al.*, 2010)**, as well as impacting farm incomes and food security **(Dublin and Ogutu, 2015).** As climate patterns continue to evolve, it is imperative for Egypt to implement adaptive strategies to mitigate these effects and ensure agricultural sustainability **(Habeeb, 2020).** These strategies include investment in research and development such as breeding programs for disease-resistant livestock and improved vaccination protocols, enhanced water resource management, and the promotion of sustainable agricultural practices **(Khamees *et al.*, 2022).** By addressing these challenges proactively, Egypt can strengthen its food security and preserve the viability of its agricultural sector in the face of a changing climate **(El-Tantawi *et al.*, 2021).**

To understand the harmful impact of climate change on livestock in Egypt, it is necessary to know the relationship between the geographical location and the seasonal climatic patterns, which have an impact on livestock throughout the year. The summer months (June to September) are marked by extreme heat, especially in southern and desert regions such as Upper Egypt and the Western Desert, where daytime temperatures frequently exceed 40°C **(Nashwan and Shahid, 2019).** In contrast, the winter period (December to February) is characterized by milder temperatures, with daytime highs ranging from 15°C to 25°C. In the northern Delta, nighttime temperatures may drop significantly, contributing to cooler ambient conditions **(Omran *et al.*, 2023).** Spring (March to May) and autumn (October to November) present more moderate conditions, with warm days and cooler nights, which are generally less stressful for livestock **(El-Tantawi *et al.*, 2021).**

Humidity levels across Egypt exhibit considerable variation. The northern coast and the Nile Delta region, due to their proximity to the Mediterranean Sea, experience higher humidity levels **(Zittis *et al.*, 2022).** In contrast, the southern regions, including Upper Egypt and the desert areas, generally have lower humidity, resulting in more arid conditions **(Elkhouly *et al.*, 2021).** Throughout the year, Egypt benefits from abundant sunshine, especially in its desert regions, which contributes to the overall climatic conditions experienced across the country **(Khamees *et al.*, 2022).**

Mechanism of temperature regulation in ruminants

The mechanism of temperature regulation in ruminants represents a significant evolutionary adaptation that allows homeothermic animals to maintain their physiological functions despite fluctuations in environmental temperatures and instances of fever **(McKechnie, 2022).** This regulatory ability also serves as a crucial signal for managing various physiological processes. The reception of temperature is facilitated by peripheral thermoreceptors and thermosensitive units located within the central nervous system **(Xiao and Xu, 2021).**

When the preoptic area of the hypothalamus is warmed, it triggers all physiological and behavioral mechanisms aimed at heat loss **(Mota-Rojas *et al.*, 2021).** In conditions of HS, the rostral cooling center of the hypothalamus is activated, which subsequently suppresses the lateral appetite center, leading to a reduction in food intake and consequently a decline in milk production **(Sesay, 2023).** The body employs various mechanisms, such as vasodilation and sweating, to expel excess heat into the environment **(Lim, 2020).** When the core body temperature exceeds 98.6 °F, vasodilation occurs, increasing blood flow to small arteries in the skin's upper layers, thereby facilitating the transfer of excess heat to the cooler external environment **(Chernobay *et al.*, 2020).** If enhancing blood circulation to the skin fails to sufficiently cool the body, or if the ambient air temperature is higher than that of the skin, the brain signals the sweat glands to release perspiration onto the skin **(Lim, 2020).**

The evaporation of sweat further aids in heat dissipation as it transitions from liquid to vapor **(Shephard and Maloney, 2023).** However, elevated ambient humidity can impede the evaporation rate of sweat, thereby diminishing the body's capacity to regulate heat through this mechanism **(Krishnan *et al.*, 2023).**

The influence of climate change on livestock production

In Egypt, most livestock are raised by small-scale farmers, with government-operated farms accounting for less than 2% of the total production **(Habeeb *et al.*, 1989).** The livestock sector in Egypt primarily relies on water buffaloes, cattle, sheep, and camels, which are essential for annual milk production, while male animals and non-breeding females are utilized for meat production **(Goma and Phillips, 2021).**

