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Evaluation of Substitution of Meteorological Data from the Korea Meteorological Administration for Data from a Cattle Farm in Calculation of Temperature-Humidity Index

Ataallahi, Mohammad[*] · Park, Geun Woo[*] · Kim, Jea-Chul[**] and Park, Kyu-Hyun[***†]

[*]*PhD. Student, Department of Animal Life Sciences, Kangwon National University, Chuncheon, Korea*
[**]*Research Professor, Department of Environmental Research, Kangwon National University, Chuncheon, Korea*
[***]*Associate Professor, Department of Animal Life Sciences, Kangwon National University, Chuncheon, Korea*

ABSTRACT

Relative humidity (RH%) data are inaccessible in the majority of cattle farms; however, such data often are available at local meteorological stations. Thus, this study purposed use of dry bulb temperature (DBTºC) data from a cattle barn and RH% data of Korea Meteorological Administration (KMA) for calculation of temperature-humidity index (THI). The scope of research was analysis of three cattle barns, categorized as barn 1 (sidewalls-closed and adjustable with windows, 1,071 m^2), barn 2 (sidewalls-opened and adjustable with winch curtain, 1,067 m^2), and barn 3 (sidewalls half opened, 544 m^2) located at a livestock research farm at Kangwon National University. The microclimate data of the barns were recorded by Hobo loggers and compared with KMA data from June to September 2019. Comparison of maximum DBTºC between KMA and the barns showed no difference in the study period. On the other hand, minimum RH% at KMA was lower than those of barn1 and barn3 in June and September, and minimum RH% at KMA was lower than that of barn1 in August ($p < 0.05$). The maximum THI based on KMA data was not different from that based on barns data. Moreover, the maximum THI based on KMA data was not different from that of modified THI (combination of maximum DBTºC of barns and minimum RH% of KMA). Furthermore, maximum THI based on barns data was not different from modified THI of barns. The THI calculation in barns was correlated with KMA data. Overall, microclimate information from KMA can be used as effective barn microclimate data for THI calculation. We recommend using RH% data provided by KMA in the absence of microclimatic RH% data from a cattle barn as an effective way of regulating THI inside the cattle farm.

Key words: *Barn Environmental Condition, Meteorological Data, Temperature-humidity Index*

1. Introduction

The negative influences of warming of earth's climate event on domesticated animal species and specifically of cattle have been the subject of numerous animal welfare researches (Rojas-Downing et al., 2017; Bernabucci, 2019; Hempel et al., 2019; Sammad et al., 2020). In this regard, monitoring weather and climate information provides farmers to manage better cattle husbandry. Major important of environmental stressing elements including the solar radiation, air movement, precipitation, dry bulb temperature or DBTºC, and relative humidity or RH% should be considered in order to minimize heat stress risk in cattle farming system (Silanikove 2000; Trajchev and Nakov, 2017; Herbut et al., 2018). Heat stress of cattle occur when the cattle's heat load is higher than its ability

†**Corresponding author** : kpark74@kangwon.ac.kr (24341, Dept. of Animal Life Sciences, 4th floor, Kangwon National University, Kangwondaehakgil 1, Chuncheon, Republic of Korea. Tel. +82-33-250-8621)

ORCID Ataallahi, Mohammad 0000-0003-0234-8863 Kim, Jea-Chul 0000-0001-7527-6771
Park, Geun-Woo 0000-0003-0336-4080 Park, Kyu-Hyun 0000-0002-6390-5478

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to lose heat, and therefore lead to damage general health, immunity, and productivity (Kadzere et al., 2002; West, 2003).

