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Impacts of Climate Change on Animal Production and Product Quality

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Abstract

Climate change is very challenging for global livestock production because it effects both production efficiency of animals and product quality. The complex impacts of climate change on animal production cover several aspects including effects on animal health, reproduction imparity, alteration of product composition, and concerns about global food security. Frequent heat waves, changing season and precipitation patterns, changes in atmospheric temperature and humidity, and altering disease dynamics affecting livestock productivity either in a direct or indirect way. Reproduction imparity such as poor fertility rate is occurring more frequently among animals due to high ambient temperatures. In addition, climate-induced vegetation changes affecting forage quality that is causing scarcity of feed resources. Water quality is also being affected due to rises in sea level and salination. Among environmental stressor, heat stress is causing the most distress to animals by compromising their health and welfare. Therefore, declining overall profitability for farmers. Apart from this, climate change has a huge impact on animal product quality and composition. Heat stress along with altered forage quality is a potential factor responsible for reduced milk yield, protein, and fat composition in dairy cattle. Meat texture and flavor can also be affected by higher ambient temperatures. High temperature-humidity index (THI) is believed to be negatively affecting most quality parameters in eggs. There is an urgent need to address these challenges by implementing comprehensive mitigation and adaptation strategies such as improved management practice in hot regions, genetic selection of more resilient breeds, and introduction of smart agricultural practices and technologies. Moreover, collaboration among organizations, farmers, and researchers is essential to mitigate the adverse effects of climate change on livestock production and ensure global food security in a sustainable way.

Keywords: Climate, Heat stress, Animal health, Production systems, Milk quality

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INTRODUCTION

Global climate change is currently a hot topic all over the world. It is a complicated challenge with significant influence on the environment, agriculture, livestock, and other social disciplines (Feliciano et al., 2022). Climate change is any prominent change in the natural weather pattern of a region in a specific period (Mahato, 2014).

It is a natural phenomenon, but anthropogenic involvement is influencing the rate of global warming significantly and causing irreversible changes. Earth's temperature rose approximately 1ºC in 100 years (Mikhaylov et al., 2020), resulting in frequent temperature and precipitation changes. Consequences of climate change are now more visible such as the melting of glaciers, rising of sea level, causing reduction of arable land, frequent drought waves, and rising temperature, and projections are that the frequency of natural disasters will increase more and more (Adedeji et al., 2014). Intergovernmental Panel on Climate Change (IPCC, 2021) reported a projected scenario that by 2050 the average temperature rise could be 2ºC per decade if there is no immediate reduction in the current greenhouse gas emissions. Agriculture is among the most susceptible sectors to climate change with implications for livestock and crop production (Mendelsohn, 2008).

Among the agricultural sectors climate change has an adverse impact on livestock production not only related to animal health and productivity, but also associated with their feed resources and processing activities of their products (Godde et al., 2021). Livestock products are very crucial to support the nutritional demands of growing population. According to (FAO, 2020) livestock contributes to 31% and 15% of global protein and energy supply per capita respectively. It has also been reported that the demand for animal products which are high in protein such as red meat will tend to be double in the coming years due to the fact that animals provide high quality products to meet the nutritional requirements of consumers (Michalk et al., 2019; Reynolds et al., 2015). Furthermore, animal products are enriched in micronutrients such as zinc, iron and several essential vitamins which assist in overcoming malnutrition (Randolph et al., 2007). In addition, livestock contributes to several other services such as financial support and resilience of communities, as a fertilizer for poor soils, and transportation services in many countries (Tourrand et al., 2015). Therefore, livestock sector plays a crucial role in sustaining global food security and economy.

The purpose of this review is to address the currents challenges livestock sector is facing due to increased climate change, how animal product quality is affecting as a result of those challenges and what could be the possible mitigation or adaptive strategies towards a sustainable livestock production for the global food security.

IMPACTS OF CLIMATE CHANGE ON ANIMAL

Livestock and climate change have a distinctive relationship as livestock are accountable for climate change at the same time affected by it. The extremities of climate are held responsible for the impairment of livestock potential. Livestock are very susceptible to climatic components such as air humidity, temperature, intense solar radiations, and wind velocity (Sejian et al., 2022).

Temperature changes affect the animal both directly and indirectly. Direct impact comprises ambient temperature-related disease or death in case of extreme weather, while indirect impact is related to problems such as poor adaptation, feed and water scarcity, increased frequency of occurrence of infectious diseases mainly due to the influence of climatic conditions on causative agents, and distribution of food and vector-borne diseases (Nardone et al., 2010).