Climate change poses both direct and indirect challenges to livestock production. Rising temperatures lead to various health issues in livestock, including HS, metabolic disorders, oxidative stress, and immune suppression, alongside an increased risk of disease **(Ali *et al.,* 2020).** The direct impacts stem from alterations in environmental factors such as air temperature, humidity, precipitation patterns, droughts, and flooding. HS is particularly detrimental, acting as a severe climate shock that threatens livestock productivity**.** The negative consequences of HS arise from a combination of weather variables, including elevated ambient temperatures, humidity levels, solar radiation, and wind speed, all of which adversely affect animal welfare and productivity **(Thornton *et al.,* 2022).** Consequently, livestock experience elevated body temperatures, prompting compensatory and adaptive responses to maintain homeostasis. This condition leads to increased mortality rates, decreased fertility, altered behaviors, and weakened immune systems, rendering animals more vulnerable to diseases **(Das *et al.,* 2016).** Furthermore, climate change adversely impacts livestock by diminishing body weight, reproductive performance, milk production, and meat quality, primarily due to its negative effects on feed intake **(Sejian *et al.,* 2018).** Indirectly, climate change influences animal health and production through factors such as increased microbial density, the spread of vector-borne diseases, and shortages of food and water, as well as the prevalence of foodborne illnesses **(Das *et al.,* 2016).**

Pathophysiology of Extreme Climate Stress in relation to growth parameters of ruminants

The pathophysiological effects of extreme climate stress significantly impair the growth parameters of ruminants, especially in tropical and subtropical regions. Studies indicate that environmental stressors such as high temperatures disrupt various biological and biochemical processes, resulting in adverse impacts on animal health and productivity **(Habeeb *et al.* 1989).** Under extreme heat conditions, animal performance can decline by up to 50% in both male and female ruminants **(Habeeb, 2020).** A study conducted by **Habeeb *et al.,* (2007)** demonstrated that buffalo calves exposed to elevated ambient temperatures of 36.0 °C and 32.0 °C showed significant reductions in daily body gain (DBG) compared to those kept under moderate temperatures of 18.0 °C and 22.6 °C. In a related study, **Habeeb *et al.,* (2009)** found a notable decline in body weight gain among calves during the extreme summer season, with observable individual variation. Further evidence from **Habeeb *et al.,* (2012)** revealed that high ambient temperatures led to significant reductions in DBG among buffalo calves by 18.1%, 17.41%, and 8.65% during the first, second, and third months of summer, respectively. Similarly, **Atta *et al.,* (2014)** reported that calves experienced substantial reductions in weight gain during summer, 55.2%, 60.2%, and 57.4% in the first, second, and third months compared to the cooler winter season. Moreover, **Habeeb *et al.,* (2014)** observed that summer heat stress caused an overall loss of 30 kg in body weight over three months in bovine calves, with a daily reduction of 333.9 g representing a decline of more than 45% compared to gains achieved during winter.

This decline in growth performance is closely linked to reduced daily dry matter intake (DMI) and elevated temperature-humidity index (THI). **Habeeb *et al.,* (2022)** reported a significant reduction in both DBG and DMI as THI increased. Interestingly, while DMI decreased, the decline in DBG was more severe, resulting in a higher DMI-to-DBG ratio (i.e., reduced feed conversion efficiency). The efficiency of converting DMI into DBG improved by 13.1% at a THI of 74.9 during spring and by 33.6% at a THI of 85.5 during summer, compared to winter conditions at a THI of 68.1. This indicates that elevated THI impairs growth efficiency in ruminants, with DBG being more sensitive to climatic stress than DMI.