Nowadays, heat stress is simply a matter of husbandry animals around the world, especially in temperate climate countries such as Korea especially during summer periods as the DBTºC increases. In Korea, livestock farms were classified into cattle, swine, chicken, and duck with variability in small, big, traditional, innovative farms (KOSTAT, 2020). The country surrounded by the mountain and climate conditions is hot and humid in summers and long cold winters with moderate in springs and autumns (Kang et al., 2016; Ataallahi et al., 2019). Currently, DBTºC in Korea is rising 0.5 per decade that is higher than the rest of the world due to climate change event (Allen et al., 2018). In this condition, many risks increase with extreme DBTºC and extreme RH% of environment and have negative impacts on livestock health status (Lovarelli et al., 2020). In particular, cattle production (milk, meat) and reproduction (Gernand et al., 2019; Tao et al., 2020). Researchers have recommended to use ventilation systems, shades, shelter, and etc in preventing of solar radiation or heat stressing condition in a closed-cattle barn specially in temperate climatic condition (Schütz et al., 2009; Lovarelli et al., 2020).

Numerous studies have been investigated heat stress of cattle by obtaining microclimate data (DBTºC and RH%) from the nearest meteorological stations (Ravagnolo et al., 2000; Schüller et al., 2013; Ataallahi et al., 2019; Ghassemi Nejad et al., 2019a), however the value of information from meteorological stations may not be totally representative of the cattle farm condition. The DBTºC and RH% are essential microclimate elements for calculation of temperature-humidity index or THI. The term THI is one of the well-known and non-invasive metric among the indicators to study easily the effects of DBTºC and RH% and estimating heat stress status of a large number of cattle to assure cattle health and welfare status (Mader et al., 2006; Bohmanova et al., 2007; Morton et al., 2007; Ghassemi Nejad et al., 2019b). The THI equation was invented by Thom, (1959) and then gradually has been developed (NRC, 1971; Berman et al., 2016). The result of measuring THI depends on suitable THI models in climatic condition to interpret accurately (Dikmen and Hansen, 2009; Liu et al., 2019). Considering this fact, the current study was carried out based on literature (Ataallahi et al., 2019; Kim et al., 2020) that widely used THI models to evaluate heat stress in Korean native cattle or Hanwoo. The THI level can be calculated easily with the DBTºC and RH% data provided by nearest meteorological station mostly (Berman et al., 2016), and in another option it can be calculated with microclimate data from recorder sensors in the cattle barn. However, calculating THI by meteorological station data may not represent the THI of cattle barn appropriately and in another option due to limitation to accessibly of the RH% data in the majority of cattle barns (Soldatos et al., 2005) may not determine THI status of cattle barn. In the current research we verified how different were the DBTºC and RH% inside the cattle barn and the Korea Meteorological Administration or KMA to improve the methodology of THI calculation in particular absences of RH% data in the cattle barn. Thus, this study was aimed the possibility of using DBTºC data of inside cattle barn and RH% data provided by KMA for calculation THI in order to better represent environmental condition of cattle barn.

2. Materials and Methods

2.1 Livestock research farm

This study was conducted on Hanwoo, *Bos taurus coreanae* (Kim et al., 2020) barns located at the livestock research farm of Kangwon National University of Chuncheon (37°56'24.1"N 127°46'57.1"E) (Fig. 1).

The cattle farm was categorized into three major barns that had no access to the pasture area and the barns were geographically close to each other as follows; barn 1 was designed with closed-sidewalls and adjustable with windows (manually opened or closed windows, doors, or ventilation system) it consisted of 45 Hanwoo breeding cattle (geographical location; 37°56'22.5"N 127°46'53.4"E, volume of house; 1,071 m^2), barn 2 was designed with adjustable opening-sidewalls (manually opened and closed winch curtains, doors) and it housed of 23 Hanwoo breeding cattle, 4 horses, 2 donkeys, and 4 sheep (geographical location; 37°56'23.9"N 127°46'57.0"E, volume of house; 1,067 m^2), and barn 3 was designed with half opening-sidewalls and it housed of 11 lactating Holstein cattle with 12 Hanwoo breeding (geographical location; 37°56'23.1"N 127°46'57.0"E, volume of house; 544 m^2). All cattle had free access drinking water troughs and eating normally *ad libitum*. The photography of the barns was shown in Fig. 2 Each barns equipped with fans, ceilings, walls, shed, roof with windows for light and better ventilation.

