OPEN ACCESS JOURNALS
Indiana Journal of Agriculture and Life Sciences
Abbriviate Tittle- Ind J Agri Life Sci
ISSN *(Online)*- 2583-1623
Journal Homepage Link- https://indianapublications.com/journal/IJALS
DOI- https://doi.org/10.5281/zenodo.17015842

INDIANA PUBLICATIONS
PRODUCTIVE AND QUALITY RESEARCH

Review Article

Volume-05|Issue-04|2025

Global Climate Change Effects on the Reproductive Efficiency, Milk Output, and Composition in Dairy Cattle

Alsaied Alnaimy Mostafa Habeeb

Egyptian Atomic Energy Authority, Nuclear Research Center, Radioisotopes Application Davison, Biological Applications Department.

Article History
Received: 08.08.2025
Accepted: 22.08.2025
Published: 31.08.2025

Citation
Habeeb, A. A. M. (2025). Global Climate Change Effects on the Reproductive Efficiency, Milk Output, and Composition in Dairy Cattle. *Indiana Journal of Agriculture and Life Sciences, 5*(4), 44-65.

Abstract: Temperature, relative humidity, air movement, and sun radiation are climate elements that affect dairy cows. Temperature and relative air humidity are the two main factors affecting animal production. As the temperature outdoors rises, cows' primary non-evaporative cooling systems (radiation, conduction, and convection) become less effective; thus, they also depend on evaporative cooling, such as sweating and panting. An imbalance between the body's metabolic heat production and its release into the environment can lead to heat stress in uncomfortable weather. Heat stress has a detrimental effect on dairy cows' health and productivity. Climate change causes material and financial losses for farm animals, particularly in the summer months, in most regions of the world. When dairy cows are inseminated in the summer, the majority of the fertility reduction is caused by summer heat stress. Heat stress has a major detrimental impact on numerous reproductive features and, consequently, the milk output of dairy cows, which is a major financial burden in many dairy-producing regions of the world. Heat stress has a number of serious and expensive effects on dairy cows. Decreases in dry matter intake (DMI), milk output, and milk efficiency are linked to ambient temperature and temperature-humidity index (THI) increases over acute thresholds.

Keyword: climate change, dairy cattle, heat stress, reproduction, milk yield, milk composition.

INTRODUCTION

Human activities and natural sources emit greenhouse gases (GHG) into the atmosphere. Atmospheric GHG concentrations increased by around 39% and the concentration of CH_4 have more than doubled due to the industrial revolution (**WHO, 2009**). More than 60% of GHG emissions are from the agriculture sector. The animal is responsible for 18% of GHG emissions, 65% N_2O, 37% methane, and 9% CO_2 as presented in Figure 1 **(FAO, 2022**).

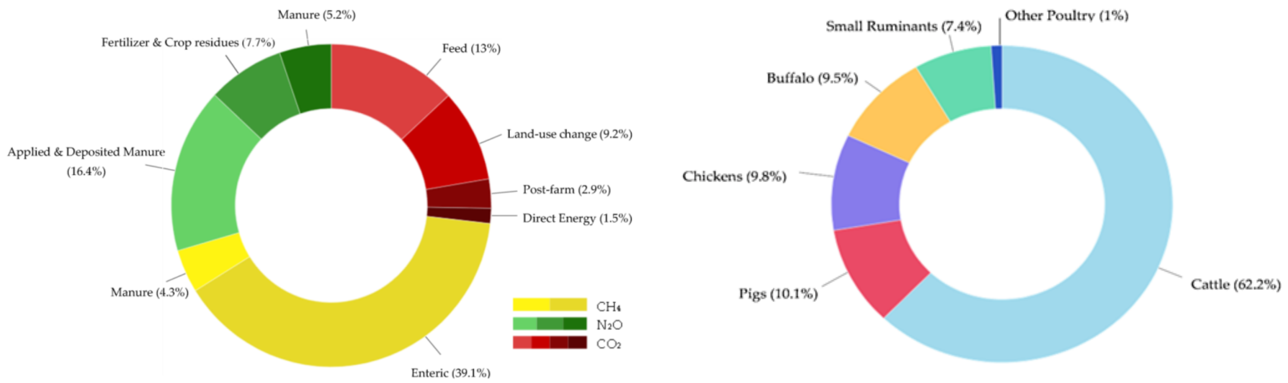

Figure 1: Greenhouse gases emissions and its effect on global climate change

Methane emissions are from enteric fermentation, manure and management of cattle. N_2O is from animal dung, while CO_2 is from changing land usage due to feed grains, grazing land, and agricultural energy. Rising GHG concentrations in the atmosphere caused the increase in environmental temperatures and, consequently, climate change. The rising average temperature of the atmosphere, or global warming, is the most evident sign of climate change.

According to predictions, weather alteration will happen swiftly. According to the **IPCC (2014)** report, the globe's temperature has been rising by 0.2°C every ten years. By 2040, worldwide heating is predicted to increase by 1.5 °C; by 2050, environmental temperatures might rise by up to 2.0 °C (**Herbut *et al.*, 2018a**). By the year 2100, the average surface temperature is expected to have climbed to 1.88–5.8°C due to global warming **(Geiger *et al.*, 2021**). Climate models predict a temperature rise of 0.3 to 4.8°C over the next century, and this continual rise in temperature will have a serious impact upon food production and farming. Climate change-related high-temperature stress is one of the main factors affecting livestock productivity worldwide, and several interconnected aspects determine the degree of heat stress (**Wankar *et al.*, 2021).**

Dairy cattle suffer from heat stress when the outside temperature rises over the thermo-neutral zone or the comfort zone, which is between the lower critical temperature and the higher critical temperature. The lower critical temperature is the ambient temperature at which an animal produces more metabolic heat to sustain body temperature. The higher critical temperature refers to the temperature at which an animal raises its body temperature to make up for inadequate evaporative heat loss. The range of 21–27°C for growth rates and 24–30°C for milk production is the higher critical temperature for cattle, whereas the range of -16 to -37 ºC is the lower critical temperature for farm animals **(Collier *et al.*, 2019)**. Animals that are exposed to temperatures higher than their thermoregulation zone will experience heat stress as a result of a confluence of environmental factors (**Dash *et al.*, 2015)**.

Cattle being homoeothermic can control their body temperature through several physiological and behavioral reactions through the integration of numerous organs and systems, such as the immune system, endocrine system, behavioral system, and cardio-respiratory system, modifying some physiological processes during heat exposure to support heat balance (**Habeeb *et al.*, 2023**). Homeostatic processes and behavioral changes, such as decreased activity, increased water intake, and decreased feed intake, can identify heat stress in dairy animals (**M'hamdi *et al.*, 2012).** Heat stress directly affects and damages the cellular activities of numerous bodily parts and tissues, including reduced food intake, respiratory alkalosis and fertility (**Abdelatif and Alameen 2012**). These consequences include altered immunological response and heightened vulnerability to illness, reduced appetite and ruminating, oxytocin release suppression, and lower fertility (**Habeeb *et al.***, **2022a, b).** Extremely low heritability in dairy cow reproductive parameters suggests that environmental or non-genetic factors account for most fertility variability.

The population is expected to grow to 9.6 billion by 2050, and with that comes a 70% increase in demand for livestock products worldwide. Moreover, more than 50% of cattle are found in tropical regions, and heat stress has been shown to severely reduce profitability in about 60% of dairy farms worldwide (**FAO, 2015**). As global warming continues, animals' problems with heat stress will get worse.

The dairy industry experiences commercial losses due to a decline in milk output, a slowdown in reproduction, a rise in metabolic issues, and weakened immune systems (**Zigo *et al.*, 2021**). The dairy production has annual economic harms as a result of high-stakes syndrome, with a decline in the milk supply being the most important of the several causes (**Vitali *et al.*, 2009).** Heat stress, for instance, costs cattle producers billions of dollars annually in lost productivity. In Florida and Texas, the annual economic losses ascribed to nursing cows have been estimated to be $337 and $383 per cow, respectively **(St-Pierre *et al.*, 2003**). Based on current milk prices, losses were anticipated in 2014 to be US$ 670 million/year; by the end of the century, this amount is likely to increase to US$ 2.2 billion annually (**Mauger *et al.* 2015**). According to recent economic research, the US dairy sector may suffer financial losses of up to $810 million yearly if cows are not chilled during the dry season (**Ferreira *et al.*, 2016**). Heat stress has a significant negative influence on the financial performance of dairy farms in the United States. Heat stress causes the cattle business in the United States to lose between $1.69 and $2.36 billion annually in revenue. Between $897 and $1500 million of these losses are attributed to the dairy sector each year (**Osei-Amponsah *et al.*, 2019**).

Research by meteorologists and climatologists has revealed a specific hazard to all of Europe. For a herd of 100 cows, the predicted losses in dairy output in the European Union in 2015 compared to previous years range from 70 to 550 kg of milk per day. The most detrimental consequence of heat stress on cows is reduced milk output, as the economic effects generally become apparent within a few days (**Herbut *et al.*, 2018b**).

This study aims to investigate the detrimental effects of global climate change on reproductive efficiency, milk output, and composition in dairy cattle.

First: Global Climate Change Effects on the Reproductive Efficiency

One of the main elements influencing the performance of any dairy herd is fertility. Numerous elements including heredity, diet, hormones, pathophysiology, management, and climate, affect the fertility of cows (**Chawicha and Mummed, 2022**). The effects of hot weather on reproduction may probably become increasingly noticeable in tandem with climate change. Heat stress has detrimental effects on reproductive events because heat stress inhibits embryonic development, decreases the appearance of estrous behavior, grows ovarian follicles, and decreases oocyte competence **(Mondal *et al.*, 2017).** Heat load also interferes with several processes related to becoming and maintaining pregnancy. These processes include modifications to follicular development and dominance patterns, regression of the corpus luteum, decreased ovarian function, oocyte quality and competence, development of the embryo, elevated rates of early fetal loss and embryonic mortality, endometrial function, decreased uterine blood flow, and decreased expression of estrus and behaviors linked to estrus (**Schüller *et al.*, 2017).** Numerous publications have reported negative correlations between THI and animal reproductive outcomes. **Gaafar *et al.* (2011)** found that the **s**ummer heat stress led to a considerably longer first estrus, interval service, days open and calving interval, more services per conception, and a lower conception rate in Frisian cows. The same authors found that as THI grew from 57.98 in January to 80.40 in July, the number of services per conception rose from 2.44 to 3.02 and the conception rate dropped from 78.69 to 63.29%**. Mondal *et al.* (2017**) mentioned that heat stress negatively impacts reproductive events by reducing the expression of estrous behavior, changing the growth of ovarian follicles, impairing oocyte competence, and suppressing embryonic development; heat stress impacts reproductive events. Reduced frequency and length of estrus, calving rate, and an increase in the number of inseminations per conception were the outcomes of heat stress (**Patel *et al.*, 2018**). **Parikh *et al.* (2024)** showed that compared to heifers born during the winter and rainy seasons, those born during the summer had noticeably longer ages at sexual maturity, first conception, and first calving. **Reisi-Vanani *et al.* (2025**) found a significant impact of heat stress on productive life among the reproductive traits of Holstein dairy cows, which is defined as the number of days from the first calving to the last milk record. Impaired reproductive success is mostly caused by low estrous signs and embryonic losses **(Gantner *et al.*, 2011**). Summer heat stress is a key cause of decreased fertility in dairy cattle, according to **Wolfenson and Roth (2019**). As a result, cows cannot conceive. A poor rate of evaporative heat loss and excessive metabolic heat generation lead to severe hyperthermia. Oocyte competence, embryonic growth, gonadotropin secretion, ovarian follicular growth, steroidogenesis, corpus luteum development, and uterine endometrial responses are among the several reproductive processes that are compromised. From a different angle, improving reproductive performance in dairy cow herds prolongs productive life and eventually boosts profitability (**Habeeb *et al.*, 2018**).

The consequences of high temperatures are linked to a rise in reactive oxygen species generation, which causes cellular death and interferes with fertilized egg development. Furthermore, alterations in progesterone levels and a reduction in ovarian follicles' generation of estradiol are linked to reproductive abnormalities under heat stress (**Khan *et al.*, 2020**). Oxidative stress coexists with heat stress. Animals often possess defense mechanisms against the emergence of oxidative processes, such as glutathione peroxidase, catalase, and superoxide dismutase. However, because stress dramatically raises the requirement for vitamins (ascorbic acid, tocopherols, and carotenoids) and microelements (Se, Cu, and Zn), these defensive mechanisms are restricted **(Pragna *et al.*, 2017**).

Global climate change effects on puberty and estrus induction

High ambient temperatures delay both male and female puberty onset. Research indicates elevated temperatures impact the reproductive process throughout several phases, such as pubertal maturation, implantation, and embryonic death (**Williams and Walsh, 2010**). **Hansen and Arechiga (1999)** revealed reductions in estrous behaviors in dairy cows under heat stress and more evidence that the frequency and length of estrous mounting behaviors in beef cattle are significantly shorter in the summer than in the winter. During the hot summer months, the morning and evening see the highest levels of sexual activity, while the afternoon has the lowest levels. **El-Wardani and El-Asheeri (2000)** found that the estrus symptoms were most noticeable in the morning and evening (37%) while the smallest percentage (12%) occurred around midday. Cows that consumed more dry matter had a greater chance of exhibiting estrous behavior during their first ovulation and becoming pregnant by day 150 of lactation (**Westwood *et al.*, 2002).** When European breeds are relocated to tropical regions, shorter estrus lengths have been observed; these discrepancies have been ascribed to temperature, diet, and parasites **(White *et al.*, 2002**). According to Florida research, **Bridges *et al.* (2005**) found that the average number of undiagnosed estrus occurrences throughout the summer months (41 °C) is 76–82%, compared to 44–65% from October to May. Cows that experience high ambient temperatures are more likely to have silent heat and anestrus, which also results in a reduction in the length and intensity of estrus and a noticeable decline in the quality of produce **(Raval and Dhami, 2005)**. Heat stress shortens the length and intensity of estrus, which makes it harder to reproduce because quiet heat or weak estrus expression results (**Bolocan, 2009**). The ovary may be directly impacted by heat stress if it becomes less sensitive to gonadotropin stimulation **(Sartori *et al.*, 2009**). The summer estrous cycle in Japanese cattle was longer (23.4 days vs. 21.5 days), and the cattle exhibited less roaming behavior during estrus than in the winter (**Sakatani *et al.*, 2012**). Identifying estrus becomes more difficult in dairy cows with fewer symptoms and shorter estrus durations during heat stress (**Singh *et al.*, 2013**). Heat stress significantly lowers the number of heat detected and increases the number of days open, which leads to significant financial losses for dairy farms (**Boni *et al.*, 2014**). This was found to be the case for high-producing dairy cows calving from January to July, which had a significantly higher number of days open than those calving from August to December. Heat stress affects reproduction by preventing the synthesis of gonadotropin-releasing hormone and luteinizing hormone, which are essential for ovulation and the display of estrus behavior (**Temple *et al.*, 2015**). Heat stress has a major impact on cows' expression of estrus by shortening and intensifying estrus in animals and increasing the frequency of anestrous and silent heat (**Abrar *et al.*, 2015**). The summer estrus cycle of non-lactating cows was found to be much longer than the winter cycle, and the rates of estrus and conception decreased when the THI exceeded 72 (**Temple *et al.*, 2015**). Inadequate identification of estrous cycles and losses of embryos are the main reasons for subpar reproductive outcomes. Approximately 50% of standing periods of estrus go unnoticed during the postpartum period. This inability to detect estrus can result in an average interval of 40–50 days between successive inseminations, which lowers reproductive efficiency and profitability (**El-Tarabany and El-Tarabany 2015**). Cattle that experience heat stress may silently heat up, and their estrus may be shorter and less intense, which may result in less mounting activity. **Dash *et al.* (2015)** showed that heat stress reduces the intensity and duration of behavioral estrus, making it less common to see cows in estrus under these circumstances. The later authors reported that the expression of estrus at the first ovulation, the time between calving and conception, and the chance of conception and pregnancy were all strongly correlated with heat stress. Warm weather shortens and weakens the estrous expression period, which is bad for a cow's ability to participate in natural mating behavior. Heat stress changes follicular development and shortens and weakens estrus (**Chawicha and Mummed, 2022**). The delay in the recovery of complete estrous cycles in cows following calving is the primary impact of heat stress on reproduction. The synthesis and release of glucocorticoids are stimulated by the adrenocorticotropic hormone in reaction to stress, which can negatively impact the hypothalamic-pituitary-gonadal axis and estrous cyclicity **(Skliarov *et al.*, 2022).**

