Journal of Farm, Companion and Aquatic Animals (2022)1:23-27

Heat Stress Affecting the Reproductive Performance in Dairy Cattle: A Review

D. Sengupta[1] and J. K. Prasad[2]

Abstract

Heat stress due to rising environmental temperature by global warming is an emerging challenge to the dairy industry severely affecting the production and reproduction of dairy animals. The review seeks to explain the various aspects of reproduction of dairy cattle and buffalo affected by heat stress and the strategies to mitigate the effect of heat stress. The comfort zone or thermo-neutral zone of dairy cattle and buffaloes is 25-26° C and THI above 75 has been considered to exert heat stress. Heat stress upsets the reproductive endocrinology by suppressing the synthesis of estrogen by the dominant follicle, increasing the level of blood cortisol and together inhibiting or delaying LH surge that results in failure of fertilization. Moreover the production of inhibin by the dominant follicle is also suppressed that leads to increased circulating FSH level resulting in greater incidences of double ovulation. Heat stress is also responsible for the suppression of estrus symptoms that leads to difficulty in estrus detection and artificial insemination. Heat stress delays follicular maturation particularly after the formation of antrum, prolongs follicular dominance and affects the maturation of germinal vesicle oocyte and metaphase II oocyte besides delaying the first two embryonic division should a successful fertilization occur. Mitigation strategies from heat stress include selection of heat tolerant animals through identification of heat tolerance gene like HSP70, providing gluconeogenic precursors with anti-oxidants, evaporative environmental cooling strategies like planting trees around dairy farms and the use of technologies like fogging and misting along with fixed time artificial insemination protocols.

Key Words: dairy cows, oocyte, embryo, ovulation, heat stress

Introduction

The cattle and buffaloes contribute approximately 96% to total milk production in India. Though milk production in India has been reached to 132.4 million tonnes in 2012-13 with a growth rate of 3.5%, but there is high demand of milk (BAHS, 2014) and it is projected that by 2030 India will be able to produce 200 million tonnes of milk (NDRI vision, 2030). This target will be achieved if there is the optimum balance between productivity and fertility. Fertility is a very broad term which is influenced by various factors including genetic, nutritional, hormonal, physiopathology, management and environment or climate. The fertility traits in dairy animals show a very low heritability value, and this indicates that most of the variations in the fertility are determined by non-genetic factors or environmental effects (Thiruvenkadan et al., 2010).

Global warming has risen the surface temperature by 0.7° C since the early 20th century and it is anticipated that the temperature rise will be 4° C by 2100 (Intergovernmental Panel on Climate Change, 2014). Selection of dairy cows and buffaloes for high milk yield has resulted in decline in the reproductive performance worldwide in the past few decades. Moreover, cattle with high milk yield have higher metabolic heat production e.g. cows yielding 30 kg/day milk produce twice as high as maintenance heat than non-lactating cows. Therefore high milk yielders are highly vulnerable to the effect of heat stress in the event of ever increasing environment temperature due to the global warming. Extreme heat stress on high yielders produce stress and they are unable to maintain their normal temperature resulting to rise of internal body temperature. The rise of internal body temperature during the summer is responsible for the impaired reproductive performance. Body temperatures of high milk yielding cows were found to start rising exponentially at air temperatures of 26–27 C. Thus, even a small rise in air temperature, on the order of 1–2 C, due, for instance, to global warming, may induce severe hyperthermia in dairy cows.

Temperature Humidity Index as a Model to Measure Heat Stress

The physical factors affecting the productive and reproductive performance of farm animals are air temperature, relative humidity, solar radiation, atmospheric pressure and dust (Hahn et al., 2003). Looking into the ever changing climatic condition of the world and the effect of global warming, a variety of indices have been used to estimate the degree of heat stress in animals, amongst which the most commonly used one is Temperature Humidity Index (THI). THI is measured by combining the dry bulb, wet bulb temperature and including the relative humidity by various methods (Table 1).

dip96sen@gmail.com

Department of Veterinary Gynaecology & Obstetrics, Bihar Veterinary College, Patna- 14
Dean, Bihar Veterinary College, Patna- 14.