2.2. Environmental Measurements

Microclimate information including daily mean, minimum, and maximum DBTºC and RH% were downloaded from the website of KMA, (http://www.kma.go.kr/eng/index.jsp) for the study period of warm months (June, July, August, and September) in Summer 2019. The KMA of Chuncheon station (37°56'50.1"N 127°45'17.5"E) is located at the Gangwon-do, Korea. Chuncheon is a city in the north east part of the Korea with the largest dam on the Soyang river. In Chuncheon, the summer is hot and the winter is cold, with a mean annual temperature is 11.1ºC, in Aug 24.6ºC and in Jan -4.6ºC (KMA annual report, 2018). The nearest KMA station is located within 2.5 km north from the cattle barns. The distance between KMA and the cattle barns was measured by Google map distance calculator (https://www.daftlogic.com/projects-google-maps-distance-calculator.htm#).

At the same time, microclimate parameters including DBTºC and RH% of inside the barns were recorded by Hobo data loggers (HOBO U23-001 Pro v2, Bourne, Massachusetts, USA). Hobo logger was an automated system that simultaneously and continuously records DBTºC from -40 to 70 ± 0.2°C and RH% from 0 to 100 ± 2.5%. One Hobo logger was installed in each Hanwoo barn at the height (~1.5 m) above the bedding surface, and recorded data per minute. The environmental conditions of Hanwoo barns were download by Hobo programme every two weeks. In this study, the data were then converted into daily maximum DBTºC and minimum RH%. The following equation was applied to calculate the THI levels of the barns and KMA based on collection of DBTºC and RH% data;

$$(1.8 \times DBT + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times DBT - 26)] = THI.$$

Where, DBT is the daily maximum temperature (ºC), RH is daily minimum relative humidity (%), and THI is index of synthesizing of DBTºC and RH% (Ravagnolo and Misztal, 2000; Ouellet et al., 2019).

Maximum DBTºC and minimum RH% as climate parameters were used for calculation the maximum THI level because higher DBTºC was accompanied by lower RH% and those parameters were critical variables to quantify heat stress (Ravagnolo and Misztal, 2000; De Rensis et al., 2015; Ouellet et al., 2019). According to Berman et al. (2016) the aforementioned THI formula consider the value of RH% in equation, and it estimates water vapour present in air as percentage of moisture the air would contain when saturated with moisture at the given air temperature. In present study, THI level based on microclimate data of three barns were compared with the climate data collected from KMA during experimental period. Combination maximum DBTºC of barns and minimum RH% from KMA as an alternative choice for monitoring barns condition were used to evaluate THI level, because of RH% values may not present in the most cattle farms. Additionally, the THI levels among three barns were compared to investigate climate condition of the barns.

The microclimate data recorded by Hobo digital loggers inside the barns and KMA data were extracted into excel spreadsheets (Microsoft Office 2016) and the differences of maximum DBTºC, minimum RH%, maximum THI levels, and the maximum THI-modified between KMA and cattle barns were analyzed by ANOVA using one-way analysis procedure in SAS software (Version 9.4, SAS Institute Inc., NC., USA). Simple correlation was performed for maximum THI levels between KMA and cattle barns with SAS CORR procedure. Treatment means were separated by Tukey multiple range tests at $p < 0.05$ statistical levels.

