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Review Article

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Temperature-Humidity Indices as Indicators to Heat Stress of Climatic Conditions with Relation to Production and Reproduction of Farm Animals

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Article Info

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Abstract

The changes in the environmental factors like ambient temperature, relative humidity, wind speed and solar radiation causes stresses in lactating cattle. Heat stress is a condition in which the animal body has problems dissipating excess heat. Results of inadequate heat dissipation range from general discomfort to symptoms of heat rash, heat syncope, heat cramps, heat exhaustion and heat stroke. Heat stress assessment methods were carried out using some equations presented temperature-humidity index (THI) or heat stress index (HSI) or using different heat index charts. Temperature Humidity Index is calculated based on the relationship between environmental temperature and relative humidity. The heat stress index is a simple combination of temperature and humidity and has been designed as a measure of animal comfort. Heat Index Chart is a chart used by dairy producers to estimate the severity of heat stress of a dairy cow. This chart utilizes ambient temperature and relative humidity, which are readily available to the dairy producer on a daily basis and indicate from slight to severe heat stress of dairy cattle from some equations

Keywords: THI; Climate change; Livestock comfort; Animal; Heat stress; Heat index chart

Introduction

Heat stress is influenced by air temperature, humidity, air movement, solar radiation, and precipitation [1]. However, temperature-humidity index (THI) is a single value depicting the integrated effects of air temperature and humidity associated with the level of heat stress. The THI incorporates the effects of both temperature and relative humidity and is commonly used to quantify the degree of heat stress on dairy cattle**.** This index has been developed as a weather safety index to control and decrease the heat stress-related losses [2]. THI is widely used in hot areas all over the world and is commonly used as a practical indicator for the degree of stress on dairy cattle caused by weather conditions because THI incorporates the effects of both ambient temperature and relative humidity in an index. THI used extensively to estimate the degree of heat stress in dairy and beef cattle and showed that various THI were predictive of milk yield in cows in the southeastern United States. THI is better predictors of body temperature in heat-stressed cows than other measurements of environmental conditions [3]. THI indices are often placed into classes to indicate the degree of heat stress and the terms used to describe these classes and the ranges of THI used to define each class are arbitrary [4] [5]. The THI as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals is the main objective this review article.

Assessment methods of heat stress of climatic conditions

Assessment of heat stress using temperature-humidity index (THI) equations

Heat stress is caused by a combination of environmental factors (temperature, relative humidity, solar radiation, air movement, and precipitation). Many indices combining these different environmental factors to measure the level of heat stress [6]. The majority of studies on heat stress in livestock have focused mainly on temperature and relative humidity because data on the amount of thermal radiation received by the animal, wind speed, and rainfall are not publicly available and temperature and humidity records can be usually obtained from a meteorological station located nearby. The temperature-humidity index (THI) is a simple combination of temperature and humidity and has been designed as a measure of animal comfort. THI is a parameter widely used to describe heat load on animals and was calculated using the equation: THI = 0.8DBT+ RH x (DBT-14.4) + 46.4 where, DBT is dry bulb temperature ($^{\circ}$C) and RH is relative humidity in decimal form. A THI of 74 or less is considered normal, 75 to 78 is alert status, 79 to 83 is danger status, and a THI equal to or above 84 is an emergency [7]. THI is a parameter widely used to describe heat load on animals and is a good indicator of stressful thermal climatic conditions. The THI is arrived at from a combination of wet and dry bulb air temperature in Fahrenhiet for a particular day and expressed in a formula as follows: THI = 0.72 (W°C + D°C) + 40.6 where W°C = wet bulb and D°C = dry bulb.

Temperature-humidity index values of 70 or less are considered comfortable, 75-78 stressful, and values greater than 78 cause extreme distress and animals are unable to maintain thermoregulatory mechanisms or normal temperature [8].

THI has been used for estimation of the level of heat stress. THI offers a method of combining two of the more important and easily measured weather factors into a possible measure to compare temperature and humidity data and animal response at different locations [9]. THI is still the simplest and most practical index for measuring environmental warmth which causes heat stress in cattle. The same author added that it is also practical, easy to determine and relatively trust worthy to use body temperature and respiratory rate as parameters to determine heat stress in cattle, i.e. these physiological parameters must always be used together with THI values to determine and evaluate heat stress in cattle [10]. The author mentioned that the THI has been used for several years in USA as a guide for the use of precautionary measures. Recommendations for action are based on forecast THI values categorized as follows: THI =<70: normal, no heat stress precautions needed. THI = 70- 80: alert, be prepared to take extra precautions and do not leave a vehicle loaded with animals standing in the sun. THI =79-83: danger, additional precautions should be taken to protect animals and use of sprinklers and fans in loading areas. THI =>84: emergency; minimize any animal handling, take precautions listed for danger and complete operations in early morning hours. Wet down transport vehicle and bedding before loading and at any stop made during shipment. West [11] shows ambient temperature and relative humidity combinations that produce mild heat stress (THI 72 to 79), moderate heat stress (THI 79 to 89) and severe heat stress (THI > 89). Livestock and Poultry Heat Stress Indices, Clemson University [12] developed indices including the effects of both ambient temperature and relative humidity as follows: In big animals (cattle, buffaloes, sheep and goats) when the temperature is in Fahrenheit. Author proposed the equation of THI as follows: THI=db°F–[(0.55 -0.55 x RH) (db°F–58)] where db°F = dry bulb temperature (in Fahrenheit) and RH = relative humidity percentage (RH%)/100.

THI values obtained are classified as followed: Less than 72= absence of heat stress, 72 to <74= Moderate heat stress, 74 to <78= severe heat stress and 78 and more = very severe heat stress. In small animals (rabbits and poultry), the same equation mentioned will be used and THI is classified to : <82 = absence of heat stress, 82 to <84 = moderate heat stress, 84 to <86 = severe heat stress and 86 and more = very severe heat stress. The equation applied when the ambient temperature is expressed in Celsius as followed by [13] as followed: THI = db °C- [(0.31-0.31RH) (db°C-14.4)] where db °C= dry bulb temperature in Celsius and RH= relative humidity percentage (RH)/100. In larger animas, the values obtained are then classified as follows: <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=very severe heat stress. In small animals, the values obtained are classified as follows: <27.8= absence of heat stress, 27.8 to <28.9= moderate heat stress, 28.9 to <30.0= severe heat stress and 30.0 and more = very severe heat stress.

THI was also suggested by [4] as following, THI= (1.8*AT+32)−[(0.55−0.0055*RH)× (1.8* AT −26)], where AT = air temperature (◦C), and RH = relative humidity (%) and reported that THI thresholds for heat stress in cattle as following: comfort (THI < 68), mild discomfort (68 < THI < 72), discomfort (72 < THI < 75), alert (75 < THI < 79), danger (79 < THI<84) and emergency (THI> 84). Comparison of the values of THI used for larger animas with that of small animals, shows that small animals tolerate higher climatic stress than do large mammals. This may be due to the small animals higher body temperature. Preferably, average daily THI should be the average of THI calculated at one or two hour intervals.

An average THI calculated from maximum and minimum ambient temperature with respective THI will also give an estimate of the average THI of the day that can serve well for productive purposes.

The THI is calculated by combining temperature and humidity into one value with the following expression according to [15] :THI=(9/5 temperature °C+32) – (11/2- 11/2 ×humidity) ×(9/5 temperature°C-26). Formulas that associated mild, moderate, andsevere heat stress in dairy cattle as a function of THI was developed by [2]. According to his formulas, heat stress in dairy cattle starts at a THI of 72, which corresponds to 22°C at100% humidity, 25°C at 50% humidity, or 28°C at 20% humidity. There are several THI to estimate the degree of thermal stress experienced by dairy cows as following: THI according to the formula of the National Research Council [16]: THI = (1.8 × T + 32) (0.55- 0.0055 × RH) × (1.8 × T- 26) where T = air temperature in degrees Celsius and RH= relative humidity in percent. Numerous studies established THI thresholds for heat stress in cattle: comfort (THI < 68), mild discomfort (68 < THI < 72), discomfort (72 < THI < 75), alert (75 < THI < 79), danger (79 < THI < 84), and emergency (THI > 84). Other THI suggested by [17] as follows, THI = (1.8 × T + 32) (0.55- 0.0055 × RH) × (1.8 × T- 26) and assigned the THI categories to <70 normal; 70 to 78 alert; 79 to 82 danger; and >82 emergency according to the Livestock Weather Safety Index. THI accounts for the combined effects of environmental temperature and relative humidity and is a useful and easy way to assess the risk of heat stress [18]. THI is calculated using this equation: THI = (Dry bulb temperature °C) + (0.36 x dew point temperature °C) + 41.2. As you can see in this chart, a THI of 78 occurs at: 31°C and 40 % relative humidity; or 27°C and 80% relative humidity.