Heat stress is associated with a reduced ovarian response to FSH and LH, which leads to hot seasonal anoestrus and heat stress also increases the ACTH/cortisol ratio, which alters endocrine secretion and results in anoestrus (**Al-Dawood, 2017**). Elevated amounts of blood corticosteroids released in response to heat stress also cause changes in the secretory pattern of pituitary gonadotropins, which in turn cause anoestrus (**Abeni and Galli, 2016**). The dominant follicle grows in low LH levels at high ambient temperatures reducing estradiol secretion and resulting in extended follicular dominance, delayed ovulation, and poor estrus expression **(Siddiqui *et al.*, 2010**). The hormone that causes the expression of estrus is estradiol. Estrus is impacted by the decrease in estradiol production which is low in females rose in warmer climates (**Masoumi and Derensis, 2013**). Heat stress inhibits estradiol-induced sexual behavior by increasing the release of ACTH and cortisol (**Kadokawa *et al.*, 2012**). Low estradiol production inhibits gonadotropin surge, ovulation, gamete transport, and indications of estrus (**Das *et al.*, 2016**). In addition, silent heat issues in cows or heifers are caused by low progesterone along with low estrogen levels (**Habeeb *et al.*, 2018**). Moreover, **Patel *et al.* (2018)** found that heat stress influences the production of FSH, LH, and gonadotropins from the anterior pituitary gland in addition to gonadotropin-releasing hormone from the hypothalamus. The production of LH and gonadotropin-releasing hormone is reduced in response to heat stress, which inhibits ovulation and the manifestation of estrus activity. Lower amounts of estradiol-17α and LH secretion may cause dairy cows to be less anestrous and have a longer summer estrous cycle and the hormone estradiol is found in lower concentrations when heat stress results in a reduction in the production of 17 hydroxylases (**Temple *et al.*, 2015**). Infertility and the cessation of estrous cycles are caused by elevated circulating prolactin under heat stress (**Singh *et al.*, 2013**). Heat stress also raises the level of prolactin in the blood which has anti-gonadotrophic properties and is the main reason for postpartum anoestrus in lactating animals (**Alamer, 2011**). Long-term stress reduces the amount of estradiol released by follicles, which has an immediate impact on the animal's ovaries; estrous behaviors may become unclear or nonexistent **(Sammad *et al.*, 2020**).

Global climate change effects on conception rate

The percentage of services that produce lactating dairy cows pregnant is known as the conception rate. Elevated ambient temperatures can potentially impact the rates of conception and pregnancy. In lactating dairy cows, summertime records revealed a 20–27% drop in conception rates (**Chebel *et al.*, 2004**). Compared to findings from the winter, there might be a 20–30% drop in conception rate during the summer season (**Raval and Dhami, 2005**). Reduced conception rate was consistently linked to heat stress in the lead-up to breeding day (**Morton *et al.*, 2007**). **Garcia-Ispierto *et al.* (2007)** observed that heat stress reduces breastfeeding dairy cows' conception rate by about 30.6% compared to breeding days. When THI is higher than 80 for three to one day before artificial insemination, the conception rate drops from 30.6% to 23.0%. **Morton *et al.* (2007)** noted that the nursing dairy cows' conception rate was substantially lower during the hot season (July to September) at 29.5% than it was during the cold period (October to June), when it was 38.2%. Dairy cows have much lower summertime conception rates than in other seasons (**Flamenbaum and Galon 2010**). Conception rates were adversely correlated with the maximum ambient temperature on the day following insemination (**Nabenishi *et al.*, 2011**). Summer heat stress has a detrimental impact on dairy cows' reproductive performance, according to **Ghavi *et al.* (2013**), who also found that summer-calved cows had lower conception rates and more services per conception than cows calved in other seasons. The linear regression of conception rate percentage on THI is $y = 0.70 x^2 - 3.95 x + 72.57$ ($R^2 = 0.75$), where x is THI and y is conception rate %. Heat stresses before and after the breeding day had a detrimental effect on the conception rate of nursing dairy cows. The highest detrimental effect of heat stress on the conception rate was shown 21 to 1 day before breeding, and the rate of conception dropped from 31% to 12% when the mean THI was 73 or higher (**Schüller *et al.*, 2014**). In Egypt, the conception rate in purebred Holstein cows dropped dramatically from 31.6 at the smaller THI to 11.5% at the larger THI. The conception rate in purebred Holstein cows dropped dramatically from 26.3% at the lower THI to 9.9% at the higher THI (**El-Tarabany and El-Tarabany, 2015**). **Lacerda and Loureiro (2015**) found that during the months with high and low temperatures and humidity, the artificial insemination conception rate ranges from 55% to less than 10%. **Schuller *et al.* (2017)** discovered a correlation between the mean THI on the day of breeding and the subsequent conception rate and determined that 73 was the THI threshold for the impact of heat stress on the conception rate. According to **Polsky and Keyserling (2017**), there are clear seasonal variations in the conception rate, and the drop in the conception rate during summer months might range from 20 to 30%. In contrast to 40–50% at the ideal temperature, the likelihood of effective fertilization might decrease to 10% during the hottest months of the year. The authors discovered that when the THI was over 70, a one-unit rise in THI led to a 4.6% drop in the rate of conception **(Krishnan *et al.*, 2017).** During the mild heat stress phase (THI 73-78), the highest rates of conception were seen in inseminated cows (41.7%), while during severe heat stress (THI above 90), the conception rate decreased to 32.5% **(Penev *et al.*, 2020)**. The later authors mentioned that the percentage of conceptions dropped from around 40 to 60% in the colder months to 10 to 20% or less in the summer, according to the intensity of heat stress. **Wolfensen and Roth (2019**) reported that conception rates dropped from 40 to 50% in months with higher ambient temperatures to fewer than 10% in months with lower temperatures. A significant decline in the rate of conception in dairy cows globally is caused by heat stress throughout the summer, which interferes with many reproductive processes. In the summer months, lactating cows' conception rate was 27.7%, but in the cold winter months, it was 42.6% (**Wolfenson and Roth, 2019).** The level of gonadotropin-releasing hormone released from the hypothalamus is reduced in cows under acute stress. As a result, cells are less susceptible to the effects of FSH, LH, and estradiol hormones, and the gonads release less of these hormones (**Marai and Habeeb, 2010).** Reduced levels of gonadotropins, estrogen, and LH brought on by heat stress disrupt the regular cycle of estrus and suppress follicular growth, which accounts for the decline in the conception rate (**Wang *et al.*, 2020**).

Global climate change effects on Oocytes

Heat stress can affect an oocyte and hence affect the fertility of cows. Heat stress affects both the oocyte quality and the embryo development. Heat stress affects several parts of the female reproductive tract, including the follicle, oocyte, and embryo, in manifestations of cellular activity. Heat stress also impairs oocyte competence and heat stress is bad for the developing oocyte throughout the later stages and its ability to become fertilized. Higher summertime ambient temperatures have been linked to lower fertility in dairy animals due to heat stress's detrimental effects on oocyte maturation (**Wolfenson and Roth, 2019**). In repeat-breeder Holstein cows, poor oocyte quality has been associated with reduced fertility, and heat stress intensifies this adverse effect **(Ferreira *et al.*, 2011**). The damaging consequences of heat stress start when the egg is still growing and continue through subsequent stages, affecting the egg's ability to fertilize, the development and implantation of the embryo, and even the fetal calf (**Hansen, 2009**). Summer Holstein cow oocytes through in vitro fertilization were less competent than winter cow oocytes to grow into the blastocyst stage (**Gendelman *et al.*, 2010).** Furthermore, heat stress results in incomplete dominance, which promotes the growth of subordinate follicles while inhibiting the growth of the dominant follicle (**Bajagai, 2011**). Heat stress also affects embryo development and implantation in the uterus, and even extends toward the developing calf (**Sammad *et al.*, 2019).** Oocyte competence is lower in summer than in winter, as indicated by the developmental rate following fertilization (**Habeeb, 2020a**).

Heat stress reduces the quality of oocytes and modifies follicular steroidogenesis by affecting follicle selection and lengthening follicular waves. Furthermore, cows are subjected to heat stress in their ovaries and lose their ability to fertilize and grow to the blastocyst stage (**Roth *et al.*, 2001**). **De Rensis and Scaramuzzi (2003)** state that low levels of insulin, glucose, and IGF-I, which are essential for folliculogenesis, cause problems with follicular development, and produce oocytes of low quality. The synthesis of oocyte growth proteins or the production of transcripts necessary for later embryonic development is adversely affected by high temperatures. Heat stress has the potential to inhibit oocyte formation through several different methods. The first is the depression in LH and estradiol production during the pre-ovulatory surge (**Hansen, 2009**). Heat stress modifies follicular development by decreasing the synthesis of steroid hormones and these modifications in follicular steroid concentration may cause problems for oocyte formation (**Hansen, 2007**). One of the best strategies to reduce the severity of heat stress is embryo transfer, which shields the egg and early embryo from its effects (**Kadokawa *et al.*, 2012**). The body's natural reaction to heat stress lowers metabolism by altering blood hormone levels. Growth hormone, T_4, and T_3 levels are so reduced, while noradrenaline and adrenaline levels rise. A tenfold increase in cortisol levels inhibits oxytocin, resulting in a decrease in milk supply and an increase in leftover milk after milking. Furthermore, cortisone inhibits immunity, delays ovulation, interferes with the estrous cycle, and decreases the production of milk protein in udder cells (**Aggarwal and Upadhyay, 2013a).** The disruption of gonadotropin secretion under heat stress causes a reduction in plasma progesterone levels, steroid production, and follicle formation. These alterations are related to pre-implantation complications, reduced oocyte development and embryo survival, and impaired estrus (**Roth, 2020**).

Global climate change effects on fertility and follicular development

The animal's capacity to become pregnant and keep it pregnant if inseminated at the right time for ovulation is known as fertility in farm animals. The reproductive features of dairy animals have a relatively low heritability value, indicating that environmental influence or non-genetic variables affect fertility (**Garcia-Ispierto *et al.*, 2007**). The latter authors reported that heat stress causes oocytes to grow less, leading to acyclicity and infertility in animals. High-yielding dairy cows have a lower fertility rate in the summer than in the winter, and nursing cows are more adversely affected than heifers due to their noticeably higher internal heat production (**Takahashi, 2012**). Heat stress on fertility results in a larger percentage of cows having various kinds of anestrus, a decrease in the incidence of conception, and an increase in days open. Heat stress affects the ovary, uterus, gametes, embryo, and early fetus after pregnancy, which lowers the cow's capacity to procreate (**De Rensis *et al.*, 2015**). The main cause of the decreased fertility in farm animals is higher ambient temperatures. Cattle under heat stress have lower fertility rates, which lowers reproductive efficiency. The fertilization rate in nursing cows bred using artificial insemination dropped from 88% in the winter to 55% in the summer (**Hackbart *et al.*, 2010).** The fertilization rate falls when the uterine temperature rises by 0.5 °C on a hot day (**Alejandro *et al.*, 2014**). Heat stress has been linked to lower fertility in animals due to its detrimental effects on early embryo development and oocyte maturation (**Dash *et al.*, 2015**). Heat stress reduces fertility by preventing the production of luteinizing hormone and gonadotropin-releasing hormone, which are necessary for ovulation and the expression of estrous activity (**Temple *et al.*, 2015**). In a subtropical region, buffaloes are particularly susceptible to heat stress fertility loss over THI threshold 75 (**Dash *et al.*, 2014**). According to **Biani *et al.* (2016**), heat stress influences the poor fertility of dairy cows conceived in the late summer, with low fertility during the months with high temperatures and humidity. **Habeeb *et al.* (2018)** showed that the effects of heat stress on fertility are negative throughout the summer months. Heat stress reduces the quality of an ovary cell that may go through meiotic division to generate an ovum, alters hormonal balance, disturbs reproductive tract activities, and ultimately decreases embryo development and survival, all of which affect dairy cattle fertility (**Chawicha and Mummed, 2022**). The different ranges of variables, including genetic, dietary, hormonal, physiological, managerial, and environmental or climatic conditions, might affect fertility (**Habeeb *et al.*, 2023).**

Due to the suppression of hormones and proteins linked to reproductive organs and the changes in tissue and organ functioning, heat stress in dairy cows can result in decreased fertility (**Durmuş and Koluman, 2019**). The most important variables influencing ovarian function are the anterior pituitary, the hypothalamus, gonadotropin (FSH and LH), and the gonadotropin-releasing hormone. FSH and gonadotropins are luteinizing hormones that control ovulation, follicular development, and corpus luteum formation. The release and activity of luteinizing hormones are decreased by heat stress (**Chawicha and Mummed, 2022**). Physiological and reproductive functions in cows are both impacted by heat stress; however, the reduction in fertility is the most notable consequence for dairy farmers (**Sesay, 2023**). The synthesis of some proteins and hormones can be hindered by heat stress, which is related to decreased fertility (**Habeeb *et al.*, 2023).**

Concerning follicular development**,** dairy cow's follicular growth has been demonstrated to be directly impacted by heat stress. The quantity of dominant ovarian follicles in dairy cows under heat stress started to decrease earlier during the first follicular wave than in the animals that were cooled, as demonstrated by **Wolfenson and Roth (2019**). The heat-stressed animals had 53% more big follicles than the cooled animals due to a substantial increase in the total of large follicles in that animal. The percentage of cows in the heat-stressed animals and the thermo-neutral animals that had two follicular waves was 18% and 91%, respectively (**Wilson *et al.*, 1998).** The latter authors found that the heat-stressed animal's dominant ovarian follicles during the second follicular wave were either smaller or the same size as those of the thermo-neutral animals. The detrimental effects of heat stress on oocyte maturation and early embryo development have been linked to decreased fertility in animals (**Dash *et al.*, 2016**).