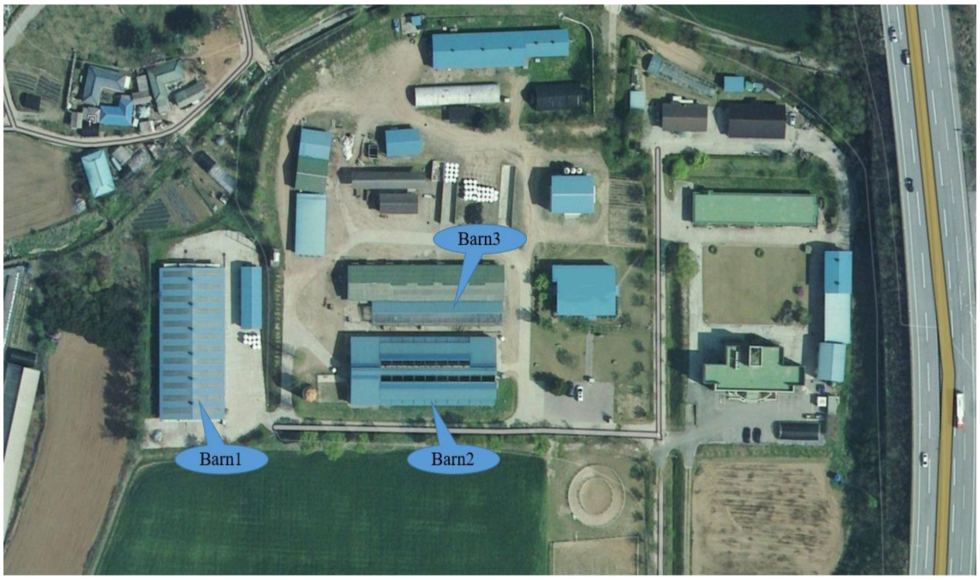

Fig. 1. Location of Kangwon National University livestock research farm in Chuncheon city including the position of the barns
(source: NAVER map)

Fig. 2. Photography of outside and inside of the barn 1 (A, B), barn 2 (C, D), and barn 3 (E, F)

3. Results and Discussion

The THI has been used as a standard metric to determine the effects of DBTºC and RH% on ruminants. The microclimate data were presented according to KMA of Chuncheon city and cattle barns of livestock research farm in Kangwon National University during summer months from June to September in 2019.

The results of comparing between maximum DBTºC at the KMA and the barns from June to September were represented in Fig. 3(A). In addition, the difference calculated between minimum RH% at KMA and the barns during same period of study were represented in Fig. 3(B).

No significant differences ($p > 0.05$) were observed in maximum DBTºC extracted at KMA in comparison with the maximum DBTºC in the barns during each month, which was in contrast to the experiments conducted on a commercial dairy farm in Sachsen Anhalt, Germany by Schüller et al., (2013), in a commercial dairy farm in Ontario, Canada (Shock et al., 2016), and dairy farm in Québec, Canada (Ouellet et al., 2019). They reported the DBTºC was higher in the barn versus with nearest meteorological stations. Probably, the geographical distance (2.5 km) between KMA and the barns was a reason for not detecting significant differences in maximum DBTºC at KMA with the barns in the present study. Furthermore, circulating fans inside the barns increased airflow across the cows and ventilation system removed the heat, moisture and replenish by cooler outside air in the cattle barns during hot weather months.

However, minimum RH% at KMA (41.9 ± 2.6) was significantly lower ($p < 0.05$) than the barn 1 (49.5 ± 2.1) and barn 3 (48.3 ± 1.9) in June and no significant difference ($p > 0.05$) was observed in July. The result indicated that the minimum RH% at KMA (51.1 ± 1.9) was lower ($p < 0.05$) than minimum RH% data of the barn 1 (61.2 ± 1.4) in August. Additionally, the minimum RH% at KMA (49.5 ± 2.5) was lower ($p < 0.05$) than barn 1 (60.7 ± 2.5) and barn 3 (59.9 ± 3.0) in the September. The Hobo logger was positioned at approximately 1.5 m from the ground near to the entrance of barn 1, which was a cooler area of the building due to entering the fresh air flowing inside of the barn 1, may make higher minimum RH% of the barn1 versus KMA. Moreover, the type of