Direct impacts

Animal health

Livestock being warm blooded animals have ability to sustain their body temperature but prolonged exposure to high temperature negatively affects the animal potential (Sejian et al., 2022). Impact of climate change on animal health stays under the shadow of economical and production losses and often neglected (Godde et al., 2021; Sejian et al., 2022). Among the environmental stressors, livestock are extremely affected by heat stress, which is a great concern of today and future owing to global warming. Animals encounter several physiological and metabolic changes reported in Table 1, under heat stress which adversely affect their overall health (Gonzalez-Rivas et al., 2020).

During the high ambient temperatures animals reduce the feed intake as an adaptive strategy to lower the production of internal heat (Sejian et al., 2022). Exposure to prolonged high temperatures and feed reduction cause negative energy balance (NEB) in animals which is driving force for several metabolic disorders (Nardone et al., 2010). Apart from NEB, animals encounter metabolic and hormonal disruption in heat stress (Li et al., 2020). Cortisol, a well-known stress hormone, is released when hypothalamus-pituitary axis is triggered as a result of heat stress. Furthermore, abnormal secretions of triiodothyronine (T_3) and thyroxine (T_4) occurs which disrupts metabolic activities (Sejian et al., 2022). Non-esterified fatty acids (NEFA), β-hydroxybutyric acid (BHBA) and several other toxic compounds are produced in animal's body as a result of heat stress-induced metabolic disruption. Liver dysfunction, lower plasma cholesterol and albumin content are observed after animals were exposed to higher temperatures (Ronchi et al., 1999). In addition, production of glucocorticoids which severely affects the cytokines by inhibiting their synthesis and causing immune suppression in heat stressed animals has also been reported (Inbaraj et al., 2016). There are several studies present, exposing the negative impacts of heat stress in animals (Bernabucci et al., 2010; Joo et al., 2021; Li et al., 2020; Xia et al., 2022).

Table 1. Physiological and metabolic changes occurring in ruminants and non-ruminants as a result of heat stress. Adapted from (Gonzalez-Rivas et al., 2020).

Physiological changes	*Metabolic changes*
↑Respiration	↑Body fat
↑Heart rate	↑Protein catabolism
↓Feed intake	↓Thyroid hormone
↑Water intake	↑Glycolytic potential
↑Body temperature	↓GIT barrier
↓Carcass weight	↑Intracellular Ca ion
↓Live weight	↑Heat shock proteins
↓Muscle glycogen	↑Acidosis
↓Muscle dry matter	

Animal fertility

High ambient temperature has adverse effects on the reproductive performance of livestock species. Both genders are affected by heat stress (Bernabucci et al., 2010). In females, heat stress causes hormonal impairment which affects the ovulation cycle. Females failed to ovulate because heat stress alter the normal cycles of their reproductive hormones including progesterone, follicle stimulating hormone and luteinizing hormone (Ronchi et al., 2001). Furthermore, females show reduced estrus cycles (Cheng et al., 2022). A study reported that in cattle summer fertility rates reduces significantly due to hormonal suppression and silent heats are more common (Amundson et al., 2006). Sows experience late estrus after parturition and higher mortality rate during birth (Nardone et al., 2010). Research reported that in buffalos, progesterone and prolactin profiles during summer and winter seasons were significantly different. It was stated that during the summer season the plasma prolactin was higher, and progesterone was lower and consequently, infertility rates were higher (Roy and Prakash, 2007). In poultry, heat stress causes delay in ovulation, impaired ovulation process and poor egg hatchability (Ayo et al., 2011; Nawab et al., 2018).

It has been reported that male birds tend to affect more from higher ambient temperatures than females (Cheng et al., 2022). In males, heat stress causes impaired spermatogenesis. Lower quality sperms, poor testicular development, and reduction in fertile sperm production are some defects seen in males (Bernabucci et al., 2010). Major sperm defects are reported in summer bulls as compared to winter bulls and a decline in spermatozoa is observed (Mathevon et al., 1998; Nichi et al., 2006). Poor embryonic development can also occur when animal expose to heat stress during gestation period (Nardone et al., 2010; Naqvi et al., 2012).

Animal production

Climate change directly affects animal production by declining production rates. Lower feed intakes and health related issues in stressed animals are major forces influencing production rates and performance potential (West, 2003).

