Review Article

Temperature Humidity Index and Its Relationship with Production Traits of Dairy Cattle and Buffaloes - Review

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Rec. Date:	Oct 26, 2018 07:34
Accept Date:	Feb 07, 2020 07:23
DOI	10.5455/ijlr.20181026073415

Abstract

Increased pressure for intensified milk production and simultaneous rise in environmental temperature due to global warming has increased the thermal load on dairy animals. Elevated environmental temperature combined with high humidity causes discomfort and escalates the stress level in animals which is reflected in terms of reduced physiological and metabolic activities that results in reduced growth, drop in production and reproduction in farm animals. Heat stress is one of the most vital environmental stressor that has negative impact on milk yield, milk composition (fat%, SNF%, protein % etc). Construction of Temperature Humidity Index (THI) by combining several climatological parameters like dry bulb, wet bulb temperature along with relative humidity to quantify the thermal stress is one of the best methods to assess heat stress on animals. Several research workers have reported that there exists a threshold THI value, above which the negative effects of heat stress is observed on animals. Mitigation strategies to combat heat stress includes selection of heat tolerant animals and their breeding, inclusion of heat tolerance as a trait while constructing selection index, providing balanced nutrition to the animals and implementation of good ventilation along with suitable cooling system in the farm.

Key words: Buffalo, Cattle, Heat Stress, Milk Production, Milk Composition, THI

How to cite: Behera, R., Mandal, A., Rai, S., Karunakaran, M., & Mondal, M. (2020). Temperature Humidity Index and Its Relationship with Production Traits of Dairy Cattle and Buffaloes - A Review. International Journal of Livestock Research, 10(3), 38-48. doi: 10.5455/ijlr.20181026073415

Introduction

Climate change is defined as the long-term imbalance of routine weather parameters like temperature, humidity, rainfall, radiation, wind speed and wind direction of a particular geographical area. Increased pressure for more milk production and simultaneous rise in environmental temperature due to global warming has increased the thermal load on dairy animals (Polsky *et al.*, 2017). The constant change in climatic conditions is probably one of the foremost challenges for human beings, animal husbandry and agricultural practices. One of the major climate changes observed is global warming. Due to global warming the surface temperature of earth has been increased about 0.7°C since the early 20th century and has large impact on reproductive and productive performances of cattle and buffaloes. Present climate models have forecasted an increase in temperature by 0.2°C per decade and rise in earth's mean surface temperature between 1.8°C to 4.0°C by 2100 (IPCC, 2007). Elevated environmental temperature combined with high humidity escalates the stress level in animals which is reflected in terms of reduced physiological and metabolic activities that results in reduced growth, production and reproduction in farm animals.

Research workers have defined stress in different ways. Dobson and Smith (2000) defined stress as the failure of an animal to adjust with its environment thus inability to express its full genetic potential. Rosales (1994) have described stress as the combined negative effect of different factors on health and performance of animals. According to Khansari *et al.* (1990), stress is the body's reaction to stimuli that upset normal physiological equilibrium or homeostasis, many a times resulting in detrimental effects. According to Stott (1981), stress is the result of atmospheric forces cumulatively acting upon animals and disturbs the homeostasis resulting in new adaptations that can be detrimental or advantageous to the animal. Among the stressors, heat stress has been of prime concern in decreasing animal's productivity in tropical, sub-tropical and arid areas (Silanikov *et al.*, 1999). Stress is the magnitude of exogenous force on the body which tend to shift body systems from their resting or ground state. According to these definitions, high production also comes in the criteria of stressor as production stress. When the stress is due to some element of the environment, the resultant stress is termed as environmental stress (Yousef, 1985). Heat stress occurs when the effective temperature of the environment is beyond the animal's thermo-neutral zone under the influence of environmental factors (Armstrong, 1994). Thermal stress is the major stress imposed by environment particularly in the tropical and subtropical climatic conditions and is a major hurdle for animal productivity. Temperature with high relative humidity further exacerbates the stress level (Marai *et al.*, 2007; Shelton, 2000). The thermo-neutral zone is bounded by the lower critical temperature (LCT) and Upper Critical Temperature (UCT). Lower critical temperature is the environmental temperature below which metabolic heat production rate increases by shivering and or non-shivering heat generating processes to retain body's heat balance. Ambient temperature above which thermoregulatory evaporative heat loss processes gets activated is the upper critical temperature (Yousef, 1985; Curtis, 1981). Adverse environmental conditions compromise the cooling ability of the animals, causing drop in production and reproductive performances of the animals (Jordan, 2003; West, 2003).