Global climate change effects on embryonic development

The reductions in the number of successful inseminations increase the risk of early embryo death and obstruct the embryo's ability to thrive (**Rivera and Hansen, 2001)**. Compared to the winter, the period between conception and parturition was 24-67 days longer, and a body temperature of more than 39 °C might harm developing embryos from day 1 to day 6 and result in miscarriage (**Bouraoui *et al.*, 2002**). During the earliest phases of pregnancy development, heat stress had the most detrimental impact on embryos. In dairy cows, heat stress impacts embryonic development and survival. Heat-stressed cows have changed intrauterine environments, which can lead to implantation failure, depressed embryonic growth, and embryonic death (**De Rensis and Scaramuzzi, 2003**). The vulnerability of nursing cows to heat stress reduced the growth of embryos to the blastocyst stage after the first day of estrus (**Demetrio *et al.*, 2007**). The percentage of embryos that reached the blastocyst stage was lowered in lactating cows exposed to heat stress on the first day after estrus. Holstein heifers exposed to heat stress from the start of estrus had a higher percentage of abnormal and developmentally disturbed embryos (**Khodaei-Motlagh *et al.*, 2011**). Fetal starvation and, eventually, fetal development retardation under heat stress (**Kadokawa *et***

***al.*, 2012**). Furthermore, a cow may experience heat stress shortly after fertilization, hindering the embryo's growth (**Paula-Lopes *et al.*, 2012**). Cattle's exposure to high temperatures during the first three or seven days of pregnancy, or ovulation and oocyte maturation, reduced the viability and growth of the embryo (**Hansen, 2013**). Embryos on the first day are more susceptible to maternal heat stress than those on days three through seven (**Wakayo *et al.*, 2015).** Numerous pieces of evidence suggest that the bovine embryo is susceptible to thermal stress from the mother, especially, in the first two weeks following conception (**Lacerda and Loureiro, 2015**). Heat stress, however, negatively affects ova quality, which may affect the viability of developing embryos (**Hansen, 2015**). Heat-stressed cows have altered intrauterine environments, reduced blood flow, and elevated uterine temperatures. These modifications will lower the percentage of successful inseminations in the summer and raise early embryonic loss (**Abrar *et al.*, 2015**). According to **Roth (2017**), heat stress affects embryonic development, lowers the appearance of estrous behavior, changes follicular advance, and grows the roles of the dominant follicle.

The development of embryos and endometrial function is restricted by low progesterone levels in heat-stressed cows. Increased endometrial prostaglandin production in response to heat stress result in early corpus luteum regression and embryo loss. Fewer animals are visible in estrus in heat-stressed habitats negatively impacts embryonic mortality (**Beatty *et al.*, 2006**).

Global climate change effects on abortions and fetal loss

In normal bovine populations, abortions denote a harm of reproductive efficiency. Spontaneous abortion of dairy cows is a progressively significant issue that significantly adds to low herd viability and production (**Thurmond *et al.*, 2005).** In dairy cattle, heat stress during pre-implantation was strongly correlated with early fetal death by **Lopez-Gatius *et al.* (2005).** Moreover, heat load has been linked to early fetal death between days 21 and 30 of gestation, which is known to compromise gestation during the per-implantation phase (**Garcia-Ispierto *et al.*, 2007**). Cow embryos exposed to high temperatures until day 7 of gestation had lower conception rates than those exposed at day 30, and those exposed at day 42 of gestation had greater rates of embryonic loss **(Demetrio *et al.*, 2007**). The same investigators concluded that the greatest pregnancy loss occurs between days 8 and 17 in cows exposed to high temperatures during the early embryonic period. Follicle and oocyte development in postpartum oestrous cycles may be slowed down by the endocrine changes caused by heat stress in the middle to late stages of pregnancy (**Nardone *et al.*, 2010**). The frequency of Holstein fetal loss, abortion, and stillbirth rates rose sharply from 3.6%, 3.8%, and 17.1% with low THI to 7.2%, 5.9%, and 24.9% with high THI, respectively. The rate of embryonic loss dramatically increased from 11.5% at the low THI to 22.2% at the high THI (**El-Tarabany and El-Tarabany, 2015).** Elevated body temperature in animals under heat stress raises the temperature in the uterus because blood flow is restricted in the uterus and is diverted to the body's periphery to aid in heat removal. As a result of the uterus receiving less blood, there is a reduction in the rate of gestation, loss of the embryo, and availability of nutrients and hormones **(Alves *et al.*, 2017**). Age at first service increases in heat stress, silent heat conditions, longer time to first postpartum insemination, more inseminations per conception, lower conception rates, longer number of days open, and a higher incidence of reproductive issues such as dystocia, retained fetal membranes, premature abortions, and weaker calves are among the negative effects of heat stress (**Sammad *et al.*, 2019).**

Due to altered intrauterine environments brought on by decreased blood flow to the uterus and elevated uterine temperature, heat-stressed cows have lower rates of successful inseminations, early embryonic loss and suppressed embryonic development (**Rivera and Hansen 2001**). Heat stress lowers the level of progesterone in the blood, slows down follicle selection, and decreases the dominant follicle's degree of dominance. These results imply that heat stress is a major factor in early embryonic mortality, implantation failure, and aberrant oocyte maturation in dairy cattle (**Khodaei-Motlagh *et al.*, 2011**). In the luteal phase of the pre-conception estrous cycle, decreased progesterone levels might impair follicular growth, resulting in improper egg maturation and premature embryo mortality (**Khodaei-Motlagh *et al.*, 2013**). Furthermore, heat stress causes the endometrium to produce more prostaglandin secretion ($GF_{2\alpha}$), which might cause the embryos to die or the corpus luteam to regress too soon (**Abrar *et al.*, 2015**). In heat-stressed cattle, a negative energy balance can also lead to abnormalities in steroid concentration, alter the development of germinal vesicles, encourage the creation of ovarian cysts, and perhaps cause embryonic death (**Herbut *et al.*, 2018a, b**).

Global climate change effects on pregnancy

Heat stress lowered the pregnancy rate in dairy cows and increased its impact when it lasted longer and was more intense. Pregnancy rates are significantly impacted by heat stress. When THI = 78.0, only 39.4% of dairy cows were pregnant. The conception rate of dairy cows drops by 1.03% for every unit rise in THI when it exceeds 72.0 **(Lozano *et al.*, 2005**). Heat stress was linked to lower levels of glucocorticoids, prolactin, growth hormone, and thyroxin in the blood, which lowered the conception and pregnancy rate in dairy cows (**Avendano-Reyes *et al.*, 2006).** The least-square means of Holstein cow pregnancy rates and the monthly THI means recorded throughout the year have a negative linear ratio, according to **Domínguez *et al.* (2005**). This equation had a determination coefficient (R^2) of 0.895, meaning that pregnancy rates dropped by 0.7% for every unit increase in THI. Heat stress during late gestation significantly lowers the chances of conception and pregnancy on the day of artificial insemination (**Morrill, 2011).** Heat stress was one of the main causes of the notable drop in the pregnancy rate of crossbred cows in India (**Khan *et al.*, 2013).** The latter authors revealed that pregnancy rates in the heat stress group were significantly lower (20.5%) than in the thermo-neutral group. Reduced conception rates, reduced estrus length and intensity, significantly worse oocyte quality, and decreased pregnancy rates. Oocyte quality and oviductal function decline in response to heat stress, causing a drop in the pregnancy rate **(Kobayashi *et al.*, 2013).** Pregnancy by artificial insemination reduced from 47% to 26% when THI increased from < 70 to ≥ 95 units (**Mellado *et al.*, 2013**). Moreover, under heat stress, only less standing heat is recorded, which might eventually result in a lower pregnancy rate (**Temple *et al.*, 2015)**. The pregnancy of buffalo significantly declined at the threshold of THI 75, while the pregnancy rate in dairy cattle was shown to drop above THI 72 **(Dash *et al.*, 2015**). In cows that were exposed to the sun and those that were not, **Alves *et al.* (2017)** found that heat stress affected the pregnancy rate in cows that were exposed to the sun by 51.85% and 70.37%, respectively. THI states that high humidity and temperatures harm feed intake and hormone levels, which affects dairy cow pregnancy (**Brown *et al.*, 2016**).

Global climate change effects on pre-partum period

Heat stress during the dry season has a detrimental impact on dairy farm profitability. So heat stress at any time during the dry period shortened the length of the dry period and the gestation period (**Fabris *et al.*, 2019**). Dry animals are mistakenly believed to be less susceptible to heat stress therefore; dry cows receive little protection from heat stress. Abrupt physiological, dietary, and environmental changes occur during the dry period, adding to the stresses (**Bajagai, 2011**). These alterations may make the cows more vulnerable to heat stress and impact their fertility, milk supply, and postpartum health. The dry phase is important since it is associated with fast fetal growth, induction of milk, and mammary gland involution and subsequent development (**Sesay, 2023**). During pre-partum time, heat stress may have an impact on endocrine responses that might lead to an increase in fetal abortions, a shorter gestational period, a decrease in calf birth weight, and a reduction in the maturation of follicles and oocytes related to the postpartum reproductive cycle **(Nardone *et al.*, 2010**). The calving season impacts the length of time cattle serve, and summer-calving cows had the longest service periods (**Dash *et al.*, 2015**). Pre-partum heat stress may raise blood levels of non-esterified fatty acids while lowering thyroid hormones and placental estrogen levels. These changes may impact the development of the placenta and udder, the nutrition provided to the developing calf, and the subsequent milk supply (**Habeeb, 2020b**). According to **Habeeb (2022a,b**), dairy cows that were subjected to heat stress during their late gestation gave birth to calves that weighed less and produced less milk than cows that were not. Additionally, heat stress harms feed intake and metabolic rate in the early postpartum period, which may make it more difficult for dairy cows to increase their output after giving birth (**Marai and Habeeb, 2010**).

Global climate change effects on male reproductive performance

The side effects of heat stress on reproductive function compromise the fertility of both males and females. The fertility of a bull is just as important as that of an egg in fertilizing it to create a viable, healthy, and genetically potential conception because males make up over half of the herd. Bull testes are known to need to be 2-6°C lower than the body's core temperature to produce viable sperm. Therefore, high testicular temperatures caused by heat stress may change seminal and biochemical properties, potentially leading to reproductive problems in bulls (**Habeeb *et al.*, 2018**). Seasonal differences in semen quality, sexual behavior, hormone profiles, and testicular volume impact male reproductive success **(Cardozo *et al.*, 2006**). High temperatures often interfere with the oxidative metabolism of glucose in sperm cells because of mitochondrial malfunction, the accumulation of reactive oxygen species, and enhanced lipid peroxidation. The rise in primary defects in sperm is indicative of this **(Nichi *et al.*, 2006). Balic *et al.* (2012**) found that Simmental bulls revealed deterioration in semen quality due to summer heat stress and the younger bulls are more vulnerable to the high air temperatures in the summer. **Mishra *et al.* (2013)** found significant differences in the membrane integrity status of fresh spermatozoa between four different breeds of bulls compared to spermatozoa that were not subjected to heat stress. **Bhakat *et al.* (2014**) revealed a noteworthy seasonal variation in the properties of semen. The authors noted that semen quality was best in the winter, bad in the summer, and intermediate during the rainy season. Therefore, heat stress dramatically affects male conception and fertility rates per insemination, which in turn lowers male fitness. In Africa, the quantity, concentration, total number, and percentage of normal sperm cells decreased in bulls during the hot season. Subtropical summers cause identical kinds of animals to lose weight, size, tone, scrotal circumference, and testicular consistency (**Chauhan and Ghosh, 2014**). Heat stress causes sperm concentrations to drop, motility to decrease, and sperm abnormalities to increase (**Katie *et al.*, 2016**). Male libido and reproductive performance are reduced in high-temperature times. Testicular bulk, texture, and diameter variations are the problems found during external assessment (**Alves *et al.*, 2017).** Reduced sperm production, both in quantity and quality and decreased fertility are the most noticeable impacts of heat on male animal reproductive systems. Regarding the impact of heat stress on bulls, reduced ejaculate concentration, motility, vigor and counting of live spermatozoa; lower quality of semen is noted (**Habeeb *et al.*, 2018**).

However, **Cheng *et al.* (2022**) did note that severe declines in sperm count and semen quality may also occur in male animals. Almost half of the year is spent in extremely high temperatures for dairy cows during the hot summer months. Their ability to reproduce and produce is diminished by these circumstances, which promote sudden alterations in their biological processes. Consequently, to perform at your best in a hot setting, management strategies are required to decrease the impacts of temperature stress conditions, particularly in the summer (**Habeeb *et al.*, 2023**).

Alterations in the processes of spermatogenesis and steroidogenesis result in testicular degeneration and fibrosis, which in turn cause a loss in fertility, sperm mutation, sterility, and germinal epithelium degradation.