Milk production

Milk production of ruminants greatly suffers under high temperature and temperature-humidity index (THI) above 72 (Gorniak et al., 2014; Ravagnolo et al., 2000). Studies stated that milk yield decline due to nutrient intake is 35% while heat-induced milk decline during early and mid-lactations are 14% and 35% respectively (Bernabucci et al., 2010; Rhoads et al., 2009; Lacetera et al., 1996). A significant relation between the THI and milk yield of cow is reported that for every unit increase in THI above 69, daily milk yield decreases by 0.41kg (Bouraoui et al., 2002). Thresh hold temperature for dairy cattle is reported to be 26ºC (West, 2003). Sensitivity of cow to heat stress depends on both the stage of lactation and production capacity. In mid-lactation, milk yield losses are higher than early lactation. This is because of nutritional-metabolic condition, as cow becomes more heat sensitive in mid phase as compared to early lactation phase where milk production is also supported by body tissues when feed intake reduces. It has been stated that the production of metabolic heat during early lactation is comparatively lower than in the mid-phase of lactation because metabolic utilization of fat tissue is more efficient as compared to metabolic utilization of feedstuff (Bernabucci et al., 2010).

Furthermore, metabolic heat production in high yielding cows is more than low yielding cows that is why high yielding cows are more likely to be affected by higher ambient temperatures (Abdurehman and Ameha, 2018). Increased metabolic heat production in high producing cows is correlated with milk losses (Purwanto et al., 1990).

Meat and eggs production

Thermal stress affects meat production significantly which make it another critical economic trait (Sejian et al., 2022). All the commercial livestock species are vulnerable to heat stress and relative humidity changes (Gonzalez-Rivas et al., 2020). Reportedly, decline growth rates, body weights, carcass weight, and feed conversion ratio have been observed in animals (Sejian et al., 2022). A study reported that steers exposed to high temperatures showed significant reduction in dry matter intake, daily average gain, carcass weight, and more surveillance of diseases among the herd (Mitlöhner et al., 2001). The outdoor production systems for beef cattle make them particularly sensitive to heat stress and sudden temperature changes (Nardone et al., 2010). Fat and darker hair coat cattle appear to be extremely sensitive to high temperatures (Bernabucci et al., 2010). The threshold temperature above which growth, feed efficiency and dry matter intake in beef cattle are affected is 30ºC if relative humidity is below 80% and 27ºC if relative humidity is above 80% (Hahn, 1999). Pig production is also negatively affected by thermal stress. When encounter higher ambient temperature, fatter pigs produced leaner carcass at slaughter (Nardone et al., 2010). Reduction in meat quality and carcass weight and a decline in average daily gain up to 9.8% is reported in pigs (da Fonseca de Oliveira et al., 2019; Pearce et al., 2013).

In poultry, poor growth performances are observed in hot regions (Zaboli et al., 2019). Broilers show higher mortality rates when the temperature rises above 30ºC (De Basilio and Picard, 2002). Higher susceptibility of broilers to thermal stress is associated with the selection and development of rapidly growing breeds (Berrong and Washburn, 1998). Heat stress significantly reduced feed efficiency, growth rates, carcass weight, daily weight gain, protein concentration in meat, and breast muscle weight (Song and King, 2015).

Deleterious effects of heat stress on layers and egg production are seen (Sejian et al., 2022). In layers, the decline in egg production as a result of heat stress is assisted by reduced feed intake and hormonal disruption (Novero et al., 1991). Problems related to eggshell resistance, egg mass, egg production, daily feed intake and in addition poor eggshell quality are more frequent (Mignon-Grasteau et al., 2014).

Indirect impacts

Feed and water availability

Impacts of climate change on livestock’s feed and water resources are also a point of concern. Apart from direct effect on livestock, climate change associated feed and water scarcity issues are becoming frequent. Droughts and precipitation changes have a huge impact on feed and water supply. Livestock feed is mainly composed of forage and some cereal grains. Forages can be further classified into two large groups grasses and legumes (Cheng et al., 2022). Legumes can be divided into two categories; warm season crops (C_4) and cold season crops(C_3) (Pearcy and Ehleringer, 1984).

It has been observed that C_3 crops (wheat, cotton, soybean) can be influenced by elevated levels of atmospheric CO_2 while C_4 (sorghum and corn) category crops are not influenced by CO_2 (Hatfield et al., 2011). Additionally, high atmospheric CO_2 hugely impacts the herbage growth in C_3 species while having little impact on their grain yields (Chapman et al., 2012). However, temperature increases above 30ºC favors the growth of C_4 species as they benefit from temperature rises strictly depending on production system, area, and species (Hadi et al., 2020). Moreover, corn and soybean production is affected by precipitation (Cho and McCarl, 2017).

