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THE EFFECTS OF CLIMATE CHANGE ON ANIMAL NUTRITION, PRODUCTION AND PRODUCT QUALITY AND SOLUTION SUGGESTIONS

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Abstract: This article has been prepared to examine the effects of heat stress on livestock nutrition, yield and product quality, and to reveal strategies for adaptation and mitigation of climate change. Global climate change is primarily caused by greenhouse gas emissions, which result in warming of the atmosphere. Therefore, soil, air, water pollution and reductions in biodiversity may occur. At the same time, climate change can directly and indirectly affect livestock and animal nutrition. Heat stress results from inability to dissipate enough heat to maintain homeothermy of the animals. High ambient temperature, relative humidity and radiant energy compromise ability to dissipate heat of the animals. Ruminants, pigs and poultry are susceptible to heat stress due to their species-specific characteristics such as their metabolic rate and growth, high yield levels, rumen fermentation, sweating disorder and skin insulation. The indirect effects of climate change on livestock are changes in crop and forage production and quality, decrease in pasture/rangeland quality as a result of decrease in biodiversity and decrease in water availability. The direct effects are on the feed and water consumption, growth, milk, meat, egg, wool/hair and honey yield and product quality of the animals. These effects are primarily the result of a combination of temperature and increase in atmospheric carbon dioxide concentration, variation in precipitation, and relative humidity. Heat stress can cause significant losses in animal production, some of these may be immediate and some may be delayed. Animals under heat stress can decrease feed consumption to reduce metabolic heat. The decrease in feed consumption may cause a decrease in the growth rate of animals, decrease in milk, meat, egg, wool/hair yield and quality. The rations of animals can be manipulated to mitigate the negative effects of climate change.

Keywords: Climate change, Heat stress, Animal nutrition, Production, Product quality, Solution suggestions

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1. Introduction

The combination of elements such as temperature, air movement, barometric pressure, radiation, humidity, precipitation and ionization creates the climate. In many parts of the world there can be differences in climatic zones, the reason for these differences is latitude, winds, evaporation conditions, water availability, altitude, proximity to mountains, etc. are factors (West, 2003). The climate system is under the influence of its own internal dynamics and may change over time depending on the changes in external factors affecting the climate. Climate change is a natural phenomenon that has occurred throughout history. In recent years, the term 'climate change' has mostly been used to describe changes in the Earth's climate. These changes started from the pre-industrial period (from about 1850) primarily by human activities. The use of fossil fuels, which causes a relatively rapid increase in the CO_2 concentration in the world's atmosphere, and the removal of forests are the biggest reasons for these changes (Pachauri et al., 2014).

Climate change includes not only rising average temperatures, but also extreme weather events, changing wildlife populations and habitats, sea level rise, changes in river flows and water levels, and many other effects. While precipitation is increasing in some parts of the world, others are experiencing severe droughts, increasing the risk of wildfires, crop loss and drinking water shortages (IPCC, 2021). The human population is expected to increase from 7.2 to 9.6 billion by 2050, and this corresponds to a population increase of 33% (UN, 2013). The demand for animal products is also increasing for the adequate nutrition of the increasing human population. Therefore, even as average global temperatures increase and precipitation patterns change, the increasing demand for food must be met. The impact of extreme climatic conditions and seasonal fluctuations on feed quality and quantity is considered a compelling source of influence on animal welfare. Animals grazing in poor pasture conditions in arid and semi-arid regions are exposed to malnutrition. In extremely hot environments, the productivity of animal decreases due to the lack of sufficient and quality feed (Naqvi et al. 2015). In a dry and warm environment, animals expend a lot of energy because they have to walk long distances to find food and water. Thus, in addition to many other factors, the quality of animal products is probably most affected by feed quantity and quality. Therefore, most of the research has focused on improving the quality of animal products through manipulations in animal nutrition (Babinzski et al., 2011). Animal nutrition strategies should be developed and solutions found to reduce the negative effects of global climate change on animal nutrition.

2. Global Climate and Global Warming

The global climate is the interconnected system of everything humans do, with the sun, earth and oceans, wind, rain, snow, forests, deserts and savannas. Very important changes in the global climate are occurring. Climate change refers to long-term changes in temperatures and weather patterns. These changes can be natural, such as changes in the solar cycle. But since the 1800s, humans primarily burning fossil fuels such as coal, oil and gas, cutting and burning forests and producing lime have been the most important drivers of climate change. Climate change is primarily caused by greenhouse gas emissions, which result in warming of the atmosphere. It is a term often used interchangeably with climate change, as one of the most important measures of global climate change is global warming. Global warming refers to the increase in average global temperatures associated with significant impacts on people, wildlife and ecosystems around the world (IPCC, 2021). Three important gases, mainly CO_2, CH_4 and N_2O are shown as the main causes of global warming and climate change. The ones that increase greenhouse gas emissions the most are CH_4 (%44), N_2O (%29) and CO_2 (%27) (IPCC, 2013). The livestock sector contributes to 14.5% of global greenhouse gas emissions (Gerber et al., 2013). In addition, the increase in the level of water vapor in the atmosphere contributes to global warming. Climate change and heat stress affect livestock health and productivity, natural resources, quantity and quality of feed, and animal production through loss of biodiversity (Chapman et al., 2012).

2.1. Temperature and Relative Humidity

Animals are adversely affected by the harmful effects of extreme weather conditions. The effects of climatic extremes and seasonal fluctuations on feed quantity and quality can affect livestock welfare, leading to reductions in production and reproductive efficiency (Sejian et al., 2013). The quantity of heat stress is generally related to relative humidity. The increase in relative humidity with the ambient temperature exceeding the normal limits (5-25 °C) adversely negatively affects the thermoregulation ability of the animal. As the relative humidity increases, the lower the temperature at which a dairy cow shows signs of heat stress. For example, the most suitable environmental conditions for dairy cattle; it is defined as an ambient temperature of 13-18 °C and a relative humidity of 60-70% (McDowell, 1972). This relationship between ambient temperature and relative humidity has led to the development of the Temperature-Humidity Index (THI) (Table 1).

Table 1. Temperature and humidity index values for animals (NADIS, 2017)

C	20	30	40	50	60	70	80	90	100
22	66	66	67	68	69	69	70	71	72
24	68	69	70	70	71	72	73	74	75
26	70	71	72	73	74	75	77	78	79
28	72	73	74	76	77	78	80	81	82
30	74	75	77	78	80	81	83	84	86
32	76	77	79	81	83	84	86	88	90
34	78	80	82	84	85	87	89	91	93
36	80	82	84	86	88	90	93	95	97
38	82	84	86	89	91	93	96	98	100
40	84	86	89	91	94	96	99	101	104

Green= heat stress moderate, Yellow= heat stress acute, Red= deadly, THI= temperature humidity index.

According to the Table 1, when the THI value is 71 and below, the animals are not affected by heat stress, when the THI reaches 72, the cows show signs of moderate heat stress, if the THI is between 72-79, some yield losses may occur, and when the THI is 80 and above significantly affected by the heat stress of the animal.

2.2. Thermoneutral (Comfort) Zone for Animals

The heat produced during the digestion, excretion and metabolism of nutrients is called "temperature increase". The temperature range in the immediate environment where a healthy adult animal can maintain its normal body temperature without needing to use energy outside of its normal basal metabolic rate is called the “thermoneutral zone” (Metze, 2016). In other words, the range of environmental conditions in which an animal can regulate its heat excretion with minimal effort is defined as the “Thermo neutral zone”. In a thermoneutral environment, the animal's heat production is minimal and therefore dietary energy can be used efficiently for production (growth, meat, milk, eggs, etc.). The thermoneutral zone in cattle differs according to race, age, sex, reproduction and lactation status, and milk yield and milk composition. The thermoneutral zone for dairy cattle is between 13.9 °C and 27.2 °C, within this range the changes in core body temperature are minimal. The thermal comfort zone (TCZ) represents the range of ambient temperatures at which an animal feels thermally comfortable (Figure 1) (Curtis, 1981).

Homeotherms (warm-blooded) have zones of optimum temperature for production, where no additional energy is spent above the HP requirement to warm or cool the body. The upper critical air temperature for dairy cows has been reported to be 25 to 26°C (Berman et al., 1985).

3. Heat and Cold Stress in Animals

The heat dissipation capacity of animals due to high temperature and humidity is exceeded and there is an increase in body temperature beyond physiological limits, this situation is called heat stress (Ronchi et al., 1997). Extreme heat in the summer can adversely affect grazing animals and cause nutritional imbalances. In the arid and semi-arid tropics, insufficient and poor quality feed is the most important factor in animal malnutrition.

