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Effects of Air Temperature and Relative Humidity on Milk Yield of Holstein Dairy Cattle Raised in Hot-Dry Southeastern Anatolia Region of Türkiye

Orhan DEMİR, Kemal YAZGAN*

Department of Animal Science, Faculty of Agriculture, Harran University, 63300, Sanliurfa, Türkiye

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Corresponding Author: Kemal YAZGAN, E-mail: kemalyazgan@gmail.com
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ABSTRACT

The aim of this study is to investigate the possibility of using meteorological data obtained from a public meteorology station in determining the effect of air temperature and relative humidity on milk yield in Holstein dairy cattle raised in Diyarbakir province of Türkiye. Records on daily milk yield obtained from a commercial farm were used in the study. Meteorological records including daily maximum and minimum temperatures and daily maximum and minimum humidity data were obtained from the nearest public weather station. A total of 185 healthy Holstein dairy cattle, with five different lactation parities, as well as details on some environmental conditions such as, year, month, lactation period, weather temperature, and the humidity that the animals are exposed to are included in the dataset relating to milk production. Five different temperature-humidity index variants, including THI_a (maximum temperature and humidity), THI_b (minimum temperature and humidity), THI_c (average temperature and humidity), THI_d (maximum temperature and minimum humidity), and THI_e (minimum temperature and maximum humidity), were considered to evaluate the effect of heat stress on milk production. The critical values at which the milk yield began to decrease due to heat stress in this study slightly deviated from the critical value of 72, which is accepted as the threshold value for the start of heat stress and determined as 77, 54, 64, 69, and 54 for THI_a, THI_b, THI_c, THI_d, and THI_e, respectively. Based on these values, the loss of milk production of one cow per year was calculated as 98.25, 157.68, 207.36, 164.30, and 190.08 kg when using THI_a, THI_b, THI_c, THI_d, and THI_e, respectively. This study confirmed that weather stations located away from farms provide useful information for research on heat stress in dairy cows. It can be concluded that THI_d, which shows the least deviation from the critical value of 72 (only 3 unit), better reflects the stress condition that animals are exposed to due to temperature and humidity. For this reason, the highest daily air temperature and lowest daily humidity appear to be the most important factors in this investigation to assess heat stress and both variables can be combined into a THI.

Keywords: Heat stress, Temperature-humidity index, Milk production loss, Meteorological data

1. Introduction

Climatic conditions are known to affect the welfare of farm animals and their productivity (Hill & Wall 2015). Climatic change, which occurs with the deterioration of the atmospheric synthesis on a global scale, is widely considered to be one of the biggest threats facing the planet. Climate models predict a temperature rise of 0.3 to 4.8 °C over the next century (Wankar et al. 2021) and this continual rise in temperature will have a serious impact upon food production and farming.

In many species, including cattle, the body temperature is constant. In order for the body temperature to remain constant, there is a balance that compensates for the increase in body temperature depending on the increase in ambient temperature. A disruption of this balance is referred to as heat stress (West 1994). Radiation, convection, and conduction are less effective in dissipating body heat in cattle when the ambient temperature reaches their body temperature. In order to maintain a stable body temperature, more moisture must be removed from the skin via evaporation and a higher respiratory rate (high panting score) is necessary (Kadzere et al. 2002). In addition, high relative humidity (RH) reduces the efficiency of evaporative cooling. As a result, a high ambient temperature combined with a high humidity level reduces the cooling capacity and causes the body temperature to rise (West 1994), resulting in significant milk yield losses (Herbut & Angrecka 2012; Konyves et al. 2017; Gantner et al. 2017; Yazgan 2017). Moreover, heat stress negatively affects performance not only for dairy cattle but also for beef cattle (Yazgan et al. 2013).

The effect of heat stress on test-day milk yield can be described as a function of four variable groups or variables (Ravagnolo et al. 2000). The first of these groups is highest, average, or lowest temperature and humidity values during the 24 hour-period prior to milk yield recording. Second is heat stress measures (e.g. fan, shading, and sprinkler applications), third is duration of current heat stress and finally duration of previous heat stress. There are many methods to quantify heat stress and the simplest of these is the temperature-humidity index (THI), calculated by the combination of temperature and humidity into one value and defined by several formulas (Thom 1959; Bianca 1962; NRC 1971; Leonard 1985; Mader et al. 2006).

Ravagnolo et al. (2000) reported that meteorological data obtained from public weather stations contain useful information for studies on heat stress in dairy cattle, since daily yields are affected by weather conditions and they reflect the effect of weather temperature and humidity. This means that the impact of heat stress on animals can be determined when weather conditions, such as temperature and humidity, prior to the test days are recorded. Another important problem encountered while calculating the effect of heat stress on animals is deciding which values to consider as the maximum, minimum, or average temperature and humidity variables while calculating THI. Because the temperature and humidity values do not remain constant throughout the day, they change constantly, and it may not always be appropriate to only use average values.