Heat Stress Models	Formulae	References
THI 1	$[0.4 (T_{db}+T_{wb})] 1.8+32+15$	Thom, 1959
THI 2	$(0.55 T_{db}+0.2 T_{dp}) 1.8+32+17.5$	NRC, 1971
THI 3	$T_{db}+(0.36 T_{dp})+41.2$	Yosuf, 1985

Table 1: Different heat stress models for formulating temperature humidity indices.

T_{db}=Dry bulb temperature, T_{wb}=Wet bulb temperature, RH=Relative humidity, THI=Temperature humidity index

Comfort Zone Versus Heat Stress Zone

The comfort zone or thermo-neutral zone (TNZ) can be explained as the inter-relationship between the animal and the environment and it is defined as the range within which metabolic rate is minimal i.e. a healthy animal can make physical adaptation to maintain the normal body temperature with minimal change in metabolic activity. In general, the TNZ is surrounded by lower critical temperature and higher critical temperature. The upper critical temperature has been defined in dairy cows as 25-26 C (Berman et al., 1985). Armstrong (1994) categorized THI values into five different classes as no stress with THI value <72, mild stress (72-78), moderate stress (79-88), severe stress (89-98) and dead cows with THI >98. The importance of classifying the THI into different classes involves the determination comfortable zone or HSZ where the animals have been exposed to heat stress. The acute exposure to extreme heat load is associated with disturbance to a physiological mechanism to the body like rapid respiration and excessive saliva production along with significant depression in reproductive performances in animals.

Heat Stress affecting the Reproductive Endocrinology

Follicles from heat stressed cows have been found to secrete lower levels of estrogen under gonadotropin stimulation (Bridges et al., 2005). Other studies have showed lower concentrations of GnRH-induced LH surge under heat stress (Gilad et al., 1993). A reduction in the steroidogenic capacity of follicles under thermal stress is characterized by less aromatase activity of granulosa cells and decreased estradiol concentration in the dominant follicle (Wolfenson et al., 1997). In agreement with this, Roth et al. (2000) showed a pronounced decrease in plasma inhibin concentration in heat-stressed cows, which in turn caused an increase in plasma FSH concentration, known to stimulate follicle growth in the ovaries. These alterations might explain the significant rise of double ovulation and the marked rise in calving of twins following summer inseminations. Exposing cows to short-term, acute heat stress is not associated with a reduction in progesterone concentration. In fact higher concentration of progesterone has been found in acute type study that has been related to adrenal secretion of progesterone or to the severity of the thermal stress (Bridges et al., 2005). In contrast, a significant decrease of progesterone is typically obtained when cows are exposed to long-term, chronic, seasonal heat stress (Wolfenson et al., 2002). This can be attributed to disruption of the process of CL formation, or to low synthesis of progesterone under hyperthermia, or may be a result of impaired preovulatory follicles which subsequently form a CL with suboptimal function (Wolfenson et al., 2002).

Effect of Heat Stress on the Expression of Estrus Symptoms

Heat stress reduces the length and intensity of estrus, besides increases the length of anestrus and silent heat in dairy cattle and buffaloes (Kadokawa *et al.*, 2012 and Sengupta and Kumar, 2022). Heat stress increases ACTH and cortisol secretion that has been found to down-regulate estrogen receptors both at the level of pituitary and uterus (Zamorano et al., 1992), decrease the tissue uptake of estrogen (Campbell, 1978) and estrogen stimulated DNA synthesis in the uterus (Bigsby, 1993). Thus decreased synthesis of estrogen by the developing follicle as has been discussed earlier and suppression of the effect of estrogen by cortisol is responsible for the decreased intensity of estrus symptoms. In fact, reduction in blood cortisol level by administration of antioxidant vitamin E and selenium and feeding glycerol to buffaloes during the hot summer months have been found to potentiate the secondary symptoms of estrus in Murrah buffaloes (Sengupta and Kumar, 2022).

