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Invited Review Article

Climate change and livestock reproductive health: Mechanisms, adaptation and mitigation strategies

P. Pal[1*], F. Josan[2], P. Biswal[3], and S. Perveen[1]

[1]Department of Veterinary Physiology, College of Veterinary and Animal Sciences, Bihar Animal Sciences University, Kishanganj- 855 107, Bihar, India; [2]Animal Biotechnology Centre, ICAR- National Dairy Research Institute, Karnal- 132 001, Haryana, India; [3]Department of Livestock Production Management, College of Veterinary and Animal Sciences, Bihar Animal Sciences University, Kishanganj- 855 107, Bihar, India

Abstract

The livestock sector is a critical contributor to global food security and economic growth, providing essential products such as meat, milk and fibres while supporting rural livelihoods. However, climate change poses significant challenges to this sector, including increased heat stress, altered rainfall patterns and reduced feed availability, negatively affecting animal productivity, reproduction and health. Particularly, all the reproductive parameters including follicular growth and development, induction of ovulation, estrus expression, endocrine status, luteolytic mechanism, conception rate, fetal and embryonic growth etc. in females and semen parameters in males are altered. It eventually impacts the productivity of the animals and results in economic loss for the farmer or producer. Implementation of appropriate mitigation strategies like housing and nutrition management, assisted reproductive technologies, hormonal interventions, selection of heat tolerant breeds and reduction of livestock origin greenhouse gases can ensure sustainable livestock production in this scenario.

Keywords: Climate change, Heat stress, Livestock reproduction and health, Mitigation strategies

Highlights

- The livestock sector is vital for food security and economic growth.
- Climate change creates challenges like heat stress and reduced feed quality.
- Heat stress affects reproduction, fertility, and overall livestock productivity.
- Adaptive strategies like genetic selection and better management can help.
- Sustainable practices are essential for long-term livestock productivity.

INTRODUCTION

The livestock sector is one of the most significant contributors globally, providing nutritional security and employment to a significant portion of the human population. The humans largely depend on domestic animals for several purposes, including meat, milk and other non-dairy products like eggs and fibres like wool or cashmere as well as other purposes such as transport, draft, and provision of fertilizers, particularly in rural and agricultural communities. It also contributes to global economies through trade, by-products and labour. However, the livestock sector faces mounting challenges from climate change, including an increase in worldwide air and ocean temperatures, leading to rising sea levels and widespread snow and ice cover reduction. As per the IPCC (Intergovernmental Panel on Climate Change) report, "Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate" (IPCC, 2019). Livestock production in India and worldwide will need to adapt various challenges associated with climate change. This includes higher temperatures, shifts in rainfall patterns, increased incidence of heat waves etc. The effects of climate change on livestock production systems include food resource/crop scarcity, increased heat stress and altered disease dynamics. Whenever the temperature or other parameters are higher or lower than the threshold value for peak production, the production efficiency of livestock is greatly compromised (Baumgard *et al*., 2012). The impacts of global climate changes on livestock production are direct and indirect. The indirect impact includes quality and availability of feed and forages and animal diseases, whereas heat stress directly impacts livestock, increasing their morbidity and mortality. The homeorhetic mechanism of body prioritizes the needs of the body and mobilizes the available nutrients of animal body for maintaining homeostasis, then synthesizes milk, meat and foetus, and

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*Corresponding Authors, E-mail: drpalprasanna@gmail.com

then towards animal health needs. Climate change increases the susceptibility of animals towards several other diseases. Heat stress leads to reduced feed intake, which affects both male and female reproductive physiology, ultimately affecting high quality semen and higher milk production (Khan *et al.*, 2023). Heat stress also disrupts hormonal balance, impairing estrus cycles and reducing conception rates in females. In males, it compromises spermatogenesis, resulting in lower sperm motility and viability. These reproductive inefficiencies lead to decreased fertility rates, ultimately limiting the herd's productivity and profitability. So, it is evident that climate change may impart a significant economic burden on this sector, including small and large producers.

In addition, the human population is also increasing specially in the tropical and subtropical areas of the globe (Hance, 2014), presenting us with the challenge of finding a balance between productivity, household food security, and environmental conservation (Wright *et al.*, 2012). As per the World Population Prospects 2024 report, India's population will peak in the early 2060s to 1.7 billion (United Nations, 2024), and India is already the most populous country. To meet the demands of the increasing population along with challenging global and local climatic conditions with limited resources in terms of croplands and water, we need to expand livestock productivity in terms of milk, meat and other animal products. That's why, understanding the reproductive physiology through which heat stress affects animal performance is essential. This article briefly discusses the climatic factors affecting livestock, their effects on reproductive parameters, and adaptation and mitigation strategies.

Climatic factors affecting livestock

Temperature, humidity and solar radiation are the major environmental factors resulting heat stress to the animals. Solar radiation is again influenced by photoperiod and ozone layer depletion. Whereas wind speed and rainfall help to reduce these effects (Bohmanova *et al.*, 2007). Temperature and relative humidity are generally considered the most substantial causative agents of heat stress and are often combined together in a thermal heat index (THI) (Dikmen *et al.*, 2009). The climatic factors affecting livestock are as follows.

Extreme temperature and heat stress: Temperature fluctuations outside the optimal range for livestock can severely affect their physiological functions. Animals are homeotherms and they maintain a stable internal body temperature. Exposure to extreme temperatures, especially high heat, disturbs the animals' physiology and affects both production and reproduction. One of the rising concerns for gradual temperature increase is global warming. It has been discussed separately in the next section of this article.

Humidity: Combined effect of high temperature and humidity increases the stress level increases. Animals struggle to combat heat stress through evaporative cooling mechanism as humidity hampers sweating and panting. That's why the temperature and humidity are considered together to measure the stress level in animals.

Drought and nutritional deficiencies: Drought and dietary deficiencies caused by climate change profoundly impact livestock by reducing water availability and limiting forage growth. Water scarcity leads to dehydration, heat stress, and reduced animal productivity, while diminished pastureland and forces farmers to rely on expensive or low-quality feed alternatives. Poor nutrition weakens animals' immune systems, reduces reproductive performance, and slows down growth rates. Additionally, long-term drought can damage land, reducing its future grazing potential and leading to overgrazing.

Environmental pollution: Environmental pollution exacerbated by climate change significantly impacts livestock by degrading essential resources critical for their health and productivity. Pollution from agricultural runoff, industrial waste, and atmospheric contaminants leads to toxic exposure, respiratory issues, and various animal diseases. This contamination also diminishes the nutritional quality of forage, exposing livestock to harmful chemicals that can accumulate in their bodies. As a result, animals experience weakened immune systems, lower reproductive efficiency, and increased disease susceptibility (Nkuruma, 2023).