When the THI exceeds 72, cows are likely to begin experiencing heat stress and their in calf rates will be affected. When the THI exceeds 78, cows milk production is seriously affected. When the THI rises above 82, very significant losses in milk production are likely, cows show signs of severe stress and may ultimately die (Figure 1).

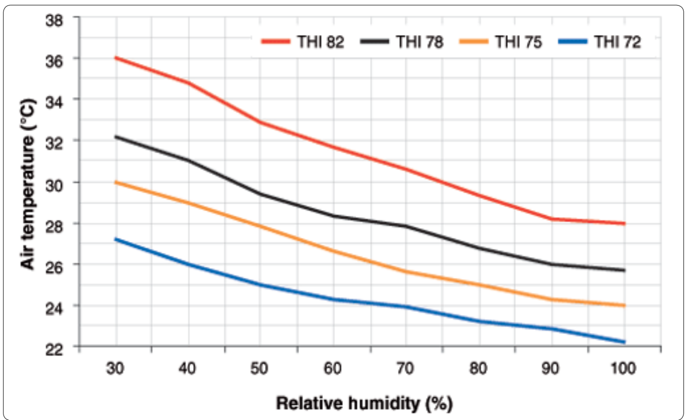


Figure 1. Calculated THI from air temperature and relative humidity [18]

Approximate THI values of 80 and 70 were the maximum and minimum THI, respectively, above which the number of deaths in dairy farms starts to increase [19]. Maximum and minimum THI values of 87 and 77 were the upper critical THI above which the risk of death for dairy cows becomes a maximum.

A number of important points should be made about the THI: A THI of 72 may under estimate heat load in high yielding Holstein Friesian cows, increasing milk yield increases sensitivity cows to heat stress. Recent research shows that increasing milk production from 35 to 45 liters /day reduces the threshold temperature for heat stress by 5°C. THI does not account for solar radiation or air movement, those two factors along with air temperature and relative humidity determine the heat gained and lost between the cow and the environment. THI does not enable you to measure the accumulation of heat load over time, e.g. after several days. Despite these limitations, THI is still a useful and easy way to assess and predict the risk of heat stress; however, it is wise to be conservative. If you have a herd of high producing Holstein Friesian, it is better to overestimate the risks of heat stress using a lower THI than get caught out.

From another point of view, various temperatures and humidity values that yield a THI of 72 are illustrated by [20] and the point at which signs of heat stress begin to develop in the dairy cow. For example, a temperature of 80° F, with a relative low humidity value of 35%, will yield a THI of 72 and create conditions that could impact the health and performance of dairy cow (Table 1).

Table 1. Temperature and humidity combinations yielding a THI of 72 [20]

Temperature, °F	Relative Humidity %	THI
72	100	**72**
74	80	**72**
76	60	**72**
80	35	**72**
84	15	**72**

Assessment of heat stress using heat stress index (HSI) equations

The Heat Stress Index (HSI) is a relative index that evaluates how animals respond to variable meteorological conditions based on location and time of season [21]. The HSI is a relative index designed to evaluate daily meteorological stress or daily relative stress values on animals for locations based on deviations from average conditions during the months of May through September. The index is based on a combination of factors, including apparent temperature, cloud cover, cooling degree hours, and the number of consecutive days of extreme heat. The HSI is designed to be operational from mid May through late September.

The index can vary from 0 to 10, with 10 representing the most stressful conditions, 0 the coldest conditions, and 5 normal conditions for that time of year. A value of 9.9 for a given day indicates that 99 percent of days at the particular location for the particular time of year would be expected to have less meteorologically stressful conditions. The HSI is the only existing index that considers many of these factors and along with its relative nature, the index is a unique and accurate way to determine the meteorological stress impacts upon humans and animals. The daily HSI value ranges from 0 to 10 according to [21] as following: 0.0 - 3.9 none, 4.0 - 6.9 low, 7.0 - 8.9 moderate, 9.0 - 9.5 high and 9.6 - 10.0 extreme. The daily HSI value is based on a scale from 0 to 10. An index value ranging from 4 to 6 indicates that the conditions at a given location are typical for that time of year. Therefore, when the index values are between 0 and 3, conditions are cooler than average and added stress due to heat will not be a factor on those days.

However, index values ranging from 7 to 10 are indicative of above average heat stress conditions. There may be some discomfort associated with heat stress when the index is between 7 and 9. A HSI above 9.0 indicates severe stress, and people or animal need to take precautions because they are not acclimated to such extreme conditions. However, the HSI thus adjusts from place to place; for example, the HSI accounts for the fact that a sunny day with an apparent temperature of 95°F with clears skies in June would be significantly more stressful in Philadelphia (HSI above 9) than in Phoenix (HSI below 5), where it is much more common during the summer months. In addition, a temperature of 90°F in Philadelphia in July would create little problem, but similar temperatures in late April would induce stressful conditions. Similarly, the same type of weather becomes less stressful as summer progresses, with the HSI in Philadelphia under similar conditions in mid July.

The effective temperature from ambient temperature (dry bulb temperature, DBT) and radiation (black globe temperature GBT) was calculated by [22] by multiple regression analysis using respiration rate and body temperature as the dependent response variable as following: ET= 0.24 DBT + 0.76 BGT**.** This equation suggests that long wave and short wave (solar radiation) as measured by black globe temperature contributes substantially more to the heat load than doe's ambient temperature.

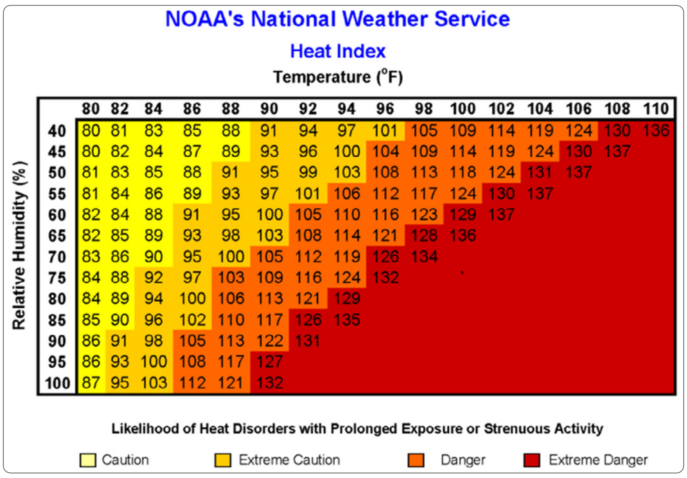
Assessment of heat stress using heat index charts

A chart to be used by dairy producers to estimate the severity of heat stress of a dairy cow was developed by [2]. This chart utilizes ambient temperature and relative humidity, which are readily available to the dairy producer on a daily basis and indicate from slight to severe heat stress of dairy cattle as mild heat stress (THI 72 to 78), moderate heat stress (THI 79 to 89) and severe heat stress (THI > 89)

T °F	Relative humidity																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
75														72	72	73	73	74	74	75	75
80							72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
85			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
95	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
100	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	
105	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97						
110	81	83	84	86	87	89	90	91	93	94	96	97					Mild Stress				
115	84	85	87	88	90	91	93	95	96	97							Medium Stress				
120	88	88	89	91	93	94	96	98									Severe Stress				

Figure 2. Temperature Humidity Index (THI) for dairy cows [2]

A chart was developed by [21] to be used by dairy producers to estimate the severity of heat stress of a dairy cow (Figures 3).



