

## Intercomparison of seven Temperature-Humidity Index (THI) equations for assessing the impact of heat stress in relation to milk production to find out best THI for central zone of Kerala

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**सार** – मवेशियों द्वारा अनुभव किए गए ऊष्मा प्रतिबल को तापमान आर्द्रता सूचकांक (THI) द्वारा निर्धारित किया जा सकता है। इस शोध पत्र में केरल के मध्य क्षेत्र में दुग्ध उत्पादन के संबंध में ऊष्मा प्रतिबल के प्रभाव का मूल्यांकन करने के लिए पूरे विश्व के अलग-अलग वैज्ञानिकों द्वारा विकसित किए गए सात प्रकार के तापमान आर्द्रता सूचकांक (THI) की तुलना की गई है जिससे कि सर्वश्रेष्ठ THI का पता लगाया जा सके। THI का आकलन करने के लिए शुष्क बल्ब, आर्द्र बल्ब, औसत सापेक्षिक आर्द्रता और तापमान का उपयोग किया गया है। 2013-2017 की अवधि के दौरान के आर्द्र बल्ब, शुष्क बल्ब, अधिकतम और न्यूनतम तापमान, पूर्वाह्न तथा अपराह्न की सापेक्षिक आर्द्रता और औसत सापेक्षिक आर्द्रता के दैनिक आँकड़े प्रमुख कृषि मौसम विज्ञान वेधशाला वेल्लनिककारा से एकत्रित किए गए और दैनिक आँकड़ों को मासिक औसत आँकड़ों में परिवर्तित कर दिया गया। इन आँकड़ों का उपयोग करके तापमान आर्द्रता सूचकांक की गणना की गई और चारों ऋतुओं की गणना के लिए सात समीकरणों का उपयोग किया गया। ऋतुओं में महीनों के समूह के लिए भारत मौसम विज्ञान विभाग की मानक विधि अपनाई गई जैसे-शीत (जनवरी-फरवरी), मॉनसून पूर्व (मार्च-मई), दक्षिण-पश्चिमी मॉनसून (जून-सितम्बर) और मॉनसूनोत्तर (अक्टूबर-दिसम्बर)। प्रत्येक THI समीकरणों की वार्षिक और ऋतुनिष्ठ औसत मानों से गणना और तुलना की गई। यदि ऋतुनिष्ठ औसत मान THI के वार्षिक औसत मान से अधिक हो जाता है तो ऐसी ऋतुओं को ऊष्मा प्रतिबल की ऋतु माना गया। होल्सटीन फ्रीशियन नर्सल की सात गायों के दूसरी बार बच्चा देने के बाद दैनिक दुग्ध उत्पादन के आँकड़े वेल्लनिककारा के विश्वविद्यालय फार्म से एकत्र किए गए और मासिक औसत दुग्ध उत्पादन की गणना की गई। परिणामों से पता चला है कि ऋतुनिष्ठ औसत मान केवल मॉनसून पूर्व ऋतु के दौरान THI के वार्षिक औसत मान से अधिक था। मॉनसून पूर्व ऋतु के लिए परिकल्पित THI के मान को दुग्ध उत्पादन के साथ सहसंबद्ध किया गया और जिस THI का  $R^2$  उच्चतम था उसे सर्वश्रेष्ठ THI के रूप में चयन किया गया। NCR 1971 द्वारा विकसित किया गया तापमान आर्द्रता सूचकांक अधिकतम  $R^2$  मान को बताता है अतः मॉनसून पूर्व ऋतु के दौरान ऊष्मा प्रतिबल का पता लगाने के लिए यह सबसे उपयुक्त समीकरण है। समीकरण इस प्रकार है,

$$THI\ 1 = (1.8 \times T_{db} + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26.8)] \quad (R^2 = 0.1711) \quad (NRC, 1971).$$

**ABSTRACT.** Heat stress experienced by cattle can be quantified using Temperature Humidity Index (THI). Seven different THI developed by different scientists all over the world were compared in this study to find out best THI for assessing the influence of heat stress in relation to milk production for central zone of Kerala. The dry bulb, wet bulb, average relative humidity and temperature were used to estimate the THI. The daily data of wet bulb, dry bulb, maximum and minimum temperature, forenoon and afternoon relative humidity and average relative humidity during the period of 2013-2017 were collected from principal agro meteorological observatory, Vellanikkara and daily values were converted into monthly average values. Using these data THI was calculated using seven equations for four seasons. The standard method of IMD was followed to group months into seasons, i.e., winter (January-February), pre monsoon (March-May), south west monsoon (Jun-Sep) and post monsoon (October-December). Annual and seasonal mean values of each THI equations were calculated and compared. If seasonal mean value exceeded annual mean value of THI, such seasons were considered as the season of heat stress. Daily milk yield data of seven Holstein- Friesian cows after second calving were collected from university farm, Vellanikkara and monthly average milk yield was calculated. Results showed that seasonal average value exceeded annual average value of THI only during pre monsoon season. Calculated THI values for pre monsoon season were correlated with milk yield and THI having highest  $R^2$  was selected as the best THI. THI developed by NRC, 1971 showed maximum  $R^2$  value hence found to be most suitable equation to assess the heat stress during pre monsoon season. The equation is given as follows :