DOI 10.5455/ijlr.20181026073415

Temperature Humidity Index (THI)

Several ways are there to measure heat stress on animals. Constructing Temperature Humidity Index (THI) is one of the best ways because we can get a single THI as indicator of heat stress by combining several environmental parameters like dry bulb and wet bulb temperature, relative humidity and dew point temperature (Thom, 1959). McDowell *et al.* (1976) proposed that temperature humidity index (THI) value can be a single marker of thermal climatic conditions to assess impact of heat stress on animals. A number of heat stress models have been developed by different research workers to estimate THI. The indices are prepared by giving different weights to environmental parameters like dry bulb temperature, wet bulb temperature, relative humidity and dew point temperature. The THI was initially formulated by Thom (1958) and applied to cattle by Berry *et al.* (1964). Following are a few THI models developed using the climatic parameters viz; dry bulb temperature (T_{db}) in ^{0} C, wet bulb temperature (T_{wb}) in ^{0} C, RH = relative humidity in %, dew point temperature (T_{dp}) in ^{0} C presented in Table 1.

Table 1: List of THI models available to estimate thermal load

S. No.	THI Model	Developed by
1	$THI = [0.4 \times (T_{db} + T_{wb})] \times 1.8 + 32 + 15$	(Thom, 1959)
2	$THI = (0.35 \times T_{db} + 0.65 \times T_{wb}) \times 1.8+32$	(Bianca, 1962)
3	$THI = (0.15 \times T_{db} + 0.85 \times T_{wb}) \times 1.8 + 32$	(Bianca, 1962)
4	$THI = (T_{db} + T_{wb}) \times 0.72 + 40.6$	(NRC, 1971)
5	$THI = (0.55 \times T_{db} + 0.2 \times T_{dp}) \times 1.8 + 32 + 17.5$	(NRC, 1971)
6	$THI = (1.8 \times T_{db} + 32) - (0.55 - 0.00\,55 \times RH) \times (1.8 \times T_{db} – 26.8)$	(NRC, 1971)
7	$THI = (0.8 \times T_{db}) + [(RH/100) \times (T_{db} - 14.4)] + 46.4$	(Mader *et al*., 2006)
8	$THI = T_{db} + 0.36 \times T_{dp} + 41.2$	(Yousef, 1985)
9	$THI = T_{db} – [(0.31 - 0.31\ RH) (T_{db} - 14.4)]$	(Marai *et al*., 2001)
10	$THI = 9/5\ t +32 - 11/2(1-h)\ (9/5t-26)$	(NOAA,1976)

The index constructed by Thom (1959) and Bianca (1962) uses only dry bulb and wet bulb temperature. The model given by National Oceanic and Atmospheric Administration (1976) uses daily maximum temperature and minimum relative humidity to estimate THI. National Research Council has formulated three indices constituting dry bulb temperature and wet bulb temperature, dry bulb temperature and relative humidity, dry bulb and dew point temperature independently. The formula developed by Mader (2006) constituted dry bulb temperature and relative humidity. Bohmanova *et al.* (2007) compared seven THI models in humid and semi-arid climate for their ability to detect drop in milk yield due to heat stress. The index giving larger weight on humidity was served best to study the negative impact of heat stress on milk production in the humid climate while index giving larger weight on temperature proved to be the best thermal stress indicator in the semi-arid climate. Dash *et al.* (2015) analysed seven THI models to study the effect of heat stress on pregnancy rate of Murrah buffaloes and found that THI model THI = [(0.4 × (Tdb + Twb)] × 1.8 + 32 + 15) developed by Thom, 1959 was the most suitable THI model for studying the

  DOI 10.5455/ijlr.20181026073415

effects of heat stress on pregnancy rate of buffaloes. THI model[THI = (0.55 × Tdb + 0.2 ×Tdp) × 1.8 + 32 + 17.5] developed by NRC(1971) was identified as the best THI model to assess the impact of heat stress on milk composition traits (Behera *et al.*, 2018a) and Daily Milk yield (Behera *et al.*, 2018b) in Murrah buffaloes.