RH (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Figure 3. Heat index chart [21]

Relation of heat stress (THI) with production of farm animals

Increasing population, which is estimated to reach 9.6 billion by 2050, the global demand for livestock products is projected to increase by 70% [23]. Over 50% of the cattle population is located in the tropics and it has been appraised that heat stress causes severe economic loss in approximately 60% of the dairy farms around the world [24]. Cattle can withstand low temperatures to -37°C but temperatures over 23°C can cause stress when combined with high humidity, low air movement or direct sun. Animal has several mechanisms to help dissipate body heat including conduction, where the cow conducts heat to a cooler surface, convection, where thermal currents leave the cow's body, radiation, where the cow radiates heat to a cooler environment and evaporation, where moisture is evaporated from the surface of her body (sweating) and from her lungs (panting) [25].

The animal body protects itself by dissipating excess heat to the environment through mechanisms that include vasodilatation and sweating. When the body's core temperature exceeds 98.6 degrees Fahrenheit, vasodilatation begins as the heart increases blood flow to microscopic vessels in the upper layers of skin and consequently excess heat is then transferred to the cooler exterior environment. If increasing the blood circulation to the skin cannot sufficiently cool the body or if the surrounding air is warmer than the skin, then the brain signals sweat glands to release sweat to the skin. The sweat then evaporates, carrying additional heat from the body as it undergoes the phase transition from liquid to vapor. High ambient humidity decreases the rate of sweat evaporation and consequently the body's capacity to dissipate heat through this mechanism [26]. The severity of heat stress issues on cows will increase as global warming progresses. Climate change is even beginning to cause unease associated with the increase of global greenhouse gases and the most important impacts of climate change will occur precisely among producers with a subsistence economy in tropical regions of developing countries [27] [28].

The potential effect of climate change on cattle has been linked to the economic viability of the various animal production systems, since the increase of ambient temperature during summer periods is associated with the decrease of voluntary intake of food, causing reductions in weight in feedlot cattle and a drop in milk production in dairy cattle [29]. Milk production is lower during heat stress compared to thermoneutral periods was found by [1]. During heat stress, the cool period of hours per day with temperature less than 21 degrees C provides a margin of safety to reduce the effects of heat stress on decreased milk production. Using minimum, mean and maximum ambient temperatures, the upper critical temperatures for milk production are 21, 27 and 32 degrees C, respectively. Using the temperature-humidity index as the thermal environment indicator, the critical values for minimum, mean and maximum THI are 64, 72 and 76, respectively.

Heat stress has adverse effects on production of dairy cattle [30] [31] [32] [33] [34].

In addition, livestock with health problems and the most productive animals (e.g., highest growth rate or milk production) are at greatest risk of heat stress [35]. Stress starts to occur when the temperature humidity index is 68°F or above and becomes serious above 79/80°F. The negative effect of heat stress on farm animal include: Increased body temperature (>102.6F), the normal body temperature of dairy cow is 101.5 F, increased panting >80 breaths per minute (35-45 normal), reduced activity, water intake will increase by 30% or more during heat stress, reduced feed intake (>10-15% reduction) to produce less metabolic heat and finally reduced Milk Yield (10-20% or more) [11].

Heat stress will reduce milk production in dairy cows: a 10% drop in yield at 27-32°C (80-90°F) and 50-90% humidity; and more than 25% drop at 32-38°C (90-100°F) with 50-90% humidity and the effects is more pronounced in higher producing cows [36]. Heat stress also lowers natural immunity making animals more vulnerable to disease in the following days and weeks, Reduced feed intake (which is a natural response to reducing metabolic heat) and rapid shallow breathing; open mouth breathing with panting at higher temperatures. Respiration rates increase with increasing temperatures from 14 to 34°C (57-93°F). If more than 20% of cows have respiratory rates exceeding 100 breaths per minute, action is needed to reduce stress. Start of sweating and increased saliva production. Increased water intake e.g. cows 10 gal/day at 20°C (68°F); 32 gal at 35°C (95°F) and more for high producing cows and requirements for beef cattle increase 150% between 21-32°C (70-90°F) [37] [38].

A THI account is a useful and easy way to assess the risk of heat stress. Generally, mild heat stress is considered to begin at a THI of 72 for cattle with stress increasing to moderate levels at 79 and severe levels at 89 [39]. Same author suggested THI equation as $THI = T_{db} + 0.36 \times T_{dp} + 41.2$ where, DBT is dry bulb temperature (°C) and RH is relative humidity in decimal form. Heat stress in dairy cows occurs when the THI index is higher than 72 [40] and milk yield and feed intake start to decline [41]. In Turkey [42] found that THI values at 14.00 pm in January, February, March

April, November and December were <72 whereas THI values at 14.00 pm obtained in June, July, August and September were >72. Milk production and feed intake begin to decline when THI reaches 72 and continue to decline sharply at a THI value of 76 or greater and concluded that milk yield decreases of 10-40% have been reported for Holstein cows during the summer as compared to the winter. It was also suggested that as the THI values increased from 68-78, dry matter intake decreased by 1.73 kg and milk production by 4 kg under Mediterranean climatic conditions [43]. Heat stress could be reason of the significant increase of production cost in the dairy industry. The effect of THI values on the daily production of dairy cattle in Croatia was evaluated by [44] and found that heat stress conditions indicated with mean daily values of THI>72 were determined during spring and summer season and absence of heat stress conditions during autumn and winter season. The same authors found that a highly significant decrease of daily milk yield a swell as of daily fat and protein content due to enhanced THI in all cows regardless the parity number. Heat stress induces increase of body temperature and when the body temperature is significantly elevated, feed intake, metabolism, body weight and milk yields decrease to help alleviate the heat imbalance and the permanent drop in the lactation is proportional to the length of the heat stress [45] [46].

Milk production is affected by heat stress when THI values are higher than 72, which corresponds to 22°C at 100 % humidity, 25 °C at 50 % humidity, or 28 °C at 20 % humidity. The amount of milk yield decrease during the summer period in comparison with the winter period for Holstein cows about 10 % to 40 % [47]. Under Mediterranean climatic conditions, milk yield drops by 0.41 kg per cow per day for each point increase in the value of THI above 69 [43]. Moreover, heat stress is associated with changes in milk composition; milk Somatic Cell Counts and mastitis frequencies [47] [48].

A significant negative correlation between THI and DMI was determined for cows in the south-eastern U.S. [49]. Feedlot cattle performance and mortality rate are related to the THI [50]. Milk yield declined by 0.2 kg per unit increase in THI when THI exceeded 72 [51]. The daily THI was negatively correlated to milk yield ($r = -0.76$) and feed intake ($r = -0.24$) [43]. Same authors also determined that milk yield decreased by 0.41kg per cow per day for each point increase in the THI>69. During hot weather, milk yield for Holsteins declined 0.88 kg per THI unit increase for the 2-d lag of mean THI, while DMI declined 0.85 kg for each degree (°C) increase in the mean air temperature [31].

The authors presume that the delayed impact of climatic variables on production could be related to alter feed intake, delay between intake and utilization of consumed nutrients, or changes in the endocrine status of the cow. A mean daily THI average above 72 reduces milk yield, increasing THI in a range of 71 to 81 reduces the milk yield and intake of total digestible nutrient of protein for dairy cows [11].

In the research of [41] in Poland, the increase in THI value led to the decrease in daily milk yield from 0.18 to 0.36 kg per THI unit. The study of [52] showed that the daily milk yield decreased around 2.2 kg/day when the THI values increased from 65 to 73. However, in the warning to critical range of THI of 70-72, performance of dairy cattle is inhibited and cooling becomes desirable [53]. At THI of 72-78, milk production is seriously affected. In the dangerous category at THI of 78-82, performance is severely affected and cooling of the animals becomes essential [53]. Milk yield reductions of 10 to 40% have been reported for Holstein cows during summer as compared to winter [47]. In Germany, [48] indicated a milk yield decline between 0.08 and 0.26 kg for every increase in THI unit, depending on the region. When the THI value increased from 68 to 78, milk production was reduced by 21% and dry matter intake was reduced by 9.6% [43].