Global warming and heat wave: Many of the changes observed in the climate are slow and may take hundreds or thousands of years to show effects, while many are already set in motion, such as global warming (IPCC, 2024). It is well known that the emission of greenhouse gases due to human activities is the major reason behind this increase in temperature. Interestingly, the effects are not the same in every place globally, and the warming over land is greater. The effects of global warming can be measured and witnessed grossly, such as a rise in sea level, decreased snow and ice surface coverage and increased frequency of hot days

(Pasqui and Giuseppe, 2019). Due to these effects, the agricultural sector, including livestock, is going to be greatly affected and will be affected for a longer duration until some serious steps are taken. It is a matter of concern that common people, including livestock owners, are unaware of global warming and their impact on productivity. Though the effects of global warming are visible and are going to be more detrimental in the future, human actions still have the potential to decrease their consequences.

Reproductive physiology affected by climate change

Heat stress occurs when the animals are exposed to hot and humid environments and they are unable to adapt effectively. The physiological responses to regulate the body temperature are overwhelmed, resulting in decreased feed intake, milk production etc. The effect of heat stress on reproduction is more profound and persisting as it affects the hypothalamic-hypophyseal-gonadal (HPG) axis (Roth, 2017). Hence, the fertility of the animals may be affected for several weeks or months after the onset of stress. The overall effects of heat stress on the reproductive system of male and female animals are depicted in Fig. 1.

In the case of females, heat stress reduces the degree of dominance of the selected follicle, and there is also reduced steroidogenic activity of its theca and granulosa cells, resulting in a fall in blood estradiol level. The metabolic state of the animal and the nature of heat stress (acute/chronic) can increase or decrease the plasma progesterone levels (Khodaei-Motlagh *et al*., 2011). These endocrine changes diminish follicular activity and modify the ovulatory mechanism, leading to a decline in oocyte and embryo quality. The uterine environment is also altered, reducing the chance of embryo implantation.

At birth, the bovine ovary contains about 150,000 primordial follicles, each with an oocyte arrested at prophase I. Throughout the female's life, these follicles are recruited into a growing pool, which leads to the development of the preovulatory follicle. The development of primordial follicles in the preovulatory stage involves primary, secondary, early antral, and antral follicles. The primary and secondary follicles are gonadotropin-independent, and the recruitment is triggered by paracrine ovarian factors such as stem cell factor, epidermal growth factor, basic fibroblast growth factor, leukemia inhibitory factor, nerve growth factor,

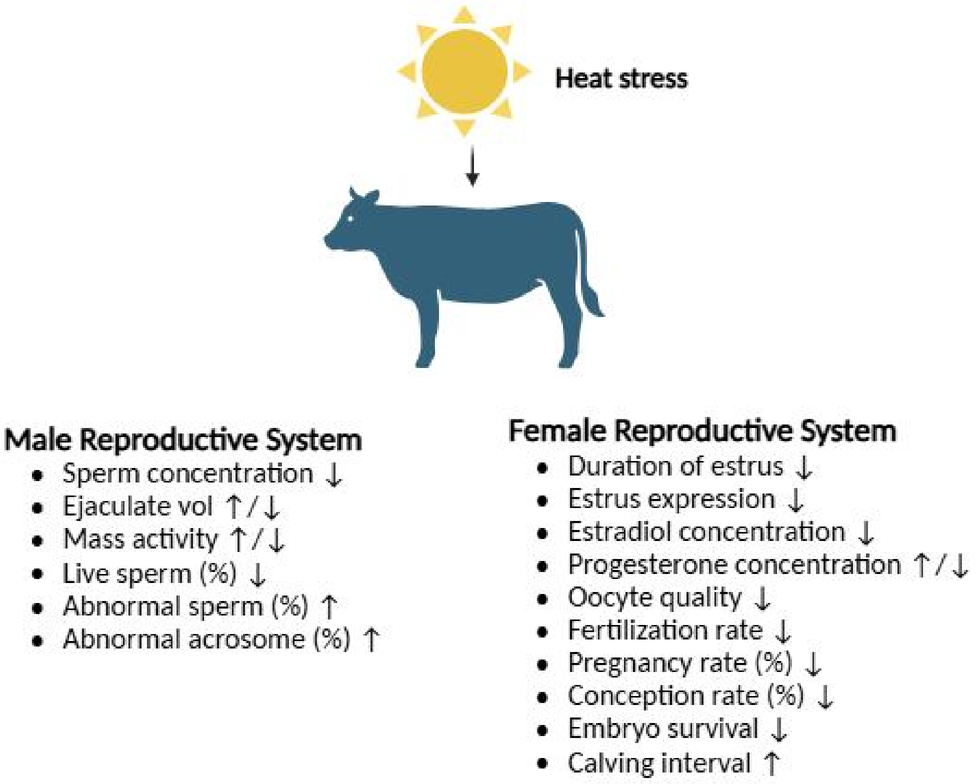

Fig. 1. Depiction of the overall effects of heat stress on reproductive system of male and female animals (Created in Biorender.com)

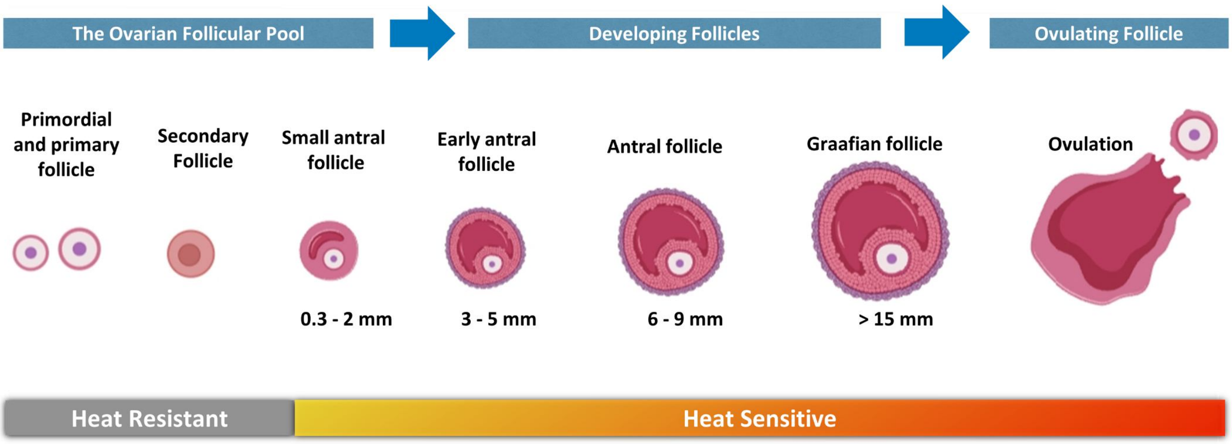

Fig. 2. Diagram illustrating a stage-dependent pattern of resistance/sensitivity of the ovarian pool of follicles to heat stress. The primordial, primary, and secondary follicles are heat resistant, whereas the developing antral follicles, including the dominant and preovulatory follicles, are sensitive to heat exposure (Roth, 2017) (Created in Biorender.com)