Drought causes a significant reduction in the production of most forages (Ray et al., 2018). Not only production rates but also the quality of feed is affected by climate change. Water soluble carbohydrates and nitrogen content of forage decline when the crop is exposed to higher temperatures and water scarcity (Hopkins and Del Prado, 2007). On the other hand, higher temperatures are associated with the lignin content of plants and significantly increase it which has negative impact on digestibility (Polley et al., 2013). Climate changes are also influencing the length of the growing season which is linked to the quality of feedstuff (Abdurehman and Ameha, 2018). These feed changes have a negative impact on livestock when they are being fed. Poor quality forage reduces the feed efficiency rate and lowers the utilization, as a result, livestock produce more methane (Benchaar et al., 2001).

Water demand is increasing all over the world as temperature rises. Animals and humans both are competitive for water as they both need water to ensure optimum body function. According to the estimation of (The World Bank, 2022) agricultural sector alone is responsible for using 70% of freshwater. Animals in tropical regions are drinking 2-3 times more water as they encounter longer hot temperatures (Abdurehman and Ameha, 2018). Rising water demand for livestock production is a point of concern as climate change is adversely affecting the water supply and this scenario is likely to get worse in future. It has been stated that global warming could force the livestock breeders to develop genetically modified animals that require lesser amounts of water (Abdurehman and Ameha, 2018). As a result of temperature rising, water usage per unit is increasing (Gerten et al., 2011). Furthermore, water quality is also declining as a result of salination and rise in sea level (Tully et al., 2019; Juniad and Gokce, 2024). Animals suffer greatly when they drink poor quality water.

Vector-borne diseases

Vector and feed-borne diseases increase as a result of fluctuating climate. Increased temperature and high relative humidity of air provide an ideal scenario for the vectors and pathogens to thrive and cause diseases in animals (Abdurehman and Ameha, 2018). Temperature variations are associated with ability of some insect vectors like ticks, midges, and flies to carry the pathogens (Wittmann and Baylis, 2000). It has been reported that as a result of global warming, an advancement of midges from Africa to northwards has been observed which carries a specific type of virus called bluetongue infecting various livestock species like cattle, sheep, and goats (Maggiore et al., 2020).

IMPACTS OF CLIMATE CHANGE ON ANIMAL PRODUCTION SYSTEMS

Animal production units are suffering from adverse effects as a result of climate change. Livestock species are different in terms of their production systems. Production of animal products from different production systems is reported in Table 2. Mainly, three types of production systems are common; mixed-crop livestock system, grazing or pastoral system and industrial livestock system (Abdurehman and Ameha, 2018). Mixed-crop livestock production system utilizes about 2.5 million hectares and is suitable for rearing all kinds of livestock species (Nardone et al., 2010). Two sub-categories of this system are; rain-fed and irrigated systems. Rain-fed systems are mainly located in Central Africa, Central and Eastern Europe, on the border between Canada and the United States, and India while irrigated systems cover Central America, Central Europe, Eastern and Southern parts of Asia. Grazing or pastoral systems use more than 3 billion hectares of land and cover the areas of Australia, Asia, America, Africa, and Europe. Lastly, the industrial systems are located in Europe, Central and Southern America, and wide parts of Eastern Asia (Nardone et al., 2010).

Table 2. Production of different livestock species from the different production systems (Nardone et al., 2010).

Production Systems	**Milk**	**Ruminant Meat**	**Non-Ruminant meat**	**Egg**
Mixed-crop livestock system	90%	70%	25%	40%
Grazing or pastoral system	-	20% (cattle) 30% (sheep, goats)	-	-
Industrial livestock system	-	6%	70% (poultry) 55% (swine)	60%

Mixed-crop livestock system

Mixed-crop livestock systems comprise beef, dairy cattle, dairy sheep, and dairy goat farming. Climate change affects these systems by influencing animal health, performance, feed availability, and feed quality (Abdurehman and Ameha, 2018). Extreme heat stress is a potential factor affecting these kinds of production systems. Moreover, rain-fed systems are comparatively more vulnerable than irrigated systems (Nienaber and Hahn, 2007). Animal performance is adversely affected by higher temperatures. Furthermore, the effects of heat waves and drought on forage quality and availability are deleterious. Drought-tolerant forage crops could be an answer for future productions while low producing and better thermo-tolerant animals in mixed systems can be foreseen.