Climate change effects on milk production in cattle and buffaloes

The impact of climate change on milk production in cattle and buffaloes is significant, particularly since over half of the global cattle population resides in tropical regions. This geographical distribution highlights the vulnerability of dairy farms to HS, which can lead to considerable economic losses in profitability worldwide, as noted by **Wolfenson *et al.,* (2000).** While **Collier *et al.,* (2011)** further illustrated that those temperatures exceeding 35°C trigger thermal stress responses that diminish feed intake, resulting in a negative energy balance that adversely affects milk production. Specifically, for dairy cows without access to shade, each increment above THI value of 71 correlates with a reduction of 0.2 kg of milk yield per day. Additionally, research by **Kamal *et al.,* (1989)** indicates that Friesian cows produce, on average, 30% less milk in hot conditions (38 °C) compared to cooler environments (18 °C). Furthermore, **Lambertz *et al.,* (2014)** observed a decline in the protein content by 19.1% and fat by 24.2% of milk from Friesian cows when temperatures ranged between 8 and 37 °C. Similarly, **Habeeb *et al.,* (2000)** reported that buffaloes experienced a notable decrease in average weekly milk production during the hot summer months compared to winter, with a 16.6% reduction in output for those exposed to elevated ambient temperatures across all lactation stages.

Effects of climate stress on milk and meat production in sheep and goats

The impact of climate stress on the production of milk and meat in sheep and goats is profound, as climate change significantly alters temperature and humidity levels, which in turn affects both productivity and the quality of the products **(Marino *et al.,* 2016).** Research has indicated that increased temperatures have a negative effect on milk yield across various sheep breeds. For example, Comisana sheep experience a 20% reduction in milk production when temperatures rise above 35 °C, while Sarda sheep see a 30% decrease in milk yield when maximum and average temperatures exceed 21°C to 24 °C and 15°C to 21 °C, respectively. Additionally, high temperatures lead to immediate 30% declines in milk production, a 22.9% reduction of fat, and a 23.6% reduction of protein content in Manchego sheep, compounding the difficulties presented by climate change **(Ramón *et al.,* 2016).** Regarding meat production, HS caused by climate change negatively influences carcass characteristics, meat quality, and health safety in sheep. Rising ambient temperatures, along with humidity, solar radiation, and increased body temperatures, induce physiological changes that affect meat color, pH levels, and tenderness **(Ruiz-Ortega *et al.,* 2022).** Moreover, dehydration and metabolic alterations resulting from HS contribute to tougher meat and lower carcass yields, further intensifying the challenges encountered by the sheep industry **(Gregory, 2010).**

The interconnections among climatic change, oxidative stress, immune suppression, and the subsequent pathological alterations in body organs

The impact of oxidative stress on livestock has increased due to climate change **(Omotosho *et al.,* 2024).** Oxidative stress in livestock may be associated with several pathological conditions such as hepatocellular damage **(Lykkesfeldt and Svendsen, 2007).** Environmental changes increase the oxidative stress in the body of an animal; there is an enhanced production of free radicals in the body and a decrease in the antioxidant defense system **(Abeyta *et al.,* 2023).** Besides these, different metalloenzymes, such as glutathione peroxidase, catalase and superoxide dismutase (SOD), are very crucial in the detoxification of superoxide anion and hydrogen peroxide to protect the internal cells from oxidative damage **(Maurya *et al.,* 2015).**

Lipid peroxidation is commonly measured in terms of thiobarbituric acid-reactive substance (TBARS). Erythrocytes, which are rich in polyunsaturated fatty acids (PUFA), on being exposed to high concentrations of oxygen, are highly susceptible to peroxidation damage **(Clemens and Waller, 1987).** The thermal stress increases the oxidative stress in the cell, and this leads to the increase of TBARS in the animals' blood, which leads to increased erythrocyte membrane fragility **(Maurya *et al.,* 2015).** The total serum antioxidant as total carotenes, vitamin E, SOD and catalase peroxidase in farm animals decreases during the summer because of HS **(Mirzad *et al.,* 2018).**

HS has harmful effects on the immune system of livestock by altering the immune function and increasing susceptibility to diseases **(Lacetera *et al.,* 2013).** HS increases the secretion of glucocorticoids, which act as inhibitors of the pro-inflammatory cytokines such as TNF-α, IL-6, and IL-8, initiating the innate immune responses by the inhibition of the p38 MAPK pathway, which maintains the stability of the immune system in animals **(Abraham *et al.,* 2006).**