The relationship of THI with milk production, feed intake and feed efficiency of Holstein-Frisian cows in different seasons of the year [54]. The authors found that the heat stress reduced daily milk yield, decreased forage intake and increased the efficiency of conversion of feed to milk (from 1.6 to 1.59 kg milk/kg milk) as the THI value was 79 in the summer period The regression equation obtained indicates that daily milk yield drops, daily forage intake drops per cow per day and food efficiency increases per kg food when the value of THI increases. The critical periods of year for dairy cows using the THI was during time from mid May and the end of October and concluded that Farmers should take measurements when the THI is above 72 during the summer months to prevent the losses in milk production and changes in milk composition, milk somatic cell counts and mastitis frequencies [42].

Therefore, it is likely that the losses in the milk production and changes in milk composition, milk somatic cell counts and mastitis frequencies are inevitable during the mid may, June, July, August and September due to increase in THI. Therefore, farmers should take measurements when the THI is above 72 during the summer months to prevent the losses in milk production and changes in milk composition, milk somatic cell counts and mastitis frequencies.

The THI has been used as a heat stress as the heat stress effects on milk production and pregnancy rate in cows [55] and also used to determine different groups of cows according to animal responses to heat stress and associate them with their bio-production [56]. According to [19], a high THI is a risk factor for the survival of cattle, especially for neonates and mature cows. Heat stress in the dairy cow has been defined as the point at which rectal temperature exceeds 39.2°C (102.6°F) with breaths exceeding 60/minute. Lactating dairy cows experience heat stress when THI rises above 72, with severe heat stress occurring when THI exceeds 88 and some factors such as level of milk production, air movement, sun exposure and duration of these conditions may impact THI values, such that animals may experience more severe heat stress at lower temperature and relative humidity values [57].

Moderate signs of heat stress may occur when the temperature is between 26.7 to 32.2°C with humidity ranging from 50 to 90%. These signs include rapid shallow breathing, profuse sweating and an approximately 10% decrease in milk production and feed intake. As temperature rises to 32.2 to 37.8°C and humidity remains as 50 to 90 %, the cow shows severe depression in milk yield, usually greater than 25%, in feed intake. As body temperature elevates, cows begin exhibiting more significant signs of heat stress, such as open mouth breathing with panting and tongue hanging out THI value is greater than 90 results in severe signs of heat stress in the high producing cows and moderate signs in lower producing cows. In severe cases, cows may die from extreme heat, especially when complicated with other stresses such as illness or calving [58].

The Livestock Conservation Institute evaluated the biological responses to varying THI values and categorized them into mild, moderate and severe stress levels for cattle. The sensitivity of cattle to thermal stress is increased when milk production is increased thus reducing the threshold temperature when milk loss begins to occur. For example when milk production is increased from 35 to 45 kg/d, the threshold temperature for heat stress is reduced by 5°C [59]. This is due to the fact that metabolic heat output is increased as production levels of the animal increase. When evaluating test day yields results showed a decrease of 0.2 kg per unit of THI increase above 72 when THI was composed of maximum temperature and minimum humidity [60].

THI and the impact of heat stress on dairy production are shown below in Figure (4).

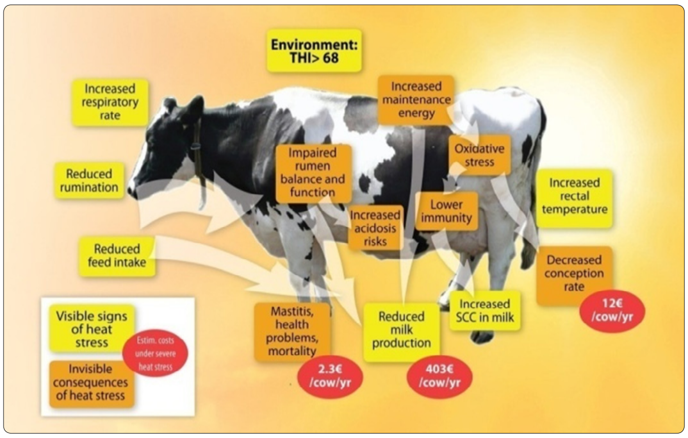


Figure 4. THI and the impact of heat stress on dairy production [57].

In order to avoid economic production losses, dairy producers need to be informed of the level of cooling to be implemented immediately when heat stress occurs. Research has indicated that the effects of a given temperature on milk production are maximal between 24 and 48 hours following heat stress [61]. It has also been reported that ambient weather conditions two days prior to milk yield measurement had the greatest correlation to decreases in milk production and dry matter intake [31]. The heat stress adversely affects both the quantity and quality of milk during first 60 days of lactation and high yielding breeds are more susceptible than the low yielding breeds [62].

Cattles that are affected by heat stress show reduction in feed intake and milk yield and shift metabolism, which in turn reduces their milk production efficiency. Heat stressed cattle may try to reduce the body heat through thermoregulatory mechanisms which in turn affect feed conversion efficiency and lead to decreased milk production [63].

A significant depression in milk production and reproduction occurs at an average daily THI of above 76 and some depression may also occur between 68 and 76 in animals milking at high levels or acclimated to a lower THI [9]. Heat stress lead to reduced dry matter intake, productivity, increased rectal temperature, respiration rate and panting to maintain body temperature. Decreased dry matter intake and alterations in physiological activities can adversely affect milk production. Elevated core body temperature will reduce milk output, percentages of milk protein, fat, solids and lactose [61]. Per unit increase in THI beyond 72, 0.2 kg reduction in milk yield was recorded in dairy cows [31].

For each point increase in the value of THI beyond 69, milk production drops by 0.41 kg per cow per day in the Mediterranean climatic regime [44]. Further, for every 1°C in air temperature above thermal neutral zone cause 0.85 kg reduction in feed intake, which causes ~36% decline in milk production [43].

High yielding cows are more susceptible to heat stress than low yielding cows, as feed intake and milk production increases thermoneutral zone shifts to lower temperature. Hence, heat stressed cow activates its physical and biochemical process to counter stress and to maintain thermal equilibrium. Regulations made by cow include heat dissipation to the environment and reduced production of metabolic heat [30]. In non-cooled farms heat stress can cause 40-50% decline in milk yield while in cooled farms it can go up to 10-15% [31]. Heat stress can makes changes in the feeding pattern, rumen function and udder health ultimately leads to decreased milk production.

Figure (5) describes the impact of heat stress on milk production in dairy cattle.

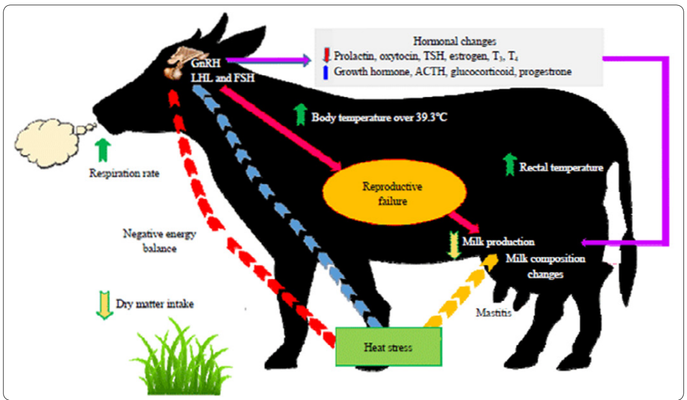


Figure 5. Pictorial representation of heat stress impacting milk production in dairy cattle [62].

Most livestock species perform well in the temperature range of 10-30°C, beyond this limit cattle tend to reduce milk yield and feed intake [64]. Temperature above 35°C may activate thermal stress in animals directly reducing the feed intake of animal thereby creating a negative energy balance which ultimately affects synthesis of milk [65]. Heat stress can cause yield loss up to 600 or 900 kg milk per cow per lactation [31]. Heat stress can alter metabolic activity and reduce feed intake which may ultimately culminate in reducing the milk yield [66].

