Measurement of Severity of Heat Stress in Sheep

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Abstract

Animals show optimum growth, health, and productivity within a range of environmental temperatures. Exposure of the sheep to higher temperature leads to heat stress, which negatively affects their well-being and productivity. In addition to ambient temperature (AT), other climatic factors like humidity (RH), wind speed (WS), and solar radiation (SR) also influence the degree of heat stress in sheep. Further, climate change caused a higher rate of temperature increase in the tropical region. Hence, there is an urgent necessity to develop a simple, reliable,

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V. Sejian et al. (eds.), *Sheep Production Adapting to Climate Change*,
DOI 10.1007/978-981-10-4714-5_14

and easy method to assess the degree of heat stress in sheep particularly during summer. In the mid-twentieth century, temperature-humidity index (THI) was introduced to evaluate the severity of summer stress and was extended to dairy animals as a tool to explain the welfare of the animals. Moreover, several THI equations were developed by various scientists based on prevailing AT and RH. However, the main drawback of the THI was that it did not account for other weather parameters like WS and SR, even though they also equally influenced the level of heat stress in animals. Research efforts pertain to establishing a suitable thermal index by incorporating all cardinal weather parameters. With this background, heat load index (HLI) was developed as an alternative to THI relating RH, WS, and black-globe temperature (accounts both AT and SR). The few other modern indices available to assess the severity of heat stress in sheep are black-globe temperature-humidity index (BGTHI), thermal comfort index (TCI), and global comprehension index (GCI). In addition to weather indices, some physiological indices are also used to assess heat stress in sheep. Physiological responses like rectal temperature and respiration rate are considered as good indicators of heat stress in sheep. Moreover, strong correlations between blood parameters like hemoglobin, packed cell volume, and endocrine parameters such as cortisol and thyroid hormones production are well established in sheep. Further, genomics and proteomics tools are providing advanced options to evaluate the adaptation processes of sheep. Some of the genes identified in sheep during heat stress are heat shock protein, heat shock factor-1, thyroid hormone receptor, and prolactin receptor genes. Besides, the identified thermo-tolerant genes could be used as an ideal marker for assessing the level of heat stress and may be further utilized for marker-assisted selection breeding programs to develop superior thermo-tolerant breeds.

Keywords

Climate change • Heat load index • Heat stress • Solar radiation • Temperature-humidity index • Thermo-tolerant genes • Wind speed

Contents

14.1 Introduction

Thermo-neutral zone is a narrow range of ambient environmental temperatures that are favorable for normal production and well-being. The upper critical temperature is the point at which heat stress begins to affect the animal adversely. There are a number of climatic factors like temperature, relative humidity (RH), wind speed (WS), and solar radiation (SR) that influence the degree of heat stress in animals. In order to characterize and quantify thermal comfort zones, several thermal comfort indices were developed for different species. Currently, the primary focus for livestock and poultry industry has been on developing new heat-stress indices for risk assessment associated with stress response and performance (Eigenberg et al. 2005; Baccari 2001). These efforts may provide suitable inputs and thus an empirical relationship can be developed termed as "biological response function." Such developed thermal indices might help in quantifying the biological responses of livestock to heat-stress challenges. Further, such indices might help to assess the magnitude of impact of heat stress on the productive functions of livestock. Thus, the heat-stress indices might serve as useful surrogates for establishing the complex interactions between the physical and biological components associated with the livestock response mechanisms to stressful environment (Hahn et al. 2003).

Stressful climatic conditions may serve as a limiting factor in the tropics as there are evidences of extended episodes of high temperature and humidity. The sheep is well adapted to overcome the consequences of elevated ambient temperatures (ATs) by modulating its various physiological responses. The higher heat tolerance of sheep could be attributed to their high insulating fleece that prevent free air movement apart from resisting the inward convection of heat due to solar radiation (Mount 1979). Sheep depend on both panting and sweating mechanisms for effectively dissipating the body heat when subjected to adverse environmental condition. The cover of wool limits the efficiency of sweating in the nonsheared sheep.