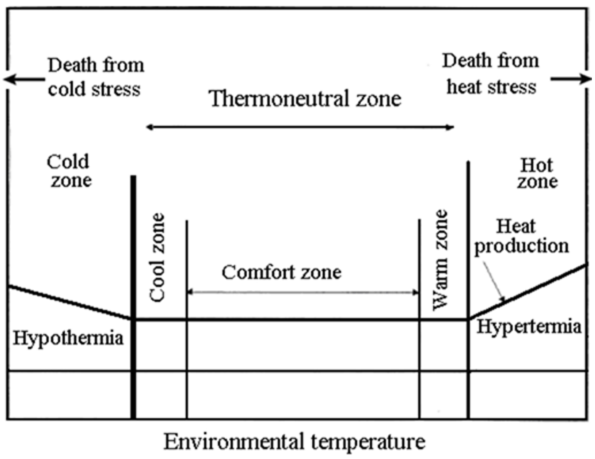

Figure 1. Thermoneutral Zone for dairy cattle (Curtis, 1981).

Cold stress (low critical temperature) is the animal body's response to low temperatures when the ambient temperature falls below the thermal neutral zone. Cold stress is the opposite of heat stress (upper critical temperature). If the environmental temperature falls below the thermal neutral zone of the animal, its body's metabolic rate increases (Metze, 2016). Cold stress can also be critical for more on rangeland grazing animals. As cold stress causes an increase in basal metabolic rate, it also causes an increase in additional energy requirements. Thus, in ruminants; rumination, digestive system activity, feed and fluid passage rate increases and digestion ends in a shorter time. This rapid digestion results in a reduction of energy from feed consumption (Navratil et al., 2015).

4. The Effects on Animal Nutrition of Climate Change

According to the studies and reports, it is understood that the average temperature of the world has increased and will continue to increase, and this will have a significant impact on agricultural production. Heat stress has direct and indirect effects that negatively affect the health, nutrition and productivity of animals. The direct effects are primarily due to increased temperatures and the frequency and intensity of heat waves. The most important direct impact of climate change on animal production is due to heat stress. These environmental conditions cause metabolic disturbances, oxidative stress, infections and impaired immune system in animals and may adversely affect animal health (NRC, 1981; Gaughan et al., 2009). Indirect effects are those related to changing the availability and quality of feed raw materials and drinking water (Lacetera, 2019). Drought caused by climate change affects water availability, quantity and quality of forage production, rangeland vegetation diversity, this, in turn, leads to reduced feed consumption, malnutrition, reduced body weight, reduced reproductive efficiency and weakened resistance to diseases of animals (Naqvi et al., 2015).

4.1. Effect on Rumen Metabolism of Climate Change

4.1.1. Cattle

High ambient temperature in summer can have a significant impact on rumen physiology, which in turn affects the nutritional status of animals. Heat stress may cause deterioration in rumen physiology, decrease in rumination, rumen activity and reticulo-rumen motility, metabolic disorders, slowdown of digestive transit rate and decrease in production performance (Nardone et al., 2010; Yadav et al., 2013). It has been determined that when Holstein heifers are exposed to ambient temperatures ranging from 20°C to 33°C, the rumen pH decreases (Tajima et al., 2007), and the rumen microbial population of cows changes at high ruminal temperatures (Yadav et al., 2013; Correia Sales et al., 2021). Microbial change in the rumen is important in determining the digestibility of fibrous feeds, feed transition rate, growth rate and feed consumption of ruminants. It is known that the degradability of roughage in the rumen depends on the presence of microorganisms (bacteria, protozoa and fungi) in the rumen (Özel and Sarıçiçek, 2009). The residence time of the feeds in the rumen varies according to the temperate and tropical regions, this suggests that the potential degradability of feeds may be affected by climate and ambient temperature.

Since heat stress causes an increase in lactic acid concentrations in ruminants, it reduces the animal's production, energy availability and lowers the rumen pH, the rumen water content rises, and accordingly the osmotic pressure of the rumen fluid decreases (Yadav et al., 2013). The electrolyte concentration (K and Na) in the rumen fluid of the cow under heat stress decreases, which causes loss of Na in the urine and K loss from the skin, feed consumption is reduced and the rumination period is shortened (Sammad et al., 2020), due to the shortening of the rumination period, the secretion of saliva, which acts as a buffer, also decreases (Meneses et al., 2021). It was determined that the ammonia nitrogen (NH3-N) concentration of ruminants exposed to heat stress also decreased significantly. This indicates that heat stress can also affect rumen fermentation and digestion of dietary proteins and the metabolism of other nitrogenous compounds (Cai et al., 2019).

In heat stress, the acetate ratio in the rumen decreases and the butyrate ratio increases (Cai et al., 2019). The reduction in acetate may be the result of the reduction in the presence of acetobacter (Zhao et al., 2019), in addition, total volatile fatty acids (VFA) and propionate concentrations in the rumen of animals under heat stress are significantly reduced. Concentrated feed consumption increases significantly during heat stress, this causes an increase in propionate production (Uyeno et al., 2010). Decreased feed consumption and changes in the amount and/or activity of microorganisms in the rumen are important factors affecting VFA production (Özel and Sarıçiçek, 2009). It is also stated that changes in VFA concentrations in the rumen may be due to the increase in water consumption of the animal and the high water content in the rumen (Cai et al., 2019). Although the rumen contains the greatest number and diversity of bacteria, ciliate protozoa that affect the production of VFAs can account for about half of the rumen microbial biomass. In addition, heat stress may cause changes in the amount of other microorganisms such as anaerobic fungi, archaea and protozoa (Özel and Sarıçiçek, 2009). While acetic acid, one of the volatile fatty acids produced in the rumen and transported to the bloodstream, is mainly used in lipid synthesis, the level of propionic acid affects the protein content of milk. The decrease in feed consumption due to high ambient temperatures causes a decrease in sulfur uptake, which negatively affects the methionine synthesis of rumen bacteria. Decreased microbial protein synthesis or inhibition of methionine synthesis, which has a very important role in meeting the protein needs of ruminants, causes a significant decrease in milk protein (Sarıçiçek, 2007).

4.1.2. Buffalo

Omran et al. (2011) determined that the adaptation process of the rumen is significantly affected when the buffalo is exposed to heat stress in the laboratory environment at 40°C and 25°C. Rumen movements in buffaloes are slower than in cattle, and the rate of passage of digested content through the rumen is lower (Sarıçiçek, 2007). According to Wang et al. (2012), heat stress changed the rumen fermentation of water buffalo, in particular, it caused a decrease in the concentration of acetic and butyric acid, which are the precursors of fatty acids and total cholesterol. Rumen fermentation provides a dynamic response to changes in rumen microorganisms. Among the microorganisms (archaea, fungi, protozoa and bacteria) in the rumen of the buffalo under heat stress, the most changes were seen in bacteria. While heat stress did not have a significant effect on the alpha diversity of rumen bacteria, visible changes in the β-diversity of the bacterial community were detected (Wang et al., 2022).

4.1.3. Goat

It decreased rumen pH level and rumen fermentation (Castro-Costa et al., 2015), decreased rumen VFA production (Choubey and Kumar, 2012), acetate and acetate/propionate ratios and increased butyrate production (Tajima et al., 2007) of Murciano-Granadina dairy goats exposed to heat stress. Hirayama et al., (2004) stated that Saanen goats exposed to heat (35 °C) had a decrease in plasma acetate and VFA concentrations compared to those kept in thermoneutral conditions (20 °C), which was caused by the reduction in feed consumption and the change in the rumen microbial population. Pragna et al. (2018) determined that rumen acetate concentrations decreased in Osmanabadi and Malabari goats exposed to heat, whereas there was no change in Salem goats. This suggests that there may be differences between varieties against heat stress.

4.2. Effects on Feed Consumption of Climate Change

The relationship between the increase in ambient temperature and body temperature and dry matter consumption (DMT) has been explained (West, 2003). The terms appetite and hunger need to be explained to explain the animal's desire to consume food. appetite; the desire to eat a previously tried and admired food, hunger; It is the state of saturation felt by the animal as a result of the animal's inability to get the nutrients it needs and insufficient nutrition (mechanical and physiological) (Sarıçiçek, 2007). Ghrelin is a hormone secreted by ghrelinergic cells in the gastrointestinal tract when the stomach is empty, it increases hunger and gastrointestinal motility (Pearce et al., 2014). Decreased appetite and feed intake due to heat stress may result in a decrease in metabolic body weight, and as a result, the animal may enter physiologically negative energy balance, and then is decrease in body condition score of the animal (Rhoads et al., 2009).