etc. (Roth, 2017). Interestingly, the different follicular phases respond differently to heat stress. The primordial, primary and secondary follicles are heat resistant, whereas the developing antral follicles, including the dominant and preovulatory follicles are sensitive to heat exposure (Roth, 2017). The stage-dependent pattern of resistance/sensitivity of the ovarian pool of follicles to heat stress has been depicted in Fig. 2.

In case of bovine males, the testes and epididymis are located below the abdomen inside the scrotum to maintain a 4-5°C lower temperature. Several other mechanisms, including contraction/relaxation of the cremaster muscle, pampiniform plexus, scrotal evaporation, etc, are also there for the thermoregulation of the testes. Maintaining the testicular temperature around 32°C is important for normal spermatogenesis, and high environmental temperature and humidity can interfere this process (Morrell, 2020). In different stages of spermatogenesis, the sperms are susceptible to heat stress. However, they are most vulnerable during the meiosis phase before DNA compaction occurs (Morrell, 2020). Under thermal stress, the sperm DNA becomes predisposed to ROS, and the animal's fertility is affected (Kastelic, 2013). The effect of heat stress on different reproductive parameters of male and female domestic animals are listed in Tables 1 and 2.

Table 1. Effects of heat stress on reproductive parameters of female animals

Parameters	Effects of heat stress	Species, Breed	Location	References
Duration of estrus (hours)	↓	Cattle, Holstein	Louisiana, USA	Gangwar *et al*., 1965
		Buffalo	India	Janakiraman, 1978
	↓	Sheep, Merino	Australia	Sawyer *et al*., 1979
		Buffalo	India	Singh *et al*., 2000
Length of estrus cycle (Days)	↑	Cattle, Holstein	Louisiana, USA	Gangwar *et al*., 1965
Estrus expression (%)	↓	Cattle, Holstein	Louisiana, USA	Gangwar *et al*., 1965
	↓	Sheep, Merino	Australia	Sawyer *et al*., 1979
	↓	Buffalo, Murrah	India	Reddy *et al*., 1999
	↓	Buffalo	India	Singh *et al*., 2000
Blood estradiol concentration	↓	Cattle, Holstein	Florida, USA	Collier *et al*., 1982
	↓	Cattle	Iran	Khodaei-Motlagh *et al*., 2013

Cont. Table 1.

Table 1., Cont. ...

Parameters	Effects of heat stress	Species, Breed	Location	References
	↓	Buffalo, Murrah	India	Aggarwal & Upadhyay, 2013
	↓	Buffalo	Egypt	Megahed *et al*., 2008
Blood progesterone concentration	↑	Cattle, Holstein	Florida, USA	Collier *et al*., 1982
	↑	Buffalo	Egypt	Shafie *et al*., 1982
	↑	Buffalo	India	Takkar *et al*., 1983
	↑	Buffalo	India	Singh & Chaudhary, 1992
	↓	Cattle	Israel	Wolfenson *et al*., 2000
	↑/↓	Cattle	Iran	Khodaei-Motlagh *et al*., 2013
Blood LH concentration	↓	Cattle	Israel	Wolfenson *et al*., 2000
Blood FSH concentration	↑	Cattle	Israel	Wolfenson *et al*., 2000
Blood prostaglandin concentration	↑	Cattle	Iran	Khodaei-Motlagh *et al*., 2013
Number of large follicles	↓	Buffalo, Egyptian	Egypt	Ali, 2015
Size of first and second wave dominant follicle	↓	Cattle, Holstein	Florida, USA	Badinga *et al*., 1993
	↓	Cattle, Holstein	Missouri, USA	Wilson *et al*., 1998
Diameter of preovulatory follicle	↓	Buffalo, Egyptian	Egypt	Ali, 2015
Oocyte maturation	↓	Cattle	—	Roth, 2017
Oocyte quality	↓	Sheep	USA	Dutt, 1964
	↓	Cattle	Israel	Wolfenson *et al*., 2000
	↓	Cattle	Iran	Khodaei-Motlagh *et al*., 2013
Delay in ovulation	↑	Goat		Ozawa *et al*., 2005
Diameter of mature corpus luteum (CL)	↓	Buffalo, Egyptian	Egypt	Ali, 2015
Incidence of presence of developed or mature CL (%)	↓	Buffalo, Egyptian	Egypt	Ali, 2015
Fertilization rate	↓	Sheep	USA	Dutt, 1964
Pregnancy rate (%)	↓	Cattle, Holstein	Egypt	El-Wishy, 2013
	↓	Murrah	India	Dash *et al*., 2014
	↓	Murrah	India	Dash *et al*., 2015
	↓	Buffalo, Murrah	Haryana, India	Dash *et al*., 2015
Conception rate (%)	↓	Cattle, Holstein	Hawaii, USA	Ingraham *et al*., 1976
	↓	Cattle, Holstein-Friesian	Spain	Garcia-Ispierto *et al*., 2007
	↓	Cattle, Holstein-Friesian	Australia	Morton *et al*., 2007
	↓	Cattle, Holstein-Friesian	Japan	Nabenishi *et al*., 2011
	↓	Buffalo, Murrah	India	Verma *et al*., 2015

Cont. Table 1.

Table 1., Cont. ...