Thermal Comfort and Heat Stress Zones for Optimal Production in Dairy Cows and Buffaloes

Thom (1959) categorized thermal discomfort zones based on Temperature Humidity Index value. THI value 70 ≤ THI ≤ 74 "uncomfortable" zone, THI of 75 to 79 as "very uncomfortable" zone, THI above 80 as "serious discomfort" zone with respect to heat stress. McDowell (1976) developed THI by using the formula NRC, (1971) described (≤ 70) as comfortable, (71 – 78) as stressful and (> 78) as extreme distress zone. Armstrong (1994) and Moran (2005) classified THI into five different groups: no stress zone (THI < 72), mild heat stress (72-78), moderate heat stress (79-88), severe heat stress (89-98) and dead cows with THI above 98. Evaporative heat loss from the respiratory tract is viewed as one of the primary means for maintenance of thermal balance (McDowell, 1976). Armstrong (1994) explained that THI below 72 imparts no stress to animals and the cattle and buffaloes exhibit optimal production and reproduction. THI range 72-78 imparts mild stress to cattle and buffaloes and dairy cows search for shade and there is raised respiration rate accompanied by dilation of blood vessels. In buffaloes elevation in rectal temperature and respiration rate occurs as a primary response. THI range 79-88 imparts moderate stress to the animals and there is rise in body temperature, respiration rate and saliva secretion, declined feed and water consumption and negative effect on reproductive performances observed in cattle. In buffaloes, very high respiration rate, reduced dry matter intake and decreased ratio of forage to concentrate intake is observed while water intake is remarkably increased. THI range 89-98 imparts severe stress to the animals. There is significant increase in respiration and high saliva production. There is notable decrease in reproductive performances in cows. In buffaloes, excessive panting and restlessness observed along with lowered rumination and urination and on reproductive performances in buffaloes is adversely affected. THI above 98 is fatal for both dairy cows and buffaloes.

Bohmanova (2005) used the THI model proposed by NRC, (1971) and reported that the threshold value of THI for heat stress was 72 which denoted if THI was below 72 there was no effect on milk production. Broucek (2009) used formula proposed by Thom (1959) to estimate THI and reported that THI value of 70-72 is like an alarm of the heat stress that is going to be observed in near future. The initial drop in milk production is observed when THI reaches 72. THI range 72-78 may severely drop milk production. Though, the utmost drop in milk production seen when THI is in the range of 76-78 and THI exceeding 82 may be fatal to animals.

  DOI 10.5455/ijlr.20181026073415

Zimbelman *et al.* (2009) recommended that for dairy cows yielding above 35 kg per day the threshold THI for milk yield drop should be 68 rather than 72. Smith *et al.* (2012) and National Pork Board, (2014) studied the level of heat stress with corresponding THI for dairy and non-dairy cattle and recorded that THI below 69 imparts no heat stress to non-dairy cattle while THI below 67 imparts no heat stress to dairy cattle. THI range of 70-74 is threshold for non-dairy cattle while 68-71 is for dairy cattle. Mild signs of heat stress are evident in non-dairy cattle at THI range 75-78 but most animal can adjust to the stress while the dairy cattle mild signs of heat stress start at THI 72-79. Moderate danger zone begins at THI 79-83 for non-dairy cattle and at 80-89 THI for dairy cattle where some animals will be significantly affected. THI above 91 is extremely fatal. De Rensis *et al.* (2015) defined THI less than 68 to be thermal comfort zone for cows. Mild signs of heat stress begin at THI of 68 to 74, drastic drop in production observed at THI above 75. Behera (2016) reported that months January, February, March, October, November and December were the thermal comfort period and April to September were the heat stress period in relation to effect of heat stress on monthly test day fat%, monthly test day SNF% in buffaloes under sub-tropical climatic conditions of Karnal, India while periods from October to mid-April were the thermal comfort zone and periods from mid- April to last week of September were the heat stress periods for daily milk yield in the buffaloes.