Grazing or pastoral system

Grazing systems are mainly for rearing ruminants. In many parts of the world, ruminants are raised extensively in open areas, depending on grasslands and paddocks. Grazing systems are strongly influenced by changes in climate conditions. During summer, animals experience prolonged heat stress, and as a result their production declines. Moreover, extended heat waves are responsible for the surveillance of many vector-borne diseases among those extensively produced herds. Water availability in tropical and sub-tropical regions is also a point of concern due to the reduction in rainfall (Nardone et al., 2010). Technological adaptation and production of heat-tolerant species of both plants and animal can have the potential to sustain these kinds of systems.

Industrial livestock systems

Industrial livestock systems as compared to mixed-crop and grazing system have less influence from climatic changes because of controlled environmental and feeding conditions (Nardone et al., 2010). But they are not completely out of the picture. Industrial systems are dependent on market-feed resources. Projected climate change scenarios describe that there could be reduction in the production of some crops due to water scarcity and alteration in growing parameters which, consequently, decreases industrial livestock production. Cost variation and availability of some grains can significantly disrupt the sustainability of these systems (Nardone et al., 2010).

IMPACTS OF CLIMATE CHANGE ON ANIMAL PRODUCT QUALITY

Climate-induced changes in the livestock sector eventually affect the food products obtained from them. Alterations in production rates and product compositions occur when animals suffer as a consequence of climate change. Temperature changes, especially heat stress, play a major part in this context causing both direct and indirect effects on livestock production. Prolonged exposure to heat causes a decline in feed intake and production of several thermo-regulator components by animals which induce changes in the composition of animal products. Lower- quality products decrease consumer demand as they are unable to fulfill the nutrient requirements of consumers and sometimes adversely affect the consumer's health. Poor-quality products are thus responsible for economic loss of the industry (Warner et al., 2022). The impacts of climate change on milk quality, meat quality, and egg quality are discussed below.

Milk quality

Climate-induced changes such as higher temperatures along with higher humidity levels severely affect milk production, milk quality, and cow's health (West, 2003). Higher temperatures are associated with altering the fat and protein content of milk (Sevi and Caroprese, 2012). An experiment conducted on Friesian Holstein cows showed a decline in the protein content of milk up to 1.3% when cows were exposed to higher THI for an additional hour. A decline of 1.3% in protein content reflects 0.455 mg/liter where the average protein content was 35 mg/liter (Vroege et al., 2023). Heat stress causes alterations in the rumen metabolism especially fermentation of volatile fatty acids (VFAs). Acetic acid and propionic acid are produced as a result of fermentation which are utilized by animal and responsible for milk fat and protein content (Babinszky et al., 2011). A study reported a significant decline in rumen acetic acid content when cows were exposed to 30ºC instead of 20ºC (Bandaranayaka and Holmes, 1976). Reduced feed intake limits the sulfur intake which adversely affects the protein metabolism by microbes and is responsible for lowering the essential amino acids, especially methionine in cow which eventually leads to a decline in milk protein content (Babinszky et al., 2011). It can be said that additional sulfur supplements can somehow reverse the impacts of heat stress on milk protein content.

Meat quality

Meat from animals is a rich source of protein and that's why consumer demand for good quality meat is increasing. Increasing climate changes adversely affect meat-producing animals and as a result, animals undergo stressful conditions.

When a productive animal encounters such events the impact on its product is deleterious. When beef cattle are exposed to higher temperatures, several metabolic and physiological changes occurs in them and their meat color darkens as a result (Adzitey and Nurul, 2011). The dark color of meat is associated with depletion of muscle glycogen reserves which causes an increase in pH. Furthermore, the predominance of purple deoxymyoglobin is also responsible for darker meat (Warner et al., 2022; Suman and Joseph, 2013). Beef cattle produce darker meat in summer as compared to winter months (Hughes et al., 2018). In sheep, exposure to higher temperatures and transportation stress resulted in low glycogen level in muscles (Pighin et al., 2013). Moreover, feedlot beef cattle are at higher risk of heat stress because of continuous exposure to the sun and high energy feed composition (Renaudeau et al., 2012). Meat from feedlot cattle is more vulnerable to show poor quality (Gonzalez-Rivas et al., 2020). A study showed that beef cattle slaughtered in hot weather had significantly higher marbling scores and smaller ribeye areas in comparison with those slaughtered in other seasons (Kang et al., 2009).