Parameters	Effects of heat stress	Species, Breed	Location	References
	↓	Buffalo	Egypt	Nasr, 2017
	↓	Cattle, Sahiwal	Haryana, India	Parveen *et al*., 2022
	↓	Buffalo	Egypt	Hussein *et al*., 2024
Embryo development	↓	Cattle	Israel	Wolfenson *et al*., 2000
Embryo survival	↓	Sheep, Merino	Australia	Lindsay *et al*., 1975
	↓	Sheep, Merino	Australia	Kleemann *et al*., 2005
Embryo quality	↓	Cattle	Iran	Khodaei-Motlagh *et al*., 2013
Fertility	↓	Sheep, Merino	Australia	Lindsay *et al*., 1975
	↓	Sheep, Merino	Australia	Kleemann *et al*., 2005
Calf birth weight	↓	Cattle, Holstein	Florida, USA	Collier *et al*., 1982
Dry period (days)	↓	Buffalo, Murrah	India	Jakhar *et al*., 2016
Service period (days)	No change	Buffalo, Murrah	India	Jakhar *et al*., 2016
Calving interval (days)	↑	Cattle, Sahiwal	Haryana, India	Parveen *et al*., 2022

Table 2. **Effects of heat stress on reproductive parameters of male animals**

Parameters	Effects of heat stress	Species, Breed	Location	References
Ejaculate volume (mL)	↑	Cattle, Simmental	Križevci, Croatia	Baliæ *et al*., 2012
	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
	↑ NS	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017
	↓	Cattle, Sahiwal	Punjab, Pakistan	Bhutta *et al*., 2020
Mass activity	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
	↓	Cattle, Sahiwal	Punjab, Pakistan	Bhutta *et al*., 2020
Individual motility	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
Concentration (X 10^9/mL)	↓	Cattle, Simmental	Križevci, Croatia	Baliæ *et al*., 2012
	↓	Cattle, Crossbred	Pantnagar, India	Sharma *et al*., 2017
	↓	Cattle, Sahiwal	Punjab, Pakistan	Bhutta *et al*., 2020
	↑NS	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017
Live sperm (%)	↓	Cattle, Crossbred	Pantnagar, India	Sharma *et al*., 2017
Abnormal sperm (%)	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
Abnormal acrosomes (%)	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
HOST (%)	↓	Cattle, Crossbred	Pantnagar, India	Sharma *et al*., 2017
	↑	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017
pH	↓ NS	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012
MBRT (min)	↓ NS	Cattle, Crossbred	Pantnagar, India	Sharma *et al*., 2017
SP LDH (uKat/L)	↓ NS	Goat, Spanish	Cordoba, Spain	Arrebola & Abecia, 2017
SP K (mmol/L)	↓ NS	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017
SP testosterone (nmol/L)	↓	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017
Plasma testosterone (nmol/L)	↑	Goat, Spanish	Cordoba, Spain	Arrebola and Abecia, 2017

Cont. Table 2.

Table 2., Cont. ...

Parameters	Effects of heat stress	Species, Breed	Location	References
SP Alanine Transaminase (IU/L)	↑	Buffalo, Bhadawari	India	Pandey*et al.*, 2014
SP Aspartate Transaminase (IU/L)	↑	Buffalo, Bhadawari	India	Pandey *et al.*, 2014
SP Alkaline Phosphatase (IU/L)	↑	Buffalo, Bhadawari	India	Pandey *et al.*, 2014
SP Amylase (IU/L)	↓	Buffalo, Bhadawari	India	Pandey *et al.*, 2014
SP Cholesterol (mg/dL)	↑	Buffalo, Bhadawari	India	Pandey *et al.*, 2014
SP Triglycerides (mg/dL)	↑	Buffalo, Bhadawari	India	Pandey *et al.*, 2014
SP Bacterial count (X 10^3/mL)	↑	Ram, Awassi	Mosul, Iraq	Azawi and Ismaeel, 2012

NS- Non-significant, SP- Seminal plasma

Can livestock adapt to climate change?

Like other living organisms, animals also try to minimize the impact of environmental stress on their physiological systems. These responses are termed acclimation, acclimatization, and adaptation. Acclimation is the coordinated response the animal develops against a single prolonged environmental stimulus, whereas acclimatization is the response against several simultaneous stressors (e.g., temperature, humidity, etc.) (Collier *et al*., 2019). Acclimation can occur in two stages: acute or short-term and chronic or long-term (Horowitz, 2002).

Acclimation and acclimatization incorporate only phenotypic changes, while adaptation involves animal genetic changes when adverse environments persist for several generations. All these responses help the animal to cope up with the environment. But, when the stress is removed, the acclimation and acclimatization decline gradually (Collier *et al*., 2019). Examples of acclimation include adjustments in feed intake, reproductive activity, and insulation in response to environmental change. “If the environmental stressors are present for prolonged periods of time (e.g., years), these metabolic and physiologic adjustments can become ‘fixed genetically’, and the animal is considered “adapted” to the environment” (Collier *et al*., 2019).

Mitigation strategies to combat climate stress

The top-down (economy-wide measures) and bottom-up (particular mitigation techniques) technologies are available for reducing climate change, and both have the potential to counterbalance or even lower predicted increases in global emissions. There is a “medium” degree of consensus that agricultural methods in particular might greatly improve soil carbon sinks at cheap cost and simultaneously provide biomass feedstock for energy usage. All sectors have the capacity to contribute. Enhancing livestock and manure management to lower methane emissions and better crop and grazing land management to increase soil carbon storage are examples of mitigation techniques.

Environmental groups actively support raising public knowledge of the links between the use of cattle products, health, and environmental consequences. However, data reveals that, up to a consumption level of around 60 kg of meat and 100 kg of milk per year, demand for meat and milk products demonstrates strong income elasticity. This suggests that cutting back on consumption in emerging nations would be difficult because rising incomes frequently result in greater demand for these goods. The best chances are found when manufacturers are encouraged to become more environmentally conscious. Farmers, especially those in their youth teaching about the potential for more sustainable production forms, yield substantial rewards. One important future goal for global livestock production is to increase the production capacity of certain domestic animal species and breeds using genetic selection techniques. As a result, private farms using a market-oriented strategy will probably produce the majority of livestock in the future. This will require large amounts of high-quality livestock feed, such as concentrates and fodder. The growth of animal output will also be accelerated by offering market-oriented farmers incentives to improve productivity and product quality and by giving them access to loans with longer grace periods and cheaper interest rates (Getu, 2015).

The mitigation strategies livestock producers can directly adopt include management practices, nutritional approaches, administration of hormones, assisted reproductive technologies (ART), selection of heat-tolerant breeds, reduction of animal-origin greenhouse gas, etc. These are discussed briefly below.

Housing management: Better management can always reduce the effects of heat stress on animals. Cares should be taken to protect the animals from direct sunlight with the proper use of a shed and housing system (Razdan, 1990). Sprinkling of water or washing can be beneficial for the animals. Several studies have reported an enhancement in production and reproduction after doing physical modifications (Singh *et al.*, 2014; Aarif *et al.*, 2016; Ghosh *et al.*, 2018; Aarif *et al.*, 2023).