It has been established that only 35% of the reduction in milk yield is due to decreased feed intake remaining 65% reduction is due to direct physiological effect of heat stress [67]. Decreased nutrient absorption, alteration in rumen function and hormonal imbalance are other factors which contribute to reduced milk production during heat stress [68]. Holstein lactating cows exposed to short term heat stress showed significant reduction in milk production of 1.7±0.32 kg. However, during recovery phase, milk decline was recorded to be much lesser of about 1.2±0.32 kg [69]. In an experiment on Holstein cows to assess the decrease in milk yields due to heat stress in tropical conditions, a yield loss of 0.23 kg day^{-1} was observed for unit rise of THI above 66 [70]. In southern Brazil, [71] observed 21% milk yield loss in commercial heard of Holstein cows due to heat stress. Similarly in an experiment conducted in Missouri on Holstein cows showed 0.56 milk yield decline for the temperature range 24-35°C [72]. Milk production and feed intake begin to decline when THI reaches 72 and continue to decline sharply at a THI value of 76 or greater and Milk yield decreases of 10 to 40% have been reported for Holstein cows during the summer as compared to the winter [73]. Effects of THI in spring period (68 ± 3.75) and 78 ± 3.23 in summer period on milk production, milk composition and dry matter intake (DMI) in lactating Friesian-Holstein cows under the Mediterranean climate were studied by [43]. Authors reported that daily THI was negatively correlated to milk yield ($r = -0.76$) and feed intake ($r = -0.24$) and when the THI value increased from 68 to 78, milk production decreased by 21% and DMI by 9.6%. The negative slope of the regression line indicates that milk production decreases as THI increases [43]. This is best expressed by the following equation: Milk production (kg/cow/day) = (47.722 – 0.4129 × THI (R^2=0.760).

This regression indicates that, in general, for each point increase in the THI value above 69, there was a decrease in milk yield of 0.41 kg per cow per day. The value of this relationship for predictive purposes is relatively high, as depicted by an R^2 value of 0.760. As the THI values increases from 68 to 78, DMI decreased by 1.73 kg and milk production by 4 kg. The regression equation indicates that milk yield drops by 0.41 kg per cow per day for each point increase in the value of THI above 69. Milk yield decreased by 0.41 kg per cow per day for each point increase in the THI values above 69. Milk fat (3.24 vs. 3.58%) and milk protein (2.88 vs. 2.96%) were lower for the summer group. THI was positively correlated to respiration rate ($r = 0.890$), heart rate ($r= 0.880$), rectal temperature ($r = 0.850$) and cortisol (0.310), and negatively with free thyroxin (–0.430) [43]. Same authors concluded that as the THI values increased from 68 to 78, rectal temperature increased by 0.5°C, heart rate by 6 beats, and respiration rate by 5 inspirations per min. The average concentration of cortisol increased from 21.75 to 23.5 nmol.L^{-1} ($P> 0.05$), while that of free thyroxin decreased from 15.5 to 14.5 pmol·L^{-1}($P>0.05$). The most appropriate THI to measure losses in milk production due to heat stress in the semiarid climate of Arizona and the humid climate of Georgia and used different THI with different weightings of dry bulb temperature and humidity was identified by [3] and concluded that indices with higher weights on humidity were best in the humid climate, whereas indices with larger weights on temperature were the best indicators of heat stress in the semiarid climate and humidity was the limiting factor of heat stress in humid climates, whereas dry bulb temperature was the limiting factor of heat stress in dry climates.

The reason for reduced milk production is the negative energy balance as the animal try to maintain homeostasis to avoid hyperthermia. Decrease in milk yield gets further intensified, due to reduced feed intake by the cattle to counter the heat stress [74]. Further, heat stress causes decline in the level of nonesterified fatty acid and hepatic glucose leading to reduced supply of glucose to the mammary glands which in turn negatively affect lactose synthesis leading to reduced milk yield in Holstein cows [75].

The decreased milk production during heat stress can be due to dwindled nutrient uptake by portal drained viscera of the cattle and decreased nutrient uptake [44]. It has been observed that milk yield starts declining by 0.2 kg for every unit rise in THI value above 72 [76]. There are further reports establishing the negative correlation between THI values and milk yield [65]. Reduced milk yield and milk protein fraction was also recorded in cattle exposed to heat stress [77]. For every 1°C in temperature above 21-27°C production decline of approximately 36% was recorded in dairy cattle [67]. Heat stress during dry period also affects mammary gland development before parturition which ultimately leads to reduced milk yield in subsequent lactation [78]. High yielding cows are most affected due to heat stress than low yielding cows. High yielding cows have to consume more feed to meet their dietary requirements; reduced feed intake during heat stress may curb the cow to meet its dietary requirement for milk synthesis. When THI exceeds above 65-73, a milk yield reduction of 5 pounds per cow per day is observed, for a herd of 150 cow's loss can go up to $3375 per year [79].

Correlations between THI values and increase in each of rectal temperature and respiration rate and decrease in milk yield in heat stressed cattle were studied by [80]. As THI values increased, the rectal temperatures of cows increased ($P<0.0001, r^2=0.2691$); $y=0.0587x+34.888$, x=THI, y=rectal temperature.

As respiration rates increased, the respiration rate of cows increased ($P<0.001, r^2=0.5658$); $y=0.028x+37.438$, x=respiration rate, y=rectal temperature. Respiration rates increased by 2.0 breaths per minute per increase in THI unit ($P < 0.001$; $r^2= 0.4343$). As rectal temperatures of cows increased, evaporative heat loss at the skin increased ($y = 0.0052x + 38.581$, x= evaporative heat loss, y= rectal temperature. Evaporative heat loss at the skin (grams/meter squared/hour) was also found to increase as rectal temperatures were increased ($P< 0.001$; $r^2= 0.0556$) [80].

These increases in evaporative heat loss indicate that the cow is at or above its upper critical temperature. As rectal temperatures of cows increased, milk yield decreased ($P <0.001$, $r^2 = 0.0494$; $y = -2.0746x + 112.32$, x= Rectal Temperature, y=Milk yield (kg/day). Finally, as THI, rectal temperatures, respiration rate and evaporative heat loss increased while milk yields decreased linearly and this decrease was linear between THI values of 60 and 80 indicating that milk yield losses were occurring well below a THI threshold of 72 ($P<0.001$ $r^2 = 0.0137$; $y = -0.1313x + 40.666$; x= THI, y=Milk yield (kg/day) [80]. Besides having an effect on milk yield, heat stress could also alter the milk composition. In Mediterranean dairy sheep, a decrease of daily fat-plus-protein production by 8.6 g (4.4 %) per unit increase of the THI value registered at the day before the test day over the threshold of 23 was observed by [81]. Losses in fat plus protein yield, as a response to heat stress, which represent up to 1.9 and 3.1 % of annual fat plus protein yields of Payoya and Murciano-Granadina dairy goats, respectively [82]. Lactose and solids-not-fat percentages in dairy Baladi goats were significantly decreased at high THI in comparison with low and moderate THI [83]. Same authors found a significant positive correlations between THI values and total leucocyte count (r =0.250, p=0.012) and total antioxidant capacity (r =0.210, p=0.037) and a negatively correlated with serum glucose (r = .0.370, p= 0.013) and serum total protein (r=0.660, p=0.001).

Heat stress reduces milk yield of dairy animals; however, half of this decrease in milk yield is due to decreased DMI and the other half of milk production losses might be demonstrated by the increment in maintenance requirements [84], reduction in the secretion of growth hormone, and dropping blood influx to the udder, up-regulating the activity of apoptosis genes in the mammary tissues and down regulating the expression of milk protein genes [85].

The gross efficiency of conversion of feed to milk (kg FCM per kg DMI) was lower significantly for heat-stressed cows (0.82 vs. 0.99) [43]. Therefore, authors suggested that an adaptive mechanism must have occurred in the heat stressed cows, resulting in higher maintenance requirements and lower efficiency of energy use for milk production. Reduced efficiency of energy utilization for milk production by 30 to 50% has been reported for dairy cows in hotter environments [86]. The reduction in milk production during heat stress may be due to decreased nutrient intake and decreased nutrient uptake by the portal drained viscera of the cow. Blood flow shifted to peripheral tissues for cooling purposes may alter nutrient metabolism and contribute to lower milk yield during hot weather [44].