Impact of Climate change on Vulnerable Organs of Ruminant Animals

Climate change poses significant challenges to the health and functioning of various organs (liver, kidneys, heart, lung and lymph nodes) in farm animals **(Swanson *et al.,* 2020).** Extreme HS associated with climate change can lead to an increase in liver and kidney size. The liver and kidney may appear enlarged and congested due to the accumulation of blood in the organ **(Shokry *et al.,* 2024).** This congestion is a result of the body's attempt to dissipate heat, as the liver plays a crucial role in thermoregulation. Oxidative stress induced by climate change can cause damage to hepatocytes. This damage may manifest as swelling, vacuolization, and even cell death **(Rebez *et al.,* 2023).** Histopathological examination may reveal the presence of inflammatory cells and signs of cellular degeneration **(Assumaidaee *et al.,* 2010).** On the other hand, oxidative damage can lead to glomerular injury, characterized by swelling, thickening of the glomerular basement membrane, and even glomerular sclerosis (hardening) **(Sula *et al.,* 2012).**

Prolonged exposure to high temperatures can cause liver and kidney hemorrhages, particularly in farm animals **(Shokry *et al.,* 2024).** HS can induce vascular damage, leading to bleeding within the liver tissue. Additionally, severe HS may result in liver cell necrosis **(Angel *et al.,* 2018)**. Chronic exposure to environmental stressors and metabolic imbalances can lead to the development of liver and renal cortical fibrosis as well as, in severe cases, cirrhosis of hepatic tissue **(Cooper *et al.,* 2012).** Climate change-induced nutritional imbalances and metabolic disorders can contribute to the development of fatty liver syndrome **(Angel *et al.,* 2018).**

Climate change can impact the immune system's response within the liver. So, increasing susceptibility to infections and inflammatory cell infiltration in liver tissue **(Skibiel *et al.,* 2018).** Chronic inflammation can contribute to the development of liver diseases and compromise the organ's ability to perform its vital functions **(Kahl *et al.,* 2021).** HS causes tubular cell damage, leading to the formation of tubular casts and inflammatory cell infiltration in interstitial tissue **(Pons *et al.,* 2013).** Tubular damage can disrupt the kidneys' ability to maintain electrolyte balance **(Sula *et al.,* 2012).**

Climate change-related factors can influence the activity of liver enzymes, which are crucial for various metabolic processes **(Hrkovic-Porobija *et al.,* 2017).** Changes in enzyme levels may indicate liver damage or dysfunction. For instance, elevated levels of certain liver enzymes, such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST), can be indicative of hepatocellular injury **(Sharma and Kataria, 2011).**

Climate change can lead to the development of pulmonary edema, a condition characterized by the accumulation of fluid in the lungs **(Sula *et al.,* 2012).** This fluid buildup can cause the lungs to appear swollen and congested, impairing their ability to exchange gases efficiently **(Ayroud *et al.,* 2000).**

Increased air pollution and respiratory pathogens associated with climate change can lead to excessive proliferation of bronchial epithelial cells, resulting in the thickening of the bronchial walls **(Rahal *et al.,* 2014).** Bronchial hyperplasia can restrict airflow and contribute to respiratory disorders. In addition, alterations in weather patterns and humidity levels can impact the pleural space surrounding the lungs **(Ayroud *et al.,* 2000).** Pleural effusion, the accumulation of fluid in the pleural cavity, may occur due to increased capillary permeability or inflammatory responses. This condition can compress the lungs and impair their function **(Liu *et al.,* 2018).**

Oxidative stress induced by climatic change can cause damage to the alveolar epithelium and trigger an inflammatory response within the lungs, such as neutrophils and macrophages infiltrating the lung tissue **(Szulc *et al.,* 2020).** Prolonged exposure to environmental stressors and respiratory infections can lead to the development of interstitial fibrosis in the lungs. This condition involves the excessive deposition of fibrous tissue in the interstitial spaces between the alveoli. Interstitial fibrosis can impair lung elasticity and reduce lung capacity, making breathing more difficult **(Szulc *et al.,* 2020).**