Nutritional strategies: It is one of the most feasible and rapidly incorporated approaches for amelioration of climatic stresses (Chauhan *et al.*, 2021). It includes supplementation of antioxidants, minerals, vitamins, etc., along with providing a balanced diet. Minerals like phosphorus, calcium, selenium, zinc, copper, manganese, cobalt, iodine, potassium etc, are important for the improvement of the reproductive efficiency of animals (Bindari *et al.*, 2013). Supplementation of vitamin A, vitamin E and trace minerals like selenium, copper and zinc improve the mammary gland immunity and health particularly in heat stressed condition (Conte *et al.*, 2017). As there is a reduction in feed intake at the time of heat stress, the focus should be on providing more concentrate feed to the animals. Feeding of ruminally-protected fats and proteins are other approaches to reduce metabolic heat production in the animals (Conte *et al.*, 2017). It is also recommended that *ad libitum* water be provided to the animals.

Hormonal interventions and assisted reproductive technologies (ART): Heat stress disturbs the endocrinological balance of the reproductive system. Hormonal treatment can be effective in many of the conditions. Appropriate use of GnRH, Progesterone, PGF2α and other hormones can induce estrus in the anestrus animals. Following estrus induction, timed artificial insemination (TAI) can be performed to conceive the animals. The suitable programs for hormonal treatment include sov-synch protocol, co-synch protocol, hybrid-synch protocol, CIRD (Controlled Internal Drug Releasing), PRID (Progesterone Releasing Intravaginal Device), etc (Krishnan *et al.*, 2017; Pal and Dar, 2020).

Among the assisted reproductive technologies such as timed-artificial insemination (TAI), superovulation (SOV), ovum pick-up (OPU), in vitro embryo production (IVEP) and timed-embryo transfer (TET) can enhance the reproductive success in domestic animals.

Selection of heat-tolerant breeds: Selective breeding of dairy animals for higher milk production has increased the susceptibility of the animals to environmental stresses. Compared to the exotic breeds or the crossbreds, the indigenous animals have more tolerance to heat stress. They have a higher sweating ability, light-coloured coats, and large body surface areas. So, it is recommended that the percentage of exotic blood should be determined based on climatic zone, and more emphasis should be given to the indigenous milch breeds like Gir, Sahiwal, Red Sindhi and Tharparkar. Also, genetic marker-based selection of the animals can also help to overcome this challenge.

Reduction of livestock greenhouse gas emission: Nearly 16.5% of global greenhouse gas emissions are contributed by the livestock sector. It consists of 27% carbon dioxide, 29% nitrous oxide and 44% methane. Each of them comes from different factors associated with animal-based food production (Molinaro, 2022). As per a report by the Environmental Protection Agency (EPA), US, in 2019, the livestock sector produced more methane than the petroleum and natural gas sectors combined (The White House Office of Domestic Climate Policy, 2021). It clearly shows the importance of reduction greenhouse gas emission from this sector. Addition of feed supplements (algae, bromoform, polyphenolic substances, essential oils, flavonoids etc), increasing rumination time, genetic selection (on the basis of traits like methane intensity and methane yield) etc are some of the steps that can be taken to reduce the emission of greenhouse gases from domestic animals (Bačėninaitė *et al.*, 2022)

Perception of climate change

An effective response to climate change needs both an understanding of people's perspectives and the ability to expand local adaptation efforts into international policies (Ostrom, 2010; Burton *et al.*, 2015). "Perception not only shapes knowledge, but knowledge also shapes perception" (Nguyen *et al.*, 2016b). In agriculture and livestock sector, farming activities are greatly influenced by local climatic conditions and weather updates. However, farmers' decisions about managing the farm from a climate change perspective are full of uncertainty. They understand the environment in their own way and make decisions accordingly, which

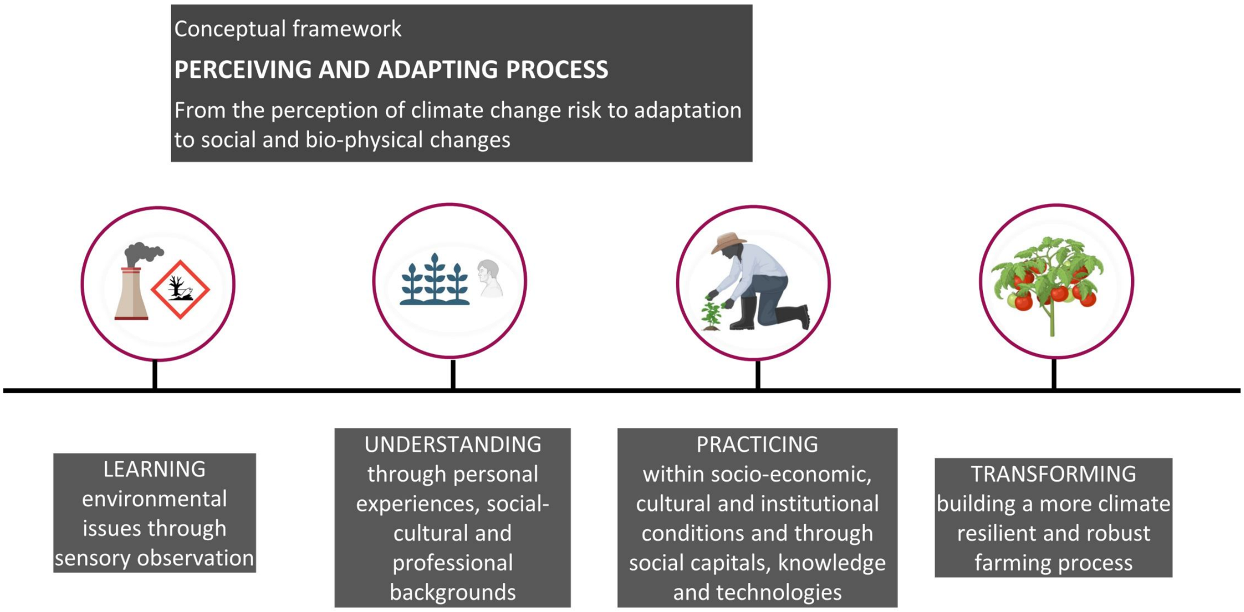

Fig. 3. The cognitive process: a conceptual framework of perceiving and adapting process (Nguyen *et al.*, 2016b; Pasqui and Giuseppe, 2019) (Created in Biorender.com)

often results in maladaptation due to biasedness (Etkin and Ho, 2007; Mubaya *et al.*, 2012). It can eventually make them a victim of the changing scenario and degrade their financial condition (Dono *et al.*, 2013). So, in order to fight the problem of climate change, it is important to understand the cognitive processes associated with perceptions of climate change (Pasqui and Giuseppe, 2019). This cognitive process is divided into several phases as follows (Nguyen *et al.*, 2016a, b).

i. The initial phase involves the farmer gaining knowledge about local environmental conditions through direct observation.

ii. The second phase is achieved when the farmer gains an understanding of the area's economic, professional, social, and cultural context. This understanding is developed through direct experience in their field of operation.

iii. In the third phase, the farmer practices within a specific socioeconomic, social, cultural, and institutional setting. This stage is enhanced by social, scientific, and technological knowledge gained through personal and institutional connections.

iv. The final phase is achieved when decision-making processes are successfully transformed to become more resilient and robust to climate change.