$$THI\ 1 = (1.8 \times T_{db} + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26.8)] \quad (R^2 = 0.1711) \quad (NRC, 1971).$$

**Key words** – Temperature humidity index, Heat stress, Pre monsoon season.

## 1. Introduction

Dairy cattle in tropical humid provinces are subjected to high ambient temperature and relative humidity. Kerala is a tropical humid state in India. Elevated temperature and relative humidity may cause heat stress on animal and may reduce the milk yield. High temperature, solar radiation and relative humidity for long periods compromise the capacity of the lactating cow to dissolve heat, to deal with it; the cow develops many physiological mechanisms. In this condition the animal has to compromise on the energy, which should be used for milk production in order to maintain homeostasis. These responses have a negative consequence on milk yield (Bouraoui *et al.*, 2002). Discomfort of any location is characterized to recognize the efficiency of livestock performance. Temperature Humidity Index is used to quantify heat stress. THI depicts the combined effects of air temperature and humidity related with the degree of heat stress. To regulate and reduce the heat stress associated losses in milk production, THI can be used as a weather safety index (Bohmanova *et al.*, 2007). Many THI equations relating various environmental factors to quantify the degree of heat stress have been offered. Majority of the equations focuses on temperature and relative humidity. Threshold value of THI is different for different equations and it differs with locations. When THI exceeds the threshold level, it leads to heat stress. The thermal stress on lactating cross breed cattle was assessed by Pramod *et al.* (2021) using THI at Thiruvizhamkunnu, located in the central zone of Kerala. According to them the values of THI varied between 70.78 and 83.93 during the study period (January to March), indicating that the cows were exposed to mild and moderate stress. The regions lies in the central zone experiences a humid and sub-humid climate with an average rainfall of 2171 mm per year (Premakumar *et al.*, 2015). Influence of heat stress on livestock production is lightened by heat abatement systems like sprinkler and fan. When the water is sprayed to the animal the heat required for evaporation is lost from its body, this evaporative cooling reduces the body temperature and there by heat stress. Armstrong (1994) testified that by evaporative cooling, 7.5 kg extra milk per day was produced by cow when the temperature was 40.5°C (RH less than 30%). The objective of current study was to recognize most suitable THI among seven different THI for assessing impact of heat stress in relation to milk production in central zone of Kerala.

## 2. Data and methodology

Weather data including wet bulb temperature ( $T_{wb}$ ), dry bulb temperature ( $T_{db}$ ) maximum ( $T_{max}$ ) and minimum temperature ( $T_{min}$ ), relative humidity (RH) were collected

from the principal agro meteorological observatory, Vellanikkara, located at 10° 31' N, 76° 13' E, located at an altitude of 22 m from mean sea level, for the period of 2013-2017. The region experiences a mild to moderate humid climate. Daily average temperature ( $T_a$ ) was calculated by taking mean of  $T_{max}$  and  $T_{min}$ . Milk yield data for the period of 2013-2017 were collected from seven Holstein-Friesian cross cows after second calving from university farm, KAU, Vellanikkara and wet average was calculated.

$$\text{Wet average} = \frac{\text{Milk yield at peak lactation period}}{\text{Number of cows}}$$

Seven Temperature Humidity Indices (THI) were calculated from the weather data using following equations.

$$\text{THI 1} = (1.8 \times T_{db} + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T_{db} - 26.8)] \text{ (NRC, 1971)}$$

$$\text{THI 2} = (0.35 \times T_{db} + 0.65 \times T_{wb}) \times 1.8 + 32 \text{ (Bianca, 1962)}$$

$$\text{THI 3} = (0.15 \times T_{db} + 0.85 \times T_{wb}) \times 1.8 + 32 \text{ (Bianca, 1962)}$$

$$\text{THI 4} = [0.4 \times (T_{db} + T_{wb})] \times 1.8 + 32 + 15 \text{ (Thom, 1959)}$$

$$\text{THI 5} = (T_{db} + T_{wb}) \times 0.72 + 40.6 \text{ (NRC, 1971)}$$

$$\text{THI 6} = (0.8 \times T_{db}) + [(\text{RH}/100) \times (T_{db} - 14.4)] + 46.4 \text{ (Mader et al., 2006)}$$

$$\text{THI 7} = 1.8T_a - (1 - \text{RH})(T_a - 14.3) + 32 \text{ (Kibler, 1964)}$$

Temperatures were in degree Celsius (°C) for calculation of all equations.