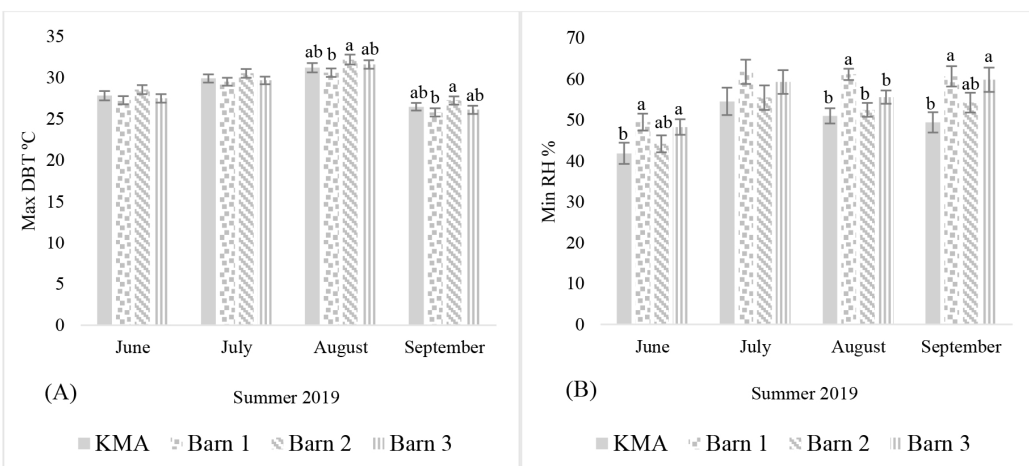

Fig. 3. (A) Comparison of maximum dry bulb temperature (DBT℃) and (B) comparison of minimum relative humidity (RH%) at the Korea meteorological administration (KMA) with the maximum DBT℃ barns during summer months on June, July, August, and September in 2019. Error bars were represented standard error of the mean. The different letters above the error bars display significant differences for each month ($p < 0.05$)

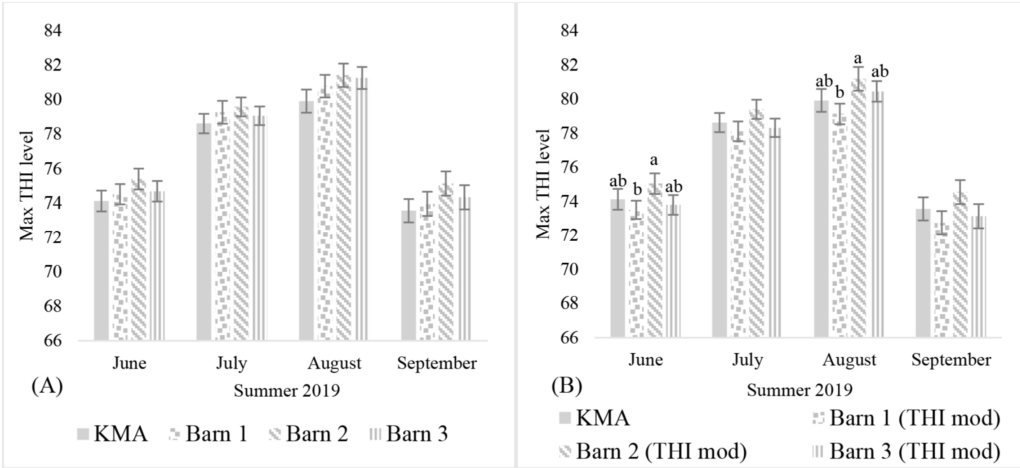

Fig. 4. (A) Comparison of maximum temperature-humidity index (THI) level and (B) comparison modification of maximum THI of the barns which was calculated by combination of maximum DBT℃ data of barns and minimum RH% data of KMA (THI mod), between the Korea meteorological administration (KMA) and the barns during summer months, June, July, August, and September in 2019. Error bars were represented standard error of the mean. Comparison maximum THI was not significant difference in each month ($p > 0.05$)