Similarly, poultry products are also under the negative influence of climate change. The more improved varieties are more susceptible to elevated temperatures because of faster growth rates and increased metabolic heat production (Gonzalez-Rivas et al., 2020). Heat stress encounters trigger the defensive mechanism in birds, and it has been seen that the plasma thyroid hormone concentrations elevate as a response (Bowen and Washburn, 1985). This response can result in increased incidences of pale soft exudative (PSE) meat. Broilers kept under high ambient temperatures (34-36ºC) from 4 to 6 weeks of age until slaughter, showed higher rates of glycolysis in their thigh and breast muscles demonstrated a reduction in meat pH, higher lactate production, more light-colored meat, cooking loss, and Warner-Bratzler shear force (WBSF) as compared to those kept under thermoregulated conditions (23ºC) (Zhang et al., 2012). Furthermore, oxidative modification of proteins and lipids has been reported in chickens exposed to heat stress (Lu et al., 2017).

Egg quality

The quality of eggs is also compromised as a result of climate change. Heat stress negatively affects egg production and quality in layers. Several studies have shown that higher ambient temperatures can cause feed intake reduction, lower body weights, reduced fertility rates, and egg masses. A study reported that birds raised in hot environments had significantly lower-quality eggs in terms of egg weight, shell thickness, shell weight, and specific gravity (Mashaly et al., 2004). Poor shell quality eggs are generally not prioritized by consumers. Another study found that egg yolk color and Haugh unit of eggs from layers kept under 85 THI were significantly reduced as compared to 68, 72, and 78 THI groups (Kim et al., 2024). Higher relative humidity affects the eggshell weights, eggshell thickness, Haugh unit, yolk weight, and albumen weight (Kim et al., 2022). Furthermore, (Allahverdi et al., 2013) stated that as the temperature rises from 22ºC to 36ºC for laying hens, their egg weights and specific gravity tend to decrease.

MITIGATION AND ADAPTATION STRATEGIES

The threat of climate change to the food production systems, especially livestock production systems is a prevalent motivational factor for livestock producers to take voluntary actions against climate change. Climate change is a serious threat and many organizations worldwide are working to reduce or mitigate the impacts of climate change.

The livestock sector needs a better understanding of the threat, and more exploration should be done to cope with the existing challenges. However, several models are being implemented in the livestock sector to mitigate the risks related to climate change that have proved to be effective. Heat stress is a great threat to animals, and it causes detrimental effects on animal health and production. It is crucial to alleviate the impact of heat stress to sustain animal production. Providing cooling and shading areas for cows is a common practice in farms to reduce the heat impact. This strategy resulted in a significant improvement in cattle performance and yield (West, 2003). Breed selection is also important in this context. It has been reported that indigenous, adaptive, or high thermo-tolerant breeds perform much better than imported breeds in hot regions (Osei-Amponsah et al., 2019). Furthermore, there should be genetic modifications of breeds to tolerate higher temperatures. Similarly, genetic modifications of forage crops against drought and hot conditions should be done. Apart from genetic selection, nutritional management plays a vital role. Animals should be provided with a high-energy and nutritive diet in hot environmental conditions as they reduce their feed intake. Rotational grazing systems can be used to minimize damage to pasture and lands (Gomez-Zavaglia et al., 2020). Additionally, training livestock farmers about climate challenges and mitigation strategies is of utmost importance.

CONCLUSION

Climate change poses a great risk to all food production systems including livestock. The vulnerability of the livestock sector increases as it is greatly affected by several climate variables. From heat stress to surveillance of vector-borne diseases and scarcity of water and feed resources for animals, all are great points of concern for the world. Livestock contributes to global food security and provides a wide range of essential nutrients to consumers. Furthermore, the economic status of this sector is also huge and is a source of income and sustainability for many households around the world.

Climate-induced changes are adversely affecting animal productivity, growth, welfare, reproduction, composition of animal products, forage quality, feed, and water supply. Stressful thermal conditions can catastrophe the production rates of most livestock species. The extended impacts on livestock production systems are convoluting the sustainability of the sector. In addition, climate change is responsible for altering the composition of animal-origin food. Reduction in protein and fat content of milk and certain nutrients in meat and eggs are consequences of poor animal performance as a result of temperature changes.

There is a need to do more intensified research on various environmental stressors other than heat stress which is predominantly known in depth. Furthermore, detailed information about the consequences of climate variables on product quality is still limited and needs to be explored more. The development of more effective mitigation and adaptation strategies considering sustainability of the sector should be proposed more often. It is recommended to establish digital agriculture frameworks in the livestock sector to reduce emissions and hence, to eventually lower the impact of climate change.

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