A significant amount of cattle milk production is carried out in the Diyarbakir province of Türkiye. Since, however, the province is one of the hottest regions of Türkiye, milk production is adversely affected. In the summer seasons, in particular, temperatures can reach as high as 46 °C (Kallioglu et al. 2015). Accordingly, the average daily maximum air temperature is around 37 °C, which negatively affects milk production due to heat stress.

This study (1) investigates the relationship between milk production and air temperature and RH in Holstein dairy cattle raised in Diyarbakir province of Türkiye by using publicly available weather information and (2) calculates milk yield losses that occur due to heat stress.

2. Material and Methods

2.1. Data

The milk production data were obtained from a modern commercial dairy cattle farm located in Diyarbakir. The farm is located at 37°59'03" N latitude and 40°21'37" E longitude, with the altitude of 665 meters. The cattle were kept in an open-system free stall barn, fed ad libitum, had free access to water, and were milked three times a day with their yield recorded by an automatic milking system. Each cow had at least total 270 records to be part of the analysis. Records with milk production <8 kg or >50 kg, daily records of animals during the first four days of lactation and those after 350th day for extended lactations were eliminated from the data set. There were five parities in lactation records for daily milk yields and only one lactation record (non-repeated observation) for each cow. Weather data included daily maximum, minimum and average temperature, and humidity were obtained from the public weather station located in Diyarbakir that belongs to the Turkish State Meteorological Service authorised by Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye. While the distance between the weather station and the farm was 15.32 km as a straight line (crow flies), the altitude difference between the farm and the weather station was only 15 m.

The formula proposed by Mader et al. (2006) is highly correlated with the panting score. For this reason, the formula given below (Eq. 1) was used for THI calculations in this study.

$$THI = (0.8 \times T) + [(RH / 100) \times (T - 14.4)] + 46.4 \quad (1)$$

Where;

THI : Temperature humidity index;

T : Dry bulb weather temperature (°C);

RH : Relative humidity (%).

According to this formula, heat stress in dairy cattle begins when the THI value reaches 72, which corresponds to 100% humidity at 22 °C, 50% humidity at 25 °C or 20% humidity at 28 °C. Using combinations of maximum, minimum or average temperature and humidity value with this equation THI_a (maximum temperature and humidity), THI_b (minimum temperature and humidity), THI_c (average temperature and humidity), THI_d (maximum temperature and minimum humidity) and THI_e (minimum temperature and maximum humidity) were calculated daily. Figure 1 shows all calculated THI variants for each day of the year (averaged over 3 years) for the present data set. Each test-day record was assigned the daily THI_a, THI_b, THI_c, THI_d, and THI_e values of the previous days and put together with the daily milk production data. Final data comprised 46 438 various parity daily records of milk collected from 2018 through 2020 from 185 healthy Holstein dairy cattle (Tables 1, 2).

Table 1- Descriptive statistic of milk production data

			Milk yield (kg)	
OLP	***N***	***n***	***Mean***	***SD***
1	26	6,834	27.55	7.17
2	36	8,655	30.86	8.02
3	64	16,150	29.03	9.77
4	51	12,590	28.64	9.12
5	8	2,209	27.29	7.64
Total	185	46,438	28.96	8.89

Order of lactation parity (Each animal has only one lactation record), N: Number of lactations, n: number of daily milk yield records, SD: Standard deviation

Table 2- Means and standard deviations of milk yield and THI on the farm by months between 2018 and 2020

	Milk yield (kg)			THI_a		THI_b		THI_c		THI_d		THI_e	
Month	***n***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
January	5,324	29.61	6.43	47.32	6.08	39.95	4.05	42.86	4.45	49.15	5.31	35.28	4.76
February	4,804	26.96	6.63	52.25	3.79	42.81	2.52	46.42	2.56	53.35	3.65	37.38	3.78
March	4,949	24.35	6.58	57.02	5.57	45.70	3.40	50.26	3.54	56.77	4.55	41.39	3.92
April	3,949	23.00	6.00	64.64	5.56	50.02	2.62	56.06	3.28	62.25	3.58	46.91	3.22
May	3,110	20.97	5.66	79.77	6.60	57.44	3.55	66.46	4.32	71.64	3.88	57.16	5.20
June	2,054	19.15	5.95	86.55	2.72	64.08	2.11	73.81	1.95	78.07	1.66	66.48	2.69
July	1,420	18.59	5.77	85.13	2.95	66.36	1.94	74.67	1.83	78.73	1.91	68.92	2.24
August	597	17.81	5.96	86.75	2.94	68.44	1.51	76.67	1.30	80.35	1.61	71.08	1.71
September	4,460	35.95	7.44	82.82	2.52	62.14	2.00	71.20	1.65	76.04	1.74	63.79	2.53
October	5,333	36.15	7.02	74.51	6.07	57.64	3.59	64.99	4.37	69.99	4.32	57.25	5.56
November	5,129	34.81	7.13	60.89	6.50	48.30	3.45	53.47	3.93	59.52	4.71	45.18	4.22
December	5,309	32.64	6.83	50.86	5.38	42.80	4.98	46.39	4.86	51.70	5.07	40.21	5.37