Heat Stress affecting Folliculogenesis, the Timing of Ovulation and Fertilization Rate

Cows generally have two to three follicular waves during their 21 days cycle. In each wave, a single follicle matures as the dominant follicle and the dominant follicle of the last wave becomes the pre-ovulatory follicle whereas the dominant follicles of the previous waves become atretic. Two mechanisms associated with attenuation of follicular dominance are worth mentioning. The first is associated with decreased synthesis of inhibin by the dominant follicle leading to elevation of circulating FSH level and growth of sub-ordinate follicles (Roth et al., 2000) leading to increased incidence of twin ovulations. The second is the extended period of follicular dominance due to its early emergence (Wolfenson et al., 1995) that has detrimental effect on oocyte maturation and quality thus affecting the fertilization rate. Since heat stressed cows have low level of circulating estrogen (Bridges et al., 2005) and higher levels of cortisol (Zamorano et al., 1992) that mitigate the effect of estrogen, the positive feedback of estradiol on pre-ovulatory hypothalamic center for LH surge is disturbed leading to delayed ovulation, follicular and luteal cyst and luteal insufficiency (Wolfenson et al., 2000).

Heat Stress Affecting the Quality of Oocyte and Embryo

The ovarian pool of oocytes is sensitive to heat stress in a stage dependant manner (Figure 1). Oocytes of Holstein cows during the summer months exhibited a delay in the first two embryonic divisions (Gendelman et al., 2010) and a reduced proportion of oocytes that were fertilized and further developed to the blastocyst stage under heat stress. A period of two to three estrous cycles was found to be required for recovery from summer heat damage and appearance of competent oocytes in the subsequent autumn (Roth et al., 2001), indicating a long-lasting effect of heat stress on the ovarian pool of oocytes. This might explain the reduced fertility during the autumn, when cows are not exposed to environmental thermal stress. It should be noted that only a subpopulation of the ovarian follicles, rather than the entire follicular reservoir, is damaged upon maternal hyperthermia, reflected by spontaneous recovery of oocyte competence and conception rate during the autumn and subsequent winter (Roth et al., 2001). The molecular mechanism behind the oocyte damage is the impaired rearrangement of their micro-tuble and micro-filaments that lead to damaged spindle apparatus and fertilization failure (Roth and Hansen, 2005).

Pre-implantation embryos are also sensitive to elevated temperature, in a stage-dependent manner (Hansen, 2007). Two-cell stage embryos are more sensitive to heat stress than those at four- and eight-cell stages. Embryos at later developmental stages (i.e., morula, blastocyst) are more resistant to heat stress (Hansen, 2007). Interestingly, heat shock differentially affects embryonic development in different breeds, with a moderate negative effect in *Bos indicus* (Brahman and Nelore) and a larger negative effect in *Bos taurus* (Angus, Holstein).