The first two phases are the farmer's adaptation, while the last two phases are the farmer's ability to adapt and change. So, the process of adaptation to climatic change must include "perceiving to learn and to adapt" and "learning to perceive and to adapt" to attain a sustainable goal (Pasqui and Giuseppe, 2019). The process is illustrated in Fig. 3.

Conclusion

It is evident that heat stress affects both the male and female reproductive systems of domestic animals to a great extent. Additionally, climate change particularly the global warming is worsening the situation. This results in loss of production and economic damage to farmers. Though animals try to adapt the condition to some extent, mitigation strategies must be taken to reduce the adverse effects of thermal stress. It includes housing management, nutritional strategies, hormonal interventions, assisted reproductive technologies, selection of heat-tolerant breeds and reduction of livestock greenhouse gas emissions. These will minimize the stress and improve the reproductive health of the animals resulting a better economic condition for the producers.

Conflict of interest: The authors have declared that no conflict of interest exists in the study.

Author's contribution: PP: Conceptualization; PP, PB, FJ, SP: Writing original draft; PB, FJ: Reviewing and editing of the manuscript; PP: Critical evaluation of the manuscript; PP, PB, FJ, SP: Final approval of the version to be published; PB, FJ: Contributed equally.

Data availability statement: No specific research data was used for the review article and information is compiled from the available literature.

REFERENCES

Aarif O and Aggarwal A, 2016. Dry period cooling ameliorates physiological variables and blood acid base balance, improving milk production in Murrah buffaloes. Int J Biometeorol, 60: 465-473, doi: 10.1007/s00484-015-1044-4

Aarif O, Aggarwal A and Sheikh AA, 2023. Evaporative cooling in late gestation heat-stressed transition Murrah buffaloes improves milk production through hormone-metabolite interaction. Biol Rhythm Res, 54(2): 199-212, doi: 10.1080/09291016.2022.2129487

Aggarwal A and Upadhyay R, 2013. Heat Stress and Hormones. In: Heat Stress and Animal Productivity, pp 27-51, doi: 10.1007/978-81-322-0879-2_2

Ali A, 2015. Seasonal variations of the ovarian activity and pregnancy rate in the Egyptian buffalo cows (*Bubalus bubalis*). Tropic Anim Health Prod, 47: 815-818, doi: 10.1007/s11250-015-0793-8

Arrebola F and Abecia JA, 2017. Effects of season and artificial photoperiod on semen and seminal plasma characteristics in bucks of two goat breeds maintained in a semen collection center. Vet World, 10(5): 521-525, doi: 10.14202/vetworld.2017.521-525

Azawi OI and Ismaeel MA, 2012. Effects of seasons on some semen parameters and bacterial contamination of Awassi ram semen. Reprod Domest Anim, 47(3): 403-406, doi: 10.1111/j.1439-0531.2011.01888.x

Bačėninaitė D, Džermeikaitė K and Antanaitis R, 2022. Global warming and dairy cattle: How to control and reduce methane emission. Animals, 12(19): 2687

Badinga L, Thatcher WW, Diaz T, Drost M and Wolfenson D, 1993. Effect of environmental heat stress on follicular development and steroidogenesis in lactating Holstein cows. Theriogenology, 39(4): 797-810, doi: 10.1016/0093-691x(93)90419-6

Balić IM, Milinković-Tur S, Samardžija M and 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, doi: 10.1016/j.theriogenology.2012.02.022

Baumgard LH, Rhoads RP, Rhoads ML, Gabler NK, Ross J *et al.*, 2012. Impact of Climate Change on Livestock Production. In: Sejian V, Naqv S, Ezeji T, Lakritz J, Lal R (eds) Environmental Stress and Amelioration in Livestock Production. Springer, Berlin, pp 413-468, doi: 10.1007/978-3-642-29205-7_15

Bhutta MF, Tariq M, Tunio MT, Sufyan A, Rauf HA *et al.*, 2020. Season-induced changes in seminal characteristics of Sahiwal breeding bulls. Adv Anim Vet Sci, 8(6): 601-607, doi: 10.17582/journal.aavs/2020/8.6.601.607

Bindari YR, Shrestha S, Shrestha N and Gaire TN, 2013. Effects of nutrition on reproduction- A review. Adv Appl Sci Res, 4(1): 421-429

Bohmanova J, Misztal I and Cole JB, 2007. Temperature-humidity indices as indicators of milk production losses due to heat stress. J Dairy Sci, 90(4): 1947-1956, doi: 10.3168/jds.2006-513

Burton I, Bizikova L, Dickinson T and Howard Y, 2015. Integrating Adaptation into Policy: Upscaling Evidence from Local to Global. In: Integrating Climate Change Actions into Local Development, Routledge, pp 371-376

Chauhan SS, Rashamol VP, Bagath M, Sejian V and Dunshea FR, 2021. Impacts of heat stress on immune responses and oxidative stress in farm animals and nutritional strategies for amelioration. Int J Biometeorol, 65: 1231-44

Collier RJ, Baumgard LH, Zimbelman RB and Xiao Y, 2019. Heat stress: physiology of acclimation and adaptation. Anim Front, 9(1): 12-19, doi: 10.1093/af/vfy031

Collier RJ, Doelger SG, Head HH, Thatcher WW and Wilcox CJ, 1982. Effects of heat stress during pregnancy on maternal hormone concentrations, calf birth weight and postpartum milk yield of Holstein cows. J Anim Sci, 54(2): 309-319, doi: 10.2527/jas1982.542309x