At increased ambient temperatures above 36 °C, the ears and legs serve as a major channel for heat dissipation. If the physiological mechanisms are not sufficient to dissipate excess body heat, the rectal temperature rises substantially, which is often accompanied by events of biological and behavioral changes (Marai et al. 2007). The thermal stress is well known to negatively affect the efficiency of the production, reproduction system, and health. Any attempt to alter the internal microclimate closer to the boundaries of the thermal neutral zone (TNZ) will surely aid in minimizing the impact of extreme environmental conditions. Hence, it turns out to be an important affair to evaluate the thermal environment more precisely so as to assess the stress profile of an animal subjected to specific period and locus. Further, in a similar focus certain indices are designed and proposed by a few researchers describing the comfort of the animals. These indices comprise various climatic variables to arrive at a unique value and hence on a conclusive remark of whether the animal is stressed or not. Based on the implications of different inputs these indices have their own applicability.

There are several indices used to calculate thermal comfort. Moreover, a single index cannot be figured as optimal and used widely, because there are different climatic, animal, and management factors that need to be taken into account (Gaughan et al. 2008). And some of the indices are specific to some species or breed and hence cannot be replicated as such until well tried, tested, and compared. Therefore, this chapter aims to compile information on different thermal indices that are used for assessing the severity of heat stress in sheep. Further, efforts have also been made to highlight both phenotypic and genotypic indicators for heat stress in sheep.

14.2 Significance of Temperature-Humidity Index

During the twentieth century, there was a necessity to evaluate the effect of heat stress on animal productivity by a simple, reliable, and easy method to quantify the level of heat stress. Consequently, the measurement involving ambient temperature and relative humidity (RH) was developed—temperature-humidity index (THI)—to reveal the degree of stress and to establish its influence on animal production (Bianca 1962; NRC 1971). In the middle of the twentieth century, THI came into existence for the human beings to evaluate the discomfort during summer using the index developed by Thom (1958). In continuation, it was extended to dairy animals, which has become a reliable tool in animal biometeorology (Johnson et al. 1961; Hahn et al. 2003). Further, many computational methods were developed to establish an accurate tool encompassing all the major environmental factors except for environmental temperature and relative humidity. The THI formulas varies according to the authors who defined them based on the weightage given to dry bulb temperature (Tdb), moisture content of air, solar radiation, wind speed etc. (Kelly and Bond 1971; NOAA 1976; LPHSI 1990; Finocchiaro et al. 2005; Mader et al. 2006). However, few used wet bulb temperature (Twb), which represents the equilibrium of temperature (Thom 1959; Bianca 1962; NRC 1971), or dew point temperature (Tdp), which represents the temperature at which RH is 100% (NRC 1971; Yousef 1985). Thermo-neutral zone and heat tolerance threshold level vary in sheep between 5 and 25 °C, depending upon the breeds and climatic regions (Curtis 1983). Finocchiaro et al. (2005) established that heat stress affects Mediterranean dairy sheep production at THI ≥ 23, whereas Sevi et al. (2001) reported that the heat stress affects Comisana dairy sheep when THI ≥ 27.