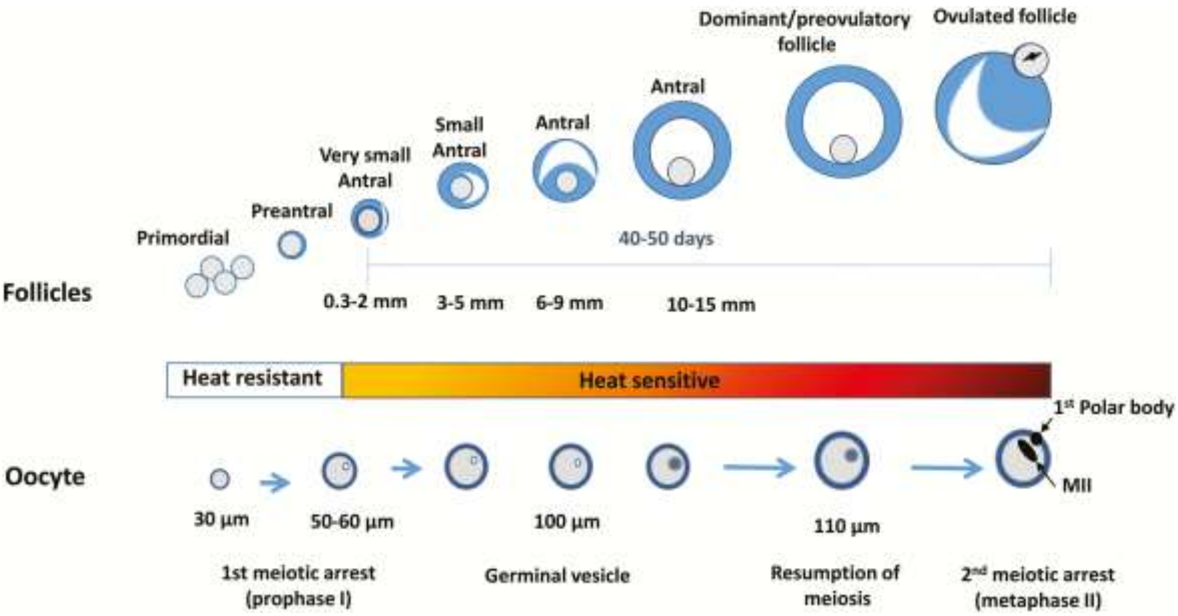

Figure 1: Diagram illustrating stage-dependent pattern of resistance/sensitivity of the ovarian pool of follicles and their enclosed oocytes to heat stress. The primordial, primary, and secondary follicles are heat-resistant, whereas the developing antral follicles, including the dominant and preovulatory follicles, are sensitive to heat exposure with a prominent effect on the germinal vesicle-stage oocyte (developing stage) and metaphase II (MII)-stage oocyte (ovulation). Adapted from Roth (2017).

Mitigation Strategies to Combat Heat Stress

Basically three mitigation strategies are applied to mitigate the negative effect of heat stress in dairy cattle. The first strategy is the development of heat tolerant dairy breed through introgressing heat adaptation genes from a local breed into a commercial herd. Slick hair gene has been identified as increased thermal tolerance due to its association with increased sweating rate and low metabolic rate in animals (Dikmen et al., 2008). Similarly heat shock protein 70 (HSP70) is a family of genes responsible for the expression of heat shock proteins (HSPs) during exposure to heat shock and modulates the immune and endocrine system of the animals for acclimatization. The HSP70 is highly expressed in Sahiwal and Tharparkar cattle and buffaloes in India that enables to tolerate the tropical heat (Kumar et al., 2015). The identification of major genes associated with thermo-tolerance that reduces the effects of heat stress in cattle and buffaloes and its subsequent incorporation into breeding program through marker assisted selection should be the breeding strategy for enhancing both the reproductive ability and adaptability to the warm climate.

The second strategy to mitigate heat stress in dairy cattle is through nutritional modification. During heat stress the dry matter intake is reduced with concomitant increase in maintenance energy requirement that leads to a state of negative energy balance. High nutrient density energy supplements like glycerol and anti-oxidants like vitamin E and selenium have been proven to reduce the cortisol level and increase the intensity of estrus symptoms in buffaloes (Sengupta and Kumar, 2022). The third strategy to mitigate heat stress is through modification of surrounding environment through provision of shades and evaporative cooling strategies. Shades provide protection from direct solar radiation and can be artificial or trees. Trees are excellent as shades combined with beneficial cooling as moisture evaporates from the leaves (McDowell, 1976). Evaporative cooling strategies are very effective in mitigating heat stress in cows and buffaloes and two technologies are commonly used i.e. fogging and misting. Fogging uses find droplets of water dispersed into the air stream that quickly evaporates and cool the surrounding air while the principle involved in misting is the same except that the size of droplets are larger. Productive and reproductive performance of dairy cows has been proven to have improved by using these evaporative cooling technologies (Ryan et al., 1992).