Table 1. Comparison between maximum temperature-humidity index (THI) of the barns and modification of maximum THI of the barns (THI mod), which was calculated by combination of maximum DBT℃ data of barns and minimum RH% data of KMA during summer months, June to September in 2019

Date	Barn 1		Barn 2		Barn 3	
	[a] THI	[b] THI mod	[a] THI	[b] THI mod	[a] THI	[b] THI mod
June	74.5 ± 0.6	73.5 ± 0.5	75.4 ± 0.6	75.0 ± 0.6	74.7 ± 0.6	73.8 ± 0.6
July	79.3 ± 0.7	78.1 ± 0.6	79.6 ± 0.5	79.4 ± 0.6	79.1 ± 0.5	78.3 ± 0.5
August	80.8 ± 0.7	79.1 ± 0.6	81.4 ± 0.7	81.2 ± 0.7	81 ± 0.6	80.4 ± 0.6
September	74.0 ± 0.7	72.7 ± 0.7	75.1 ± 0.7	74.6 ± 0.7	74.3 ± 0.7	73.1 ± 0.7

[a] $THI = (1.8 \times Max\ DBT^{o}C_{Barns} + 32) - [(0.55 - 0.0055 \times Min\ RH\%_{Barns}) \times (1.8 \times Max\ DBT^{o}C_{Barns} - 26)]$.
[b] $THI\ mod = (1.8 \times Max\ DBT^{o}C_{Barns} + 32) - [(0.55 - 0.0055 \times Min\ RH\%_{KMA}) \times (1.8 \times Max\ DBT^{o}C_{Barns} - 26)]$.
± Standard Error of the Mean (SEM).

barn 1 was a closed-sidewalls and contained ventilating system by fans that may result in higher the minimum RH% of the barn 1 than KMA. Our result in agreement with finding from Schüller et al. (2013), who measured higher RH% inside the barns compared with meteorological station and disagreement with the previous study that observed RH% inside the barns was lower than the local meteorological station (Shock et al., 2016; Ouellet et al., 2019). Another explanation of higher RH% inside the barn can be from the three main processes by cattle including convection, conduction, and radiation caused releasing of heat and humidity to the environment (Silanikove, 2000; Gernand et al., 2019). Moreover, dairy cattle are able to evaporate water up to 1.5 kg/h (Berman et al., 1985; Gernand et al., 2019), may be result the high RH% inside the barns during hot months. The cattle bed changing or cleaning process (Gernand et al., 2019) was a possible reason why minimum RH% was higher in the barns compared with extracted minimum RH% from KMA.

The maximum of DBTºC and minimum RH% data were derived from KMA used to calculate maximum THI and compared with maximum THI measured by microclimate data within the barns, and also with maximum THI-modified (combination of maximum DBTºC data of barns and minimum RH% data of KMA) of the barns from June to September 2019 (Fig. 4(A) and 4(B)).

Our result showed that the maximum THI calculated by KMA data was not significant difference ($p > 0.05$) with the maximum THI from the microclimate data of barns in each month. The results of maximum THI calculation in this study was in disagreement with other studies (Schüller et al., 2013; Shock et al., 2016; Ouellet et al., 2019), that previously compared THI levels of cattle farm with local meteorological station. They observed the barn's THI level was higher than official meteorological stations. Scanavez et al., (2016) explained that calculation of THI using DBTºC and RH% collected from the barns was more accurate than measuring THI from data of the meteorological station. Several factors may influence THI level including the number of cattle at the barns, the ventilation system of the barns, etc, however, the reason why maximum THI at KMA versus inside the barns showed no significant difference in each months could be due to well management of the barns by providing sufficient and properly fans and ventilation system to reduce the cattle's heat load during hot weather months. Moreover, maximum DBTºC between inside the barns and KMA was not different, which resulted no significant difference in maximum THI levels.