Different animal species have different sensitivities to ambient temperature and the amount of moisture in the air. Cattle can tolerate much higher temperatures at lower relative humidity than rabbits. This is due to the fact that cattle can dissipate excessive heat more effectively by sweating, whereas rabbits do not have sweat glands. However, during hot and humid weather the natural capability of cattle to dissipate heat load by sweating and panting is compromised, and heat stress occurs at these conditions in cattle much faster than in rabbits [25]. The water vapor content of the air is important because it has an impact on the rate of evaporative loss through skin and lungs. When the mean daily temperature falls outside of the animal's comfort zone, the amount of moisture in the air becomes a significant element in maintaining homeostasis of the animal. Relative humidity provides information about saturation of the air at a given temperature. Dew point temperature is the temperature to which the air must be cooled for saturation to occur; that is, the temperature at which RH is 100% [87]. The reduction in the profit of dairy farms subjected to heat stress (THI is extremely high) is not only a sequel of reduced milk production but also includes deteriorated milk quality, augmented healthcare costs, reproduction problems and even animal loss. The influence of three different levels of THI including low (less than 70), moderate (over 70 and up to 80), and high levels (over 80) on the milk composition and physiological, hematological, and biochemical traits in dairy Baladi goats was investigated by [83].

The authors found that rectal temperature and respiration rate in dairy Baladi goats were significantly greater (p = 0.016 and 0.002, respectively) at the higher THI than at low and moderate. Skin temperature of goats was higher (p= 0.001) at high THI in comparison with low and moderate THI by +2.75 and +1.67 °C, respectively. Dairy Baladi goats had decreased (p =0.031) daily milk yield in a rate of 27.3 and 19.3 % at high THI level, compared with low and moderate THI, respectively. Total leucocytes count, serum glucose, and total protein were significantly (p = 0.043, 0.001, and 0.001, respectively) reduced at high THI in comparison with low and moderate THI levels. [3] found that a dry bulb temperature of 29.7°C was associated with rectal temperature of 39°C, and a dry bulb temperature of 31.4°C was associated with rectal temperature of 39.5°C in lactating Holstein cows and concluded that dry bulb temperature is nearly as good a predictor of rectal temperatures of lactating Holsteins in a subtropical environment as THI. A dry bulb temperature (T_{db}) of 29.7°C was associated with rectal temperature of 39°C and a T_{db} of 31.4°C was associated with rectal temperature of 39.5°C and concluded that T_{db} is nearly as good a predictor of rectal temperatures of lactating Holsteins in a subtropical environment as THI [40].

Numerous studies have been performed to establish comfortable zone and heat tolerance thresholds in dairy animals on the basis of THI values [30] [81]. Heat tolerance is known as the ability of the animals to preserve expression of their hereditary functional potential during their life-time when raised under hot conditions [88]. Concerning to tolerance to heat varies, Holsteins are less tolerant than Jersey cows, beef cattle with black hair suffer more from direct solar radiation than those with lighter hair, lactating cattle are more susceptible than dry cows because of the additional metabolic heat generated during lactation, heavier cattle over 455kg are more susceptible than lighter ones, sick or previously stressed animals are susceptible as are recently fresh cows and cattle is more prone to heat stress than sheep and goats (the comfort range of goats is 0-30°C (32-86°F) [89].

Elevated temperature and humidity negatively affects feed intake ultimately leading to decreased milk production. It has been observed that heat stress can create a significant economic burden to dairy industry to a tune of about $900 million per year [90]. Further, during heat stress, decline in milk production are a common phenomenon and the reduction was recorded to be between 30-40% [91]. The impact of heat stress on dairy cattle was established and estimated the annual economic loss to be 897-1,500 million dollars to US dairy industry [90]. In another study it was established that severe heat stress caused a loss of $800 million dollars to the US dairy industry [92]. Further, it was also reported that the Californian dairy farmers lost more than 1 billion dollar of milk and animals during 2006 heat wave [93]. In addition, heat stress is estimated to have lowered annual milk production in the average dairy by about $39,000, totaling $1.2 billion loss of production for the entire US dairy sector [94]. A significant association between seasonally and deaths for all the 6 years in Italian Bovine Spongi was found by [19]. Same authors reported that summer and spring were the seasons with the highest and lowest frequency of deaths, respectively, and within summer months, the number of deaths in July and August was higher than in June. The proportion of culling and deaths from all causes in transition dairy cows was higher during the hottest calving months [95]. In an Indian study, an increase of mortality in Mecheri sheep in summer was found by [96]. During the severe and prolonged heat waves that occurred in Europe during the summer of 2003, over 35,000 people, and thousands of pigs, poultry, and rabbits died in the French regions of Brittany and Pays-de-la-Loire (http://lists.envirolink.org/pipermail/ar-news/ week-of-Mori-20030804 /004707.html).

There are several strategies were suggested to alleviate the heat stress to maintain or increase the productivity. One strategy used to minimize effects of heat stress is to modify the environment in which cows are kept by providing shade to reduce solar radiation or using sprinklers to increase evaporative cooling. Manipulation of certain diet ingredients is another strategy that may be beneficial [97]. Decreasing fiber intake within limits of maintaining adequate fiber levels for proper rumen function can be effective in partially alleviating heat stress [98].

Relation of heat stress (THI) with reproductive efficiency of farm animals

Negative relationships between THI and reproductive performances in dairy cows were documented [4] [5]. Heat stress can cause reproductive problems such as reduced semen quality and lower birth weights, and compromise the immune system [43]. Fertility in dairy cows is well-defined as the ability of the animal to conceive and maintain pregnancy if inseminated at the appropriate time relative to ovulation [99]. Poor estrous detection and embryonic or fetal losses are among the leading causes for poor reproductive performance. During the postpartum period, about 50% of standing periods of estrus are undetected and this failure in estrous detection can increase the average interval between successive inseminations to about 40-50 days and reduces both reproductive efficiency and profitability [100]. Heat stress severely reduces pregnancy rates in dairy cows. Conception rates of lactating cows decreased sharply when maximum air temperature on day after insemination exceeded 30 degrees C. In contrast, conception rates for heifers did not decline until 35 degrees C. Virgin heifers had higher conception rates for all services (50%) than lactating cows (34%) and suffered only slight depression of fertility during summer months. Heifers required 1.5 services per conception compared with 2.3 for lactating cows. Conception rates decreased from 40 to 50% during months when ambient temperatures are greater and to be less than 10% during the months of the year when ambient temperatures are lesser [101]. High temperatures affect the developing embryo and can lead to lower conception rates.

It is reported that high temperatures lowered conception rates in cows more than in heifers, since lactating cows were usually unable to maintain normal body temperature under heat stress conditions because of the high rates of lactation-associated internal heat production [102]. It is of importance to note that kids and heifers are not under the same stress as lactating animals, since lactating animals cannot maintain normal body temperatures under heat stress conditions because of the high lactation-associated internal heat production [103]. Higher environmental temperature is one of the major factors responsible for reduced fertility in farm animals. Heat stress can compromise reproductive events by decreasing the expression of estrous behavior, altering ovarian follicular development, compromising oocyte competence, and inhibiting embryonic development. Heat stress also increases the production GF2α in the endomerium, leading to the early regression of CL or the death of embryos. It was observed that heat stress from 8 to 16 days after insemination modulated the uterine environment reduced the weight of corpora lutea and impaired concepts growth [104]. In addition to effects on embryonic mortality, heat stress decreases the intensity and duration of behavioral estrus so that a smaller proportion of cows are detected in estrus under heat stress conditions [105]. The interval from parturition to conception during summer was 24-67 days longer than during the winter even though barns during summer were supplied with evaporative coolers [106]. In heat stressed cows, the intrauterine environment is compromised which results in a reduced blood flow to the uterus and elevated uterine temperature and these changes suppress embryonic development increase early embryonic loss and minimize the proportion of successful inseminations [107]. High ambient temperature will also affect pre-attachment stage embryos but the magnitude of the effect has been reduced as embryos develop [108]. The production of embryos by super ovulation is often reduced and embryonic development compromised in seasons when ambient temperatures are greater [109]. Heat stress can affect endometrial prostaglandin secretion, leading to premature luteolysis and embryo loss. However, the majority of embryo loss occurs before day 42 in heat stressed cows [110].