Heat stress increases the incidences of silent estrus and delayed ovulation as has been discussed earlier. This problem can be circumvented by the use of timed artificial insemination (TAI) protocol such as OvSynch protocol that eliminates the need for estrus detection and allows all cows to be inseminated at a particular time and have been proven to improve the conception rate of dairy cattle during the summer months (de la Sota et al., 1998). Since heat stress increases the length of follicular dominance, induction of follicular cycles by repeated administration of PGF_2 and GnRH eliminated the disruptive effect of heat stress on follicular function and improves the conception rate (Friedman et al., 2011).

Conclusion

Environment temperature above 26º C with THI greater than 75 imposes significant heat stress in high yielding dairy cattle and buffaloes. Several aspects of reproduction including the level of reproductive hormones, quality of oocytes and embryos, duration and intensity of estrus symptoms, timing of ovulation and conception rates are detrimentally affected during heat stress. Selection of heat tolerant animals through identification of heat tolerance gene like HSP70, providing gluconeogenic precursors with anti-oxidants, evaporative environmental cooling strategies like planting trees around dairy farms and the use of technologies like fogging and misting along with fixed time artificial insemination protocols can be some of the measures to improve the reproductive performance of dairy cattle and buffaloes during the hot summer months.

References

Armstrong D.V. (1994). Heat stress interactions with shade and cooling. *J. Dairy Sci.* 77: 2044–2050.

BAHS, Basic Animal Husbandry Statistics. (2014). *Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India.*

Berman, A., Folman, Y. M., Kaim, M., Mamen, Z., Herz, D., Wolfenson, A., Graber, Y. (1985). Upper critical temperatures and forced ventilation effects for high-yielding dairy cows in a tropical climate. *J. Dairy Sci.* 68: 488–495.

Bigsby, R.M. (1993). Progesterone and dexamethasone inhibition of estrogen-induced synthesis of DNA and complement in rat uterine epithelium: effects of anti-progesterone compounds. *J. Steroid Biochem.* 45: 295-301.

Bridges, P. J., Brusie, M. A. and 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. *Domest. Anim. Endocrinol.* 29: 508–522.

Campbell, P. S. (1978). The mechanism of the inhibition of uterotropic responses by acute dexamethasone pre-treatment. *Endocrinol.* 103: 716-723.

de la Sota, R. L., Risco, C. A., Moreira, F., Burke, J. M. and Thatcher, W. W. (1998). Efficacy of a timed insemination program in lactating dairy cows during summer heat stress *Theriogenology* 49: 761–770.

Dikmen. S, Alava, E., Pontes, E., Fear, J. M., Dikmen, B.Y., Olson, T. A., Hansen, P. J. (2008). Differences in thermoregulatory ability between slick-haired and wild-type lactating Holstein cows in response to acute heat stress. *J. Dairy Sci.* 91: 3395–3402.

Friedman, E., Voet, H., Reznikov, D., Dagoni, I. and Roth, Z. (2011). Induction of successive follicular waves by gonadotropin-releasing hormone and prostaglandin F(2) to improve fertility of high-producing cows during the summer and autumn. *J. Dairy Sci.* 94:2393-2402

Gendelman, M., Aroyo, A. Yavin, S. and Roth, Z. (2010). Seasonal effects on gene expression, cleavage timing, and developmental competence of bovine preimplantation embryos. *Reproduction* 140: 73–82.

Gilad, E., Meidan, R., Berman, A., Graber, Y and Wolfenson, D. (1993). Effect of heat stress on tonic and GnRH-induced gonadotrophin secretion in relation to concentration of oestradiol in plasma of cyclic cows *J. Reprod. Fertil*. 99: 315–321.