Second: Global Climate Change Effects on Milk Yield and Milk Composition

Global climate change effects on milk yield of dairy cattle

For dairy production, both intensive and semi-intensive, to remain sustainable, climate change is a crucial factor that has to be considered in the majority of nations. Climate change, especially global warming, will have both direct and indirect effects on farm animal welfare and health (**Ghosh *et al.*, 2017).** Farmers and livestock producers are extremely concerned about heat stress since it results in significant financial losses for animals' reproductive and production characteristics. Dairy producers suffer significant financial losses as a result of heat stress as it lowers feed intake, milk output, growth rate, and reproductive function, particularly in tropical nations. Climate change has a significant impact on the daily milk output. A reduction in milk production is the first obvious consequence of heat stress. The milk production of Friesian cows decreased by 30% in the hot environment (38 °C) compared to the mild climate (18°C) (**Kamal *et al.*, 1989**). When THI readings are more than 72, Holstein cow's milk output drops by between 10 to 40% (**Du Preez *et al.*, 1990**). Buffalo produced higher-quality milk in the winter than in the summer, according to research that found a 16.6% drop in the total mean milk supply over six lactation numbers (**Habeeb *et al.*, 2000**). For a THI <72, the average test-day milk yield was around 26.3 kg; for a THI ≥72, the yield dropped by approximately 0.2 kg for every unit increase in the index (**Ravagnolo *et al.*, 2000).** In the Mediterranean climate, milk production decreased by 21%, and dry matter intake decreased by 9.6% when the THI value rose from 68 to 78. The authors concluded that the milk yield exhibited a decline of 0.13 kg in each cow for one milking per rise in THI unit (**Bouraoui *et al.*, 2002**). **Ominski *et al.* (2002**) found that short-term, moderate heat stress in the spring and summer harmed lactating cow performance. **West (2003**) reported that a 1ºC increase in the environmental temperature over the thermal neutral zone results in a 0.85 kg drop in feed intake and lowers milk yield by about 36% and concluded that dairy cows yielded 0.2 kg less milk for every unit rise in THI over 72. The latter author found that at temperatures outside of 35°C and 40°C, respectively, the quantity of milk was reduced by 33% and 50% and decided that dairy cows with higher yields are more susceptible to heat stress than animals with lower milk production potential genetically. The livestock sector suffers substantial revenue losses once milk yield declines by 10-35% during the hot summer season and, milk yield drops two days after heat stress **(Spiers *et al.*, 2004**). The latter authors found that the output of milk in dairy cows under heat stress decreases by 35% in medium-lactation cows and only by 14% in early-lactation cows and concluded that milk output drops by 0.41 kg/cow/day for every THI unit increase over 69. The study of **Joksimović-Todorović *et al.* (2011**) revealed that a statistically significant difference in milking capability between the spring and summer seasons in Holstein-Friesian cows. Compared to the summer (39.60 L), the springtime season saw a considerable increase in the average milk output per cow (42.74 L) and concluded that the high-yielding dairy cows are more vulnerable to the effects of heat during the beginning of lactation. In Germany, **Brügemann *et al.* (2012**) found that, depending on the region, milk yield decreased by 0.08 to 0.26 kg for each increase in THI units. In the Polish study by **Herbut and Angrecka (2012**), the daily milk output dropped from 0.18 to 0.36 kg per THI unit as the THI value increased. As the THI values increased from 64.21 in the spring, 66.36 in the fall, and 42.34 in the winter to 79.31 in the summer, the heat stress of hot summer decreased the daily milk production of Holstein-Frisian cows in Serbia by 1.32, 0.92, and 1.27 kg (**Smith *et al.*, 2013**). According to **Aggarwal and Upadhyay (2013b**), heat stress was responsible for 3-10% of the difference in lactation milk output. Dairy cows experiencing heat stress produce 25% to 40% less milk due to reduced feed intake (**Baumgard *et al.*, 2011).** Heat stress increased the THI values from 59.82 in the winter season to 78.53 in the hot summer season, and this was interpreted into the reduction in the total (305 days) and daily milk output of 39.0% and 31.4%, respectively (**Gaafar *et al.*, 2011**). The impact of various THI (30-40, 41-50, 51-60, 61-70, 71-80, and 81-90) on Iranian Holstein cows' reproductive and productive abilities is examined by **Ghavi *et al.* (2013**). According to the authors, dairy cows in THI groups 81–90 produced less milk and fat than those in other THI groups, whereas cows in THI groups 30–40 and 41–50 made the most milk and fat. $y = -1.48x + 24.54$ ($R^2 = 0.88$) and $y = -0.03x + 0.73$ ($R^2 = 0.83$) where x is THI and y is milk yield kg/day and fat yield kg/day, are the linear regressions of milk yield and milk fat yield on THI, respectively. The findings showed that the milk output and composition of dairy cows were adversely impacted by summer heat stress. According to **Kamble *et al.* (2014**), Murrah buffaloes calving in the winter had the greatest peak milk output when compared to buffalo calving in the rainy and summer seasons. Buffaloes calving in the winter had the maximum milk output (1257.15 L/month), whereas those calving in the rainy and summer seasons had lactation yields of 1088.00 and

982.42 L/month, respectively. **Tao and Dahl (2013**) stated that high- temperature stress adversely influences the rate at which the cows' mammary cells regenerate throughout the dry season. As to the findings of **Rajeb *et al.* (2016),** there is a 2.31 kg drop in dry matter intake and a 5.59 kg decrease in milk production when THI levels increase from 65.6 to 83.2. Heat stress reduces milk output by 25 to 40%, according to **Tao *et al.* (2017**), with the decreased feed intake accounting for half of the decline in milk synthesis. THI is a single number that is frequently used as a useful indication of the level of stress on farm animals' ability to reproduce and be productive in hot climates worldwide. Additionally, compared to spring, autumn, and winter, forage consumption dropped by 1.63, 1.42, and 1.25 kg during the hot summer (**Könyves *et al.*, 2017).** According to **Reyad *et al.* (2016**), Holstein Friesian crossbred cows in Bangladesh had the greatest milk output and milk content values on average in October and the lowest values in July because of the high THI value. According to the authors, milk output and THI are negatively correlated. The degree of heat, the time of lactation, and the genetic potential of the cow to make milk all influence how heat stress affects milk production. **Habeeb *et al.* (2018**) suggests that dairy cows with high productivity lose more milk than cows with medium or low production when heat stress occurs. The production of milk decreases significantly with an increase in temperature and humidity. The daily milk production decreases (from 15 to 40 kg/d) in the more productive cows as the THI increases from 72 to 80 **(Summer *et al.*, 2019)**. In Tunisia, the milk output per milking of Holstein cows was 24% lower in the summer (THI = 77) than in the thermoneutral circumstances (THI = 54). The yields of milk, fat, and protein decreased by 0.13 kg, 0.4 g, and 0.3 g per milking for every unit increase in THI, respectively according to **Amamoua *et al.* (2019**). The authors reviewed that there is a 21% loss in milk output at THI levels between 68 and 78, and for every unit of THI over 69, there is a 0.41 kg drop in milk production per cow per day. The next authors report that the milk yield (14.75 kg) in the summer (THI = 78) was lower than the milk output (18.73 kg) of Holstein cows in the spring (THI = 68). The milk protein levels also decreased as the THI value increased. When the THI rises above 68, **Tao *et al.* (2020**) reported that there are noticeable declines in milk output. The maximum amount of milk produced by cows per day under ideal temperature circumstances was 45.62 kg, and it was shown that when THI levels increased, cow milk production fell (**Penev *et al.*, 2021**). When the average THI for the heat stress period was 83, 62, 72, 77, and 64, **Demir and Yazgan (2023**) found that the annual loss in milk production for a single cow was calculated to be 98.25, 157.68, 207.36, 164.30, and 190.08 kg, respectively. Furthermore, THI's corresponding losses in milk output per unit increase were 0.07, 0.08, 0.09, 0.07, and 0.08 kg. According to **Michael *et al.* (2022),** cows exposed to ambient temperatures that exceed their comfort zones may have a 10-40% decrease in milk output. **Garner *et al.* (2017**) found that the cows given a 4-day short-term temperature and humidity challenge reduced their dry matter intake by 48% and their milk output by 53% compared to the cows kept in thermo-neutral circumstances. On day seven, following a brief challenge in temperature and humidity, the cows' milk output returned to pre-experimental levels. On the fourth day of the post-experimental phase, the animals began to eat dry materials. Heat stress also lowers milk yield in the successive lactation in dairy cattle during the dry season, when animals are not lactating. In addition, higher milk-producing cows will be more susceptible to heat stress than lower- or dry-producing cows (**Fabris *et al.*, 2017**). The THI value is 68 ^{o} F or above, the heat stress begins to manifest and becomes dangerous when THI reaches 79/80 ^{o}F (**Habeeb *et al.*, 2018**). **Yerou *et al.* (2021**) revealed that the Holstein cows in the semiarid Mediterranean area of western Algeria reduced their daily milk output and dry matter intake by 17.6% (17.6 vs. 13.8 kg/day) and 22% (16.2 vs. 12.6 kg/day), respectively, as the THI climbed from 71.7 in the spring to 83.6 in the summer. Regression analysis revealed a negative correlation between THI score and daily milk output (kg/day) = -0.36 x THI + 40.8 (r^2 = 0.72; P<0.01). The authors determined that milk output declines by 0.36 kg per cow per day for each point rise in the value of THI over 71.7. **Chanda *et al.* (2017**) examined the effects of heat stress on the composition and milk output of Holstein-Friesian crossbred cows under both hot and cold conditions. The authors found that the average milk production during the cold season was much higher than during the warmer period. The impact of heat stress on the milk production of imported Holsteins compared to the milking records of local Holsteins under heat-stress circumstances was investigated by **Ouarfli and Chehma (2021**). The authors discovered that a considerable drop in milk output was caused by an increase in THI levels, with an average regression rate of -15.51%. The average amount of milk produced per unit of THI slightly declines under these circumstances, around -0.29 kg/THI. The native Holstein cow can adapt to the climate of the Sahara and is less susceptible to overheating.

Global climate change effects on milk composition of dairy cattle

The average yields of total solids, fat, protein, ash, and lactose in Friesian cows maintained at temperatures below 38°C were lower than those kept at thermo-neutral ambient temperatures (18°C). The observed decreases were 28.0%, 27.0%, 7.0%, 22.7%, and 30.0%, respectively (**Habeeb *et al.*, 1989**). The milk produced by buffaloes in the winter season was of higher quality than the milk produced in the hot summer season. The total solids, butterfat, protein, and lactose levels of milk significantly decreased in the summer season due to the greater outside temperature **(Habeeb *et al.*, 2000**). The test yields for fat and protein were 0.92 and 0.85 kg at a THI, respectively, and decreased at a rate of 0.012 and 0.009 kg per degree of the index (**Ravagnolo *et al.*, 2000).** Summer-calving cows exhibited lower fat (3.24%) and protein (2.88%) content than winter-calving cows (3.38% and 2.69%, respectively) (**Bouraoui *et al.*, 2002**). According to **Nardone *et al.* (2006**), of these, 20% experienced health issues that may have been caused by a disruption in the internal homeostasis process, and 80% had reduced productivity. **Joksimović-Todorović *et al.* (2011**) observed that in Holstein-Friesian cows, the amount of milk fat was significantly greater in the spring (3.25%) compared to the summer (2.62%). The milk also had a higher protein content in the spring (3.15%) compared to the summer (2.75%). Heat stress significantly reduced the composition of milk during the summer months in Egypt. In comparison to the winter season, the percentages of fat, protein, lactose, solids other than fat, total solids, and ash decreased by 7.92, 4.06, 3.97, 4.03, 5.21, and 5.63%, respectively (**Gaafar *et al.*, 2011**). **Bernabucci *et al.* (2015)** demonstrated a significant decrease in milk fat during the hot summer season (3.20 g/100 g) compared to winter and spring levels (3.80 and 3.61 g/100 g, respectively). Both the casein and milk protein levels of cows kept in heat-stressed environments tend to decline. In comparison to the hot summer season (2.27 g/100 g), the same authors discovered that the milk casein concentration was greater in the winter (2.75 g/100 g) and spring (2.48 g/100 g). **Cowley *et al.* (2015)** found that milk produced by cows under heat stress had lower protein levels than milk from cows housed at normal temperatures. The decline in milk protein content is mostly associated with the direct consequences of heat stress rather than a decrease in feed consumption. According to the same authors, cows raised in pleasant settings had a higher quantity of casein in their milk than the group that experienced heat stress (28.1 vs. 26.8 g/L, respectively). **Amamoua *et al.* (2019**) found that the yields of fat, protein, and milk dropped by 0.4 g, 0.3 g, and 0.13 kg per milking, respectively, for every unit increase in THI. The authors concluded that protein, fat, and milk products have a negative connection with THI and a continuous decreasing trend throughout THI levels. The protein fraction analysis also revealed reduced amounts of immunoglobulin G, immunoglobulin A, casein, and lactalbumin. According to **Chen *et al.* (2024),** heat stress reduced the amount of milk protein, dry matter intake and milk efficiency but did not affect milk fat content. Dry matter intake, milk efficiency, and milk protein showed substantial reductions of 19.3%, 17.9%, and 3.9%, respectively. The authors confirmed that there was a significant relationship between the drops in these parameters and the rise in THI. The dry matter intake and milk efficiency during the heat stress period were decreased by 4.13% and 3.25%, respectively, for every unit increase in THI.

How global climate change effects on milk production and composition

Most studies suggest heat stress negatively impacts milk production, primarily due to reduced feed intake and altered hormone concentrations (**Prathap *et al.*, 2017**). The profound alterations in biological processes brought on by heat stress result in a 50% reduction in milk production and reproduction (**Habeeb *et al.*, 2018**). The reproductive and productive capacities of the animals are negatively impacted by reduced feed intake, feed efficiency, and feed utilization, as well as abnormalities in the water, protein, energy, and mineral balances, enzymatic activity, hormonal secretions, and blood metabolites **(Habeeb, 2022a, b**). Several reasons for decreased milk production include altered hormone profiles, altered energy metabolism, and elevated body temperature that reduce feed intake (**Collier *et al.*, 2008**). Research has demonstrated that heat stress modifies the mammary gland, affecting milk production in dry cows during subsequent lactations (**Carabaño *et al.*, 2019**). The physiological integration of several organs and systems, including the immunological, digestive, endocrine, and cardiorespiratory systems, is necessary for adaptation to heat stress **(Asres, 2014**). The heat generated internally by the food metabolism and the ambient temperature affect cows. However, when feed consumption and milk output rise, more heat is generated during nutrition metabolism, exacerbating any heat stress brought on by external factors. According to **Nardone *et al.* (2006**), cows with higher milk production would thus experience heat stress before those with lower milk output or dry cows. Reduced food intake, abnormalities in mineral balance, enzymatic reactions, hormone and metabolite production in the blood, and metabolism of proteins and energy are all brought on by excessive heat. Dairy cows under heat stress had worse feed efficiency, lower milk output, and lower dry matter intake (**Gantner *et al.*, 2011**). The ideal temperature for breastfeeding relies on the breed, species, and heat-tolerance level. For Holstein cattle, the temperature must be over 21° C to cause a drop in milk output; for Brown Swiss and Jersey cattle, the temperature must be between 24 and 27° C (**Baumgard *et al.*, 2011**). The highest critical temperature for lactating cows is between 24 and 27 °C. High-producing dairy cows suffer when the THI rises over 72 since this is a frequent indicator of stress levels (**Patel *et al.*, 2018**). According to **Kadzere *et al.* (2002**), the optimal temperature range for lactating cows is between 5 and 25 °C, as this is when milk production peaks. The number of hours over the previous four days when THI exceeded 74 and above THI 80 on the day before were the most important factors impacting milk output in South Carolina during hot weather (**Ghosh *et al.*, 2017**). Heat stress hurts feed intake, harms reproductive capacity, and reduces milk production (**Prathap *et al.*, 2017).** In addition, heat stress during the dry season could stimulate mammary gland involution coupled with apoptosis and autophagy; a lower quantity of mammary epithelial cells might finally cause a fall in milk production (**Prathap *et al.*, 2017**). Moreover, heat stress can lead to endocrine imbalances, which can impact milk production by changing the levels of prolactin, thyroid hormones, glucocorticoids, growth hormone, estrogen, progesterone, and oxytocin (**Habeeb *et al.*, 2023**).

***Corresponding Author:** Alsaied Alnaimy Mostafa Habeeb

According to **Habeeb *et al.* (2023)**, in **Figure 2**, metabolic abnormalities brought on by heat stress result in decreased milk production, growth, and reproductive rates.