There are few THI indices solely based on dry bulb temperature (Tdb), wet bulb temperature (Twb), dew point temperature (Tdp), and relative humidity (RH). Table 14.1 describes the various thermal indices to quantify heat-stress response in sheep. In tropical regions, high ambient temperature was considered to be the limiting factor for sheep production (Shelton 2000). The high ambient temperature with an elevated relative humidity further augments the severity of heat stress (Marai et al. 2000; Marai et al. 2001; Marai et al. 2007). For THI index when measured in Fahrenheit (°F), the equation is as follows (LPHSI 1990): THI = db°F − {(0.55–0.55 RH) (db °F − 58)}, where db °F is the dry bulb temperature in °F and RH is the relative humidity (%)/100, for sheep. THI values below 82 indicate an absence of heat stress, values between 82 and 84 indicate moderate heat stress, values between 84 and 86 indicate severe heat stress, and values over 86 indicate extremely severe heat stress (LPHSI 1990). However, if the ambient temperature is expressed in °C, the equation of THI may be used as per Marai et al. (2001): THI = db °C − {(0.31 − 0.31 RH) (db °C − 14.4)}, where db °C is the dry bulb temperature (°C) and RH is the relative humidity (%)/100. The specified THI value of less than 22.2 is considered absence of heat stress, values between 22.2 and 23.3 are called as moderate heat stress, values between 23.3 and 25.6 are considered severe heat stress, and values 25.6 and below are considered extreme severe heat stress (Marai et al. 2001). Another equation was proposed to estimate the level of heat stress in dairy sheep in the Mediterranean region: THI = dbT °C − {(0.55 − 0.55 RH) × (dbT

Table 14.1 The commonly used thermal stress indices to quantify heat stress in sheep

Sheep THI	Sheep breed	References
$THI = [0.4 \times (Tdb\ °C + Twb\ °C)] \times 1.8 + 32 + 15$	Most animals, including sheep	Thom (1959)
$THI = (0.35 \times Tdb\ °C + 0.65 \times Twb\ °C) \times 1.8 + 32$ and $THI = (0.15 \times Tdb\ °C + 0.85 \times Twb\ °C) \times 1.8 + 32$	Most animals, including sheep	Bianca (1962)
$THI = Tdb\ °C + (0.36 \times Tdp\ °C) + 41.2$	Most animals, including sheep	Kibler (1964) and Yousef (1985)
$THI = AT - 0.55 \times (1 - RH) \times (AT - 58)$	Sheep	Kelly and Bond (1971)
$THI = (Tdb\ °C + Twb\ °C) \times 0.72 + 40.6$	Most animals, including sheep	
$THI = (0.55 \times Tdb\ °C + 0.2 \times Tdp\ °C)*1.8 + 32 + 17.5$	Most animals, including sheep	NRC (1971)
$THI = 0.72\ (W\ °C + D\ °C) + 40.6$, The THI values of 70 or less = comfortable, 75–78 = stressful, and values above 78 = extreme distress and animals may not able to sustain the normal core body temperature	Sheep	McDowell et al. (1976)
BGTHI $= BGT + (0.36 \times DPT) + 41$	Sheep	Buffington et al. (1981)
$TCI = (0.6678 \times AT) + (0.4969 \times PVP) + (0.5444 \times BGT) + (0.1038 \times WS)$	Sheep	Barbosa and Silva (1995)
$THI = db\ °C - \{(0.31 - 0.0031 \times RH)\ (db\ °C - 14.4)\}$	Indigenous sheep	Marai et al. (2001) and Rana et al. (2014)
THI = dry bulb (°C) −0.55 (1 – relative humidity) × (dry bulb − 14.4)	Omani and Australian Merino sheep	Srikandakumar et al. (2003)
$THI = Tdb\ °C - [0.55 \times (1 - RH)] \times (Tdb\ °C - 14.4)$	All Animals	Finocchiaro et al. (2005)
$THI = 9/5 \times ((T \times 17.778) - (0.55 - (0.55 \times RH/100)) \times (T - 14.444))$	Ossimi sheep	Abdel Khalek (2007)
$THI = T - (0.31 - 0.0031 \times RH\ T) \times (T - 14.4)$, indicates the following: <22.2 = absence of heat stress; 22.2 to <23.3 = moderate heat stress; 23.3 to <25.6 = severe heat stress; and 25.6 and more = extreme severe heat stress	Most breeds of sheep in semi-arid tropical environment	Marai et al. (2007)
$THI = td - (0.55 - 0.55RH) \times (td - 58)$	Assaf sheep	Leibovich et al. (2011)
$THI = Td - \{(0.31 - 0.31 \times RH)\ (Td - 14.4)\}$	Najdi sheep	Al-Haidary et al. (2012)
Temperature and humidity index were calculated using the following equation: THI = [0.8 × ambient temperature (°C)] + [(% relative humidity/100) × (ambient temperature – 14.4)] + 46.4	Afshari lambs	Mahjoubi et al. (2014)