Conte G, Ciampolini R, Cassandro M, Lasagna E, Calamari L *et al.*, 2018. Feeding and nutrition management of heat-stressed dairy ruminants. Ital J Anim Sci, 17(3): 604-620, doi: 10.1080/1828051X.2017.1404944

Dash S, Chakravarty AK, Sah V, Jamuna V, Behera R *et al.*, 2015. Influence of temperature and humidity on pregnancy rate of Murrah buffaloes under subtropical climate. Asian-Australas J Anim Sci, 28(7): 943-950, doi: 10.5713/ajas.14.0825

Dash S, Chakravarty AK, Singh A, Behera R, Upadhyay A *et al.*, 2014. Determination of critical heat stress zone for fertility traits using temperature humidity index in Murrah buffaloes. Indian J Anim Sci, 84(11): 1181-1184, doi: 10.56093/ijans.v84i11.44722

Dikmen S and Hansen PJ, 2009. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? J Dairy Sci, 92(1): 109-116, doi: 10.3168/jds.2008-1370

Dono G, Cortignani R, Doro L, Giraldo L, Ledda L *et al.*, 2013. Adapting to uncertainty associated with short-term climate variability changes in irrigated Mediterranean farming systems. Agric Sys, 117: 1-12, doi: 10.1016/j.agsy.2013.01.005

Dutt RH, 1964. Detrimental effects of high ambient temperature on fertility and early embryo survival in sheep. Int J Biometeorol, 8: 47-56, doi: 10.1007/BF02186927

El-Wishy AB, 2013. Fertility of Holstein cattle in a subtropical climate of Egypt. Iran J Appl Anim Sci, 3(1): 45-51

Etkin D and Ho E, 2007. Climate change: perceptions and discourses of risk. J Risk Res, 10(5): 623-641, doi: 10.1080/13669870701281462

Gangwar PC, Branton C and Evans DL, 1965. Reproductive and physiological responses of Holstein heifers to controlled and natural climatic conditions. J Dairy Sci, 48(2): 222-227, doi: 10.3168/jds.S0022-0302(65)88200-5

Garcia-Ispierto I, López-Gatius F, Bech-Sabat G, Santolaria P, Yániz JL *et al.*, 2007. Climate factors affecting conception rate of high producing dairy cows in northeastern Spain. Theriogenology, 67(8): 1379-1385, doi: 10.1016/j.theriogenology.2007.02.009

Getu A, 2015. The effects of climate change on livestock production, current situation and future consideration. Int

J Agric Sci, 5(3): 494-499

Ghosh C, Prasad S, Datta S, Roy DC, Roy A *et al*., 2018. Effect of cooling and concentrate feeding on performances of Karan Fries cattle under loose housing system. Int J Curr Microbiol App Sci, 7(12): 2657-2670

Hance J, 2014. Booming populations, rising economies, threatened biodiversity: the tropics will never be the same. Mongabay, available at: https://news.mongabay.com/2014/07/booming-populations-rising-economies-threatened-biodiversity-the-tropics-will-never-be-the-same/

Horowitz M, 2002. From molecular and cellular to integrative heat defence during exposure to chronic heat. Comp Biochem Physiol Part A: Mol Integr Physiol, 131(3): 475-483, doi: 10.1016/S1095-6433(01)00500-1

Hussein F, Metwally K and El-Nemr HS, 2024. Reproductive performance of buffalo-heifers under stressful condition. Alex J Vet Sci, 80(1): 156, doi: 10.5455/ajvs.178804

Ingraham RH, Stanley RW and Wagner WC, 1976. Relationship of temperature and humidity to conception rate of Holstein cows in Hawaii. J Dairy Sci, 59(12): 2086-2090

IPCC, 2019. Global Warming of 1.5°C. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_LR.pdf

IPCC, 2024. Climate Change Widespread, Rapid, and Intensifying. Available at: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Jakhar V, Vinayak AK and Singh KP, 2016. Genetic evaluation of performance attributes in Murrah buffaloes. Haryana Vet, 55(1): 66-69

Janakiraman K, 1978. Control and Optimizing Reproductive Cycle in Buffaloes. In: Proc. FAO/SIDA Seminar on Buffalo Reproduction and Artificial Insemination, Karnal, India, pp 220-225

Kastelic JP, 2013. Male involvement in fertility and factors affecting semen quality in bulls. Anim Front, 3(4): 20-25, doi: 10.2527/af.2013-0029

Khan I, Mesalam A, Heo YS, Lee SH, Nabi G *et al*., 2023. Heat stress as a barrier to successful reproduction and potential alleviation strategies in cattle. Animals, 13(14): 2359, doi: 10.3390/ani13142359

Khodaei-Motlagh M, Shahneh AZ, Masoumi R and Derensis F, 2011. Alterations in reproductive hormones during heat stress in dairy cattle. Afr J Biotechnol, 10(29): 5552-5558

Kleemann DO and Walker SK, 2005. Fertility in South Australian commercial Merino flocks: relationships between reproductive traits and environmental cues. Theriogenology, 63(9): 2416-2433, doi: 10.1016/j.theriogenology.2004.09.052

Krishnan G, Bagath M, Pragna P, Vidya MK, Aleena J *et al*., 2017. Mitigation of the Heat Stress Impact in Livestock Reproduction. In book: Theriogenology, pp 64-86, doi: 10.5772/intechopen.69091

Lindsay DR, Knight TW, Smith JF and Oldham CM, 1975. Studies in ovine fertility in agricultural regions of Western Australia: ovulation rate, fertility and lambing performance. Aust J Agr Res, 26(1): 189-198, doi: 10.1071/AR9750189

Megahed GA, Anwar MM, Wasfy SI and Hammadeh ME, 2008. Influence of heat stress on the cortisol and oxidant antioxidants balance during oestrous phase in buffalo cows (*Bubalus bubalis*): thermo protective role of antioxidant treatment. Reprod Domest Anim, 43(6): 672-677, doi: 10.1111/j.1439-0531.2007.00968.x

Molinaro A, 2022. Animal Agriculture's Greenhouse Gas Emissions Explained. Compassion in World Farming

Morrell JM, 2020. Heat stress and bull fertility. Theriogenology, 153: 62-67, doi: 10.1016/j.theriogenology.2020.05.014

Morton JM, Tranter WP, Mayer DG and Jonsson NN, 2007. Effects of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. J Dairy Sci, 90(5): 2271-2278, doi: 10.3168/jds.2006-574

Mubaya CP, Njuki J, Mutsvangwa EP, Mugabe FT and Nanja D, 2012. Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia. J Environ Manage, 102: 9-17, doi: 10.1016/j.jenvman.2012.02.005