HS can lead to cardiac enlargement, also known as cardiomegaly **(Swanson *et al.,* 2020).** The heart may appear enlarged due to an increase in the size of the cardiac chambers, particularly the left ventricle **(Hales, 1973).** This enlargement is a result of the heart's attempt to compensate for the increased metabolic demands and heat dissipation during periods of high temperatures **(Rana *et al.,* 2014).** Additionally, vascular damage and increased blood pressure can result in hemorrhages within the heart muscle **(Hales, 1973).** These hemorrhages may be visible on the heart surface or within the cardiac tissue **(Garofolo *et al.,* 2014).** Environmental changes cause damage to the myocardial cells, swollen and degenerated myocardial fibers, and chronic inflammation accompanied by myocardial fibrosis **(Sejian *et al.,* 2017).**

Climate change-induced exposure to pathogens and increased immune stimulation can lead to lymphadenopathy and hyperplasia within the lymph nodes, particularly B and T lymphocytes, infiltrating the lymphatic tissue **(Rashamol *et al.,* 2019).** Lymphadenopathy may be observed as palpable, firm, and enlarged lymph nodes, particularly in the regions where lymph nodes are concentrated, such as the cervical, axillary, and inguinal areas **(Mancera *et al.,* 2024).** Severe infections and immune-related disorders associated with climate change can result in the development of necrosis and abscesses within the lymph nodes **(Rebez *et al.,* 2023).**

In cases of prolonged immune stimulation, germinal centers may form within the lymph nodes **(Lacetera, 2012).** Germinal centers are specialized areas where B lymphocytes undergo rapid proliferation and differentiation, leading to the production of antibodies**.** The presence of germinal centers indicates an active immune response against specific antigens **(Lacetera *et al.,* 2013).**

The direct and indirect impacts of climate change on ruminants also impose a detrimental influence on the rumen microbes, which leads to significant alterations in rumen structures, as reported by researchers in cattle **(Kim *et al.,* 2020)**, buffalo **(Yadav *et al.,* 2022)**, sheep **(Duffy *et al.,* 2018)** and goats **(Zhong *et al.,* 2019).**

It has been reported that HS directly affects gut integrity and induces innate immune system activation, resulting in systemic inflammation in bovines **(Koch *et al.,* 2019).** HS in goats caused significant changes in histological sections of the rumen, such as the reduction in length and thickness and the higher keratinization of rumen villi, influencing the fermentation **pattern (Chaidanya *et al.,* 2017).** It is proven that HS severely affects the structure of the small intestine, including villi fracture, the shortening of the villus height, deeper crypts and mucosal epithelial cell exfoliation **(Yu *et al.,* 2010).** During HS, the blood flow to the intestine is reduced, leading to ischemia and necrosis of intestinal epithelial cells **(Hall *et al.,* 1999).** HS has been shown to disrupt tight junctions in the intestine, thereby increasing intestinal permeability in multiple mammalian species (**Baumgard and Rhoads, 2013**), including lactating goats **(Wang *et al.,* 2011)** and cows **(Guo *et al.,* 2022).** Besides, the rumen papillae were microscopically examined; it was found that the corneum sloughs off in heat-stressed cattle **(Guo *et al.,* 2022).**

Climate change and Emerging Diseases in Egyptian ruminants

Ruminants Ill-Bleeding in slaughtered animals

When animals are exposed to stress such as that caused by extreme climatic conditions, their bodies activate the fight-or-flight response, a physiological reaction that prepares the organism for immediate action. This response is primarily mediated by the sympathetic nervous system, which triggers the release of adrenaline (epinephrine) and noradrenaline (norepinephrine) **(O'Neill, 2019).**