Effect of Heat Stress on Production Traits of Dairy Cattle and Buffaloes

Ravagnolo *et al.* (2000) compared different environmental factors (average, minimum, maximum temperature, relative humidity and THI for predicting the influence of heat stress on milk production. The factor with the greatest influence on milk production was found to be THI. Milk production was decreased by 0.2 kg per unit of THI over 72. Ravagnolo and Misztal (2000) gave the idea that daily production of a cow remains unaltered over a range of low and medium ambient temperature and there after crossing a threshold value, starts declining. The decline in performance is nonlinear in nature, but can be linearized by using function f (h), where h is a heat stress index. The rate of decline in milk production traits in different heat stress levels makes the basis of classification of heat stress to different zones. Akyuz *et al.* (2010) suggested that farmers should take suitable measures to minimize heat stress when THI reaches above 72 to check drops in milk production and alterations in milk composition. Lactating dairy cows are more prone to heat stress compared to dry cows as milk production elevates body internal metabolism (Purwanto *et al.*, 1990). Furthermore, there lies positive relationship between milk yield and metabolic heat production; higher yielding cows are more sensitive to heat stress than low yielders (Spiers *et al.*, 2004). The THI threshold for lactating dairy cows yielding above 35 kg of milk per day is 68. Therefore, heat stress ameliorating methods on commercial dairy farms should be instrumented earlier to prevent the negative impact of heat stress on high yielders (Collier *et al.*, 2012). St-Pierre *et al.* (2003) stated that THI of 70, 77 and 72 to be the degrees at which heat stress begins in dairy cows, dairy heifers (0 to 1 year) and

 DOI 10.5455/ijlr.20181026073415

dairy heifers (1 to 2 years), respectively. Tripti *et al.* (2018) conducted a research on 25 stud bulls belonging to Sahiwal, Gir, Jersey cross, Holstein- Frisian cross and Murrah buffaloes for the thermo adaptability of the above said breeds of cattle and buffaloes. The authors reported that bulls of Sahiwal, Gir and Jersey cross had better thermal adaptability while Murrah buffalo and HF cross bulls exhibited poor thermal adaptability. The effect of season, genetic group and genetic group X season (GXE interaction) was highly significant (P<0.01) on thermo-adaptability of bulls.

Collier *et al.* (1981) reported a 24 to 48 hours delay between high environmental temperatures and declined milk production. Linvill and Pardue (1992) suggested that milk production only begins to decline when the THI continually goes above 74 during the previous 4 days. Summer heat stress exhibited negative effect on milk yield, milk composition and reproductive performance of dairy cows in Iran (Zadeh *et al.*, 2013). Bouraoui *et al.* (2002) found a decline of milk production by 0.4 kg for every degree above THI of 69. Ominski (2002) reported that milk production decreased by 4.8 % when cows were exposed to heat stress compared to milk production of cows in the thermo-neutral zone. Kale and Basu (1993) analysed the impact of average monthly THI on average daily milk yield in every month of Jersey and Holstein crosses reared at institute herd of Eastern Regional Station, ICAR- NDRI, Kalyani, West Bengal. The authors declared that THI has negatively influenced milk production and the adverse effects were more in Jersey crosses compared to Holstein crosses under more humid conditions. In Frieswal cattle, there is a drop in wet average by 0.29 and 0.19 percent and herd average by 0.24 and 0.13 percent per unit increase in maximum temperature above 25ºC and relative humidity above 60%, respectively (Mandal *et al.*, 2002). Bouraoui *et al.* (2002) reported that heat stress significantly reduced milk fat content from 3.58% during the spring to 3.24% during the summer. Milk protein percentage also significantly reduced as a result of summer heat load (2.96 during spring vs.2.88% at summer) under Mediterranean climatic conditions. Pawar (2013) reported that milk production, fat%, protein% and SNF% in Murrah buffalo decreases as THI increases. Milk fat, protein and SNF % were estimated to be 8.3%, 3.08% and 9.08 %, respectively during the winter which dropped down to 7.19%, 2.9% and 9.05%, respectively during summer. Behera (2016) reported a decline in monthly test day fat% (-0.03%) and monthly test day SNF% (-0.0063%) during the heat stress period (April to September) under subtropical climatic conditions at Karnal, India.

Strategies to Minimize Heat Stress

Selection and Breeding

Selective breeding of dairy animals for improving milk production has enhanced the susceptibility of animals to thermal load by reduced summer production and reproduction. Cattle with shorter and wider hair with greater diameter and lighter coat colour are better acclimatized to hot climate than their counterparts bearing longer hair and darker coat colour (Bernabucci *et al.,* 2010). *Bos. taurus* cattle possess the above

  DOI 10.5455/ijlr.20181026073415

said phenotype making these cattle better adapted in tropical climate. Slick hair gene is responsible for slick hair coat is associated with thermo-tolerance ability of cattle. Slick hair gene – a dominant gene is causes rise in sweating rate, decreased rectal temperature and respiration rate in homozygous cattleas adaptive measure in hot conditions (Mariasegaram *et al.*, 2007).