4.2.1. Cattle

Since there is a significant reduction in feed consumption under heat stress, nutrient deficiency occurs due to the interaction between stress and feeding. The reason of decrease in feed consumption may also be the result of the longer filling of the digestive tract and the decrease in the passage rate of digestion (Rana et al., 2014). Animals under heat stress reduce feed consumption to lower metabolic heat. In a hot environment, the ability to lose heat is limited when the air temperature is above the upper critical temperature, therefore, livestocks reduce feed consumption to maintain thermal balance, thus reducing the temperature rise (Kadzere et al., 2002). Studies show a strong negative correlation between rectal temperature and feed consumption in pigs, poultry and dairy cows during heat stress. High ambient temperature causes hyperthermia in the body, this reduces the activity of the appetite center in the medulla oblongata. Therefore, feed consumption decreases proportionally with the increase in ambient temperature (Brown-Brandl et al., 2001).

Feed consumption starts to decrease at an average temperature of 25-26 °C in lactating cows, and this decrease is faster at temperatures above 30 °C (NRC, 1989). Since there is an inverse relationship between high temperature and DMI, it was observed that feed consumption was suppressed after one day from the increase in high (29 °C, 50% RH) temperature (Spiers et al., 2004). According to NRC (2001), DMI decreases by 40% at 40 °C ambient temperature. In beef cattle, feed consumption starts to decrease at an ambient temperature of about 30 °C with <80% RH or 27 °C with >80% RH (Bernabucci et al., 2010).

4.2.2. Buffalo

The fact that the buffalo has dark skin and sparse hair causes the sun's rays to be absorbed at a high level (Dayal et al. 2017). In addition, the underdeveloped sweat glands of buffalo weakens their heat dissipation capacity, making them highly susceptible to global warming (Bombade et al., 2018). With the increasing effects of climate change, the heat stress problem for buffalo is likely to worsen. Heat stress in buffalo starts at THI 72, THI above this cannot maintain the heat balance, which causes a decrease in DMI and an increase in respiratory rate (Gu et al., 2018).

Buffalo are also very sensitive to cold stress and cannot maintain their internal temperatures in the thermo-neutral zone. According to Omran and Fooda, (2013), under environmental conditions in Medill Egypt there may be THI>87 for Friesians, while this threshold is THI>91 for buffaloes, this may be dangerous for Frisians. The best THI for production in both species is lower than 68, but at this threshold also Buffalo are under cold stress. Under native Egyptian conditions, Friesians are more tolerant of cold but more sensitive to heat than buffaloes.

4.2.3. Goat

It is known that due to the lip structure and foraging habits of goats, they can be satisfied with limited feed especially in arid and semi-arid regions and have the ability to evaluate low quality feeds (Sarıçiçek, 2007). Although goats are more resistant to heat stress, they are affected when exposed to temperatures above their comfort zone. While the upper critical temperatures for goats at the maintenance level were determined as 25°-30 °C', the critical temperature was not determined for growing and lactating goats (Gupta and Mondal, 2021). Goats looking for forage in open areas for most of the day are sensitive to heat stress. Feed consumption decreases in goats under heat stress, which leads to a decrease in yield. The reason for the decrease in feed consumption is the reaction of the animal to reduce the metabolic heat, since the heat increase resulting from the metabolism of nutrients is the most important source of heat production (Sejian et al., 2018).

4.2.4. Sheep

It has been observed that ad libitum roughage consumption decreases in sheep exposed to heat stress as in other species, especially when high humidity is present during the day (temperature 32 °C and relative humidity 98%). In addition, due to high heat stress, the maintenance requirements of sheep increase by 30% (NRC, 2007), and live weight loss occurs as feed consumption will not be sufficient to meet daily energy requirements (Hamzaoui et al., 2013).

4.2.5. Pig

It is stated that pigs cannot tolerate high temperatures up to 36 °C and high temperatures cause loss of appetite (Babinszky et al., 2011). The increase in the relative humidity with the upper critical temperature causes the animal to reject the feed, and with the increase in the relative humidity, the daily feed consumption of a 60-70 kg pig can decrease by 80-150 g (Huynh et al., 2005).

4.2.6. Poultry

Since the critical temperature for poultry is 30 °C, they can compensate for the energy loss up to this temperature. However, at temperatures above 30 °C, feed and energy consumption decreases, production decreases rapidly and mortality increases (Daghir, 2009). In severe heat stress (34-35 °C), feed consumption may decrease by approximately 30-50%. In addition, decreased activity of trypsin, chymotrypsin and amylase at high ambient temperatures, possibly, reduces the digestibility of nutrients in poultry (Hai et al., 2000). Chicks exposed to low ambient temperature (20 °C) cluster to maintain optimum temperature, thus, they cannot consume enough feed as they reduce the frequency in the feeder and drinker. Feed consumption of 4-6 week old broilers at 32 °C was reduced by 24% compared to that at 22 °C. In addition, in case of heat stress, broilers may refuse feed at a rate of 50% depending on age (Gonzalez-Esquerra and Leeson, 2005).

4.3. Impact on Water Consumption of Climate Change

Water is absolutely necessary for life, animals need water; water loss while animals meet their water needs from feed and metabolic water and drinking water; provided by the skin and respiratory, fecal and urinary tracts (Sarıçiçek, 2007). Problems related to the availability of water will affect the water needs of animals, the growth of forage crops and the livestock sector using the crops grown. Approximately 8% of global human water use belongs to the livestock sector. While the water requirements of heat-stressed animals increase by two to three times compared to thermoneutral conditions (Nardone et al., 2010), some species, such as camels and Bedouin goats, have water requirements of up to 30-40% of live weight loss (Cain et al., 2006).

4.3.1. Cattle

Since the comfort zone for dairy cows is between 5 and 25 °C, at a temperature of 26 °C or higher, the thermoregulatory capacity of the animals is exceeded and they enter heat stress. Dairy cattle show signs of severe dehydration when they lose 12% of their body weight of water. While the water requirement of a maintenance cow is 4-6 Lt per kg DM consumed under normal conditions (Sarıçiçek, 2007), the water consumption for a dairy cow under heat stress increases by 1.2 kg/°C of the minimum ambient temperature (West, 2003). Drinking water, which is the most important nutrient of dairy cattle, also has the feature of regulating heat distribution. Since 87% of milk consists of water, lactation cows have high water needs depending on their body weight, DMI and yield levels. Meat production is also affected when the body water content of beef cattle decreases by 10% (Herrero, 1998).

4.3.2. Buffalo

Since water buffalo is sensitive to heat and cold stress, the most important nutrient in hot climates is water. Water intake is closely related to DMI and milk yield. Water consumption increases in hot conditions, so it is important to always have plenty of water (Omran et al., 2013). Buffaloes consume 4-6 Lt of water for each kg of DM consumed for maintenance (Sarıçiçek, 2007), water consumption increases when the temperature increases, water consumption of buffalo calves in summer increases approximately twice the daily consumption or three times per metabolic weight (Ashour, 1990).

4.3.3. Goats

The thermoneutral zone for goats is 12–24 °C in the hot regions of the world. Water needs of goats in heat stress conditions have high (Salama et al., 2012). To alleviate the effects of heat stress, goats should be provided with plenty of fresh, cold water. A goat needs 4 - 8 liters of water on average per day. Young and lactating females need more water than adults. The reason for the higher of water consumption in Alpine goats compared to Saanen goats is probably to dissipate more heat released as a result of rumen fermentation, this shows that there is a difference between breeds in terms of water/DMI ratio (Kadzere et al., 2002). It is also suggested that this difference may be due to the difference in the hair color of the goats: the skin temperature in black areas in Holstein cows is higher than in whites, which causes increased sweating in black areas compared to whites (Da Silva and Maia, 2011). Thus, it explains why Alpine goats with dark brown hair drink more water/kg DMI than white Saanen goats.

4.3.4. Sheep

Sheep consume 2-3 Lt water/kg DM at temperatures between 0 and 15 °C, and this rate triples at temperatures above 20 °C. In addition, water consumption in sheep is 9-11% of total body weight in winter and 19-25% in summer (Khan and Ghosh, 1989). In general, thirst for three days or more negatively affects feed consumption of sheep as a result of increased milk production, body weight, chewing movements during rumination, respiratory rates and rectal temperatures (Aganga et al., 1990).

4.3.5. Pig

The most suitable ambient temperature for the optimum production performance of growing pigs is between 18-21 °C (Ingram, 1965). Pigs need to consume more water to reduce the effect of heat stress and to lose evaporative heat through respiration. Cold drinking water provides the greatest heat removal. A baby pig can drink 4-5 liters of water per day. Pigs at the beginning of fattening should be given 4 liters of water, 12 liters for growing pigs, 20 liters for pigs at the end of fattening, 24 liters for pregnant pigs, and 20 to 35 liters per day for lactating pigs. As a general rule, pigs should be provided with drinking water at 10% of their body weight, but pigs under heat stress typically drink six times more water than normal (Zaake et al., 2020).