These stress hormones induce vasoconstriction, particularly in non-essential regions such as the skin, gastrointestinal tract, and kidneys, redirecting blood flow toward essential organs and muscles in preparation for physical exertion **(Farooq *et al.,* 2010).** Additionally, they increase heart rate and cardiac output, thereby enhancing blood flow to the brain and skeletal muscles **(Klotz *et al.,* 2016).** Interestingly, vasodilation occurs in skeletal muscles, where increased blood supply is needed to support physical activity. This vasodilation is facilitated by the release of nitric oxide (NO), a potent vasodilator triggered during stress **(Cheng *et al.,* 2022).**

This stress-induced increase in muscular blood flow also leads to elevated lactic acid production due to anaerobic glycolysis, which muscles rely on for rapid energy. Accumulation of lactic acid adversely affects meat quality post-slaughter **(Mathew, 2002).** Stress also influences the blood coagulation system. Adrenaline can alter the balance of clotting factors, potentially causing hypercoagulability **(Chan *et al.,* 2017).** Moreover, platelet activation is enhanced during stress, making them more adhesive and likely to form clots at injury sites **(Brydon *et al.,* 2006).** However, excessive activation can lead to inappropriate clotting and compromised circulation **(Nijm *et al.,* 2007).** The stress hormone cortisol also plays a role in modulating inflammation and immune response. While acute elevations in cortisol can suppress inflammation, chronic stress may lead to dysregulated immune responses and vascular damage, further complicating bleeding tendencies in stressed animals **(Chrousos, 2000).**

Jaundice in Slaughtered animals

While climate change may not directly cause jaundice, it contributes to its emergence and severity through multiple indirect pathways. For instance, rising temperatures and altered rainfall patterns have expanded the range and activity of vectors such as mosquitoes and ticks, increasing the prevalence of vector-borne diseases that affect the liver and red blood cells. Diseases such as theileriosis, anaplasmosis, babesiosis, and leptospirosis are increasingly reported under such changing ecological conditions **(Beugnet and Chalvet-Monfray, 2013).** While climate change may not directly cause jaundice, it contributes to its emergence and severity through multiple indirect pathways. For instance, rising temperatures and altered rainfall patterns have expanded the range and activity of vectors such as mosquitoes and ticks, increasing the prevalence of vector-borne diseases that affect the liver and red blood cells. Diseases such as theileriosis, anaplasmosis, babesiosis, and leptospirosis are increasingly reported under such changing ecological conditions **(Greifenhagen and Noland, 2003).**

Prolonged HS, a direct outcome of climate change, has deleterious effects on liver function, impairing detoxification and metabolic efficiency, and potentially disrupting bilirubin metabolism, which contributes to jaundice **(Wu *et al.,* 2020).** Nutritional imbalances, particularly vitamin deficiencies (e.g., vitamin K), may also arise from reduced forage quality. These deficiencies impair liver function and blood coagulation, increasing susceptibility to jaundice **(Chaidanya *et al.,* 2015).**

Additionally, climate-related stress can weaken the immune system, rendering animals more vulnerable to infections that target the liver and red blood cells **(Jalali *et al.,* 2018; *Van Dijk et al.,* 2010).** Climate change also affects the distribution of parasites such as liver flukes, whose expanding habitat due to warmer temperatures increases the incidence of hepatic infections and subsequent jaundice in livestock **(Macrae, 2014).**

Animals affected by jaundice often show immune suppression due to compromised liver function, making them susceptible to secondary infections. From an economic perspective, jaundice leads to carcass condemnation or downgrading during meat inspection, causing substantial financial losses to producers **(Strappini *et al.,* 2009).**

Egypt climate zone and adaptive strategies:

Livestock adaptation strategies

Livestock producers have historically adjusted to various environmental and climatic changes by leveraging their extensive understanding of the ecosystems in which they operate. Nevertheless, the growing human population, urban expansion, environmental degradation, and heightened demand for animal-derived foods have made some of these coping strategies ineffective **(Osman *et al.,* 2009).** Furthermore, the alterations induced by global warming are anticipated to occur at a pace that will surpass the ability of both human communities and animal species to adapt spontaneously. The following strategies have been recognized by numerous experts **(Naskar *et al.,* 2015; Thornton *et al.,* 2019)** as methods to enhance adaptation within the livestock sector:

Production adjustments. Modifications in livestock practices may encompass (i) diversification, intensification, and/or integration of pasture management, livestock, and crop production; (ii) changes in land use and irrigation practices; (iii) adjustments in the timing of operations; (iv) conservation of natural resources and ecosystems; (v) alterations in stock routings and distances; and (vi) the introduction of mixed livestock farming systems, such as stall-fed systems and pasture grazing.