n: Number of observations, SD: Standard deviation

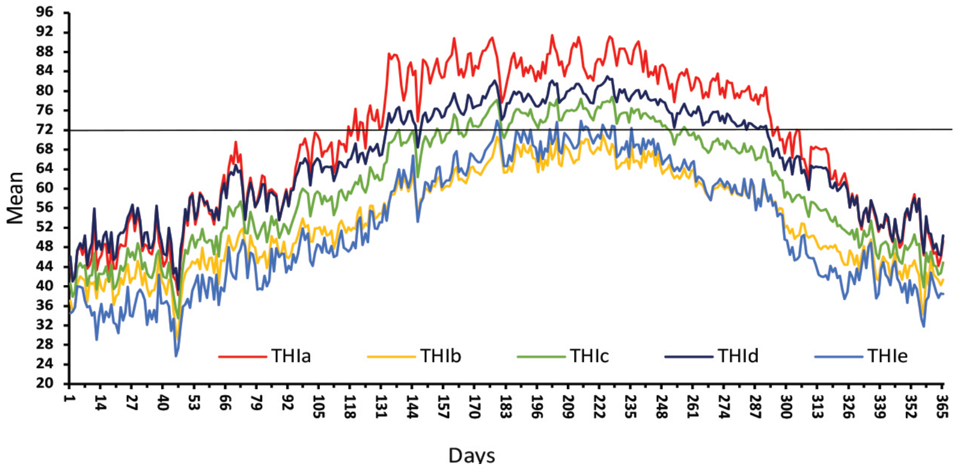

Figure 1- Three-year (2018-2020) average of THI values

2.2. Statistical analysis

The following statistical model (equation 2) was used to calculate the least square means of daily milk yield by THI variants. Since there were no repeated observations of any animals in the dataset, an element of the individual effects of animals was not added to the model.

$$Y_{ijkl} = olp_i + (ym_j) + dim_k + THI_l + e_{ijkl} \quad (2)$$

Where:

Y_{ijkl} : Daily milk yield for parity i, year-month j, days in milk class k and THI variant class l;

olp_i : Effect of order of lactation parity (Each animal has only one lactation record and i=1, 2, 3, 4 and 5);

$(ym)_j$: Year effect (2018, 2019 and 2020) nested with month (j=1 to 23);

dim_k : Days in milk class (k=1 for 5 to 35, k=2 for 36 to 65, k=3 for 66 to 95, k=4 for 96 to 125, k=5 for 126 to 155, k=6 for 156 to 185, k=7 for 186 to 215, k=8 for 216 to 245, k=9 for 246 to 275, k=10 for 276 to 305 and k=11 for >305);

THI_l : Temperature-humidity effect (l= 38 to 91 for THI_a, l=33 to 71 for THI_b, l= 35 to 78 for THI_c, l= 43 to 82 for THI_d and l= 31 to 74 for THI_e);

e_{ijk} : Random residual effect.

In order to calculate the milk yield losses, a similar approach was used as reported by Ravagnolo et al. (2000) and formulated for all THI variants as follows (equation 3);

$$MYL = [(THI_m - THI_{cr}) \times d] \times [(Y_1 - Y_2)/u] \quad (3)$$

Where:

MYL : Milk yield loss (kg) in stress zone;

THI_m : Average THI value of the interval when milk yield starts to decrease and reaches the minimum value;

THI_{cr} : Critical THI value at which milk yield starts to decrease, d is the number of days over the critical THI value (calculated from Figure 1);

Y_1 : Least squares mean of milk yield at the critical THI value;

Y_2 : Least squares mean of milk yield corresponding to THI_m;

u : Total THI unit between heat stress periods.

All analyses were conducted with the GLM procedure of SAS (2000).

2. Results and Discussion

The number of observations, mean milk yield, and standard deviation for each month of the three years are shown in Table 2. The milk yield average is the lowest (17.81±5.96 kg) in August when THI_a, THI_b, THI_c, THI_d and THI_e values reach their highest values.

The estimated values for the coefficients of determination (R^2), sums of squares (SS), and mean square errors (MSE) for the THI variants are provided in Table 3. All fixed effects in the model (equation 2) were statistically significant ($p<0.05$) for all analyses. As shown in Table 3, R^2, SS and MSE values of THI variants were determined to be very close to each other. The R^2 value of THI_e was the highest (0.4599) whereas the R^2 value of THI_a was the lowest (0.4544). Furthermore, THI_b had the lowest MSE value (43.19).