Since dairy cows show reduced estrous symptoms during summer heat stress as compared to thermal comfort periods, it is crucial to implement good heat detection strategies to identify oestrous cows with marginal heat symptoms. Artificial insemination is a better option than natural service because in natural service both bull and cows are affected by heat stress. Furthermore, there is the existence of noticeable difference for heat tolerance and heat susceptibility among breeds and also among animals within a breed. Uplifting dairy animal's adaptation to heat load can be realized in two ways viz; selection of heat tolerant animals and introgression of heat tolerant genes from a tolerant breed into a large herd (Renaudeau *et al.*, 2012). Identification and selection of heat tolerant animals and addition of heat tolerance as a trait while constructing selection index in selection programme will be a boon. Several genetic markers can help in selecting heat tolerant animals viz; slick hair gene (Dikmen, 2008). The slick hair gene when introgressed in temperate cattle breeds, produces slick hair coat that improves heat tolerance competence (Berman, 2011). There are some other genes viz., heat shock protein family (HSP) genes, ATP1A1 gene that have been identified as candidate genes responsible for thermal tolerance and adaptation in thermal stress in cattle can be used in marker assisted selection of heat tolerant animals. A Single Nucleotide Polymorphism (C2789A) was detected in exon 17 of ATP1A1 gene of Vrindavani and Tharparkar cattle. Three genotypes; CC, CA, and AA were seen in both the cattle breeds. Genotype phenotype association study revealed that the animals with genotype CC exhibited significantly lower rectal temperature and higher heat tolerance coefficient than the other two genotypes (Kashyap, 2015).

Cooling the Farm Environment

Good airy animal housing system with proper ventilation and proper cooling strategies helps in ameliorating heat load in animals. Evaporating cooling system is helpful in elevating milk production in dairy animals (Ryan, 1992). The farm should be well ventilated. Planting of trees at the farm surrounding will help in easing heat stress. In today's commercial dairy industry plantation around farm is not always a feasible option. Thus, providing artificial shade area by cloth or a naturally well-ventilated structure with open sidewalls can protect the cows from direct sun. The other options of cooling are fogging systems which uses very fine water droplets dispersed into the air stream and allowing quick evaporation, therefore cooling the air around. In a similar way misting system which generate comparatively larger droplets than fogging systems, uses the same principle to cool the air. The sprinklers are however work differently from foggers and misters. The sprinklers do not cool the air rather it cools the hair and skin of the animals. Sprinkling is

  DOI 10.5455/ijlr.20181026073415

a very effective in combination with air circulation. Installing fans along with water sprinkling provision inside the farm house serves as the best indoor cooling choice. Excessive sprinkling should be avoided as it can result into wet bedding increasing the risk of mastitis and other diseases.

In buffaloes significantly higher milk yield observed by misting and wallowing during May – June (hot dry periods) and wallowing during July (hot humid period) and maintained physiological, metabolic, endocrine and redox homeostasis (Yadav *et al.*, 2016).

Feeding Management

Heat stressed animals are more prone to have lower reproductive and productive performance. Feeding balanced rations along with high quality forages will alleviate heat stress and will enhance milk production in dairy cattle and buffaloes. Some nutritional management tips to alleviate heat load on animals are: provision of high quality feeds like total mixed rations, increase the feedings frequency, provide feed during cooler times of the day, provide feed fresh as much as possible, give high-quality forage, maintain adequate fibre content in feed, use of by–pass proteins can enhance the milk yield and protein content. Provision of sufficient cool water is very important strategy to alleviate heat stress. (Sahu and Behera, 2017). Feeding the cows with high quality forages and balanced rations will alleviate some of the negative effects of thermal stress. Increasing Potassium amount in the diet can be helpful as it is the key sweat gland regulator in cattle (Samal, 2013). Antioxidants like vit. A, selenium, zinc, etc. and ruminant- specific live yeast can be fed that helps in minimizing the impact of thermal stress on the oxidant balance, thus boosting reproduction efficiency and animal health (Sejian *et al.*, 2014).

Conclusion

Heat stress reflected through high THI value is a major concern for dairy farmers because of the associated reduction in milk production leading to economic losses. Higher THI can limit the reproductive and production ability of the animals. Implementing proper breeding programs, selection of heat tolerant animals, cooling strategies at farm with proper ventilation and feeding balanced nutrient dense ration can help to combat negative effects of heat stress. During the heat stressed periods of the year with high THI values (THI >72), proper managemental strategies should be undertaken to reduce the negative effects of heat stress and maintain optimal milk production.

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DOI 10.5455/ijlr.20181026073415