4.3.6. Poultry

At high temperatures, the water holding capacity of the body is significantly reduced, as the poultry excessive water consumption causes the electrolyte balance to change (Borges et al., 2003). Poultry consume approximately 1.6–2.0 times more water than the feed they consume (El Saidy et al., 2015). The thermoneutral temperature for seven-day-old broilers ranges from 28 to 35 °C, high temperatures above this cause hyperthermia and dehydration, feed consumption decreases and this causes growth to slow down. The water consumption of broilers exposed to acute heat stress is also high (Egbuniwe et al., 2018).

5. The Effects on Animal Production of Climate Change

Animals must be in a thermal comfort zone in order to perform their physiological functions. When the environmental temperature rises above the upper critical temperature, animals begin to be exposed to heat stress. Heat stress affects bioenergy of animal and has a negative impact on welfare. Heat stress changes the physiology of animals, causing a decrease in performance, yield and product quality. Under heat stress, feed consumption, digestibility of poor quality feeds, and absorption of nutrients decrease. In such a case, the animal may have to benefit from less nutrients for its maintenance and productivity needs. This causes a decrease in yields such as milk, meat, fleece/angora, and eggs (West, 2003).

5.1. Effects on Growth Performance of Climate Change

Growth is defined as a coordinated increase in body appearance over a given period of time. The volumetric and numerical increase of the cell, that is, the increase in live weight, adequate nutrient intake, is genetically and environmentally controlled by hormones and enzymes (Sarıçiçek, 2007). Heat stress negatively affects growth performance, body weight and daily weight gain.

The negative effects of high temperature on growth performance are the result of a decrease in anabolic activity and an increase in tissue catabolism. The decrease in anabolism is caused by the inadequacy of essential nutrients, especially ME, which is necessary for maintenance and body weight gain, due to the decrease in feed consumption (Morrison and Lofgreen, 1979).

5.1.1. Cattle

Heifers produce less metabolic heat compared to cows, so they are expected to be less affected by heat stress. However, although the maintenance requirements of cattle are higher in hot weather, their appetite has decreased, and because they are fed with low quality roughage, their growth slows down, causing them to be smaller in size (NRC, 1981). Holstein, Brown Swiss and Jersey heifers from one year to thirteen months were grown in chambers at constant temperatures of 10 °C and 26.7 °C to determine the effect of temperature. It has been determined that Holstein heifers in a 26.7 °C environment are weaker, and although they gain more weight in a cool environment, it takes longer to reach the desired weight in a warm environment (Johnson and Ragsdale, 1959). When the comfort conditions (10 °C) and heat stress conditions (35 °C) of Jersey, Brown Swiss and Holstein heifers were compared, it was determined that nitrogen retention decreased by 25.4% and 49.0%, and the nitrogen balance was positive in Holstein calves and negative in cows (Kamal et al., 1970).

5.1.2. Buffalo

The summer-born calves of Egyptian buffaloes are significantly weaker at weaning compared to calves born in other seasons, Egypt (Marai et al., 2009) and in Murrah and Surti Indian buffaloes (Bhavsar et al., 1974), it was determined that the daily live weight gain from birth to weaning was significantly affected by the birth season. The lowest daily weight gain between birth and weaning was determined in calves born in summer. This may be due to the adverse effects of exposure to moderate to very severe heat stress (during the summer) of the fetus in the last period of pregnancy (Marai et al., 2009).

5.1.3. Goat

Although live weight is an important parameter to explain the growth variability of goats, changes are also observed in the growth parameters of goats under heat stress (Habibu et al., 2016). Pragna et al., (2018), who determined that the live weight loss in Osmanabadi breed was higher than Malabari and Salem back goat breeds, stated that the decline in growth differed between different goat breeds and that heat stress had a negative effect on the body condition score of the animals.

5.1.4. Sheep

Although sheep are one of the most resistant species to high environmental temperatures, climate change has a great impact on their growth characteristics. Heat stress reduces appetite and causes a decrease in feed consumption, slowing of rumen functions and a decrease in growth rate.

Since high temperatures also reduce the rangeland quality, it causes the sheep grazing on the rangeland to not get enough nutrients, and as a result, their daily live weights decrease. According to Marai et al. (2007), when sheep are exposed to high temperatures (30-40 °C, 40% relative humidity) in the early embryonic stage, a significant reduction in total cell number, cell size, and placentome size was observed compared to thermoneutral temperatures (18-20 °C, 30% RH). During placental growth, fetal development slowed down due to temperature, feed consumption of animals decreased, water consumption and survival requirement increased. Temperature stress caused to slow down of growth performance, and energy demand increased at higher temperatures (Pérez-Barbería et al., 2020). When THI increased from 60-65 to 72-75 in Sarda sheep in a semi-arid-tropical environment, there was a 20% reduction in production performance, while the body condition scoring of the sheep also changed (Sejian et al., 2010). In addition to low precipitation in spring and summer, high temperatures can directly affect the productivity of sheep and lambs.

5.1.5. Pig

Since pigs are sensitive to heat stress, high temperatures cause loss of appetite and reduced growth (Quiniou et al., 2000). When sows are exposed to temperatures above 25 °C during lactation, milk yield decreases due to reduced feed consumption, which reduces the chance of piglets surviving. Pigs with high body weight are more sensitive to heat stress than those with low body weight (Renaudeau et al., 2011).

5.1.6. Poultry

Broilers are also sensitive to the increase in ambient temperature during the growing period, metabolic heat production also increases as their feed consumption is high. When the ambient temperature exceeds the upper limit of the thermonotral zone, this heat load must be distributed in order to maintain the body temperature of the animal, but because chickens do not have sweat glands, they do not have the capacity to dissipate heat, in this case the animal enters heat stress, feed consumption decreases and growth rate decreases (Lara and Rostagno, 2013).

5.2. Effects on Milk Yield and Quality of Climate Change

Milk yield of animals is highly affected by climate change. Increase in temperature and humidity reduces milk production, negatively affects the quantity and quality of milk, and shortens the lactation period of animals.

5.2.1. Effects on milk yield of climate change

Cattle: The effect of heat stress on milk yield performance of dairy cattle is negative. The decrease in milk yield occurs when the average daily temperature rises above 26 °C. Changes in environmental factors such as ambient temperature, relative humidity, wind speed and solar radiation cause stress in lactating cattle, and heat stress negatively affects both the quantity and quality of milk. It was determined that milk yield decreased by 33% at 35 °C and 50% at 40 °C (Rhoads et al., 2009). When THI is in the range of 72-80, 80-90 or 90-98, the effect of heat stress is respectively; mild, moderate or severe. Both increased ambient temperature (from 25 to 32 °C) and increased THI (from 73 to 82) have a negative effect on dry matter consumption and milk yield of cows (Lopez et al., 1991). There is a positive relationship between milk yield and feed consumption and heat production. In addition, during long heat stress periods, there is a loss of body weight and condition in dairy cows (Baumgard et al., 2006). According to West, (2003), milk yield decreased by 0.88 kg/day for each unit increase above THI 72, which is accepted as heat stress in Holstein cows, and in milk production potential of dairy cows exposed to climate change-related heat wave conditions showed a 10-14% reduction. Bernabucci et al. (2010) also determined that there is a 0.27 kg decrease in milk production for each unit increase in THI. In addition, exposure of cows to heat stress in the dry period affects mammary gland development before birth and causes a decrease in milk yield in the next lactation (Tao et al., 2011).

Buffalo: When the environment in which the buffalo lives exceeds THI 75, the productivity, fertility and health of the animal are significantly affected, which in turn causes a decrease in milk yield, a 1 °C increase in rectal temperature under heat stress conditions reduces the performance of dairy cows (Amamou et al., 2019). Yadav et al. (2022), in their study to determine the effect on milk yield of buffaloes of THI 79.88, 80.57 and 85.36 in May, June and July, they found a significant decrease in milk yield only in THI 85.36 in July. The negative effect of sudden temperature change (cold or heat wave), on milk yield of buffaloes was seen not only on the next day but also on the day(s) after or after the extreme event. Return to normal milk yield took 2-5 days in individual buffaloes. While the milk production performance of buffalo is less affected when THI is 75, lactation period is shortened by a few days (3-7 days) in hot summer months when THI is higher than 80 (Upadhyay et al., 2007). Buffalo experience greater heat stress when behavioral traits such as shelter-seeking, rolling over, and/or submerging are inhibited. Also, lactating buffaloes are exposed to severe heat stress with increased heat production in summer months when heat stress combined with high milk production and lactation stress.