Table 3- Coefficient of determination (R^2) and sums of squares (SS) and mean square error (MSE) for THI variants

Variant	*Combination*	*R^2*	*SS*	*MSE*
THI_a	Maximum temperature and humidity	0.4544	1 666 867	43.25
THI_b	Minimum temperature and humidity	0.4567	1 671 744	43.19
THI_c	Average temperature and humidity	0.4573	1 669 838	43.22
THI_d	Maximum temperature and minimum humidity	0.4585	1 665 540	43.25
THI_e	Minimum temperature and maximum humidity	0.4599	1 671 773	43.31

3.1. Milk yield levels for THI variants

3.1.1. THI_a

Figure 2 shows the change of least square means of the milk yields by the values of THI variants. The THI_a values obtained by using the maximum temperature and maximum humidity were in the range of 38-91, and this range was the largest of all THI variants (54 units). As shown in Figure 2 and Table 4, there were fluctuations in the least square means of the milk yields, ranging from 38 to 77. When the THI_a value exceeded 77, the milk yield began to decrease, but increased slightly after 87. In this range, the milk yields decreased from 26.64±0.318 kg to 25.33±0.385 kg and the difference was 1.31 kg ($p<0.05$). However, least square means of milk yields began to decrease at the point THI 77 instead of the critical value previously stated 72.

3.1.2. THI_b

As indicated in Figure 2 and Table 4, all possible THI_b values lies in the range of 33-71 since daily minimum temperature and minimum humidity values were used in its calculation. The lowest milk yield was obtained (24.82±0.432 kg) when THI_b was equal to 34. Between 34 and 54 THI_b values, continuous fluctuations were observed in the milk yields. However, after the 54 THI_b value, there was a continuous decrease in milk yields to 67 THI_b value. When THI_b was 54, the milk yield was 26.95±0.408 kg; however, when THI_b value reached to 67 the milk yield decreased to 25.19±0.533 kg and the difference was 1.76 ($p<0.05$) due to heat stress.

3.1.3. THI_c

As indicated in Figure 2 and Table 4, THI_c values were calculated accepting that daily average temperature and humidity values ranged between 35-78. Accordingly, the threshold THI_c value at which the milk yield started to decrease continuously was determined as 64, far behind the critical value (THI=72). The milk yield tended to increase despite fluctuating values from the point where the THI_c was 35 to 64, but after this point it decreased rapidly and reached minimum at the 78 point. While the THI_c value was equal to 64, the milk yield was 27.44±0.510 kg. When the THI_c value increased to 78, decreased to 25.19±0.486 kg and the difference was 2.25 ($p<0.05$).

3.1.4. THI_d

THI_d values calculated by considering daily maximum temperature and minimum humidity values were in the range of 43-82 as observed in Figure 2 and Table 4. This range (39 units) was not found to be larger than THI_a. However, the threshold THI_d value at which the milk yield began to continuously decrease was determined as 69 and was very close to the critical value (THI=72). In other words, THI_d had the least deviation from the critical value by 3 units. Although the THI_d values fluctuated from 43 to 69, the milk yield tended to remain constant in this range, but after this point, it decreased rapidly and reached a minimum at the 82. When the THI_d value reached 69, the milk yield was 27.08±0.398 kg. When the THI_d value increased to 82, the milk yield decreased to 25.43±0.442 kg and the difference was 1.65 ($p<0.05$).