(continued)

Table 14.1 (continued)

Sheep THI	Sheep breed	References
THI = Ta + (0.36 × To) + 41.5	Most breeds of sheep	McManus et al. (2014)
THI = 0.81 db °C + RH (db °C − 14.4) + 46.4	Merino sheep	Wojtas et al. (2014) and Mader et al. (2006)
THI = Ta + 0.36Tdp + 41.5	Santa Ines sheep	Chagas et al. (2015)

THI – Temperature Humidity Index; Tdb – dry bulb temperature; Twb – wet bulb temperature; Tdp – dew point temperature; AT – air temperature; RH – air relative humidity; BGT – black-globe temperature; PVP – partial vapor pressure; WS - wind speed (ms^{-1}); °C – Degree Centigrade; °F – Degree Fahrenheit; DPT – dew point temperature

°C − 14.4)}, where dbT is the average dry bulb temperature in °C and RH is the relative humidity in percentage (Finocchiaro et al. 2005; Saab et al. 2011).

Thom (1959) developed another THI index based on the ambient temperature (Ta) and RH as follows: THI = 9/5 × [(T × 17.778) − (0.55 − (0.55 × RH/100) × (T − 14.444)]; a value of THI < 72 indicates thermo-neutral conditions during winter and a THI value between 76 and78.5 represents mild-to-moderate heat stress in summer season. The heat stress in sheep can also be estimated through another THI using the following formula: THI = (Dry Bulb Temperature °C) + (0.36 Dew Point Temperature °C) + 41.2). In this case, a THI exceeding 72 indicates mild stress, 80 indicates medium stress, and above 90 indicates severe heat stress (Pennington and Van Devender 2004). Hahn and Mader (1997) proposed another new THI to represent a certain level of heat-stress thresholds to provide a measure of the magnitude of daily heat load (intensity and duration) on dairy cows which can be applied in sheep (Papanastasiou et al. 2014) as follows: $\text{Daily}\, THI - hrs = \sum_{i=1}^{24} THI - \text{base}$, hrs = 1…24, where THI is the hourly temperature-humidity index and is based on certain heat-stress threshold. Further, based on the daily THI-hrs, Panagakis and Chronopoulou (2010) introduced a seasonal THI to evaluate the heat-stress burden in dairy sheep as follows: Seasonal THI − hrs = $\sum$ Daily THI − Hrs. Panagakis and Chronopoulou (2010) found that heat stress in dairy sheep at noon by an increase in the daily THI-hrs culminates in higher respiration rate in the heat-stressed animals.

14.3 Limitations of Temperature-Humidity Index

The THI is currently being used in assessing the severity of heat stress both in human beings and in livestock. However, THI has two important drawbacks, of not taking into account the solar radiation (SR) and wind speed (WS). In the changing climate scenario, all the cardinal weather parameters are altered and these parameters influence the production performance of livestock. Hence to call THI as an appropriate quantification of stress response in sheep, all the cardinal weather parameters must be taken into account. This warrants the development of much more appropriate indices which can take into account all the cardinal weather parameters. Apart from temperature and humidity, solar radiation and wind speed are also equally important weather parameters which can influence significantly the stress response in animals. Hence, further research efforts are needed in this line.