Breeding strategies

Numerous local breeds are already well-equipped to endure harsh conditions. Nevertheless, developing nations frequently encounter a lack of technology pertaining to livestock breeding and agricultural initiatives that could otherwise promote faster adaptation. Adaptation strategies not only focus on enhancing livestock tolerance to heat but also on their capacity to survive, grow, and reproduce under conditions of inadequate nutrition, parasites, and diseases **(Hoffmann, 2013).** Such strategies may encompass (i) identifying and reinforcing local breeds that have acclimatized to regional climatic stresses and available feed sources and (ii) enhancing local genetics through cross-breeding with breeds that are tolerant to heat and diseases. There is a pressing need to bolster the capabilities of livestock producers and herders to comprehend and address climate change, thereby increasing their awareness of global transformations. Furthermore, training in agroecological technologies and practices for the production and preservation of fodder enhances the availability of animal feed and mitigates malnutrition and mortality rates within herds **(Osman *et al.,* 2009).**

Livestock management systems

Efficient and cost-effective adaptation strategies must be formulated for the rural poor who cannot afford costly adaptation technologies. These strategies may encompass (i) the provision of shade and water to alleviate heat stress resulting from rising temperatures. In light of the current high energy costs, offering natural (low-cost) shade as an alternative to expensive air conditioning is more appropriate for rural poor producers; (ii) a reduction in livestock numbers – having fewer but more productive animals results in more efficient production and decreased greenhouse gas emissions from livestock farming **(Hoque *et al.,* 2022)**; (iii) modifications in livestock/herd composition (favoring larger animals over smaller ones); (iv) enhanced management of water resources through the implementation of straightforward techniques for localized irrigation (such as drip and sprinkler systems), along with infrastructure to collect and store rainwater, including tanks linked to the roofs of homes and small surface and underground reservoirs **(Thornton *et al.,* 2019)**. Several vector-borne diseases are increasingly affected by climate change, including Rift Valley Fever (RVF), Lyme disease, malaria, dengue fever, West Nile virus, and chikungunya **(Biswas, 2022).** These diseases are worsened by rising temperatures, changes in precipitation patterns, and extreme weather events, which pose increasing threats to animal health **(Chevalier *et al.,* 2015).**

Climate-sensitive infectious diseases often coexist in the same ecosystems; thus, interventions targeting multiple diseases, such as the use of multivalent vaccines like Bovishield (Zoetis), which offers protection against infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), and other respiratory pathogens in cattle **(Chowdhury *et al.,* 2021)**, and Ovinespect (Hipra), a multivalent vaccine for bluetongue and other viral diseases in sheep **(Celma *et al.,* 2013)**, or insecticides like deltamethrin and chlorpyrifos that can manage various vectors, including mosquitoes, ticks, and tsetse flies, would be beneficial and cost-effective **(Okello *et al.,* 2021).**

CONCLUSION

Climate change induced histopathological alterations in all vital organs have revealed that the type and distribution of lesions vary depending on the pathologic processes encountered by the target organ. Further, this review has given a perspective about the broad knowledge deficits in understanding climate change induced pathological changes in livestock. It is pivotal that more work be done to assess and emphasize the impact of climate change on various organs in ruminant animals from a pathological perspective. This review emphasizes that climate change has a harmful effect on the spread of ruminant diseases, which negatively affects the Egyptian economy.

Further study

Egypt Vision 2030 emphasizes the importance of environmental sustainability, striving for a cohesive and sustainable ecosystem. Our objective is to examine various pathogens and the prevalence of infectious and contagious diseases related to livestock and climate change, with the goal of controlling these issues and reducing economic losses. This will be achieved through prompt diagnosis and effective management.

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