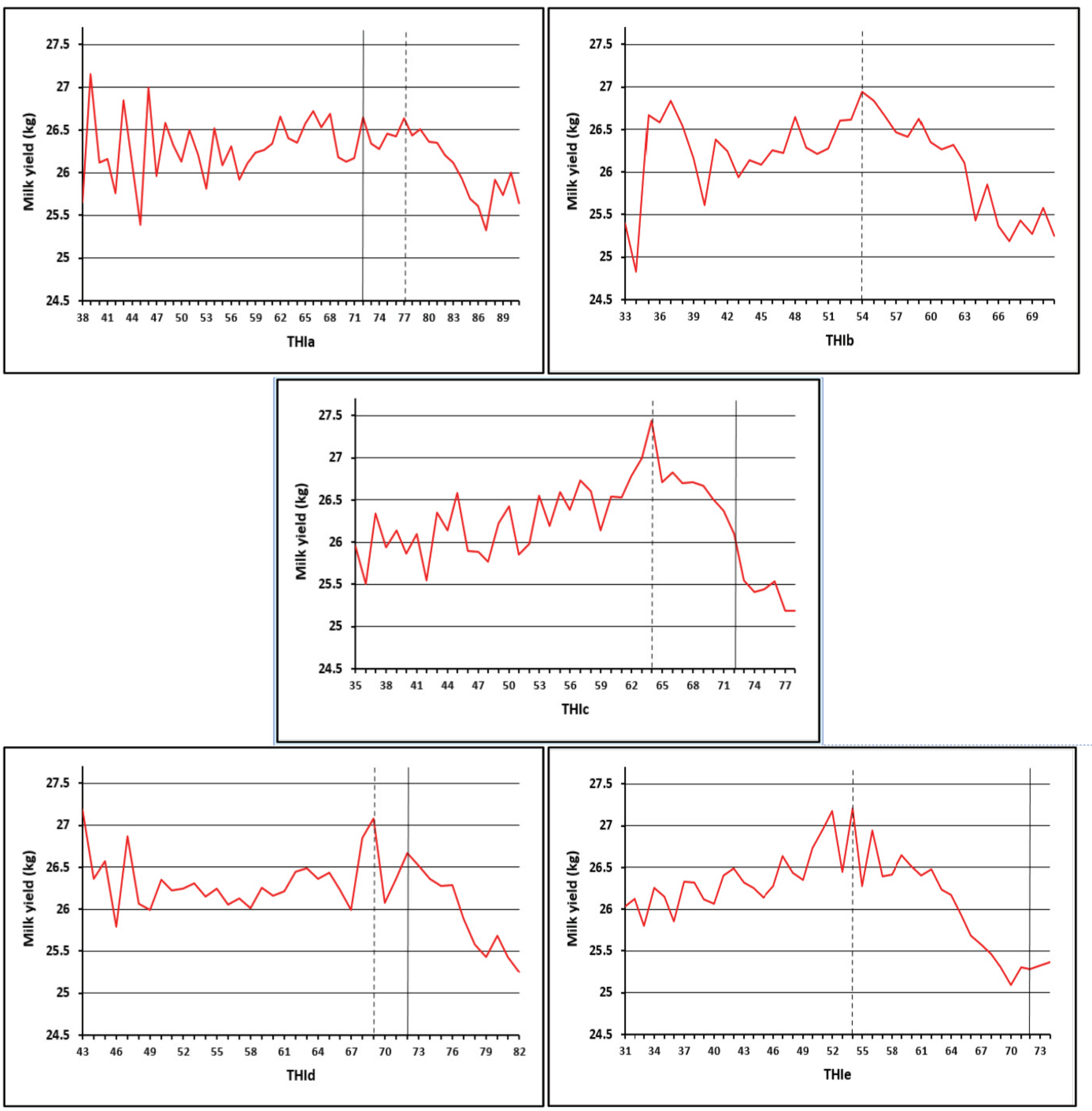

Figure 2- Least square means of milk yields by THI variants. Vertical lines show the critical THI value (72) while the dashed vertical lines show the THI value where milk yield starts to decrease continuously