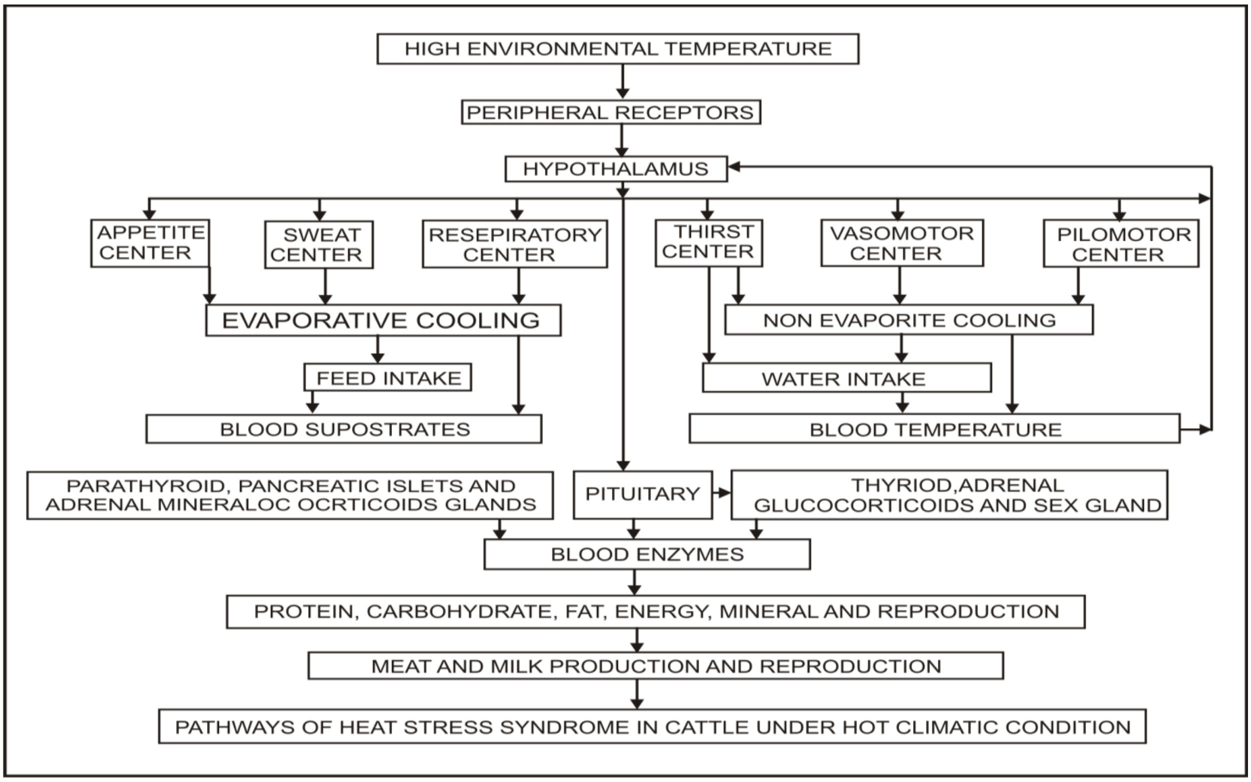

Figure 2: Pathways of heat stress syndrome in an animal under hot climatic conditions (**Habeeb *et al.*, 2023**).

Heat-stressed animals through thermoregulatory processes may attempt to lower their body temperature, which might impact feed conversion efficiency and lower milk production (**Habeeb *et al.*, 2023**). Heat stress causes an increase in body temperature, which may impact the mammary gland's ability to synthesize fat. Internal metabolic heat generation during lactation alters the milk composition and reduces milk production. The many components of milk, including fat, solid-non-fat, protein, casein, and lactose content, can all be impacted by heat stress (**Prathap *et al.*, 2017**). Furthermore, ongoing climate change and global warming are predicted to contribute to the burden of heat stress experienced by cows (**Saizi *et al.*, 2019**). In suckling Friesian calves, **Gaafar *et al.* (2021**) observed a substantial reduction in the digestibility coefficients of the nutrients, feeding values, and feeding intake in the summer ration. The same authors concluded that, in some locations, the effects of climate change on livestock systems would be particularly severe due to decreases in feed quality and quantity, resulting in lower feed intake. Dairy cows may have a 50% decrease in milk production due to the heat stress response, which profoundly alters post-absorptive lipid, protein, and carbohydrate metabolism as part of decreased feed intake (**Baumgard and Rhoads, 2013**). Only 35–50% of the decrease in milk production may be attributed to decrease dry matter consumption, according to **Baumgard *et al.* (2011**). Heat stress is the second element that lowers productivity because, as **Slimen *et al.* (2016**) explain, it causes the body to reorganize how it uses resources like fat, protein, and energy. High outside temperatures reduce farm animals' ability to reproduce and milk production. In certain regions, the effects of climate change on livestock systems may be particularly severe due to reductions in feed quality and quantity, which would result in lower feed intake (**West, 2003**). According to **Rhoads *et al.* (2009**), dairy cows under heat stress eat less and also use fewer nutrition components. According to **Gao *et al.* (2019**), heat stress exacerbates oxidative stress, which alters the molecular and metabolic activity of cells that make up the mammary secretory tissue and decreases their ability to produce milk components. Reactive oxygen species levels rise due to the oxidative stress in many animal cells and tissues, which has detrimental effects on regular bodily functions and metabolism. The animal body contains antioxidants, including enzymatic and non-enzymatic that enhance the animal body's reaction to heat stress (**Das *et al.*, 2016**). The negative effects of heat stress on dairy cows include oxidative stress, hyperthermia, and other physiological abnormalities. Consequently, it could be possible to reduce large financial losses brought on by heat stress by finding specific genomes or gene markers linked to heat tolerance and genetically selecting animals having those genes **(Sesay, 2023).** Figures 3 and 4 of **Thatcher *et al.* (2010**) and **Thornton *et al.* (2015**), respectively, illustrate THI and the effect of heat stress on dairy animal milk output.

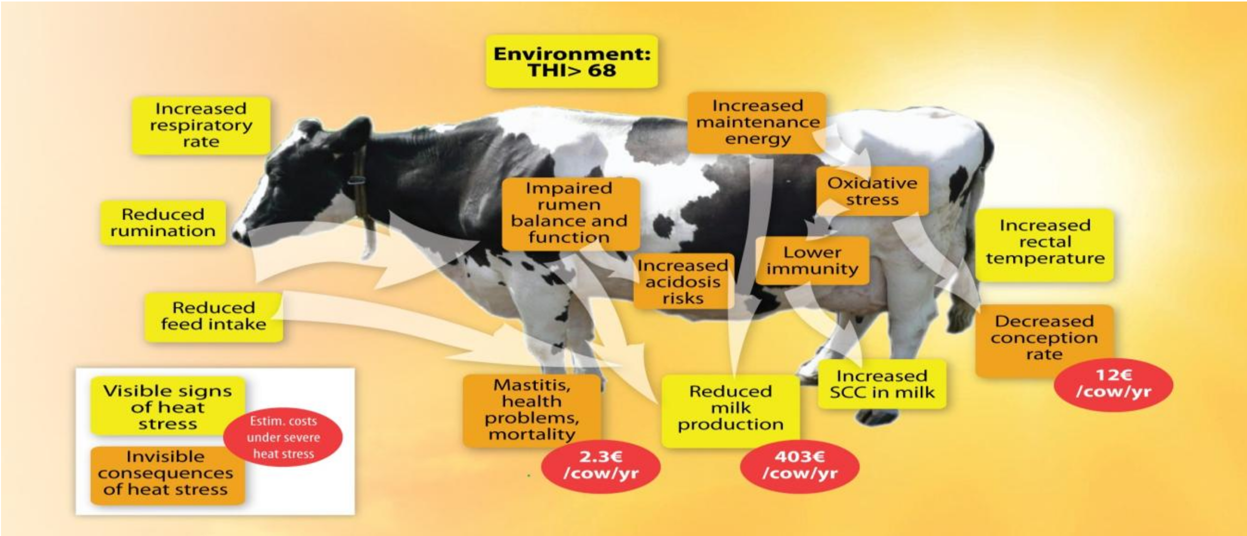

Figure 3: THI and the impact of heat stress on milk yield in dairy animals (**Thatcher *et al.*, 2010).**

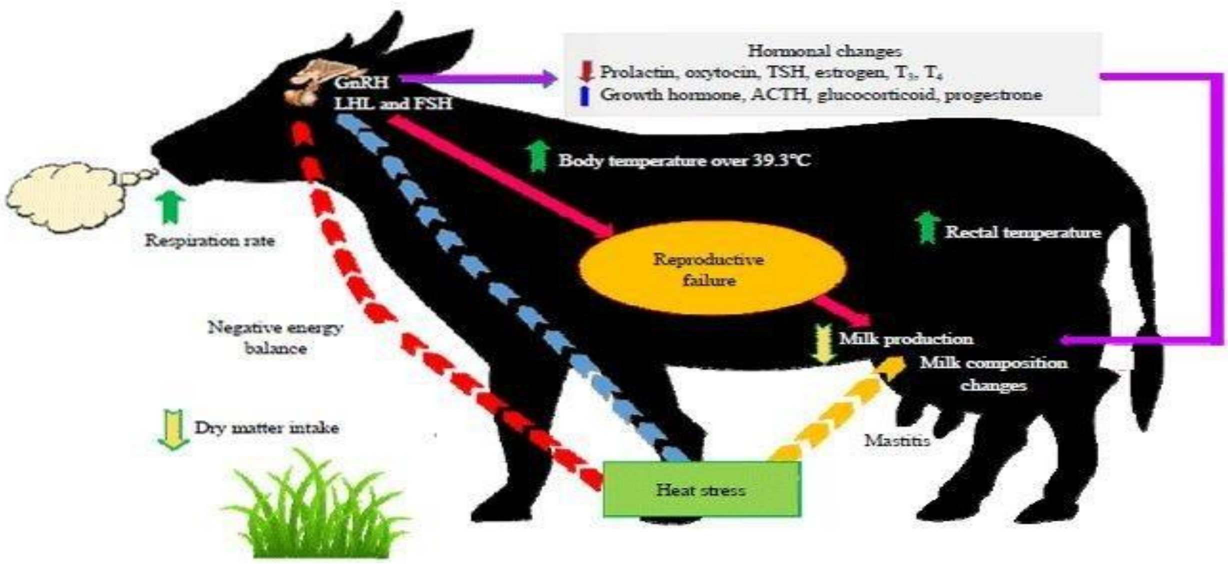

Figure 4: Impact of heat stress on milk yield of dairy animals **(Thornton *et al.*, 2015)**

In heat-stressed nursing cows, a loss of energy, substrates, and hormones may be the reason for the drop in milk production and composition. Additionally, compared to an environment at 18° C, cows consume digestible energy 35.4% less efficiently, and as a result of heat stress, their heart and respiratory rates rise, requiring more care. Additionally, elevated maintenance costs, anticipated to be 20% higher at ambient temperatures of 35°C, result in decreased energy efficiency for milk production during hot weather **(West, 1993).** A negative nitrogen balance results from the inability of protein synthesis to offset protein catabolism under certain circumstances. Protein catabolism is caused by an increase in glucocorticoid hormones, which causes the breakdown of protein tissues (**Habeeb *et al.*, 2018**). The increase in glucocorticoid hormones might be due to an increase in gluconeogenesis, which is the process that changes amino acids into their corresponding α-keto acids. Increases in catecholamines or decreases in insulin are required for protein anabolism, and can potentially result in tissue damage **(Habeeb, 2020a, b**).

We advise eating in the early morning and late evening, when digestion is at its best, three to four hours after meal intake, to avoid the hottest part of the day. Cows must be shaded from the sun by fans and sprinkler systems; fed high-quality feed with sufficient amounts of proteins, fats, minerals, and vitamins; fed smaller rations multiple times a day during the colder months; feeders must be cleaned to prevent ration spoilage; and cows must have access to an endless supply of clean, cold water.

CONCLUSION

The welfare and production of dairy cattle are greatly influenced by heat stress due to climate change. Extended periods of high environmental temperatures

***Corresponding Author:** Alsaied Alnaimy Mostafa Habeeb

with high relative humidity make it more difficult for lactating cows to expel extra body heat. Heat stress for dairy farms is expected to rise in the future due to the uncertainties around future global warming, making cows less heat tolerant. Heat stress is a significant issue that impacts farm animals' ability to reproduce virtually everywhere on the globe. The age at first service, silent heat conditions, the number of inseminations per conception, the number of days open, and the incidence of reproductive problems such as dystocia, retained fetal membranes, premature abortions, weaker calves, and lower conception rates are all increased by climate stress. Cows exposed to heat stress conditions reduced dry matter intake and milk production efficiency. In hot, humid settings, dairy cows produce less milk with worse quality characteristics. The consequences of heat stress on bulls include a detrimental impact on the amount and quality of semen, as well as its physical and chemical properties.

Acknowledgments: This work was supported by the Biological Application Department, Radioisotopes Applications Division, Nuclear Research Centre, Egyptian Atomic Energy Authority.

Author contribution: The author participated to complete of this manuscript and has directly participated in the planning, execution and analysis of this study. The author also has read and approved the final version submitted.

Data availability: The author confirmed that the availability of data and materials support their published claims and comply with field standards. The author affirmed that the information and resources available support their stated claims and adhere to industry standards. The author attest that the bespoke or available software applications support their claimed claims and adhere to industry standards.

Declarations and Ethics approval: My study-specific approval by the appropriate ethics of the Egyptian Atomic Energy Authority committee for research involving animals, and a statement on the welfare of animals. My work submitted for publication does not have any implication for public health or general welfare.

Consent for publication: The author was accepted for publication this manuscript and the content of this manuscript will not be copyrighted, submitted, or published elsewhere, while acceptance by the journal is under respect.

Conflict of Interest: The author declare no competing interests.