14.4 Advanced Indices to Quantify Stress Response in Livestock

Research efforts pertaining to developing a weather index incorporating all four cardinal weather parameters are very scanty. However, the few available reports clearly suggest the advantage of these efforts over the THI. Various adjustments to the THI have been proposed to overcome the shortcomings related to the lack of inclusion of WS and SR in the equation. To overcome these drawbacks of traditional THI, Buffington et al. (1981) used black-globe temperature (BGT) instead of dry-bulb temperature in their equation. Applications of the black-globe temperature-humidity index (BGTHI) to dairy cows suggested that values of 70 or below had little impact, while values of 75 or higher markedly reduced feed intake. On the basis of the impact on panting score in feedlot cattle, THI equation was redefined by Mader and Davis (2002) and Eigenberg et al. (2005) as follows:

$$THI_{adj} = 4.51 + THI \quad 1.992\,WS + 0.0068\,SR$$

where

WS = Wind speed, m/s
SR = Solar radiation, W/m^2

Recently, Gaughan et al. (2008) developed a heat load index (HLI) based on the behavioral responses and changes in dry matter intake of feedlot cattle summer season (Gaughan et al. 2008). The HLI is based on RH (%), WS (m/s), and black-globe temperature (BGT, °C). In case the BGT cannot be measured, it can be computed directly from the air temperature and solar radiation. The HLI consists of two parts based on a black-globe temperature threshold of 25 °C:

$$HLI_{BGT<25} = 10.66 + 0.28\ RH + 1.3\ BGT \quad WS$$

$$HLI_{BGT>25} = 8.62 + 0.38\ RH + 1.55\ BGT \quad 0.5\ WS + e^{(2.4 \quad WS)}$$

where

e is the base of the natural logarithm.

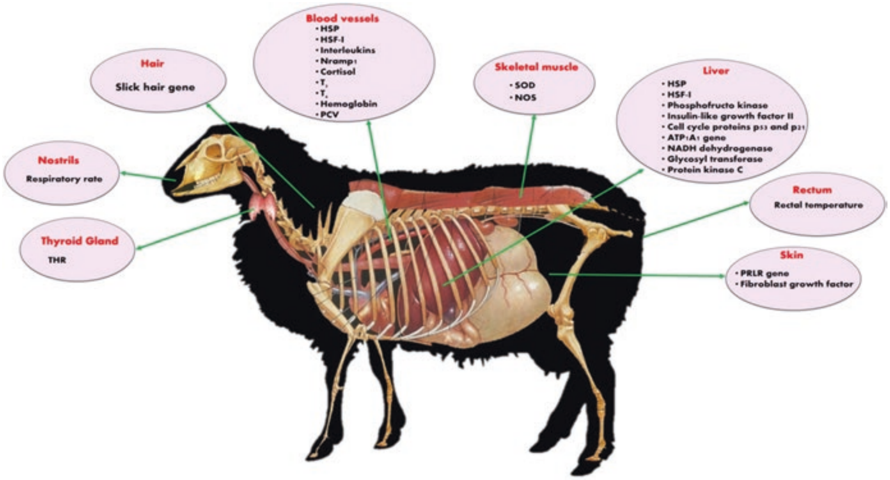
The thresholds are used to calculate the accumulated heat load (AHL) to which the animals are exposed. The AHL is based on the THI-hours concept of Hahn and Mader (1997). When an animal is exposed to an HLI above its threshold, then its core body temperature increases. The longer the duration of exposure to an HLI above the threshold, the greater is the stress and the AHL. The AHL also accounts for any potential recovery during nighttime cooling. It gives an indication of the total heat load on the animal, and is a better indicator of heat stress than a spot measure of HLI. This HLI is also applicable for assessing heat stress in sheep.

Critical levels of comfort indexes need to be established for all species of domestic animals, including sheep. The estimation of critical values of TCI would allow the realization of a bioclimatic zoning for sheep production in Pernambuco, as demonstrated by Barbosa and Silva (1995). These critical values can be generalized to the region where the study was carried out, except for the specific microclimates of some sites that may be more advantageous or more adverse, although it is in a certain zone, as reported by Barbosa et al. (2001).