Table 4- Least square means and standart errors of milk yields by THI variants*

THI	*Milk yield (kg)*														
	THI_a			*THI_b*			*THI_c*			*THI_d*			*THI_e*		
	n	*Mean*	*SE*	*n*	*Mean*	*SE*	*n*	*Mean*	*SE*	*n*	*Mean*	*SE*	*n*	*Mean*	*SE*
31	-	-	-	-	-	-	-	-	-	-	-	-	517	26.03	0.375
32	-	-	-	-	-	-	-	-	-	-	-	-	850	26.13	0.327
33	-	-	-	171	25.39	0.558	-	-	-	-	-	-	1,199	25.80	0.301
34	-	-	-	339	24.82	0.432	-	-	-	-	-	-	1,192	26.25	0.303
35	-	-	-	859	26.67	0.337	341	25.96	0.468	-	-	-	1,381	26.15	0.309
36	-	-	-	515	26.58	0.372	339	25.50	0.437	-	-	-	1,163	25.85	0.298
37	-	-	-	521	26.84	0.380	177	26.34	0.561	-	-	-	1,355	26.33	0.288
38	339	25.65	0.436	523	26.54	0.389	696	25.94	0.371	-	-	-	1,500	26.32	0.285
39	177	27.16	0.669	1,009	26.16	0.307	676	26.14	0.356	-	-	-	1,331	26.12	0.289
40	512	26.12	0.385	1,191	25.61	0.295	518	25.86	0.383	-	-	-	1,487	26.07	0.281
41	528	26.16	0.398	1368	26.38	0.293	510	26.09	0.396	-	-	-	1,669	26.40	0.280
42	174	25.76	0.561	2,,657	26.24	0.261	851	25.54	0.343	-	-	-	3,753	26.49	0.247
43	513	26.84	0.392	1,874	25.94	0.275	1177	26.35	0.311	339	27.19	0.440	1,478	26.32	0.273
44	680	26.08	0.352	2,495	26.14	0.260	1184	26.14	0.308	678	26.36	0.349	1,917	26.25	0.253
45	497	25.39	0.386	2,208	26.09	0.262	1373	26.58	0.309	178	26.57	0.553	1,022	26.14	0.304
46	858	27.00	0.334	1,657	26.26	0.278	2061	25.90	0.288	527	25.79	0.368	1,747	26.28	0.269
47	1,027	25.95	0.328	2,125	26.22	0.259	2345	25.89	0.281	849	26.87	0.344	1,764	26.64	0.270
48	826	26.58	0.336	2,789	26.64	0.246	1465	25.77	0.294	1,517	26.06	0.297	1,289	26.43	0.296
49	1,839	26.32	0.286	2,133	26.29	0.256	1216	26.23	0.307	1,167	25.99	0.302	1,207	26.35	0.279
50	683	26.12	0.347	1,864	26.21	0.253	1851	26.43	0.284	1,343	26.35	0.302	745	26.73	0.328
51	1,204	26.50	0.313	1,489	26.28	0.275	2659	25.85	0.265	850	26.22	0.329	674	26.95	0.333
52	1,182	26.20	0.306	1,497	26.61	0.267	2206	25.98	0.270	1,176	26.24	0.312	170	27.17	0.554
53	1,027	25.82	0.314	613	26.61	0.338	1424	26.55	0.285	1,357	26.31	0.293	272	26.45	0.466
54	1,985	26.52	0.276	352	26.95	0.408	1393	26.19	0.297	2,022	26.15	0.276	173	27.21	0.551
55	2,212	26.09	0.280	307	26.84	0.433	1252	26.60	0.286	1,687	26.24	0.281	354	26.28	0.424
56	1,320	26.31	0.297	465	26.66	0.377	955	26.38	0.300	2,196	26.05	0.275	499	26.94	0.375
57	861	25.91	0.331	1,359	26.46	0.284	590	26.73	0.335	1,693	26.13	0.281	1,088	26.39	0.304
58	1,313	26.11	0.297	1,298	26.42	0.293	1383	26.61	0.278	1,475	26.02	0.287	1,079	26.41	0.307
59	1,938	26.23	0.272	1,411	26.63	0.282	1019	26.14	0.315	2,187	26.25	0.262	823	26.65	0.323
60	1,350	26.27	0.280	1,748	26.35	0.272	419	26.54	0.417	1,693	26.16	0.268	1,050	26.51	0.308
61	755	26.34	0.328	2,488	26.26	0.267	1297	26.53	0.284	578	26.21	0.352	1,387	26.41	0.292
62	305	26.66	0.437	1,153	26.31	0.304	389	26.78	0.405	1,523	26.45	0.270	1,200	26.48	0.301
63	602	26.40	0.351	1,384	26.11	0.315	280	26.99	0.454	1,888	26.48	0.262	1,780	26.24	0.291
64	1,180	26.35	0.282	959	25.43	0.329	219	27.44	0.510	949	26.36	0.300	982	26.17	0.327
65	1,572	26.58	0.273	1,091	25.85	0.327	518	26.71	0.375	574	26.43	0.362	938	25.93	0.346
66	345	26.72	0.431	863	25.37	0.351	391	26.83	0.402	847	26.23	0.318	792	25.68	0.346
67	471	26.53	0.376	261	25.19	0.533	992	26.70	0.311	806	25.99	0.322	903	25.57	0.343
68	446	26.69	0.383	378	25.43	0.474	1549	26.71	0.284	961	26.85	0.303	640	25.46	0.404
69	940	26.18	0.320	340	25.28	0.498	1224	26.67	0.302	396	27.08	0.398	788	25.30	0.360
70	416	26.13	0.386	247	25.57	0.550	1829	26.51	0.290	458	26.08	0.383	291	25.09	0.509
71	256	26.17	0.473	92	25.25	0.751	2228	26.38	0.294	268	26.36	0.457	338	25.30	0.487
72	454	26.64	0.380	-	-	-	1287	26.09	0.324	1,287	26.67	0.288	305	25.28	0.516
73	235	26.34	0.474	-	-	-	914	25.55	0.359	1,817	26.52	0.273	162	25.32	0.630
74	791	26.28	0.343	-	-	-	886	25.41	0.371	632	26.36	0.345	137	25.37	0.643

Table 4- continued

THI	Milk yield (kg)														
	THI_a			THI_b			THI_c			THI_d			THI_e		
	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
75	812	26.46	0.312	-	-	-	890	25.44	0.361	2,243	26.28	0.283	-	-	-
76	618	26.43	0.352	-	-	-	780	25.54	0.410	2,440	26.28	0.304	-	-	-
77	893	26.64	0.318	-	-	-	276	25.18	0.514	1,317	25.88	0.343	-	-	-
78	423	26.43	0.395	-	-	-	372	25.19	0.486	1,041	25.57	0.343	-	-	-
79	688	26.51	0.336	-	-	-	-	-	-	1,332	25.43	0.338	-	-	-
80	1,402	26.36	0.283	-	-	-	-	-	-	444	25.69	0.448	-	-	-
81	663	26.35	0.350	-	-	-	-	-	-	517	25.43	0.442	-	-	-
82	1,598	26.20	0.298	-	-	-	-	-	-	284	25.25	0.513	-	-	-
83	1,775	26.12	0.296	-	-	-	-	-	-	-	-	-	-	-	-
84	1,092	25.92	0.321	-	-	-	-	-	-	-	-	-	-	-	-
85	1,160	25.70	0.322	-	-	-	-	-	-	-	-	-	-	-	-
86	839	25.61	0.335	-	-	-	-	-	-	-	-	-	-	-	-
87	543	25.33	0.385	-	-	-	-	-	-	-	-	-	-	-	-
88	1,037	25.92	0.330	-	-	-	-	-	-	-	-	-	-	-	-
89	485	25.73	0.388	-	-	-	-	-	-	-	-	-	-	-	-
90	238	26.00	0.494	-	-	-	-	-	-	-	-	-	-	-	-
91	281	25.64	0.486	-	-	-	-	-	-	-	-	-	-	-	-