Monthly average value of each THI as well as milk yield were calculated and arranged into four different seasons. The monthly values were grouped into different seasons by following standard methods of IMD, *i.e.*, winter (January-February), pre monsoon (Mar-May), south west monsoon (June-September) and post monsoon (October-December). Annual and seasonal average values of THI using each equations were calculated. A comparison was done between annual average THI values and seasonal average THI values. The annual average value for THI was considered as the thermo neutral zone value. If the seasonal average value exceeded annual average value of THI such seasons were considered as a period of heat stress. If the seasonal average value was below the annual average value such seasons were considered as period of no heat stress. Correlation was

TABLE 1

Average value of weather parameters observed during four seasons

Weather parameters	Pre-monsoon	SW Monsoon	Post-monsoon	Winter
Dry bulb temperature (°C)	34.06	29.76	30.44	32.46
Wet bulb temperature (°C)	26.19	25.22	25.36	22.64
Relative humidity (%)	73.04	83.79	74.47	58.90
Maximum temperature (°C)	36.90	30.4	32.1	34.11
Minimum temperature (°C)	25.5	23.3	22.7	23.00
Temperature range (°C)	16.2	7.6	8.6	11.7
Range of maximum temperature (°C)	43.1 - 33.7	31.9 - 28.4	33.0 - 31.4	35.6 - 32.5
Range of minimum temperature (°C)	26.9 - 24.2	24.4 - 21.6	24.4 - 21.1	23.9 - 22.1

carried out by drawing scatter diagrams. Scatter diagrams showing relationship between milk yield and THI values were drawn for all the seasons by taking THI values along the X axis and milk yield values along the Y axis. Suitable THI equations for the seasons experiencing heat stress was found out from the scatter diagram by comparing the  $R^2$  values. THI equation showing highest  $R^2$  value was selected as the best one.

### 3. Results and discussion

THI values were calculated using seven THI equations for four meteorological seasons. The annual average values of THI using seven equations were also calculated. The annual average value calculated by seven equations (THI1 to THI7) was 81.8, 80.8, 80.8, 86.8, 81.1, 81.7 and 78.2. THI index calculated using seven equations for pre monsoon period were 84.5, 84.0, 83.2, 90.4, 84.0, 85.7 and 80.6. THI index calculated for south west monsoon season were 80.9, 80.1, 80.5, 85.2, 80.0, 81.0 and 77.83. THI values calculated for post monsoon season were 81.7, 79.9, 80.7, 86.7, 80.1, 79.7 and 77.5. THI calculated for winter season were 80.7, 78.8, 77.9, 86.1, 80.8, 81.4 and 77.0. The annual average value of THI calculated by each equation was considered as the thermo neutral zone value. To assess the heat stress, the annual average value was compared with the seasonal average value of THI during all the four seasons. The results revealed that the seasonal average values calculated by all the seven equations exceeded annual average value only during pre monsoon season (Fig. 1). Hence pre monsoon season can be considered as the period of heat stress in central zone of Kerala during the experimental period. Season wise average weather parameters observed during the experimental period is described in the Table 1. Maximum value of  $T_{db}$  was 34.06 °C during pre monsoon period, 29.76 °C during south west monsoon, 30.4 °C