Goat: It was determined that especially in July, steaming and rolling increase milk yield, and rolling is more effective in terms of milk yield (Yadav et al., 2016). As THI value increased in dairy goats, milk yield decreased and each 1 unit increase in THI caused a 1% decrease in milk yield (Salama et al., 2014). Differences were determined between goat breeds in terms of resistance to heat stress. In comparative studies conducted with Alpine and Nubian goat breeds, it was observed that the production performances of goat breeds adapted to heat stress were relatively higher. In similar environmental conditions (34 °C temperature and 25% relative humidity; THI = 79), the milk yield of Nubian goats native to tropical regions was preserved, while the milk yield of Alpine breeds decreased when the temperature increased from 27 °C to 34 °C (Brown et al., 1988).

Sheep: The contribution to milk production of sheep is quite low compared to cows and goats. High temperature and humidity are the main factors on the productivity of sheep in tropical and subtropical regions. However, it has been reported that the effect on milk yield of cold stress in Manchega sheep is more negative compared to heat stress (Ramon et al., 2016). In addition, there was a 20% decrease in milk yield in Comisana sheep exposed to temperatures above 35 °C (Sevi et al., 2001). Similarly, there was a 15% reduction in milk yield when Sarda sheep were exposed to maximum ambient temperatures above 21-24 °C, and a 20% reduction when minimum temperatures were increased from 9-12 °C to 18, and a 30% decrease was determined when the maximum and average temperatures are higher than 21 °C – 24 °C and 15 °C – 21 °C (Peana et al., 2007).

5.2.2. Effects on milk quality of climate change

Cattle: Metabolic heat production during lactation can reduce the resistance of cattle to high ambient temperature, resulting in a reduction in milk yield as well as a change in milk composition. The default neutral temperature range for dairy cattle is –5 to 25 °C (Knizkova et al., 2002). Since there is a relationship between high milk production and high heat production, it was determined in a study that milk yield and composition may change depending on the decrease in ambient temperature, and especially protein and milk dry matter levels may decrease (Bickert and Mattiello, 2016). While heat stress causes a decrease in milk fat, protein and short-chain fatty acids, and an increase in long-chain fatty acids in milk (Kadzere, et al., 2002), increasing heat load index caused a decrease in lactose, protein and fat levels in milk (Van Laer et al., 2015). Likewise, Bernabucci et al., (2015) recorded a significant decrease in milk fat content in summer (3.20 g/100 g) compared to values in winter (3.80 g/100 g) and spring (3.61 g/100 g).

In milk, there are two groups of proteins whose chemical structures and physical properties are known: caseins and whey proteins. While caseins αS1-, αS2-, β- and κ-CN represent approximately 80% of the total milk protein, the other 20% consists of whey proteins, mainly β-LG and α-LA (Farrell et al., 2004). A decrease in milk yield and milk protein fraction was observed in cattle exposed to heat stress, and there was a decrease in milk casein, which was suggested to be due to the direct effect of heat stress. It has been determined that milk casein consists of several fractions as αs1, αs2, β, κ and γ caseins, and there is an increase in αs1 casein and a decrease in αs2 casein in the milk of cows under heat stress (Cowley et al., 2015). Similarly, Bernabucci et al., (2015) determined that the milk casein content was higher in winter (2.75 g/100 g) and spring (2.48 g/100 g) compared to summer (2.27 g/100 g). They determined that milk was lower in terms of αs casein (αs1 + αs2) and higher in terms of κ casein compared to other seasons, whereas β casein was similar. In addition, it was observed that heat stress caused a decrease in total protein, fat, casein, lactose, lactalbumin, short and medium chain fatty acids, IgG and IgA in Holstein heifers in the first four lactations (Nardone et al., 1997). There are few studies on the effect of heat stress on milk mineral content. It has been stated that all mineral content of milk is significantly affected by the season (Poulsen et al., 2015), seasonal differences are important on the mineral content of milk, and cows exposed to heat stress in summer have lower milk ash and phosphorus content (Mariani et al., 1993).

Buffalo: Buffalo milk contains higher levels of DM, fat, protein, calcium and P compared to cow's milk. The ratio of albumin and globulin is higher in milk protein (Sarıçiçek, 2007). The hot and humid climate affects the quality as well as the quantity of buffalo milk. Habeeb et al. (2000) determined that buffalo produced higher quality milk in winter (February) than in summer conditions (in July), and milk production, milk DM, fat, protein, lactose content and milk quality decreased in July at high ambient temperature. Omran et al. (2017)

determined that milk yield, milk fat, protein, lactose, total DM, lean DM content at THI 58.64 (January-March, late pregnancy) decrease significantly compared to THI 69.33 (April-June, postpartum), and reported that buffalo is more sensitive to cold stress.

Goat: There was a decrease in milk protein and protein fractions of goats under heat stress (Hamzaoui et al., 2013). The decrease in feed consumption due to heat stress also decreased feed protein consumption, and thus, insufficient amino acids required for milk protein synthesis caused a decrease in milk protein level (Salama et al., 2014). In addition, another reason for the decrease in milk protein under heat stress may be the change in the rumen environment with high water consumption and the decrease in rumen microbial protein synthesis (Hamzaoui et al., 2013). Fat content in milk of dairy goats also decreased under heat stress conditions.

In a study conducted with Saanen, Anglo-Nubian and Alpine breed goats, it has been observed that goats raised in tropical climates have lower milk yield, some milk components such as milk fat and total DM, compared to those reared in temperate climates due to high air temperature and malnutrition (Juaréz, 1986). The protein and casein levels in milk of goats under heat stress decreased by 12.5% and 11.5%, respectively, compared to those in a thermo-neutral environment.

In addition, dairy goats under heat stress conditions were also found to produce less fat milk (Hamzaoui et al., 2013). Similarly, fat and protein contents were found to be significantly lower in the milk of temperate Alpine and Nubian goats in summer (Brown et al., 1988).

Sheep: Sheep milk is of high quality, suitable for cheese and yoghurt production, due to its high DM, protein and fat content. Sheep milk has higher calorie content as it contains more fat and non-fat dry matter compared to goat and cow milk (Sarıçiçek, 2007). Sheep are most affected by climate change, especially heat stress, and the amount and quality of milk also changes. It has been stated that there is a positive relationship between milk properties and relative humidity, and when RHI is > 23, milk yield and milk fat and protein content of sheep decrease (Finocchiaro et al., 2005). It has been determined that when Comisana sheep are exposed to sunlight, saturated fatty acids such as caproic, capric, lauric, myristic and stearic acids increase (3-18%) and the oleic, linoleic and linolenic acid contents decrease (2-9%) in milk (Sevi et al., 2002).

5.3. Effects on Meat Yield and Quality of Climate Change

Meat has an important place among the proteins of animal origin in human nutrition. Animal proteins contain essential amino acids that cannot be synthesized in the human body. Meat and meat products are the most valuable protein sources with high biological value for humans due to their amino acid composition. Meat production resources; although there are cattle, buffalo, sheep, goats, pigs, poultry, there are differences in the world countries in terms of meat production and consumption.

Cattle: Beef cattle are breeds that are bred for meat yield, they are breeds with high feed efficiency and more weight gain. Nutrition level affects the quality of meat, muscle, bone and adipose tissue of the carcass (Sarıçiçek, 2007). One of the main reasons for the decrease in meat production in beef cattle is heat stress. Cattle are under heat stress when the ambient temperature is above 26-28 °C, the relative humidity is above 50% and the wind speed is below 5 km/h. High-weight, thick-haired and darker beef cattle are more vulnerable to heat stress. In addition, global warming may reduce body size, carcass weight and fat thickness in ruminants (Nardone, 2000). Changes in climatic conditions, increase in temperatures and decrease in precipitation may cause a decrease in the CP and digestible organic matter content of the feed, and the botanical structure of the pasture may weaken due to drought and water deficiency (Naqvi et al., 2015). In addition to all these negativities, the decrease in feed consumption can lead to a decrease in growth, that is, it can lead to muscle loss. Pasture has a positive effect on meat quality. It is known that the meat of beef cattle fed with pasture plants is richer in n-3 fatty acid and conjugated linoleic acid content than those fed with concentrated feed (Scollan et al., 2006). Extreme weather events reduce the growth performance (weight gain, feed consumption and feed efficiency), especially of cattle calves kept outdoors, thus decreasing the fattening and slaughter weight, less intramuscular fat and meat juiciness and tenderness and lower meat quality (Keane and Allen, 1998).