REFERENCES

1. Abdelatif, A. M., & Alameen, A. O. (2012). Influence of season and pregnancy on thermoregulation and haematological profile in crossbred dairy cows in tropical environment. *Global Veterinaria, 9*(3), 334–340.
2. Abeni, F., & Galli, A. (2016). Monitoring cow activity and rumination time for an early detection of heat stress in dairy cows. *International Journal of Biometeorology, 61*(3), 417–425. https://doi.org/10.1007/s00484-016-1220-3
3. Ahmed, R. A., Tiwari, P., Mishra, G. K., Jena, B., Dar, M. A., & Bhat, A. A. (2015). Effect of environmental heat stress on reproduction performance of dairy cows: A review. *International Journal of Livestock Research, 5*(4), 10–18. https://doi.org/10.5455/ijlr.20150421122704
4. Aggarwal, A., & Upadhyay, R. (2013). *Heat stress and animal productivity* (Vol. 188). Springer. https://doi.org/10.1007/978-81-322-0879-2
5. Aggarwal, A., & Upadhyay, R. (2013). Heat stress and hormones. In A. Aggarwal & R. Upadhyay (Eds.), *Heat stress and animal productivity* (pp. 27–51). Springer. https://doi.org/10.1007/978-81-322-0879-2_2
6. Alamer, M. (2011). The role of prolactin in thermoregulation and water balance during heat stress in domestic animals. *Asian Journal of Animal and Veterinary Advances, 6*(12), 1153–1169.
7. Al-Dawood, A. (2017). Towards heat stress management in small ruminants: A review. *Annals of Animal Science, 17*(1), 59–88. https://doi.org/10.1515/aoas-2016-0068
8. Alejandro, C. I., Abel, V. M., Jaime, O. P., & Pedro, S. A. (2014). Environmental stress effect on animal reproduction. *Advances in Dairy Research, 2*(1), 1–4.
9. Alves, J. R. A., Andrade, T. A. A., Assis, D. M., Gurjão, T. A., Melo, L. R. B., & Souza, B. B. (2017). Productive and reproductive performance, behavior and physiology of cattle under heat stress conditions. *Journal of Animal Behaviour and Biometeorology, 5*(3), 91–96.
10. Amamou, H., Beckers, Y., Mahouachi, B., & Hammami, H. (2019). Thermotolerance indicators related to production and physiological responses to heat stress of Holstein cows. *Journal of Thermal Biology, 82*, 90–98. https://doi.org/10.1016/j.jtherbio.2019.03.016
11. Asres, A. (2014). Effect of stress on animal health: A review. *Journal of Biology, Agriculture and Healthcare, 4*(27), 116–121.
12. Avendaño-Reyes, L. F. D., Alvarez-Valenzuela, A., Correa-Calderon, J. S., Saucedo-Quintero, P. H., Robinson, P. H., & Fadel, J. G. (2006). Effect of cooling Holstein cows during the dry period on postpartum performance under heat stress conditions. *Livestock Science, 105*(1–3), 198–206.
13. Bajagai, Y. S. (2011). Global climate change and its impacts on dairy cattle. *Nepalese Veterinary Journal, 30*, 2–16.
14. Balić, I. M., Milinković-Tur, S., Samardžija, M., & Vince, S. (2012). Effect of age and environmental factors on semen quality, glutathione peroxidase

activity and oxidative parameters in Simmental bulls. *Theriogenology, 78*(2), 423–431.

15. Baumgard, L. H., & Rhoads, R. P. (2013). Effects of heat stress on postabsorptive metabolism and energetics. *Annual Review of Animal Biosciences, 1*, 311–337.
16. Baumgard, L. H., Wheelock, J. B., Sanders, S. R., Moore, C. E., Green, H. B., Waldron, M. R., & Rhoads, R. P. (2011). Post-absorptive carbohydrate adaptations to heat stress and monensin supplementation in lactating Holstein cows. *Journal of Dairy Science, 94*(11), 5620–5633. https://doi.org/10.3168/jds.2011-4462
17. Beatty, D. T., Barnes, A., Taylor, E., Pethick, D., McCarthy, M., & Maloney, S. K. (2006). Physiological responses of Bos taurus and Bos indicus cattle to prolonged, continuous heat and humidity. *Journal of Animal Science, 84*(4), 972–985.
18. Bernabucci, U., Basiricò, L., Morera, P., Dipasquale, D., Vitali, A., Piccioli Cappelli, F., & Calamari, L. (2015). Effect of summer season on milk protein fractions in Holstein cows. *Journal of Dairy Science, 98*(3), 1815–1827. https://doi.org/10.3168/jds.2014-8788
19. Bhakat, M., Mohanty, T. K., Gupta, A. K., & Abdullah, M. (2014). Effect of season on semen quality of crossbred (Karan Fries) bulls. *Advances in Animal and Veterinary Sciences, 2*(11), 632–637. https://doi.org/10.14737/journal.aavs/2014/2.11.632.637
20. Biani, S., Bernabucci, U., Vitali, A., Lacetera, N., & Nardone, A. (2016). Effect of heat stress on nonreturn rate of Italian Holstein cows. *Journal of Dairy Science, 99*(7), 5837–5843.
21. Bolocan, E. (2009). Effects of heat stress on sexual behavior in heifers. *Scientific Papers: Animal Science and Biotechnologies, 42*(1), 141–148.
22. Boni, R., Perrone, L. L., & Cecchini, S. (2014). Heat stress affects reproductive performance of high-producing dairy cows bred in an area of southern Apennines. *Livestock Science, 160*, 172–177. https://doi.org/10.1016/j.livsci.2013.11.016
23. Bouraoui, R., Lahmar, M., Majdoub, A., Djemali, M., & Belyea, R. (2002). The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Animal Research, 51*(6), 479–491. https://doi.org/10.1051/animres:2002036
24. Bridges, P. J., Brusie, M. A., & Fortune, J. E. (2005). Elevated temperature (heat stress) in vitro reduces androstenedione and estradiol and increases progesterone secretion by follicular cells from bovine dominant follicles. *Domestic Animal Endocrinology, 29*(3), 508–522.
25. Brown, B. M., Stallings, J. W., Clay, J. S., & Rhoads, M. L. (2016). Periconceptional heat stress of Holstein dams is associated with differences in daughter milk production during their first lactation. *PLoS ONE, 11*(2), e0148234. https://doi.org/10.1371/journal.pone.0148234
26. Brügemann, K. E., Gernand, U., König von Borstel, U., & König, S. (2012). Defining and evaluating heat stress thresholds in different dairy cow production systems. *Archives Animal Breeding, 55*(1), 13–24.
27. Carabaño, M. J., Ramón, M., Menéndez-Buxadera, A., Molina, A., & Díaz, C. (2019). Selecting for heat tolerance. *Animal Frontiers, 9*(1), 62–68. https://doi.org/10.1093/af/vfy033
28. Cardozo, J., Fernández-Juan, M., Forcada, F., Abecia, A., Muiño-Blanco, T., & Cebrián-Pérez, J. A. (2006). Monthly variations in ovine seminal plasma proteins analyzed by two-dimensional polyacrylamide gel electrophoresis. *Theriogenology, 66*(4), 841–850.
29. Chanda, T., Debnath, G. K., Khan, K. I., Rahman, M. M., & Chanda, G. C. (2017). Impact of heat stress on milk yield and composition in early lactation of Holstein Friesian crossbred cattle. *Bangladesh Journal of Animal Science, 46*(3), 192–197.
30. Chauhan, D. S., & Ghosh, N. (2014). Impact of climate change on livestock production: A review. *Journal of Animal Research, 4*(2), 223–239. https://doi.org/10.5958/2277-940X.2014.00009.6
31. Chawicha, T. G., & Mummed, Y. Y. (2022). An overview of how heat stress impacts dairy cattle fertility. *Multidisciplinary Reviews, 5*(3), 2022014. https://doi.org/10.31893/multirev.2022014
32. Chebel, R. C., Santos, J. E. P., Reynolds, J. P., Cerri, R. L. A., Juchem, S. O., & Overton, M. (2004). Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. *Animal Reproduction Science, 84*(3–4), 239–255.
33. Chen, L., Thorup, V. M., Kudahl, A. B., & Østergaard, S. (2024). Effects of heat stress on feed intake, milk yield, milk composition, and feed efficiency in dairy cows: A meta-analysis. *Journal of Dairy Science, 107*(4), 3207–3218. https://doi.org/10.3168/jds.2023-24059
34. Cheng, M., McCarl, B., & Fei, C. (2022). Climate change and livestock production: A literature review. *Atmosphere, 13*(1), 140. https://doi.org/10.3390/atmos13010140
35. Collier, R. J., Baumgard, L. H., Zimbelman, R. B., & Xiao, Y. (2019). Heat stress: Physiology of acclimation and adaptation. *Animal Frontiers, 9*(1), 12–19. https://doi.org/10.1093/af/vfy031
36. Collier, R. J., Bilby, T. R., Rhoads, M. E., Baumgard, L. H., & Rhoads, R. P. (2008). Effects of climate change on dairy cattle production. *Annals of Arid Zone, 47*(3–4), 393–411.
37. Cowley, F. C., Barber, D. G., Houlihan, A. V., & Poppi, D. P. (2015). Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *Journal of Dairy Science, 98*(4), 2356–2368. https://doi.org/10.3168/jds.2014-8442

38. Das, R., Sailo, L., Verma, N., Bharti, P., Saikia, J., Imtiwati, & Kumar, R. (2016). Impact of heat stress on health and performance of dairy animals: A review. *Veterinary World, 9*(3), 260–268. https://doi.org/10.14202/vetworld.2016.260-268
39. Dash, S., Chakravarty, A. K., Singh, A., Upadhyay, A., Singh, M., & Yousuf, S. (2016). Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. *Veterinary World, 9*(3), 235–244. https://doi.org/10.14202/vetworld.2016.235-244
40. Dash, S., Chakravarty, A. K., Sah, V., Jamuna, V., Behera, R., Kashyap, N., & Deshmukh, B. (2015). Influence of temperature and humidity on pregnancy rate of Murrah buffaloes. *Asian-Australasian Journal of Animal Sciences, 28*(7), 943–950.
41. Dash, S., Chakravarty, A. K., Singh, A., Behera, R., Upadhyay, A., & Shivahre, P. R. (2014). Determination of critical heat stress zone for fertility traits using temperature humidity index in Murrah buffaloes. *Indian Journal of Animal Sciences, 84*(11), 1181–1184.
42. De Rensis, F., & Scaramuzzi, R. J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow: A review. *Theriogenology, 60*(6), 1139–1151. https://doi.org/10.1016/s0093-691x(03)00126-2
43. De Rensis, F., Garcia-Ispierto, I., & López-Gatius, F. (2015). Seasonal heat stress: Clinical implications and hormone treatments for the fertility of dairy cows. *Theriogenology, 84*(5), 659–666. https://doi.org/10.1016/j.theriogenology.2015.04.021
44. Demetrio, D. G. B., Santos, R. M., Demetrio, C. G. B., & Vasconcelos, J. L. M. (2007). Factors affecting conception rates following artificial insemination or embryo transfer in lactating Holstein cows. *Journal of Dairy Science, 90*(11), 5073–5082.
45. Demir, O., & Yazgan, K. (2023). Effects of air temperature and relative humidity on milk yield of Holstein dairy cattle raised in hot-dry Southeastern Anatolia region of Türkiye. *Journal of Agricultural Sciences (Tarım Bilimleri Dergisi), 29*(2), 710–720. https://doi.org/10.15832/ankutbd.1159540
46. Domínguez, R. R. L., Peláez, C. G. V., & Padilla, E. G. (2005). The effect of heat stress and milk yield on pregnancy rates of dairy cattle under intensive production systems. *Técnica Pecuaria en México, 43*(2), 197–210.
47. Du Preez, J. H., Hatting, P. J., Giesecke, W. H., & Eisenberg, B. E. (1990). Heat stress in dairy cattle and other livestock under Southern African conditions. III. Monthly temperature-humidity index mean values and their significance in the performance of dairy cattle. *Onderstepoort Journal of Veterinary Research, 57*, 243–248.
48. Durmuş, M., & Koluman, N. (2019). Hormonal changes caused on ruminant animals exposed to high environmental temperature. *Journal of Animal Production, 60*(2), 159–169.
49. El-Tarabany, M. S., & El-Tarabany, A. A. (2015). Impact of thermal stress on the efficiency of ovulation synchronization protocols in Holstein cows. *Animal Reproduction Science, 160,* 138–145. https://doi.org/10.1016/j.anireprosci.2015.08.002
50. El-Wardani, M. A., & El-Asheeri, K. (2000). Influence of season and number of heat checks on detecting of ovulatory estrus in Egyptian buffaloes. *Egyptian Journal of Animal Production, 37,* 18–22.
51. Fabris, T. F., Laporta, J., Corra, F. N., Torres, Y. M., Kirk, D. J., McLean, D. J., Chapman, J. D., & Dahl, G. E. (2017). Effect of nutritional immunomodulation and heat stress during the dry period on subsequent performance of cows. *Journal of Dairy Science, 100*(8), 6733–6742.
52. Fabris, T. F., Laporta, J., Skibiel, A. L., Corra, F. N., Senn, B. D., Wohlgemuth, S. E., & Dahl, G. E. (2019). Effect of heat stress during early, late, and entire dry period on dairy cattle. *Journal of Dairy Science, 102*(6), 5647–5656. https://doi.org/10.3168/jds.2018-15721
53. Food and Agriculture Organization of the United Nations. (2015). *Livestock and the environment.* http://www.fao.org/livestock-environment/en/2015
54. Food and Agriculture Organization of the United Nations. (2022). *Emissions totals.* In FAO. Rome. https://www.fao.org/faostat/en/#data/GT
55. Ferreira, F. C., Gennari, R. S., Dahl, G. E., & De Vries, A. (2016). Economic feasibility of cooling dry cows across the United States. *Journal of Dairy Science, 99*(12), 9931–9941.
56. Ferreira, R. M., Ayres, H., Chiaratti, M. R., Ferraz, M. L., Araújo, A. B., Rodrigues, C. A., & Baruselli, P. S. (2011). The low fertility of repeat-breeder cows during summer heat stress is related to a low oocyte competence to develop into blastocysts. *Journal of Dairy Science, 94*(5), 2383–2392. https://doi.org/10.3168/jds.2010-3904
57. Flamenbaum, I., & Galon, N. (2010). Management of heat stress to improve fertility in dairy cows in Israel. *Journal of Reproduction and Development, 56*(Suppl), S36–S41. https://doi.org/10.1262/jrd.1056s36
58. Gaafar, H. M. A., El-Nahrawy, M. M., Mesbah, R. A., Shams, A. S., Sayed, S. K., & Badr, A. A. (2021). Impact of heat stress on growth performance and some blood and physiological parameters of suckling Friesian calves in Egypt. *International Journal of Plant, Animal and Environmental Sciences, 11*(3), 545–565. https://doi.org/10.26502/ijpaes.202121
59. Gaafar, H. M. A., Abu El-Hamd, M. A., El-Gendy, M. E., Bassiouni, M. I., Halawa, A. A., & Shamiah, S. M. (2011). Effect of heat stress on performance of dairy Friesian cows. 2- Reproductive performance. *Researcher, 3*(5), 94–100.
60. Gantner, V., Mijic, P., Kuterovac, K., Soli, D., & Gantner, R. (2011). Temperature-humidity index

values and their significance on the daily production of dairy cattle. *Mljekarstvo, 61*(1), 56–63.