In this study, maximum THI of each barn based on maximum DBTºC and minimum RH% inside of the barn were compared with maximum THI modified of each barn during warm months in 2019 (Table 1). Maximum THI level calculated by microclimate data of the barns were higher than level of THI mod of the barns, but the differences were not detected significantly.

No significant differences ($p > 0.05$) were observed in comparison of maximum THI based on the microclimate data of each barn and THI mod of each barn in each month. In this study we aimed to find whether it was accurate to use RH% data from KMA to combine with the DBT°C data of the barns in order to calculate THI

Table 2. Correlations for maximum THI, maximum THI-mod (combination of maximum DBT℃ data of barns and minimum RH% data of KMA) in three barns, and KMA from June to September in Summer 2019

	Barn		
	1	2	3
[a] Max THI			
Barn	77.2 ± 4.6	77.9 ± 4.4	77.4 ± 4.5
KMA	76.6 ± 4.4	76.6 ± 4.4	76.6 ± 4.4
[#] Difference	-0.6 ± 1.3	-1.3 ± 0.8	-0.8 ± 0.7
Correlation	0.96	0.98	0.99
[b] Max THI mod			
Barn	75.9 ± 4.3	77.6 ± 4.5	76.5 ± 4.5
[c] KMA	76.6 ± 4.4	76.6 ± 4.4	76.6 ± 4.4
[#] Difference	0.7 ± 1.1	-1.0 ± 08	0.1 ± 0.9
Correlation	0.97	0.98	0.98

[a] Max THI = $(1.8 \times \text{Max DBTºC}_{\text{Barns}} + 32) - [(0.55 - 0.0055 \times \text{Min RH\%}_{\text{Barns}}) \times (1.8 \times \text{Max DBTºC}_{\text{Barns}} - 26)]$.
[b] Max THI mod = $(1.8 \times \text{Max DBTºC}_{\text{Barns}} + 32) - [(0.55 - 0.0055 \times \text{Min RH\%}_{\text{KMA}}) \times (1.8 \times \text{Max DBTºC}_{\text{Barns}} - 26)]$.
[c] Korea Meteorological Administration (KMA)
± Standard Deviation.
[#] Difference between KMA and the barns

indicator of heat stress in Hanwoo cattle. The results showed that calculation of maximum THI modification based on combination of microclimate data of the barns and KMA compared with the maximum THI measured based on microclimate data of KMA was not different significantly, neither compared with maximum THI calculated by microclimate data of the barns.

Table 2 presents the Pearson's coefficient of correlation between maximum THI based on KMA microclimate data and the barns. The correlation between maximum THI based on KMA microclimate data and the barn1 ($r = 0.96$), barn 2 ($r = 0.98$), and barn 3 ($r = 0.99$) was observed. The results of correlation between maximum THI based on KMA data and maximum THI- modified were observed as the barn1 ($r = 0.97$), barn 2 ($r = 0.98$), and barn 3 ($r = 0.98$).

In this study, we compared microclimate data at the KMA with the Hanwoo barns for the first time in order to find a proper THI calculation for evaluating environmental condition of cattle barns. There was 2.5 km distance between KMA of Chuncheon city and Hanwoo barns, without any differences in climatic condition. The positive correlation between maximum THI calculation based on microclimate data of KMA and the three barns may be due to the short distance (2.5 km) between the KMA and Hanwoo barns.

4. Conclusions

In spite of the fact that the minimum RH% of KMA was lower than the barns, a similar THI was detected in the KMA and barns, possibly due to the slight difference in maximum DBT°C between the KMA and barns. Overall, the microclimate information from the KMA can be used as effective as barns microclimate data for THI calculation. We recommend in the absence of microclimatic RH% data on the cattle barn, using RH% data provided by KMA as an effective way of regulating THI inside the cattle farm.

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