Buffalo: The body temperature of the buffalo is around 37-39 °C, the intense vascularity in the skin causes the heat to be absorbed and spread, sweat glands are less compared to cattle. This situation causes them to enter heat stress. The buffalo in the heat, cannot ruminate, becomes grumpy and irritable, and their stress increases even more (Sarıçiçek, 2007). The meat yield of buffalo is relatively higher than beef, but it has less fat, less saturated fatty acid content and lower calories than beef (Di Luccia et al., 2003). The nutritional value of buffalo meat is higher than beef due to its much lower fat and cholesterol content. It contains almost all essential amino acids, vitamins A and B necessary for human health, it is also an important source of iron, copper, zinc and selenium (Rebak et al., 2010). The average carcass yield of buffaloes is around 42%. Summer-born calves of Egyptian buffaloes are significantly weaker than calves born in other seasons (Marai et al., 2009). Similar results are found for Egyptian buffalo (Chawla and Tripathi, 1994) and Indian buffalo (Peeva and Vankov, 1994) and other buffalo species. It has been determined that the daily live weight gain from birth to weaning is significantly affected by the birth season in Egyptian (Marai et al., 2009), Murrah and Surti Indian buffaloes (Bhavsar et al., 1974). The lowest daily weight gain between birth and weaning was determined in calves born in summer. Omran, (2013), in his study on the meat quality (fiber diameter, fiber area, intramuscular fat) of buffalo calves exposed to heat stress in laboratory conditions (40 °C and 25 °C) for 6 months, it has been determined that the protein and ash content of the meat is higher, the lipid content is lower, the meat color is clear, the softness and taste test is excellent, the connective tissue and cooking loss are lower in the calves kept at 40 °C compared to those kept at 25 °C. Similarly, in another study, buffalo meat exposed to heat stress was found to have higher protein and ash content, lower lipid, lighter color, tender as veal, and excellent flavor. It has been stated that cooking loss is reduced due to low fat and moisture content, and heat stress does not affect the quality of meat (Rebak et al., 2010).

Goat: Goat meat is of higher quality for the human diet than other red meat, due to its lean, low content of saturated fatty acids and cholesterol. In a comparative study between Baladi and Damascus goat breeds, the decrease in body weight of Damascus goats under heat stress was greater (2.85% vs. 3.33%) (Helal et al., 2010). Pragna et al., (2018) also reported that the body weight and body condition score of Osmanabadi goats exposed to heat stress were significantly lower compared to Malabari and Salem Black breeds. Heat stress also reduced meat quality in goats. Kadim et al. (2006) determined that three Oman goat breeds had higher meat pH value and cooking loss after transport stress at high ambient temperatures. In the meat of animals exposed to heat stress and high ambient temperatures, the final pH value and shear force, cooking loss and drip loss were higher, crispness and water holding capacity were lower, so it was seen that heat stress affects eating and organoleptic properties (Rana et al., 2014; Kadim et al., 2004). It has also been stated that the meat of sheep and goats exposed to heat stress has higher odor, taste, water holding capacity and is susceptible to spoilage by microorganisms (Salama et al., 2014).

Sheep: Sheep are small ruminants kept in extensive conditions. Sheep meat is an important function of body weight. The average carcass yield of sheep is around 16 kg (FAOSTAT, 2014). As a result of global climate change affecting the amount and quality of feed, energy and protein intakes of sheep decrease, thus slowing down growth and causing a decrease in carcass weight (Gowane et al., 2017). On the contrary, it was observed that the Indian domestic sheep breed Malpura exposed to heat stress conditions showed no decline in growth compared to sheep kept in thermoneutral conditions (Sejian et al., 2010).

Climate change, especially high temperature and high relative humidity, has a significant impact on meat quality. According to Gregory (2010), the meat quality of sheep is more endangered in summer than in other seasons. Rana et al. (2014) stated that high temperatures will cause dehydration in thirsty animals and may affect meat quality by darkening meat color through shrinkage of myofibrils, and there will be less weight loss during cooking due to dryness of meat. Heat stress can also affect the usefulness and organoleptic quality of meat from both sheep and goats. Due to the high pH in the meat of sheep under heat stress, the color of the meat is darker (Kadim et al., 2006), the shearing force and cooking loss are higher, and the water holding capacity is lower (Archana et al., 2018). It has been determined that the pH value of the meat of Somali and Merino Sheep is higher in the hot season (5.77) than in the cold season (5.60) (Kadim et al., 2007). Similarly, the meat color of Barbados Black Bally lambs at 20 °C and 30 °C was adversely affected by heat stress. The meat color of lambs at low temperatures was brighter than those kept at high temperatures (Jallow and Hsia, 2014). In a comparative study of the effects of heat stress between Dorper and Poll Dorset × Merino/Border Leicester lambs, while the water holding capacity of Dorper lambs exposed to heat stress was lower compared to lambs in thermoneutral conditions, no negative effect was observed in crossbred lambs (Zhang, et al., 2020).

Kadim et al. (2008) found that the L*, a* and b* values of Somali Merino sheep fed in a heat stress environment (35 °C, 47% RH; 6 months) were significantly lower than those fed in the cool season (21 °C, 59% RH). Similarly, Al Amria et al. (2021), in their study examining the effects of seasonal ambient temperature and humidity on sheep and beef quality characteristics, showed that L*, a* and b* color measurements of sheep and beef meats in the hot season were significantly darker than those in the cold season. Thus, it was stated that high temperature increase (>40ºC) causes heat stress in sheep and cattle, which increases muscle pH and affects other properties of meat.

Pig: The decrease in feed consumption in pigs causes a decrease in daily live weight gain. When pigs are exposed to hot periods of 30-33 °C, it is seen that although they can compensate for growth, they cannot compensate for high temperatures of 36ºC and above (Babinszky et al., 2011). Similarly, pigs exposed to high temperatures above 25 °C have adverse effects on meat production and their feed consumption is reduced by 5-6 times compared to those exposed to 18-25 °C (lactation period), and also, the reduction in growth, carcass weight and feed consumption of larger pigs was quite evident (Nardone et al., 2010).

Studies highlight the fact that high temperatures not only slow down growth, but also change body composition and therefore can degrade the nutritional value and quality of pork. Prolonged heat stress (30-33 °C) reduced protein content in meat of growing and fattening pigs (Kerr et al., 2003). Rinaldo and Mourot, (2001) found that large white pigs (35 to 94 kg) reared in tropical climates had lower feed consumption, lower daily weight gain, leaner carcass, higher pH, lower water loss, compared to those raised in optimal climates, and a decrease in fat content on the entire back was observed. Heat stress in pigs caused decrease in growth, in feed efficiency, in carcass quality (increase in fat, decrease in protein accumulation) and reproductive performance

(Mayorga et al., 2019). Heat stress in pigs accelerates muscle glycolysis, significantly lowers muscle pH and redness (a*), increases drip loss and L* value, less protein is stored in the bodies of fattening pigs growing in hot environments, so the decrease in protein/fat ratio reduces meat quality (Gao et al., 2020).

Poultry: When poultry are exposed to heat stress, body weight gain, feed consumption, carcass weight, protein and muscle calorie content decrease (Tankson et al., 2001). High temperatures caused a decrease in protein synthesis and an increase in protein catabolism of chickens. Thus, there was a decrease in body and muscle tissue protein and a greater increase in fat level under heat stress (Gonzalez-Esquerra and Leeson, 2005). Although poultry consume more water in case of heat stress, the body's water holding capacity is significantly reduced due to the change in electrolyte balance (Borges et al., 2003). Carcass and meat quality characteristics such as crispness and color are critical to consumer acceptance. The effects of heat stress on meat quality in broilers were investigated and it was revealed that high temperature causes lower pH, denatured muscle protein and drip loss, and an increase in L* value and shear force. Exposure to heat probably accelerates the breakdown of glycogen, increasing lactic acid production due to glycolysis in the muscles, which leads to a decrease in pH (Hao and Gu, 2014). Water holding capacity is one of the important sensory properties of meat. Studies have shown that heat stress causes a decrease in body weight gain, rapid decreases in muscle pH and water holding capacity, an increase in protein and lipid oxidation of meat, dripping and cooking loss, Warner-Bratzler shearing force is significantly reduced, pale, tender, exudative It has been stated that meat is an important problem that causes economic losses in poultry meat production (Petracci et al., 2015; Wang et al., 2009). Zhang et al., 2012).

The other poultry: Heat stress also appears to affect the meat quality of other poultry. Meat of heat-stressed turkeys at 32-38 °C for 4 weeks before slaughter was found to have a pale flesh color and increased drip loss and reduced cooking loss after 24 hours compared to meat kept in thermoneutral conditions (McKee and Sams, 1997). In quail meats exposed to heat stress, drip loss increased compared to those left to the optimal temperature (Remignon et al., 1998). Similarly, heat stress caused an increase in cooking loss in rabbit meat (Zeferino et al., 2013).