14.5 Physiological Indicators of Heat Stress in Sheep

During heat stress, the primary physiological responses are accelerated, of which the foremost affected are respiratory movements. The respiratory rate is a good indicator of heat stress, and the normal range of RR in sheep is between 25 and 30 breaths per minute at thermo-neutral condition (Sejian et al. 2010a; Indu et al. 2014). The increase in respiratory frequency above 40 breaths per minute, denoted as panting, facilitates the heat loss by exhaling water vapor in the breath (Wojtas et al. 2014). Hence, the respiration rate can be used for assessing the level of heat stress based on the scale proposed by Silanikove (2000) and McManus et al. (2015) as follows: fewer than 40 movements per minute indicates absence of stress; 40–60 movements per minute indicates low stress; 61–80 movement per minute indicates medium to high stress; 81–120 movements per minute indicates high stress; 121–192 movements per minute indicates very high stress, and more than 193 movements per minute indicates severe stress. Therefore, heat stress in animals can be determined by respiratory frequency, and this can serve as an easy method as it does not involve sophisticated tools (Wojtas et al. 2014). Further, rectal temperature may also serve as an appropriate indicator of heat stress in sheep (Sejian et al. 2016). Generally, the increased body temperature due to prolonged exposure to summer stress will generally reflect in the increased rectal temperature, and it has been established that the rectal temperature can serve as a representative of body temperature in several livestock species. Hence, the increased rectal temperature can reflect the stress level in sheep (Indu et al. 2015). Figure 14.1 describes the various indicators for heat stress in sheep.

There are several blood parameters which can help to reflect the stress level in sheep. These variables are hemoglobin (Hb), packed cell volume (PCV), cortisol, thyroxin, and triiodothyronine (Sejian et al. 2013a, b). The Hb and PCV have been



THR- Thyroid hormone receptor, HSP- Heat shock protein, HSF-1- Heat shock factor 1, Nramp 1- Natural resistance associated macrophage protein 1, PCV- Packed cell volume, SOD- Superoxide dismutase, NOS- Nitric Oxide Synthase, T_3- Triiodothyronine, T_4- Thyroxin, PRLR gene- Prolactin receptor gene

Fig. 14.1 Different indicators for heat stress in sheep

established to have a strong positive correlation for heat tolerance in Brazilian sheep (McManus et al. 2009). During severe dehydration, both Hb and PCV increased in heat-stressed sheep. The increased cortisol level was correlated with the stress level in domestic ruminants, including sheep. Further, environmental temperature was established as one of the major regulators of thyroid gland activity (Rasooli et al. 2004; Sejian et al. 2010b). Heat stress suppresses the thyroid gland activity, resulting in lowering of thyroid hormone levels (Rasooli et al. 2004; Saber et al. 2009; Sejian et al. 2014).

The advancement of molecular technologies, such as genomics and proteomics tools, is providing promising results to understand the hidden intricacies of the adaptation process of sheep to environmental stresses. These tools are providing valuable information about the various genes that are associated with thermo-tolerance in sheep, and this information may pave the way for identification of animals that are genetically superior for coping with stress in near future. Such identified genes can be the ideal indicators for quantifying the heat-stress response in sheep. These advanced tools enable us to improve the accuracy and the efficiency of selection for heat tolerance.

14.6 Conclusion

Abnormal increase in cardinal weather parameters due to climate change causes severe heat stress in sheep particularly during summer. Apart from temperature and humidity, other cardinal weather parameters like solar radiation and wind speed also influence the severity of heat stress in sheep. Modern weather indices account for the degree of heat stress in sheep more accurately compared to regular temperature-humidity indices. Further, physiological indicators like respiration rate, rectal temperature, Hb, PCV, cortisol, T_3, T_4, HSPs, and other thermo-tolerant genes may also be used in assessing the heat in sheep. Although sufficient efforts have been made toward assessing the heat stress severity in sheep, still further research efforts are needed to develop an agroecological-zone-specific index for the accurate quantification of heat stress in sheep.

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