61. Gao, S. T., Ma, L., Zhou, Z., Zhou, Z. K., Baumgard, L. H., Jiang, D., Bionaz, M., & Bu, D. P. (2019). Heat stress negatively affects the transcriptome related to overall metabolism and milk protein synthesis in mammary tissue of mid-lactating dairy cows. *Physiological Genomics, 51*(8), 400–409. https://doi.org/10.1152/physiolgenomics.00039.2019
62. Garcia-Ispierto, I., Lopez-Gatius, F., Santolaria, P., Yaniz, J. L., & Nogareda, C. (2007). Factors affecting the fertility of high producing dairy herds in northeastern Spain. *Theriogenology, 67*(2), 632–638. https://doi.org/10.1016/j.theriogenology.2006.09.038
63. Garner, J. B., Douglas, A., Williams, A., Wales, A., Marett, A., DiGiacomo, B., Leury, B., & Hayes, C. D. (2017). Responses of dairy cows to short-term heat stress in controlled-climate chambers. *Animal Production Science, 57*(7), 1233–1241. https://doi.org/10.1071/AN16472
64. Geiger, T., Gütschow, J., Bresch, D. N., Emanuel, K., & Frieler, K. (2021). Double benefit of limiting global warming for tropical cyclone exposure. *Nature Climate Change, 11*(10), 861–866. https://doi.org/10.1038/s41558-021-01157-9
65. Gendelman, M., Aroyo, A., Yavin, S., & Roth, Z. (2010). Seasonal effects on gene expression, cleavage timing, and developmental competence of bovine preimplantation embryos. *Reproduction, 140*(1), 73–82. https://doi.org/10.1530/REP-10-0055
66. Ghavi, H. N., Mohit, A., & Azad, N. (2013). Effect of temperature-humidity index on productive and reproductive performances of Iranian Holstein cows. *Iranian Journal of Veterinary Research, 14*(2), 106–112.
67. Ghavi, H. N., Mohit, A., & Azad, N. (2013). Effect of temperature-humidity index on productive and reproductive performances of Iranian Holstein cows. *Iranian Journal of Veterinary Research, 14*(2), 106–112.
68. Ghosh, C. P., Kesh, S. S., Tudu, N. K., & Datta, S. (2017). Heat stress in dairy animals—Its impact and remedies: A review. *International Journal of Pure and Applied Bioscience, 5*(1), 953–965.
69. Habeeb, A. A. M., Osman, S. F., Teama, F. E. I., & Gad, A. E. (2023). The detrimental impact of high environmental temperature on physiological response, growth, milk production, and reproductive efficiency of ruminants. *Tropical Animal Health and Production, 55*, 388–402. https://doi.org/10.1007/s11250-023-03805-y
70. Habeeb, A. A. M. (2020a). Impact of climate change in relation to temperature-humidity index on productive and reproductive efficiency of dairy cattle. *International Journal of Veterinary and Animal Medicine, 3*(1), 124–133. https://doi.org/10.31021/ijnam.20203124
71. Habeeb, A. A. M. (2020b). Negative effects of heat stress on farm animals during hot summer season in tropical and subtropical countries and how to reduce the adverse effects. *International Journal of Biological & Medical Science, 3*(12), 1–35. https://gphjournal.org/index.php/bs/article/view/348
72. Habeeb, A. A. M., Gad, A. E., & Atta, M. A. A. (2018). Temperature-humidity indices as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals. *International Journal of Biotechnology and Recent Advances, 1*(2), 35–50. https://doi.org/10.18689/IJBR-1000107
73. Habeeb, A. A. M. (2022a). Side effects of high environmental temperature on reproductive efficiency of ruminants. *IASR Journal of Agriculture and Life Sciences, 2*(1), 15–18.
74. Habeeb, A. A. M. (2022b). Symptoms of heat stress in farm animals and negative effects on growth and milk production. In *Research aspects in agriculture and veterinary science* (Vol. 5, pp. 79–89). BP International. https://doi.org/10.9734/bpi/raavs/v5/1723B
75. Habeeb, A. A. M., Abdel-Samee, A. M., & Kamal, T. H. (1989). Effect of heat stress, feed supplementation and cooling technique on milk yield, milk composition and some blood constituents in Friesian cows under Egyptian conditions. In *Proceedings of 3rd Egyptian–British Conference on Animal, Fish and Poultry Production* (pp. 629–635). Alexandria University, Egypt.
76. Habeeb, A. A. M., Ibrahim, M. Kh., & Yousf, H. M. (2000). Blood and milk contents of triiodothyronine (T3) and cortisol in lactating buffaloes and changes in milk yield and composition as a function of lactation number and ambient temperature. *Arab Journal of Nuclear Sciences and Applications, 33*(2), 313–322.
77. Habeeb, A. A. M., Gad, A. E., & Atta, M. A. (2018). Temperature-humidity indices as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals. *International Journal of Biotechnology and Recent Advances, 1*(1), 35–50.
78. Habeeb, A. A. M., Ibrahim, M. Kh., & Yousef, H. M. (2000). Blood and milk contents of triiodothyronine (T3) and cortisol in lactating buffaloes and changes in milk yield and composition as a function of lactation number and ambient temperature. *Arab Journal of Nuclear Sciences and Applications, 33*(2), 313–322.
79. Hackbart, K. S., Ferreira, R. M., Dietsche, A. A., Socha, M. T., Shaver, R. D., Wiltbank, M. C., & Fricke, P. M. (2010). Effect of dietary organic zinc, manganese, copper, and cobalt supplementation on milk production, follicular growth, embryo quality, and tissue mineral concentrations in dairy cows.

Journal of Animal Science, 88(12), 3856–3870. https://doi.org/10.2527/jas.2009-2757
80. Hansen, P. J. (2009). Effects of heat stress on mammalian reproduction. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1534), 3341–3350. https://doi.org/10.1098/rstb.2009.0131
81. Hansen, P. J. (2007). Exploitation of genetic and physiological determinants of embryonic resistance to elevated temperature to improve embryonic survival in dairy cattle during heat stress. *Theriogenology, 68*(1), S242–S249. https://doi.org/10.1016/j.theriogenology.2007.04.008
82. Hansen, P. J. (2013). Cellular and molecular basis of therapies to ameliorate effects of heat stress on embryonic development in cattle. *Animal Reproduction, 10*(3), 322–333.
83. Hansen, P. J. (2015). Genetic variation in resistance of the preimplantation bovine embryo to heat shock. *Reproduction, Fertility and Development, 27*(1), 22–30. https://doi.org/10.1071/RD14395
84. Hansen, P. J., & Arechiga, C. F. (1999). Strategies for managing reproduction in the heat-stressed dairy cow. *Journal of Animal Science, 77*(Suppl. 2), 36–50. https://doi.org/10.2527/1999.77suppl_236x
85. Herbut, P., & Angrecka, S. (2012). Forming of temperature-humidity index (THI) and milk production of cows in the free-stall barn during the period of summer heat. *Animal Science Papers and Reports, 30*(4), 363–372.
86. Herbut, P., Angrecka, S., & Godyń, D. (2018a). Effect of the duration of high air temperature on cow's milking performance in moderate climate conditions. *Annals of Animal Science, 18*(1), 195–207. https://doi.org/10.1515/aoas-2017-0027
87. Herbut, P., Angrecka, S., & Walczak, J. (2018b). Environmental parameters to assessing of heat stress in dairy cattle: A review. *International Journal of Biometeorology, 62*(12), 2089–2097. https://doi.org/10.1007/s00484-018-1629-9
88. Intergovernmental Panel on Climate Change. (2014). *Climate change: Synthesis report; Summary for policymakers*. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf
89. Joksimović-Todorović, M., Davidović, V., Hristov, S., & Stanković, B. (2011). Effect of heat stress on milk production in dairy cows. *Biotechnology in Animal Husbandry, 27*(3), 1017–1023. https://doi.org/10.2298/BAH1103017J
90. Kadokawa, H., Sakatani, M., & Hansen, P. J. (2012). Perspectives on improvement of reproduction in cattle during heat stress in a future Japan. *Animal Science Journal, 83*(6), 439–445. https://doi.org/10.1111/j.1740-0929.2012.01013.x
91. Kadzere, C. T., Murphy, M. R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: A review. *Livestock Production Science, 77*(1), 59–91. https://doi.org/10.1016/S0301-6226(01)00330-X
92. Kamal, T. H., Habeeb, A. A. M., Abdel-Samee, A. M., & Marai, I. F. M. (1989). Milk production of heat stressed Friesian cows and its improvement in the subtropics. In *International symposium on the constraints and possibilities of ruminant production in the dry subtropics* (EAAP Publication No. 38, pp. 156–158). Cairo, Egypt.
93. Kamble, S. S., Bhise, B. R., & Chauhan, D. S. (2014). Impact of climatic parameters on milk production in Murrah buffaloes. *Journal of Crop and Weed, 10*(2), 71–76.
94. Kelly, K., Donna, M., & Amaral-Phillips. (2016). *Effects of heat stress on dairy cattle reproduction*. College of Agriculture, Food and Environment Cooperative Extension Service.
95. Khan, A., Khan, M. Z., Umer, S., Khan, I. M., Xu, H., Zhu, H., & Wang, Y. (2020). Cellular and molecular adaptation of bovine granulosa cells and oocytes under heat stress. *Animals, 10*(1), 110. https://doi.org/10.3390/ani10010110
96. Khan, F. A., Prasad, S., & Gupta, H. P. (2013). Effect of heat stress on pregnancy rates of crossbred dairy cattle in Terai region of Uttarakhand, India. *Asian Pacific Journal of Reproduction, 2*(4), 277–279. https://doi.org/10.1016/S2305-0500(13)60162-1
97. Khodaei-Motlagh, M., Roohan, Z., Zare Shahne, A., & Moradi, M. (2013). Effects of age at calving, parity, year and season on reproductive performance of dairy cattle in Tehran and Qazvin provinces, Iran. *Research Opinions in Animal and Veterinary Sciences, 3*(10), 337–342.
98. Khodaei-Motlagh, M., Shahneh, A. Z., Masoumi, R., & De Rensis, F. (2011). Alterations in reproductive hormones during heat stress in dairy cattle. *African Journal of Biotechnology, 10*(29), 5552–5558.
99. Kobayashi, Y., Wakamiya, K., Kohka, M., Yamamoto, Y., & Okuda, K. (2013). Summer heat stress affects prostaglandin synthesis in the bovine oviduct. *Reproduction, 146*(1), 103–110. https://doi.org/10.1530/REP-12-0479
100. Könyves, T., Zlatković, N., Memiši, N., Lukač, D., Puvača, N., Stojšin, M., Halász, A., & Miščević, B. (2017). Relationship of temperature-humidity index with milk production and feed intake of Holstein-Friesian cows in different year seasons. *Thai Journal of Veterinary Medicine, 47*(1), 15–23.
101. Krishnan, G., Bagath, M., Pragna, P., Vidya, M. K., Aleena, J., Archana, P. R., Sejian, V., & Bhatta, R. (2017). Mitigation of the heat stress impact in livestock reproduction. *Theriogenology, 8*(8–9). https://doi.org/10.5772/intechopen.69091
102. Lacerda, T. F., & Loureiro, B. (2015). Selecting thermotolerant animals as a strategy to improve fertility in Holstein cows. *Global Journal of Animal Science Research, 3*(1), 119–127.

103. López-Gatius, I., Santolaria, P., Yániz, J. L., Nogareda, C., & López-Béjar, M. (2005). Relationship between heat stress during the peri-implantation period and early fetal loss in dairy cattle. *Theriogenology, 65*(4), 799–807. https://doi.org/10.1016/j.theriogenology.2004.06.011
104. Lozano, R. R., Peláez, C. G., & Padilla, E. G. (2005). Effect of heat stress and its interaction with other management and productive variables on pregnancy rate in dairy cows in Aguascalientes, Mexico. *Veterinaria México, 36*, 245–260.
105. Marai, I. F. M., & Habeeb, A. A. M. (2010). Buffaloes reproductive and productive traits as affected by heat stress. *Tropical and Subtropical Agroecosystems, 12*, 193–217.
106. Masoumi, R., & Derensis, F. (2013). Alterations in reproductive hormones during heat stress in dairy cattle. *African Journal of Biotechnology, 10*(29), 5552–5558.
107. Mauger, G., Bauman, Y., Nennich, T., & Salathé, E. (2015). Impacts of climate change on milk production in the United States. *The Professional Geographer, 67*(1), 121–131. https://doi.org/10.1080/00330124.2014.921017
108. Mellado, M., Sepulveda, A., Meza-Herrera, C., Veliz, F. G., Arevalo, J. R., Mellado, J., & De Santiago, A. (2013). Effects of heat stress on reproductive efficiency in high-yielding Holstein cows in a hot arid environment. *Revista Colombiana de Ciencias Pecuarias, 26*, 193–200.
109. M'hamdi, N., Bouallegue, M., Hamouda, M. B., Frouja, S., Brar, S. K., & Ressaissi, Y. (2012). Effects of environmental factors on milk yield, lactation length and dry period in Tunisian Holstein cows. *INTECH Open Access Publisher*.
110. Michael, P., de Cruz, C. R., Nor, N. M., Jamli, S., & Goh, Y. M. (2022). The potential of using temperate–tropical crossbreds and agricultural by-products, associated with heat stress management for dairy production in the tropics: A review. *Animals, 12*(1), 1. https://doi.org/10.3390/ani12010001
111. Mishra, S. R., Kundu, A. K., & Mahapatra, A. P. K. (2013). Effect of ambient temperature on membrane integrity of spermatozoa in different breeds of bulls. *The Bioscan, 8*(1), 181–183.
112. Mondal, S., Mor, A., Reddy, I. J., Nandi, S., & Gupta, P. S. P. (2017). Heat stress induced alterations in prostaglandins, ionic and metabolic contents of sheep endometrial epithelial cells in vitro. *Biomedical Journal of Scientific & Technical Research, 1*(4), 1–5.
113. Morton, J. M., Tranter, W. P., Mayer, D. G., & Jonsson, N. N. (2007). Effects of environmental heat on conception rates in lactating dairy cows: Critical periods of exposure. *Journal of Dairy Science, 90*(5), 2271–2278. https://doi.org/10.3168/jds.2006-574
114. Nabenishi, H., Ohta, H., Nishimoto, T., Morita, T., Ashizawa, K., & Tsuzuki, Y. (2011). Effect of the temperature-humidity index on body temperature and conception rate of lactating dairy cows in southwestern Japan. *Journal of Reproduction and Development, 57*(4), 450–456.
115. Nardone, A., Ronchi, B., Lacetera, N., & Bernabucci, U. (2006). Climate effects on productive traits in livestock. *Veterinary Research Communications, 30*(1), 75–81.
116. Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science, 130*(1–3), 57–69.
117. Nichi, M., Bols, P. E. J., Zuche, R. M., Barnabe, V. H., Goovaerts, I. G. F., Barnabe, R. C., & Cortada, C. M. N. (2006). Seasonal variation in semen quality in *Bos indicus* and *Bos taurus* bulls raised under tropical conditions. *Theriogenology, 66*(4), 822–828.
118. Ominski, K. H., Kennedy, A. D., Wittenberg, K. M., & Nia, S. M. (2002). Physiological and production responses to feeding schedule in lactating dairy cows exposed to short-term, moderate heat stress. *Journal of Dairy Science, 85*(4), 730–737.
119. Osei-Amponsah, R., Chauhan, S. S., Leury, B. J., Cheng, L., Cullen, B., Clarke, I. J., & Dunshea, F. R. (2019). Genetic selection for thermotolerance in ruminants. *Animals, 9*(11), 948. https://doi.org/10.3390/ani9110948
120. Ouarfli, L., & Chehma, A. (2021). Effect of temperature-humidity index on milk performances of local-born Holstein dairy cows under Saharan climate. *Archiva Zootechnica, 24*(2), 24–36. https://doi.org/10.2478/azibna-2021-0010
121. Parikh, S. S., Patbandha, T. K., Gamit, P. M., & Savaliya, B. D. (2024). Seasonal influence on reproductive traits in Gir (*Bos indicus*) heifers. *Biological Rhythm Research*. Advance online publication. https://doi.org/10.1080/09291016.2024.2399561
122. Patel, B., Purwar, V., Jain, V., Gupta, D., Wankhede, P. R., Diwakar, R., Kumar, N., & Singh, M. (2018). Heat stress in dairy cows—Its impact and management: A short note. *International Journal of Science, Environment and Technology, 7*(1), 225–231.
123. Paula-Lopes, F. F., Lima, R. S., Risolia, P. H. B., Ispada, J., Assumpção, M. E. O. A., & Visintin, J. A. (2012). Heat stress induced alteration in bovine oocytes: Functional and cellular aspects. *Animal Reproduction, 9*(3), 395–403.
124. Penev, T., Dimov, D., Marinov, I., & Angelova, T. (2021). Study of influence of heat stress on some physiological and productive traits in Holstein-Friesian dairy cows. *Agronomy Research, 19*(1), 210–223. https://doi.org/10.15159/AR.21.014
125. Penev, T., Dimov, D., Vasilev, N., Mitev, J., & Miteva, Ch. (2020). Effect of heat stress on some

reproductive traits in Holstein-Friesian cows under temperate continental climate. *Bulgarian Journal of Agricultural Science, 26*(Suppl. 1), 155–162.