Heat stress in the period around the day of breeding was consistently associated with reduced conception rate [111]. Holstein heifers subjected to heat stress from the onset of estrus had increased proportion of abnormal and developmentally disturbed embryos as compared with heifers preserved at thermo-neutrality [109]. Abortions represent a loss of reproductive efficiency in normal bovine populations, and spontaneous abortion of dairy cows is an increasingly important problem that contributes substantially to low herd viability and production in efficiency by decreasing the number of potential female herd replacements and lifetime milk production and by increasing costs associated with breeding and premature culling [112]. A positive relationship between heat stress during the peri-implantation period and early fetal loss in dairy cattle was found by [113]. Heat stress define as a daily maximum THI of 72 or more from day 35 before to day 6 after the day of breeding decreases conception rate of lactating dairy cows by around 30% relative to days of breeding [111]. When maximum THI during three to one day pre–artificial insemination values were greater than 80, conception rate decreased from 30.6% to 23.0% [114]. The influence of THI on the conception, pregnancy, embryonic loss and early abortion rates in purebred Holstein cows under subtropical Egyptian conditions was studied by [115] and found that conception and pregnancy rates were significantly decreased from 31.6% and 26.3% at the lesser THI to 11.5% and 9.9%, respectively, than at the greater THI. Same authors found that conception and pregnancy rates were significantly reduced at either the lesser or greater THI while embryonic loss rate was significantly increased from 11.5% at the lesser THI to 22.2% at the greater THI. The relationship between TH and conception rate (CR) of lactating dairy cows, to estimate a threshold for this relationship, and to identify periods of exposure to heat stress relative to breeding in an area of moderate climate was studied by [116]. Authors compared three different heat load indices related to CR: mean THI, maximum THI, and number of hours above the mean THI threshold.

The THI threshold for the influence of heat stress on CR was 73. It was statistically chosen based on the observed relationship between the mean THI at the day of breeding and the resulting CR. Negative effects of heat stress, however, were already apparent at lower levels of THI, and 1 hour of mean THI of 73 or more decreased the CR significantly. The CR of lactating dairy cows was negatively affected by heat stress both before and after the day of breeding. The greatest negative impact of heat stress on CR was observed 21 to 1 day before breeding. When the mean THI was 73 or more in this period, CR decreased from 31% to 12%. Compared with the average maximum THI and the total number of hours above a threshold of more than or 9 hours, the mean THI was the most sensitive heat load index relating to CR. These results indicate that the CR of dairy cows raised in the moderate climates is highly affected by heat stress.

The relationship between temperature and breeding efficiency and found that seasonal high environmental temperatures were associated with low breeding efficiency was determined by [117]. Authors found that increased maximum temperature from 29.7 degrees C to 33.9 degrees C was associated with a decrease in conception rate on first service from 25 to 7%. Fetal loss rate of Holstein was significantly increased from 17.1% at low THI to 24.9% at greater THI and abortion and stillbirth rates were significantly increased from 3.6% and 3.8%, respectively, at low THI to 7.2% and 5.9%, respectively, at greater THI [118]. Authors concluded that Holstein cows had a significant longer calving interval and days open at high THI (449 and 173 days, respectively), compared with low THI (421 and 146 days, respectively). Heat stress affects reproduction by inhibiting the synthesis of gonadotropin-releasing hormone and luteinizing hormone which are essential for oestrus behaviour expression and ovulation [119]. Further, only fewer standing heats are observed during heat stress which may ultimately lead to decreased pregnancy rate. Body temperature greater than 39°C may have a negative impact on the developing embryo from day 1-6 and lead to loss of pregnancy. Heat stress during late gestation, may also lead to cows calving 10-14 days before their due date [120].

Symptoms of heat stress types or stages

Heat stress is a condition in which the body has problems dissipating excess heat. Results of inadequate heat dissipation range from general discomfort to symptoms of heat rash, heat syncope, heat cramps, heat exhaustion, and heat stroke as following based on guidelines from the National Service Centre for Environmental Publications [121], National Institute for Occupational Safety and Healthy [122] and National Weather Service [21].

Heat rash

Heat rash is a skin irritation caused by excessive sweating during hot, humid weather. Heat rash is the least severe of heat stress occurs when sweat clogs pores. Though heat rash is usually causes only temporary discomfort.

Heat Syncope

Heat syncope may affect animal that are not acclimatized to hot environments. Syncope generally is the sudden loss of consciousness due to lack of sufficient blood and oxygen to the brain. Heat stress can cause by diverting blood to the lower body or extremities at the expense of the brain.

Heat Cramps

Heat cramps are painful muscle cramps caused by excessive sweating which usually caused by losing too much water and salt through sweating especially when water is replaced by drinking, but not salt or potassium. Heat cramps are muscle spasms occur after strenuous activity in a hot environment when the body gets depleted of salt and water and results from reduced blood flow to the brain. Heat cramps are often extremely uncomfortable are caused by electrolyte deficiencies that result from extended periods of intense sweating. This sweating depletes the body's salt and moisture levels. Low salt levels in muscles causes painful cramps.

Heat Exhaustion

Heat exhaustion occurs when excessive sweating in a hot environment which reduces the blood volume and excessive loss of the water and salt through excessive sweating. Symptoms of heat exhaustion include: heavy sweating, extreme weakness or fatigue, dizziness, confusion, nausea, clammy, moist skin, flushed complexion, muscle cramps, slightly elevated body temperature and fast, loss of appetite, hyperventilation, shallow breathing, cool moist skin, weak and rapid pulse (120-200), and low to normal blood pressure, dehydration, reduction of blood in circulation, strain on circulatory system and reduced flow of blood to the brain.

Heat Stroke (Hyperthermia)

Heat stroke occurs when the core body temperature rises above 40.5ºC and the body's internal systems start to shut down. Heat stroke is the most serious heat-related disorder. It occurs when the body becomes unable to control its temperature: the body's temperature rises rapidly, the sweating mechanism fails, and the body is unable to cool down. When heat stroke occurs, the body temperature can rise to 106 degrees Fahrenheit or higher within 10 to 15 minutes. Heat stroke can cause death or permanent disability if emergency treatment is not given. Symptoms of heat stroke include: hot, dry skin or profuse sweating and high body temperature (103°F), a distinct absence of sweating (usually); hot red or flushed dry skin; rapid pulse; difficulty breathing; constricted pupils [123].

Regulating animal body temperature under heat stress of climatic conditions

Heat dissipate in animals bodies by varying the rate and depth of blood circulation, by losing water through the skin and sweat glands, and as a last resort, by panting, when blood is heated above 98.6 °F. Sweating cools the body through evaporation. High relative humidity retards evaporation, robbing the body of its ability to cool itself. When heat gain exceeds the level the body can remove, body temperature begins to rise, and heat-related illnesses and disorders may develop (Figure 6).

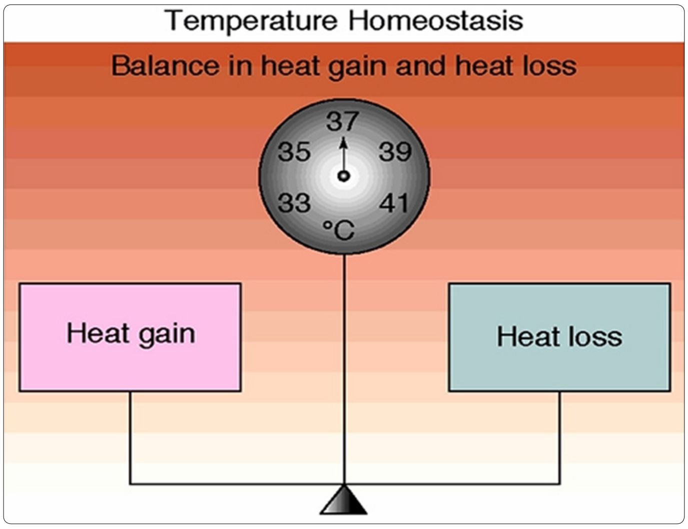


Figure 6: Balance between heat gain and heat loss [2].