*Due to the large number of means, it is not possible to show which means in the same column are statistically different from each other. Instead, some important statistical differences were noted in the text. Furthermore, the milk yield increases from light yellow to dark yellow in all columns. n: Number of observations, SE: Standard error

3.1.5. THI_e

As shown in Figure 2 and Table 4, THI_e values calculated based on average temperature and humidity values ranged between 31 and 74. The threshold THI_e value at which the milk yield started to continuously decrease was determined as 54, and it was below the critical value (THI=72), similar to THI_c and THI_d. However, THI_e had the greatest deviation from the critical value among all variants by 18 units. Even though the THI_e had fluctuating values of 31 to 54, the milk yield tended to increase in this range. After that point, however, it rapidly decreased and reached a minimum at 70 points. While the THI_e value was equal to 54, the milk yield was 27.21±0.551 kg. When the THI_e value increased to 70, the milk yield decreased to 25.09±0.509 kg and the difference was 2.12 ($p<0.05$).

3.2. Milk yield loses for THI variants

THI_a values, obtained by using the maximum temperature and maximum humidity, were in the range of 38-91 and the stress zone in the range of 77-87 (Figure 2, Table 4). The difference between the two values is 10 units. If a THI_a of 77 was considered to cause heat stress, then the cattle would be under heat stress for more than one third of the year. On average, Diyarbakir had 125 THI_a days per year with values ranges from 77 to 87 (Figure 1), and the mean THI_a on these days was 83. The difference between the two values is 6 units. This means that a lactating cow during that entire period would be exposed to 750 units (6x125) of THI_a over the comfort zone (Equation 3). As a result, cows lose a production equal to 750 units. So, the loss of milk production of one cow per year because of heat stress would be 98.25 kg with a loss of 0.07 kg (98.25/125=0.78 and 0.78/10=0.07) per unit of THI_a greater than 77. Similarly, the losses of milk yields for one cow per year during heat stress periods were calculated as 157.68, 207.36, 164.30 and 190.08 for THI_b, THI_c, THI_d, and THI_e, respectively. In addition, the losses of milk production per unit of THI greater than the threshold were 0.08, 0.09, 0.07, and 0.08 kg for THI_b, THI_c, THI_d, and THI_e, respectively (Table 5).

Table 5- Heat stress characteristics and milk yield losses in the examined cow population

Parameters	THI_a	THI_b	THI_c	THI_d	THI_e
Heat stress period (days)	125	146	162	163	144
THI range for heat stress period	77-87	54-67	64-78	69-82	54-70
Average THI during the heat stress period	83	62	72	77	64
Losses (kg/per cow)					
Loss of milk yield during heat stress period	98.25	157.68	207.36	164.30	190.08
Loss of milk yield per unit THI increase	0.07	0.08	0.09	0.07	0.08

As mentioned earlier in Table 3, all R^2 values were around 0.45, indicating that almost half of the yield variation was explained by the model, including weather variables. However, THI_d and THI_e combinations containing extreme values together (maximum and minimum) have slightly higher coefficients of determination than the others. Ravagnolo et al. (2000) reported that while the amount of moisture in the air was constant, the lowest humidity occurred when the temperature was highest. This is consistent with the findings in this study. While the coefficients of determination values for THI variants were higher than the values reported by Ravagnolo et al. (2000), West et al. (2003), Freitas et al. (2006), they were close to the values reported by Dikmen & Hansen (2009) and Yazgan (2017).

Due to the different combinations of temperature and humidity levels (maximum, minimum, or average) being used when calculating THI variants (Figure 2, Table 4), the highest and lowest values of THI variants are different. For this reason, the highest THI_b value obtained was only 71 using the minimum temperature and humidity values. This showed that THI_b was insufficient to determine the effect of heat stress under the conditions in which this study was conducted. This indicates that it is not practical to use minimum temperature and minimum humidity variables when calculating THI values in Diyarbakir conditions.