126. Polsky, L., & von Keyserlingk, M. A. G. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *Journal of Dairy Science, 100*(11), 8645–8657. https://doi.org/10.3168/jds.2017-12651
127. Pragna, P., Archana, P. R., Aleena, J., Sejian, V., Krishnan, G., Bagath, M., Manimaran, A., Beena, V., Kurien, E. K., Varma, G., & Bhatta, R. (2017). Heat stress and dairy cow: Impact on both milk yield and composition. *International Journal of Dairy Science, 12*, 1–11. https://doi.org/10.3923/ijds.2017.1.11
128. Prathap, P., Archana, P. R., Aleena, J., Sejian, V., Krishnan, G., Bagath, M., Manimaran, A., Beena, V., Kurien, E. K., Varma, G., & Bhatta, R. (2017). Heat stress and dairy cow: Impact on both milk yield and composition. *International Journal of Dairy Science, 12*, 1–11. https://doi.org/10.3923/ijds.2017.1.11
129. Ravagnolo, O., Misztal, I., & Hoogenboom, G. (2000). Genetic component of heat stress in dairy cattle: Development of heat index function. *Journal of Dairy Science, 83*(9), 2120–2125.
130. Raval, R. J., & Dhami, A. J. (2005). Effect of heat stress on animal reproduction—An overview. *Indian Journal of Field Veterinarians, 1*(2), 1–9.
131. Reisi-Vanani, R., Ansari-Mahyari, S., Pakdel, A., & Cue, R. I. (2025). Impact of reproductive traits on productive life in Iranian Holstein dairy cows. *Journal of Animal Breeding and Genetics, 142*(1), 92–101.
132. Rejeb, M., Sadraoui, R., Najar, T., & BenM'rad, M. (2016). A complex interrelationship between rectal temperature and dairy cows' performance under heat stress conditions. *Open Journal of Animal Sciences, 6*(1), 24–30. https://doi.org/10.4236/ojas.2016.61004
133. Reyad, M. A. I., Sarker, M. A. H., Uddin, M. F., Habib, R., & Harun-ur-Rashid, M. (2016). Effect of heat stress on milk production and its composition of Holstein Friesian crossbred dairy cows. *Asian Journal of Medical and Biological Research, 2*(2), 190–195. https://doi.org/10.3329/ajmbr.v2i2.29060
134. Rhoads, M. L., Rhoads, R. P., Van Baale, M. J., Collier, R. J., Sanders, S. R., Weber, W. J., Crooker, B. A., & Baumgard, L. H. (2009). Effect of heat stress and plane of nutrition of lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. *Journal of Dairy Science, 92*(5), 1986–1997.
135. Rivera, R. M., & Hansen, P. J. (2001). Development of cultured bovine embryos after exposure to high temperatures in the physiological range. *Reproduction, 121*, 107–115.
136. Roth, Z. (2017). Effect of heat stress on reproduction in dairy cows: Insights into the cellular and molecular responses of the oocyte. *Annual Review of Animal Biosciences, 5*, 151–170. https://doi.org/10.1146/annurev-animal-022516-022849
137. Roth, Z., Arav, A. A., Bor, Y., Zeron, R., Braw-Tal, R., & Wolfenson, D. (2001). Improvement of quality of oocytes collected in the autumn by enhanced removal of impaired follicles from previously heat-stressed cows. *Reproduction, 122*, 737–744.
138. Roth, Z. (2020). Reproductive physiology and endocrinology responses of cows exposed to environmental heat stress: Experiences from the past and lessons for the present. *Theriogenology, 155*, 150–156. https://doi.org/10.1016/j.theriogenology.2020.05.040
139. Saizi, T., Mpayipheli, M., & Idowu, P. A. (2019). Heat tolerance level in dairy herds: A review on coping strategies to heat stress and ways of measuring heat tolerance. *Journal of Animal Behaviour and Biometeorology, 7*(2), 39–51. https://doi.org/10.31893/2318-1265jabb.v7n2p39-51
140. Sakatanimi, M., Balboula, A. Z., Yamanaka, K., & Takahashi, M. (2012). Effect of summer heat environment on body temperature, estrous cycles, and blood antioxidant levels in Japanese Black cow. *Animal Science Journal, 83*, 394–402. https://doi.org/10.1111/j.1740-0929.2011.00967.x
141. Sammad, A., Umer, S., Shi, R., Zhu, H., Zhao, X., & Wang, Y. (2019). Dairy cow reproduction under the influence of heat stress. *Journal of Animal Physiology and Animal Nutrition, 103*(5), 1–9. https://doi.org/10.1111/jpn.13257
142. Sammad, A., Wang, Y. J., Umer, S., Lirong, H., Khan, I., Khan, A., Ahmad, B., & Wang, Y. (2020). Nutritional physiology and biochemistry of dairy cattle under the influence of heat stress: Consequences and opportunities. *Animals, 10*(5), 793. https://doi.org/10.3390/ani10050793
143. Sartori, R., Bastos, M. R., & Wiltbank, M. C. (2009). Factors affecting fertilisation and early embryo quality in single- and superovulated dairy cattle. *Reproduction, Fertility and Development, 22*(1), 151–158.
144. Schüller, L. K., Burfeind, O., & Heuwieser, W. (2014). Impact of heat stress on conception rate of dairy cows in the moderate climate considering different temperature-humidity index thresholds, periods relative to breeding, and heat load indices. *Theriogenology, 81*(8), 1050–1057. https://doi.org/10.1016/j.theriogenology.2014.01.029
145. Schüller, L. K., Michaelis, I., & Heuwieser, W. (2017). Impact of heat stress on estrus expression and follicle size in estrus under field conditions in dairy cows. *Theriogenology, 102*, 48–53.
146. Sesay, A. (2023). Effect of heat stress on dairy cow production, reproduction, health, and potential mitigation strategies. *Journal of Applied and Advanced Research, 8*, 13–25. https://doi.org/10.21839/jaar2023.v8.8371

147. Siddiqui, M. A., Ferreira, J. C., Gastal, E. L., Beg, M. A., Cooper, D. A., & Ginther, O. J. (2010). Temporal relationships of the LH surge and ovulation to echo texture and power Doppler signals of blood flow in the wall of the pre-ovulatory follicle in heifers. *Reproduction, Fertility and Development, 22*, 1110–1117.
148. Singh, M., Chaudhari, B. K., Singh, J. K., Singh, A. K., & Maurya, P. K. (2013). Effects of thermal load on buffalo reproductive performance during summer season. *Journal of Biological Science, 1*(1), 1–8.
149. Skliarov, P., Kornienko, V., Midyk, S., & Mylostyvyi, R. (2022). Impaired reproductive performance of dairy cows under heat stress: Review article. *Agriculture Conspectus Scientifi cus, 87*(2), 85–92.
150. Slimen, B., Najar, T., Ghram, A., & Abdrrabba, M. (2016). Heat stress, the effects on livestock: Molecular, cellular, and metabolic aspects, a review. *Journal of Animal Physiology and Animal Nutrition, 100*(3), 401–412. https://doi.org/10.1111/jpn.12379
151. Smith, D. L., Smith, T., Rude, B. J., & Ward, S. H. (2013). Short communication: Comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. *Journal of Dairy Science, 96*(5), 3028–3033.
152. Spiers, D. E., Spain, J. N., Sampson, J. D., & Rhoads, R. P. (2004). Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. *Journal of Thermal Biology, 29*(7–8), 759–764. https://doi.org/10.1016/j.jtherbio.2004.08.051
153. St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. *Journal of Dairy Science, 86*(E Suppl.), E52–E77.
154. Summer, A., Isabella, L., Formaggioni, P., & Gottardo, F. (2019). Impact of heat stress on milk and meat production. *Animal Frontiers, 9*(1), 39–46. https://doi.org/10.1093/af/vfy026
155. Takahashi, M. (2012). Heat stress on reproductive function and fertility in mammals. *Reproductive Medicine and Biology, 11*(1), 37–47.
156. Tao, S., & Dahl, G. E. (2013). Invited review: Heat stress effects during late gestation on dry cows and their calves. *Journal of Dairy Science, 96*(7), 4079–4093.
157. Tao, S., Rivas, R. M. O., Marins, T. N., Chen, Y. C., Gao, J., & Bernard, J. K. (2020). Impact of heat stress on lactational performance of dairy cows. *Theriogenology, 150*, 437–444.
158. Tao, S., Orellana, R., Weng, X., Marins, T. N., Dahl, G. E., & Bernard, J. K. (2017). Symposium review: The influences of heat stress on bovine mammary gland function. *Journal of Dairy Science, 101*(6), 5642–5654. https://doi.org/10.3168/jds.2017-13727
159. Temple, D., Bargo, F., Mainau, E., Ipharraguerre, I., & Manteca, X. (2015). Heat stress and efficiency in dairy milk production: A practical approach. *Farm Animal Welfare Fact Sheet No. 12*. Farm Animal Welfare Education Centre. http://www.fawec.org/media/com_lazypdf/pdf/fs12-en.pdf
160. Thatcher, W. W., Flamenbaum, I., Block, J., & Bilby, T. R. (2010). Interrelationships of heat stress and reproduction in lactating dairy cows. *High Plains Dairy Conference*, Amarillo, TX.
161. Thornton, P. K., Boone, R. B., & Villegas, J. R. (2015). *Climate change impacts on livestock* (Working Paper No. 120). CGIAR Research Program on Climate Change, Agriculture and Food Security.
162. Thurmond, M. C., Branscum, A. J., Johnson, W. O., Bedrick, E. J., & Hanson, T. E. (2005). Predicting the probability of abortion in dairy cows: A hierarchical Bayesian logistic-survival model using sequential pregnancy data. *Preventive Veterinary Medicine, 68*(3), 223–239. https://doi.org/10.1016/j.prevetmed.2005.01.008
163. Vitali, A., Segnalini, M., Bertocchi, L., Bernabucci, U., Nardone, A., & Lacetera, N. (2009). Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. *Journal of Dairy Science, 92*(8), 3781–3790. https://doi.org/10.3168/jds.2009-2127
164. Wakayo, B. U., Brar, P. S., & Prabhakar, S. (2015). Review on mechanisms of dairy summer infertility and implications for hormonal intervention. *Open Veterinary Journal, 5*(1), 6–10.
165. Wang, J., Li, J., Wang, F., Xiao, J., Wang, Y., Yang, H., Li, S., & Cao, Z. (2020). Heat stress on calves and heifers: A review. *Journal of Animal Science and Biotechnology, 11*(79). https://doi.org/10.1186/s40104-020-00485-8
166. Wankar, A. K., Rindhe, S. N., & Doijad, N. S. (2021). Heat stress in dairy animals and current milk production trends, economics, and future perspectives: The global scenario. *Tropical Animal Health and Production, 53*(1), 70. https://doi.org/10.1007/s11250-020-02541-x
167. West, J. W. (1993). Interactions of energy and bovine somatotropin with heat stress. *Journal of Dairy Science, 77*(7), 2091–2102. https://doi.org/10.3168/jds.S0022-0302(94)77150-4
168. West, J. W. (2003). Effects of heat stress on production in dairy cattle. *Journal of Dairy Science, 86*(6), 2131–2144. https://doi.org/10.3168/jds.S0022-0302(03)73803-X
169. Westwood, C. T., Lean, I. J., & Gravin, J. K. (2002). Factors influencing fertility of Holstein dairy cows: A multivariate description. *Journal of Dairy Science, 85*(12), 3225–3237. https://doi.org/10.3168/jds.S0022-0302(02)74411-1
170. White, F. J., Wettemann, R. P., Looper, M. L., Prado, T. M., & Morgan, G. L. (2002). Seasonal effects on estrous behavior and time of ovulation in nonlactating beef cows. *Journal of Animal Science, 80*(12), 3053–3059. https://doi.org/10.2527/2002.80123053x

171. World Health Organization. (2009). *World health statistics*. Department of Health Statistics and Health Information Systems.
172. Williams, E. J., & Walsh, S. W. (2010). The physiology of multifactorial problems limiting the establishment of pregnancy in dairy cows. *Acta Scientiae Veterinariae, 38*, s277–s315.
173. Wilson, S. J., Marion, R. S., Spain, J. N., Spiers, D. E., Keisler, D. H., & Lucy, M. C. (1998). Effects of controlled heat stress on ovarian function of dairy cattle. 1. Lactating cows. *Journal of Dairy Science, 81*(8), 2124–2131. https://doi.org/10.3168/jds.S0022-0302(98)75788-5
174. Wolfenson, D., & Roth, Z. (2019). Impact of heat stress on cow reproduction and fertility. *Animal Frontiers, 9*(1), 32–38. https://doi.org/10.1093/af/vfy027
175. Yerou, H., Belgherbi, B., & Homrani, A. (2021). Impact of heat stress on Holstein breeding performance conducted in a semi-arid Mediterranean climate: Case of Western Algeria. *Genetics and Biodiversity Journal, 5*(2), 116–126.
176. Zigo, F., Vasil, M., Ondrašovičová, S., Výrostková, J., Bujok, J., & Pecka-Kielb, E. (2021). Maintaining optimal mammary gland health and prevention of mastitis. *Frontiers in Veterinary Science, 8*, 607311. https://doi.org/10.3389/fvets.2021.607311