The physiological (e.g., respiration rate) and behavioural (e.g., resting pattern) controls of dairy cows attempt to maintain a constant body temperature by regulating their thermal energy balance, so that heat input through metabolism (maintenance, exercise, growth, lactation, gestation, and feeding) equals heat loss to the environment (by conduction, convection, and evaporation). When environmental conditions exceed a threshold limit that increases the core body temperature, heat stress sets in and animal welfare can be compromised. Moreover, cow health, production, and reproduction performance are reduced under heat stress [124]. Feed intake begins to decline at air temperatures of 25–26 C in lactating cows as reducing dry matter ingestion is a way to decrease heat production in warm environments [65]. More specifically the reduction of dry matter intake for heat-stressed cows is about 10 to 15% relative to cooled cows [125]. Cows under heat stress also have elevated respiration and sweating rates, which results in greater body fluid losses that increase maintenance requirements to control dehydration and blood homeostasis [30]. Reproduction is affected by high temperature because it reduces the expression of oestrous behaviour, modifies follicular growth, and inhibits embryonic development [126].

A body at work generates heat faster than at rest, often more than needed. The body protects itself by dissipating excess heat to the environment through mechanisms that include vasodilatation and sweating. When the body's core temperature exceeds 98.6 degrees Fahrenheit, vasodilatation begins as the heart increases blood flow to microscopic vessels (capillaries) in the upper layers of skin. Excess heat is then transferred to the cooler exterior environment. If, however, increased blood circulation to the skin cannot sufficiently cool the body, or if the surrounding air is warmer than the skin, then the brain signals sweat glands to release sweat to the skin. The sweat then evaporates, carrying additional heat from the body as it undergoes the phase transition from liquid to vapor. High ambient humidity decreases the rate of sweat evaporation and consequently the body's capacity to dissipate heat through this mechanism. Vasodilatation and sweating, however, can impair worker strength and comfort in three ways.

First, as blood drains from the internal organs and muscles to the skin, less oxygen is carried to the brain and muscles. Workers then experience higher levels of muscle fatigue and lower mental alertness. Second, water loss through sweating exacerbates fatigue by decreasing blood volume and increasing viscosity. These further decreases the amount of oxygen carried to muscles. In addition, as water volume diminishes, the body's ability to cool itself through vasodilatation and sweating is impaired and its core temperature rises. Third, though most diets provide ample electrolytes, prolonged periods of intense sweating can result in electrolyte deficiencies that cause severe heat cramps. To maintain comfort and health when working in a hot environment, it is critical for workers to replace both the water and electrolytes they lose through sweating. If workers' fluids are not replenished at the same rate they are lost, or if they lack the electrolytes necessary to process water, their body cannot effectively lower their core temperature and the possibility of heat stress rises and solar radiation had a major effect on the thermoregulation of grazing ruminants [127] [128] (Figures 7 and 8).

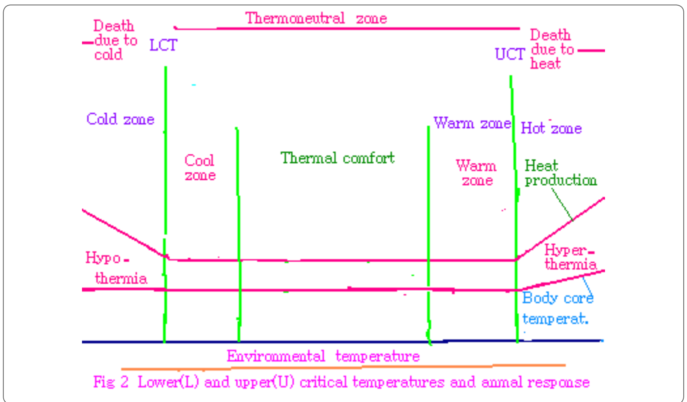


Figure 7. Lower (L) and upper (U) critical temperature and animal response [127].

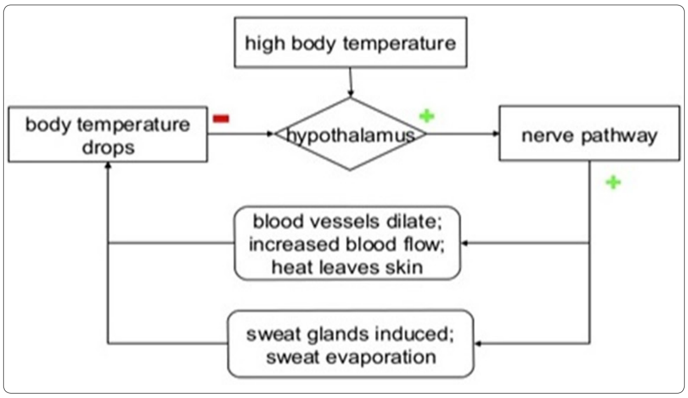


Figure 8. Thermoregulation in animals exposed to heat stress conditions [128].

As a result of the effects of thermal stress, the dairy industry experiences significant financial losses every year, with annual estimates between $900 and $1500 million in the United States (US) [90].

Signs of heat stress for animal include: Increased body temperature (>102.6 °F), the normal body temperature of dairy cow is 101.5°F, panting >80 breaths per minute (35-45 normal), reduced activity, water intake will increase by 30% or more during heat stress, reduced feed intake (>10-15% reduction) to produce less metabolic heat and reduced milk yield (10-20% or more) [129]. Same author mentioned that animal has several mechanisms to help dissipate body heat. These include: conduction, where the cow conducts heat to a cooler surface, convection, where thermal currents leave the cow's body, radiation, where the cow radiates heat to a cooler environment and evaporation, where moisture is evaporated from the surface of her body (sweating) and from her lungs (panting).

A pathways of heat stress syndrome in cattle under hot climatic conditions was suggested by [130] to clarify that production and reproduction of cattle affected negatively by heat stress conditions **(**Figure 9).

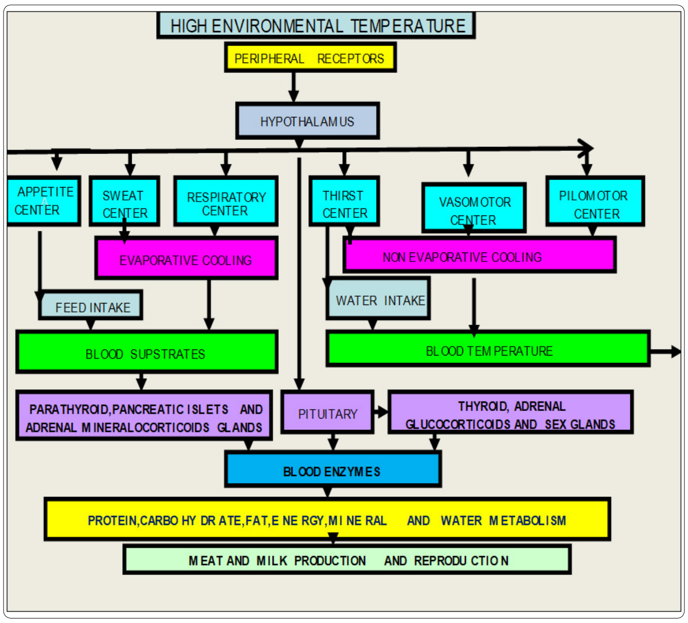


Figure 9. Pathways of heat stress syndrome in cattle under hot climatic conditions [130].

Conclusion

Heat stress is one of the major concerns which affect the production and reproduction potential of farm animals almost in every part of world. Elevated temperature and humidity as presented in THI negatively affects feed intake and altered hormone concentration leading to negatively affecting the productive and reproductive performance of farm animals.

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