Nabenishi H, Ohta H, Nishimoto T, Morita T, Ashizawa K *et al*., 2011. Effect of the temperature-humidity index on body temperature and conception rate of lactating dairy cows in southwestern Japan. J Reprod Dev, 57(4): 450-456, doi: 10.1262/jrd.10-135t

Nasr MA, 2017. The potential effect of temperature-humidity index on productive and reproductive performance of buffaloes with different genotypes under hot conditions. Environ Sci Pollut Res Int, 24(22): 18073-18082, doi: 10.1007/s11356-017-9450-2

Nguyen TPL, Mula L, Cortignani R, Seddaiu G, Dono G *et al*. 2016a. Perceptions of present and future climate change impacts on water availability for agricultural systems in the western Mediterranean region. Water, 8(11): 523, doi: 10.3390/w8110523

Nguyen TPL, Seddaiu G, Virdis SGP, Tidore C, Pasqui M *et al*., 2016b. Perceiving to learn or learning to perceive? Understanding farmers' perceptions and adaptation to climate uncertainties. Agric Sys, 143: 205-216, doi: 10.1016/j.agsy.2016.01.001

Nkuruma E, 2023. The Effects of environmental contaminants on animal health and reproduction. J Anim Health, 3(1): 1-12

Ostrom E, 2010. Polycentric systems for coping with collective action and global environmental change. Glob Environ Change (20th Anniversary Special Issue), 20(4): 550-557, doi: 10.1016/j.gloenvcha.2010.07.004

Ozawa M, Tabayashi D, Latief TA, Shimizu T, Oshima I *et al*., 2005. Alterations in follicular dynamics and steroidogenic abilities induced by heat stress during follicular recruitment in goats. Reproduction, 129(5): 621-630, doi: 10.1530/rep.1.00456

Pal P and Dar MR, 2020. Induction and Synchronization of Estrus. In: Aral, F., Payan-Carreira, R., & Quaresma, M. (Eds.) Animal Reproduction in Veterinary Medicine, pp1-14

Pandey V, Nigam R, Singh P, Sharma A, Saxena A *et al*., 2014. Influence of season on biochemical attributes of Bhadawari buffalo bull semen: effect of temperature and humidity. J Anim Res, 4(2): 201-209, doi: 10.5958/2277-940X.2014.00006.0

Parveen K, Gupta AK, Mumtaz S, Khan AH and Rathore A, 2022. Impact of heat stress on reproductive performance of Sahiwal cows. Indian J Dairy Sci, 75(2): 167-172, doi: 10.33785/IJDS.2022.v75i02.011

Pasqui M and DiGiuseppe E, 2019. Climate change, future warming, and adaptation in Europe. Anim Front, 9(1): 6-11, doi: 10.1093/af/vfy036

Razdan MN, 1990. Buffalo performance in relation to climatic environment. Proceedings, II World Buffalo Congress, New Delhi, India, December 1988. Volume II, Part II. Invited papers and special lectures, pp 173-186 ref. 38

Reddy AO, Ramesha KP and Rao MK, 1999. Effect of climate on the incidence of oestrus, conception and cycle length in Murrah buffaloes. Ind J Anim Sci, 69(7): 485-489

Roth Z, 2017. Effect of heat stress on reproduction in dairy cows: insights into the cellular and molecular responses of the oocyte. Annu Rev Anim Biosci, 5(1): 151-170, doi: 10.1146/annurev-animal-022516-022849

Sawyer GJ, Lindsay DR and Martin GB, 1979. The influence of radiant heat load on reproduction in the Merino ewe. III.* Duration of oestrus, cyclical oestrous activity, plasma progesterone, LH levels and fertility of ewes exposed to high temperatures before mating. Crop Pasture Sci, 30(6): 1151-1162, doi: 10.1071/AR9791151

Shafie MM, Mourad H, Barkawi A, Aboul-Ela MB and Mekawy Y, 1982. Serum progesterone and oestradiol concentration in the cycling buffalo. Tropic AnimProdu, 7(4): 301-308

Sharma M, Yaqoob B, Singh A, Sharma N and Rawat S, 2017. Effect of temperature humidity index on semen quality of bovine bull. Int J Curr Microbiol Appl Sci, 6(12): 1822-1830, doi: 10.20546/ijcmas.2017.612.206

Singh J, Nanda AS and Adams GP, 2000. The reproductive pattern and efficiency of female buffaloes. Anim Reprod Sci, 60-61: 593-604, doi: 10.1016/s0378-4320(00)00109-3

Singh N and Chaudhary KC, 1992. Plasma hormonal and electrolyte alterations in cycling buffaloes (*Bubalus bubalis*) during hot summer months. Int J Biometeorol, 36(3): 151-154, doi: 10.1007/BF01224818

Singh SV, Hooda OK, Narwade B, Baliyan B and Upadhyay RC, 2014. Effect of cooling system on feed and water intake, body weight gain and physiological responses of Murrah buffaloes during summer conditions. Ind J Dairy Sci, 67(5): 426-431

Takkar OP, Singh M and Varman PN, 1983. Progesterone levels vis-a-vis anoestrum in buffaloes concurrent with profile during stage of oestrus cycle. Ind J Dairy Sci, 36(2): 125-128

The white house office of domestic climate policy, 2021. U.S. Methane Emissions Reduction Action Plan

United Nations, 2024. Revision of World Population Prospects. https://population.un.org/wpp/

Verma KK, Prasad S, Mohanty TK, Kumaresan A, Layek SS *et al.*, 2016. Effect of short-term cooling on core body temperature, plasma cortisol and conception rate in Murrah buffalo heifers during hot-humid season. J Appl Anim Res, 44(1): 281-286, doi: 10.1080/09712119.2015. 1031782

Wilson SJ, Marion RS, Spain JN, Spiers DE, Keisler DH *et al.*, 1998. Effects of controlled heat stress on ovarian function of dairy cattle. 1. Lactating cows. J Dairy Sci, 81(8): 2124-2131, doi: 10.3168/jds.S0022-0302(98)75788-1

Wolfenson D, Roth Z and Meidan R, 2000. Impaired reproduction in heat-stressed cattle: basic and applied aspects. Anim Reprod Sci, 60-61: 535-547, doi: 10.1016/S0378-4320(00)00102-0

Wright IA, Tarawali S, Blümmel M, Gerard B, Teufel N *et al.*, 2012. Integrating crops and livestock in subtropical agricultural systems. J Sci Food Agric, 92(5): 1010-1015, doi: 10.1002/jsfa.4556

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