According to the THI formula (Equation 1), heat stress in dairy cattle starts at a THI of 72 and is called the critical value; after this point the milk yield continuously decreases. In this study, deviations from critical values (THI=72) were observed for all THI variants. In comparison to 72, the point at which milk yields began to decline continuously for the THI_a, THI_b, THI_c THId and THI_e variants were 77, 54, 64, 69 and 54 respectively (Figure 2). While the deviation value of the THI_a variant was greater than the critical value of 72, all other variants (THI_c, THI_d and THI_e) had values less than the critical level. The least deviation was observed in the THI_d variant by 3 units. The reason why other the THI variants deviate more from the critical 72 value than THI_d may be due to the temperature and humidity variables used in THI_a, THI_c and THI_e calculations. In other words, combining the variables of maximum temperature and minimum humidity into one THI seems to better reflect the stress conditions to which animals are exposed in Diyarbakir conditions. Another reason for deviations from the critical value may be the distance between the farm and the weather station.

Yazgan (2017) reported the critical THI values where milk yield started to decrease as 68, 76, 80, and 70 for minimum temperature and humidity, average temperature and humidity, maximum temperature and minimum humidity, and minimum temperature and maximum humidity combinations, respectively. These results differ from the values reported in this study. However, deviations from critical values (THI=72) when combinations of mean temperature and humidity (THI_c) and maximum temperature and minimum humidity (THI_d) were used in this study were similar to the values reported by Bouraoui et al. (2002) and Bohmanova et al. (2007).

As shown in Figure 2, for all THI variants, fluctuations were observed during the comfort zone, which corresponds to the range from the starting THI values to dashed vertical lines. THI_d showed the minimum deviation from the starting point of heat stress and the minimum fluctuation during the comfort zone when compared with others. Some fluctuations may be caused by the use of fans, shading, and sprinkler equipment. When such equipment is activated, heat stress may appear to be lower at higher temperatures. This also causes the THI to appear not only linear but also of zigzag shape (Figure 2). Fluctuations in all of the THI curves could also be caused by an insufficient number of daily milk yield records with a given THI, by partial confounding with other effects in the model (Equation 2) and by ignoring herd management practices (e.g. change in feeding regimen in some animals) and other conditions (e.g. prolonged exposure of animals to direct sunlight or strong wind when animals were in the paddock).

Ravagnolo et al. (2000), reported that the maximum daily air temperature and minimum daily humidity were the most critical variables to quantify heat stress. Similar results were obtained from this study as shown in Figure 2 where THI_d seems to be less affected by the factors causing fluctuations and showed a deviation of only 3 units from the heat stress beginning point (THI=72). Moreover, THI_d

performed better than other THI variants in quantifying the heat stress in this study. Therefore, it can be said that the results obtained from the use of THI_d in calculating of milk yield losses are more reliable than the other THI variants.

Considering the THI_d, the amount of milk yield loss (0.07 kg) for each unit of THI_d increase obtained from this study was similar to that reported by Konyves et al. (2017) and Gantner et al. (2017). It was, however, slightly lower than that reported by Igono et al. (1992) and Ravagnolo et al. (2000), and much lower than that reported by Ingraham (1979), Her et al. (1988), Bouraoui et al. (2002), West et al. (2003), Bohmanova et al. (2007), Zimbelman et al. (2009), Herbut & Angrecka (2012) and Yazgan (2017). Various causes might have contributed to these discrepancies. For instance, the results may be sensitive to distances between the meteorology station and the farm, 15 km in the present study and the distances were different in all studies. In addition, while in some studies (Her et al. 1988; Igono et al. 1992), the weather conditions were measured on the farm, in this study they were obtained away from the farm. Different measures towards alleviation heat stress levels (e.g., fans, shading, and sprinkler application systems) may have been used in all studies. In addition, the use of other weather variables in some of the studies may be another reason. Apart from these, some researchers' (West et al. 2003) use of temperature and humidity values 2 or 3 days before milk yield may explain the differences in milk yield loss between this study and others. Lastly, to obtain the least squares mean of milk yields, daily yield records were used in this research. Most of the other studies mentioned above, however, used monthly data.

Temperature and humidity values vary during the day, and the characteristics of this variation are different for each region. For example, while the RH level in one region is 70% during the day for 3 hours, it may remain at this level for 14 hours in another region. This is valid for the air temperature and is a determining factor for heat stress on animals. That is, if the minimum humidity level during the day does not change for a long period of time and then suddenly drops, it would not be correct to use the maximum humidity value when calculating the THI value. This also applies to other temperature and humidity variables (maximum or minimum). Findings from this study confirm this. For this reason, this type of research should be carried out when the effect of heat stress on animal production in a region is to be determined.

4. Conclusion

This study confirmed that weather stations located away from the farms contain information useful for research on heat stress in dairy cows. Using the combination of maximum daily air temperature and minimum daily humidity in the THI formula (THI_d) performed better than other THI variants in quantifying the heat stress in this study. This combination was affected less by other environmental factors, and the results obtained from this combination appear to be more biologically meaningful. As a result, it can be used to quantify heat stress in farms with conditions similar to those in this study. However, the performance of these weather variable combinations can be different in other geographic areas. The distance between a farm and weather station is another important factor for the accurate measurement of the heat stress effect. Therefore, similar studies should be carried out on farms located in different regions.

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