Hahn, G. L, Mader, T. L, Eigenberg, R. A. (2003). Perspectives on development of thermal indices for animal studies and management. *Proceeding Symposium. Interactions between Climate and Animal Production. EAAP Technical Series No. 7*:31–44.
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 (suppl. 1): S242–S249.
Roth, Z., Arav, A., Bor, A., Zeron, Y., 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.
Kadokawa, H, Sakatani, M and Hansen, P. J. (2012). Perspectives on improvement of reproduction in cattle during heat stress in a future Japan. *Anim. Sci. J.* 83(6): 439–445.
Kumar, A., Ashraf, S., Goud, T. S, Grewal, A., Singh, S.V, Yadav, B. R, Upadhyay, R. C. (2015). Expression profiling of major heat shock protein genes during different seasons in cattle (*Bos indicus*) and buffalo (*Bubalus bubalis*) under tropical climatic condition. *J. Therm. Biol.* 51: 55–64.
McDowell, R. E, Hooven, N. W., Camoens, J. K. (1976). Effects of climate on performance of Holsteins in first lactation. *J. Dairy Sci.* 59: 965–973.
National Research Council. (1971). *A Guide to Environmental Research on Animals.* Washington, DC: National Academy of Sciences.
NDRI Vision 2030. Karnal, Haryana, India: National Dairy Research Institute
Roth, Z. and Hansen, P. J. (2005). Disruption of nuclear maturation and rearrangement of cytoskeletal elements in bovine oocytes exposed to heat shock during maturation. *Reproduction* 129: 235-244.
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: 151–170.
Roth, Z., Arav, A., Bor, A., Zeron, Y., Braw-Tal, R. and Wolfenson, D. 2001a
Roth, Z., Meidan, R., Braw-Tal, R., and Wolfenson, D. (2000). Immediate and delayed effects of heat stress on follicular development and its association with plasma FSH and inhibin concentration in cows. *J. Reprod. Fertil*. 120: 83–90.
Ryan, D. P., Boland, M. P., Kopel, E., Armstrong, D., Munyakazi, L., Godke, R. A., Ingraham, R. H. (1992). Evaluating two different evaporative cooling management systems for dairy cows in a hot, dry climate. *J. Dairy Sci.* 75: 1052–1059.
Sengupta, D. and Kumar, B. (2022). Effect of lowering blood cortisol level along with progesterone priming on intensifying the secondary symptoms of estrus in Murrah buffaloes during the hot summer months. *Reprod. Domest. Anim.* (in press). https://doi.org/10.1111/rda.14218
Thiruvenkadan A.K, Panneerselvam S, Rajendran R, Murali N. (2010). Analysis on the productive and reproductive traits of Murrah buffalo cows maintained in the coastal region of India. *Appl. Anim. Husb. Rural Dev.* 3: 1–5.
Thom E.C. (1959). The discomfort index. *Weatherwise,* 12: 57–59.
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.
Wolfenson, D., Lew, B. J., Thatcher, W. W., Graber, Y. and Meidan, R. (1997). Seasonal and acute heat stress effects on steroid production by dominant follicles in cows. *Anim. Reprod. Sci*. 47: 9–19.
Wolfenson, D., Sonego, H., Bloch, A., Shaham-Albalancy, A., Kaim, M., Folman, Y. and Meidan, R. (2002). Seasonal differences in progesterone production by luteinized bovine thecal and granulosa cells. *Domest. Anim. Endocrinol*. 22: 81–90.
Yousef, M. K. (1985). *Stress Physiology in Livestock.* Boca Raton, FL, USA: CRC Press.
Zamorano, P., Steinsapir, J., Mahesh, V. B. (1992). Effects of 5alpha-dihydrotestosterone and dexamethasone on estrogen receptors of the anterior pituitary and uterus. *Steroids* 57: 18-26.

*****