5.4. Effects of Climate Change on Wool and Mohair Production and Quality

5.4.1. Sheep

Climate change caused a significant decrease in wool production between 1990 and 2000 (FAO STAT, 2010). Climate change has several potential effects on the quantity and quality of wool produced. Most of the impacts will occur indirectly, through changes in rangeland conditions, rather than the direct impact of climate. There are very few studies on the effect of climate change on wool/mohair quality. Wool production in lambs is completely related to nutrition. Extreme increases in temperature in the tropics and subtropics have reduced the wool yield (Gowane et al., 2017). In addition to the impact of climate change on wool production, sheep's nutrition, health, quality of rangeland grazing and water availability are also effective. Their deficiency also affects wool production. For example, the change in precipitation affects the amount and quality of feed, which in turn affects the feeding of the sheep. Thus, besides the wool yield, the quality characteristics of the fiber such as fineness and length are also affected by climate change. The decrease in precipitation and the increase in temperature caused the fleece fiber diameter to increase from thin to thick. However, as a result of insufficient feeding, length and strength decreased, and insufficient feeding of lambs also caused the deterioration of follicles (Harle et al., 2007). Jolly and Lyne (1970) found that by raising subcutaneous temperatures from 37 °C to 42 °C, an increase in temperature stimulates fleece growth, while a 5°C increase in subcutaneous temperature increases wool growth, but if the temperature increases too much, They stated that wool growth decreases, and if the temperature rises much more, wool growth stops.

5.4.2. Goat

Angora goats' most important yields are mohair and they depend on natural pastures for feeding. Natural pastures must have sufficient rainfall for plants to grow. Decreased precipitation or drought has a negative effect on the growth of plants in pastures, which causes goats to consume less and poor quality feed, resulting in a decrease in angora yield (De Waal, 1994). In addition, it is stated that there is a positive relationship between annual lint yield (kg) and precipitation (mm) in goats (Ng'ambi et al., 2009). Sarıçiçek (2021) found that the nutrient content and digestibility of the plants were lower, and the cell wall components were higher, especially in July and August, in low quality rangeland, as a result of this, it was determined that the mohair quality of Angora goat kids and cebich decreased, and there was a decrease in the mohair mineral (Ca, Mg, S) content.

5.5. Effects on Egg Yield and Quality of Climate Change

Poultry need a warm climate in the first days of their life (32-38 °C), but the optimal temperature decreases rapidly with age by 2.5-3.0 °C per week (FASS, 2010). The critical temperature for poultry is 30 °C. Since the feed conversion rate is better and the basal metabolic rate is lower in poultry up to this temperature, it can compensate for the energy loss that occurs as a result of the decrease in feed consumption (Esminger et al., 1990). In the case of heat stress, feed consumption decreases in poultry, and the digestibility of nutrients decreases due to decreased activity of trypsin, chymotrypsin and amylase (Hai et al., 2000). The decrease in feed consumption due to heat stress causes decrease in live weight, malnutrition, decrease in egg production and egg weight, and decrease in growth rate in broilers (Tankson et al., 2001; Nardone et al., 2010). Researchers have determined that heat stress reduces egg production and egg weight (Emery et al., 1984), feed consumption reduces feed efficiency (Muiruri and Harrison, 1991), and egg or albumin weights (Wolfenson et al., 1979). In addition, it was determined that the eggshell quality decreased shortly after the hen was exposed to heat stress, and that acute heat stress significantly reduced feed consumption of all poultry. It has been reported that there is a significant interaction between egg weight, egg surface area, yolk index, yolk weight and white weight and the relative weights of various organs except gizzard (Ghoname et al., 2022). In warmer conditions, egg quality may be adversely affected, egg weight, shell weight and thickness (Mashaly et al., 2004), egg shell breakability may increase with decreasing egg specific gravity (Yahav et al., 2000). The decrease in feed consumption due to high environmental temperatures causes a decrease in the presence of Ca required for shell synthesis of the chicken (Nidamanuri et al., 2017). During heat stress, poultry lose a lot of CO_2 by panting. Since CO_2 is required for Ca-carbonate in eggshell formation, eggshell formation is compromised and egg production may decrease, as well as nutritional deficiencies (Mashaly et al., 2004). For the deposition of calcium carbonate in the eggshell, there must be approximately 4 to 12 times higher Ca in the shell gland fluid than in the serum, and this Ca must be obtained from the digestive tract, blood and bones. Approximately 2-2.5 g of Ca is taken from the blood by the shell gland and transferred to the egg for 15 hours (Kim et al., 2012).

5.6. Effects on Honey Production and Quality of Climate Change

It is stated that sudden weather changes caused by global climate change will cause great damage to the development of plants, especially during flowering. As average monthly temperatures increase, flowers may bloom earlier in the spring, creating a potential mismatch in seasonal timing between when flowers produce pollen and when bees are ready to feed on that pollen. As temperatures increased, North American and European wasp populations decreased, bees died when exposed to high temperatures in the southern regions, and their populations decreased in the northernmost regions (Turner, 2019). The increase in the duration and severity of summer drought may cause the drying and extinction of many plant species, thus changing the flowering periods of many plant species. Loss of natural flora may also cause loss of bee colonies (Potts et al., 2010).

Due to climate change, there is a decrease in bees at very high rates. In addition, the symbiotic interactions of bees and the flowering plants they pollinate are also affected (Belsky and Joshy, 2019). Climate change is cited as one of the causes of colony deterioration, especially in the most sensitive bioclimatic regions such as the Mediterranean regions. Adverse conditions significantly affect the evolution of bee populations, honey and pollen reserves, increase food stress for bees, and also affect the pollen spectrum and commercial properties of honey (Flores et al., 2018). Continuous high temperatures (>40-45 °C) cause significant losses in the colony. The highest foraging activity takes place in the temperature range of 12-25 °C, and no activity is observed at <7 °C and >43 °C. While the increase in extreme temperatures leads to an increase in colony losses, years with spring seasons characterized by very low precipitation and extreme temperatures will become more frequent in the future, which may lead to increased winter mortality rates (Soroye et al., 2020). Heat stress affects the growth and development of bees, as well as pollen services and foraging activities; these effects may not be exactly the same in different bee species (Willmer and Stone, 2004). Global warming also negatively affects honey bees used in plant pollination (Rader et al., 2013). Extreme temperatures put pressure on bee colonies due to the interactive relationship with honey bees and ecology (Biesmeijer et al., 2006). In addition, it is stated that each honey bee breed develops at its own pace, moving from one region to an unknown region or any change in climate has a negative effect on the development of bees, since the effect of rain on honey harvest for honey bees is known, it has been determined that environmental changes directly affect honey bee development, for example, some flowers such as Acacia flowers are no longer attractive to honeybees as they dilute the nectar when washed with rain (Conte and Navajas, 2008). Extreme temperatures can also cause plants not to produce enough pollen and nectar in the spring, which may cause honeybees to leave the hive (Kevan, 1999). Honeybees at lower altitudes remain active throughout the year, while at higher latitudes they go through a period of complete inactivity due to very long winters. This indicates that activity decreases significantly with increasing altitude due to colder months (Delgado et al., 2012).

6. Suggestions for Solutions on Animal Nutrition against the Effects of Global Climate Change

Climate change can cause environmental temperature rise and extreme weather conditions in certain parts of the Earth. Climatic conditions determine the energy and nutrient metabolism of livestocks. Since heat production is high after feed intake, livestocks reduce their feeding activities at high ambient temperatures, which has significant consequences on feed consumption. To maintain nutrient intake, increase the nutrient density of the ration, or restore homeostasis, the composition of the ration can be manipulated in hot weather so that the feed contributes less to the temperature increase, reducing the overall heat production of the animals. Here, the precautions to be taken in terms of feeding are emphasized.

6.1. Dry Matter Consumption

DMI decreases in summer months when the weather gets warmer. Decreased DMI in hot weather will result in undernutrition as it means less nutrients are taken. Therefore, it is necessary to balance the dry matter (DM) amount of their rations. For best DMI in a temperature stress environment, either the feeding interval should be reduced or the energy density of the ration should be increased.