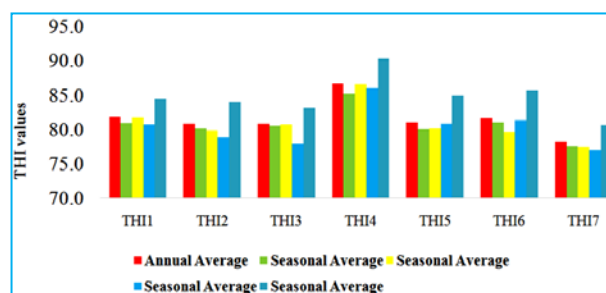


Fig. 1. Comparison of annual and seasonal average values of each THI

during post monsoon season and 32.46 °C during winter season.  $T_{wb}$  recorded was 26.19 °C during pre monsoon period, 25.22 °C during south west monsoon, 25.36 °C during post monsoon and 22.64 °C during winter season.  $T_{max}$  recorded was 36.90 °C during pre monsoon season, 30.4 °C during south west monsoon, 32.10 °C during post monsoon and 34.11 °C during winter season.  $T_{min}$  recorded was 25.5 °C during pre monsoon season, 23.3 °C during south west monsoon, 22.7 °C during post monsoon and 23 °C during winter. Temperature range reported during the period was 16.2 °C during pre monsoon period, 7.6 °C during south west monsoon, 8.6 °C during post monsoon and 11.7 °C during winter season. RH recorded was 73.04% during pre monsoon season, 83.79% during south west monsoon, 74.47% during post monsoon and 58.9% during winter. The temperature values recorded during pre monsoon period was greater than that experienced during other seasons. The relative humidity experienced during pre monsoon season was lesser than that experienced during south west monsoon season and post monsoon season. According to Pramod *et al.*, 2021, the increase in temperature has more influence in developing heat stress in dairy cattle than relative humidity does. Hence, increased values of  $T_{db}$ ,  $T_{wb}$ ,

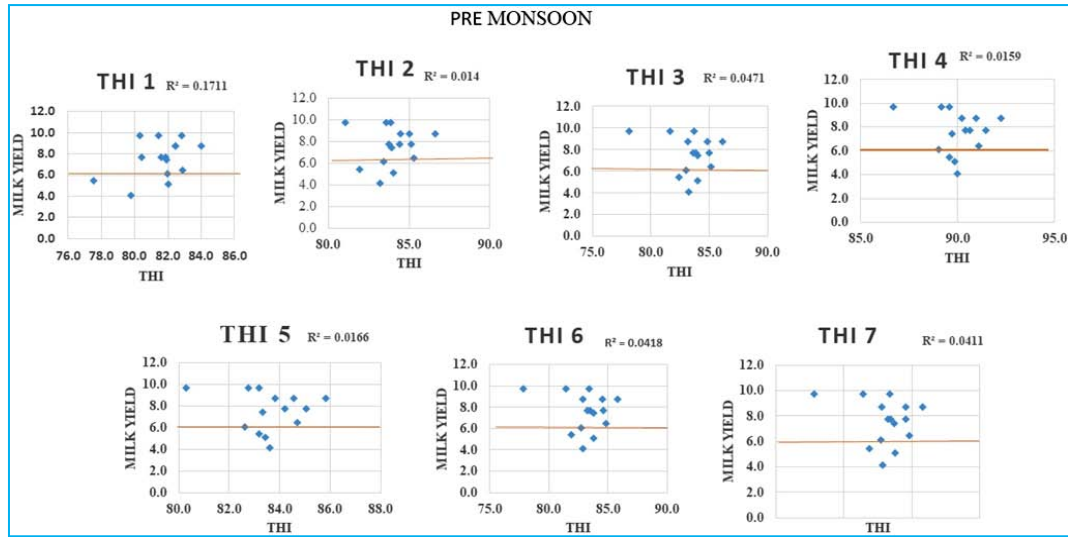


Fig. 2. Performance of different THI during pre monsoon season

$T_{max}$  and  $T_{min}$  might be the reason for the heat stress experienced during the pre monsoon season. Scatter diagrams were drawn to correlate milk yield and THI values. As per the study conducted by Singh *et al.* (2019) milk yield was found to be diminished with increase in THI value similar result was seen in this study. Fig. 2 shows the scatter diagrams plotted with THI along X axis and milk yield along Y axis.  $R^2$  values obtained from scatter diagrams for equations THI1, THI2, THI3, THI4, THI5, THI6, THI7 were 0.1711, 0.014, 0.0471, 0.0159, 0.0166, 0.0418 and 0.0411 respectively. Compared to all other THI equations THI 1, *i.e.*, THI proposed by NRC, 1971  $\{(1.8 \times T_{db} + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26.8)]\}$  was found to be the best among the seven THI equations since it has the highest value of  $R^2$  (0.1711) and shows more correlation between THI and milk yield.

#### 4. Conclusions

Among the four meteorological seasons heat stress was experienced during pre monsoon season (March-May) in central zone of Kerala. THI equations proposed by NRC, 1971 was found to be more suitable for assessing heat stress in relation to milk production during this season. Heat abatement systems like sprinkler and fan can be used during pre monsoon season to alleviate heat stress and related losses in milk production.

#### Disclaimer

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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