6.2. Ration Protein Concentration

Crude protein (HP) and crude cellulose (HS) have low availability and higher temperature increases because of higher satiety thermogenic reactions. Excess rumen degradable protein reduces ME by 7.2 kcal/g N. Excess protein in the ration will require additional energy to excrete ammonia and urea, which will be released as a result of metabolism, through the kidneys. In most cases, the cow's amino acid needs can be balanced while reducing HP consumption, by selecting appropriate protein sources and by careful use of rumen-conserved amino acids (AAs).

a) When cows are exposed to heat stress, rumen degradable protein should not exceed 61% of ration HP and total protein (NRC, 2021) should not be more than 100 g N/d. One hundred grams of N is equivalent to approximately 3.1% CP in this ration, assuming 20 kg DMI/day. Optimizing protein that is not broken down in the rumen increases milk yield in hot climates.
b) High quality protein sources should be used in the rations of farm animals.

6.3. Ration Cellulose Content

For normal rumen physiology in ruminants, a source of cellulose must be present in the diet. However, in order to reduce the effect of heat stress, it is necessary to give ruminants and high quality roughage sources with digestibility. Otherwise, the temperature increases will increase due to the low availability of CF.

a) Consumption of diets with high CF content increases metabolic heat production in ruminants. Normally, high-fiber rations cause mechanical satiety and decrease feed consumption. DMI decreases when the ration NDF concentration is in the range of 27 to 35%, so an increase in NDF in hot environments causes a further decrease in DMI.
b) Since rations with high fiber content increase heat production, a ration with low fiber and easily soluble carbohydrates should be prepared. The CF content in the ration should be reduced appropriately.
c) Feed quality and digestibility: The composition of the feed affects the digestibility. Factors such as plant type, variety, nutrient content, harvest time, maturity and storage methods affect feed quality and digestibility. As the plant matures, the structural carbohydrate content of the feed increases and the easily soluble carbohydrate content decreases. To reduce heat stress, harvesting the roughage at the right time, depending on the type, is important to maximize the amount of nutrients provided by the roughage and its digestibility.

6.4. Concentrated Feed Level of Rations

In summer, the most limiting nutrient for dairy cows, especially in lactation, is usually energy consumption. Since roughage increases heat production, it further increases heat stress when the ambient temperature is high. Roughage should be reduced and the concentrated feed level of the ration order to increase the energy density should be increased. The aim is to reduce fiber consumption, to increase the energy density of the diet with more concentrated feed.

6.5. Adding Fat to the Ration

Fat should be added to increase the energy value of the rations and to reduce the roughage content. Since the energy content of fat sources (of vegetable and animal origin) is much higher than other nutrients and concentrated feeds (about 2-2.5 times more than carbohydrates), the addition of fat increases the energy density of the ration. One of the advantages of adding fat is that high-fat diets generate less heat, the other is that it improves the digestibility of certain amino acids and the addition of fat can change the amino acid ratio. Increasing the ration fat content also increases milk production in dairy cows under heat stress. Normally, the ration fat content (based on DM) is around 3-5%. With the addition of oil seeds, this rate can be increased by 2-3%, but it should not exceed 7-8%.

6.6. Roughage Can be Wetted

When roughage consumption decreases in hot weather, adding some water to dry roughage such as hay and hay given to cattle may cause an increase in feed consumption.

6.7. Increasing Feeding Frequency in Ruminants

Increasing the frequency of feeding helps to minimize the daily fluctuation in rumen metabolites and increase the efficiency of feed use in the rumen. Feeding should be at least two meal in a day, the number of meals can be increased to 4-5 in order to reduce heat stress, feeding should be done little by little at meals.

6.8. Poultry Ration

The correct ration should be formulated to meet the needs of the birds against heat stress. The protein content of the broiler diet should be reduced: Since protein has the highest temperature rise in broilers, low protein diets should be given to reduce heat production, but the dietary amino acid composition should be adjusted. It is necessary to use high quality protein and amino acids (eg methionine and lysine) to prevent the negative effects of heat stress. Methionine and lysine are essential to make up for deficiencies caused by consuming low-quality protein. This also applies to pigs.

6.9. Poultry Should Be Fed Wet

In a hot environment, wet feeding refreshes the animal and helps to improve the live weight and daily live weight gain.

6.10. Feeding Time in Poultry

Feeding times in poultry should be in the morning or evening or the night feeding concept should be followed. It is known that night feeding can improve eggshell quality. Thus, 1/3 of the ration to hens should be given early in the morning and 2/3 in the afternoon.

6.11. Feed Restriction

Early feed restriction may be beneficial as heat stress has a negative impact on broiler growth and immunity.

6.12. Cold Water Supply

There is a relationship between water consumption, DMI and milk yield. Generally, DMI and milk yield decrease in hot weather, but water consumption increases. Water temperature also affects water consumption. In hot seasons, the temperature of the water should be between 13-18 °C. Giving chilled drinking water to dairy cows increases milk yield as it absorbs heat and lowers body temperature.

6.13. Mineral Supplementation Should Be Done

With the decrease in feed consumption of animals, increase in sweat and urine amount in hot weather, some minerals (K, Na) are excreted, blood acid-base balance deteriorates and blood bicarbonate and buffering capacity decrease. Due to the urinary excretion of electrolytes, the need for minerals increases in hot weather. Suitable salts (ammonium chloride, sodium and potassium bicarbonate, sodium and potassium hydrocarbonate, potassium sulfate, etc.) may give good results for the diets of poultry, pigs and ruminants.

6.14. Some Additives Can Be Used

The use of some additives to increase the usefulness of feeds in hot conditions may give positive results.

a) Anti-oxidant vitamins (A, C and E) should be supplemented.
b) Essential micronutrient supplementation consisting of mineral blends and antioxidants may give a better result in improving the reduction in milk production caused by heat stress.
c) Enzyme use: Adding different enzyme supplements to the ration can improve the digestibility of nutrients such as amino acids, carbohydrates, and Ca and P. However, appropriate enzymes (phytase, xylanase, β-glucanase, etc.) should be used according to the composition of the feed.
d) Adding probiotic-based lactobacillus strains to poultry exposed to high temperatures can help balance intestinal microorganisms.
e) Additives that increase feed digestibility: The use of additives such as buffers, probiotics, prebiotics, niacin and yeast can improve the digestibility of feeds by increasing rumen fermentation.

6.15. Reducing Methane Production

Starch-rich diets increase propionic acid production and reduce methane production in the rumen. For this reason, methane can be reduced by increasing the ratio of concentrated feed in the ration, using vegetable and marine oils, oilseeds or essential oils and ionophores. Physical processing of feed, such as chopping, grinding and steam treatment, also improves forage digestibility and reduces enteric methane production in ruminants. The use of antimethanogenic plants in the diet is the most important solution. Increasing animal productivity is often a good strategy to reduce greenhouse gas emissions from livestock production systems. This is because high-yielding animals produce less methane than low-yielding animals.

6.16. For Bees

Various and flower-rich plants for pollinators should be planted in pastures, mixed and arable farmlands, burned forests, roadsides, gardens of houses, plant diversity should be ensured by planting wildflower seed mixtures rich in nectar and pollen, and bees should be able to collect pollen. Grow more flowers, shrubs and trees that provide nectar and pollen for bees and other pollinators throughout the year.

6.17. Cooling

In a temperature environment, the animals can be ventilated and cooled by using sprinklers or fans. In order to reduce heat stress in buffaloes, a pond, swamp, etc. water source or fountain system should be established.

6.18. Animals Should Be Provided With Good Shading

With the high body temperature produced by ruminants and pigs, direct sunlight especially in the hot season brings too much heat load to the animal and becomes harmful. Therefore, shade should be provided.

7. Conclusion

In parallel with the increase in the human population, the global demand for animal products is also increasing. However, climate change causes negative effects on animal production and productivity. The increase in temperatures due to global climate change causes heat stress and significantly affects the physiology, metabolism and productivity of animals. In addition to the increasing temperature, the change in precipitation regimes and the increase in drought negatively affeccetvelt the amount and quality of feed materials. Decreased quality of rangeland will cause malnutrition of grazing animals. This is especially important for ruminants. There is a very close relationship between the energy metabolism of animals and ambient temperature and animal performance and the quality of their products. As a result of insufficient feed consumption and lack of energy, there will be a decrease in animal products such as milk, meat, meat, eggs, hair / fleece and their quality will decrease. The studies carried out so far on this subject can help the livestock sector in the fight against climate change. In order to reduce greenhouse gas emissions caused by animals, it is imperative to make changes in the ration. Feeding strategies should be implemented to adapt to climate change and mitigate its effects, and as a result, quality and safe animal products should be produced for human nutrition without increasing the environmental burden of production. For this, there is a need for more studies on feeding in different geographical regions and on different animal species.

Author Contributions

All tasks were done by the single author; B.Z.S. (100%) and the author reviewed and approved the manuscript.

Conflict of Interest

The author declare that there is no conflict of interest.

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