Article

Relationship of Meteorological Data with Heat Stress Effect on Dairy Cows of Smallholder Farmers

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Abstract: Global warming has been increasing heat stress threat in animals which can be monitored by Temperature Humidity Index (THI). The present study describes the relationship of THI, calculated using 35 years period weather station data, and production performances of dairy cattle in a selected area of Bangladesh. The month January and June were identified as the coolest and hottest, respectively. Based on this outcome, every year in the month of January and June production performances of 10 crossbred cows with homogenous characteristics were monitored for a period of 5 years. The average THI^{MEAN} value was found 17% higher in June as compared to January, and with this increment of THI^{MEAN} average milk production was decreased 24.4% ($p<0.05$). The milk fat and protein content were also reduced ($p<0.05$) by 14.5 and 15.2%, respectively suggesting negative correlation as like as milk production. However, ash content was increased 15.3% that indicates a positive correlation. In addition, multiple regression analysis revealed each point increase in THI^{MEAN} and rectal temperature, there was a decrease in milk yield 0.04 and 1.17 kg ECM, respectively. In contrary, each point increase in THI^{MEAN} resulted 0.059°C increase of rectal temperature. Taken together, THI^{MEAN} value calculated using metrological station data has distinct relationship with the production performances of lactating crossbred dairy cows.

Keywords: Temperature Humidity Index; Milk Production; Milk Composition; Temporal and Periodic Variation

1. Introduction

Dairy cattle are important part of the livestock sector and dairying is very common income source in rural and peri-urban areas of Bangladesh. In Bangladesh, there are about 24.55 million cattle and total milk production is 11.99 million tons [1]. Among the total cattle population, about 6.0 million are dairy cattle of which about 85-90% are indigenous and about 10-15% are crossbred cows [2]. Around 70% of Bangladesh's dairy farmers are smallholders who produce 70-80% of the country's total milk [3]. These smallholder dairy farmers rear their cattle by semi-intensive system where cattle exposed to high ambient temperatures, relative humidity and solar radiation for long periods. This affects the heat dissipation capacity of lactating cows and leads to heat stress. A number of physiological changes occur in animal body due to heat stress. These include elevated body temperature, respiratory rate, heart rate and rectal temperature, which affect animal feed intake,

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production and reproductive efficiency [4]. Consequently, cows develop many physiological mechanisms to cope with this stress. Heat stressed cows may try to cool down through thermoregulatory mechanisms, which affects feed conversion efficiency and leads to reduced milk production [5]. Heat stress adversely affects both milk quantity and quality during the first 60 days of lactation, with high-yielding breeds being more susceptible than low-yielding breeds [5]. Heat stress is a major economic burden in many milk producing regions of the globe especially in hot climate or summer month as it adversely affects performance and productivity trait of dairy cattle [6, 7].

Climate plays a pivotal role in dairy cattle production. In recent decades, global warming resulting elevated temperature has become a threat for the planet including live animals. Elevated temperatures have negative effects, such as thermal stress on cattle. Understanding the adverse effect of heat stress and taking proper adaptation strategies is a huge challenge. The severity of heat stress on dairy cattle can be quantified using a Temperature Humidity Index (THI). The THI is widely used to assess the effects of heat stress on dairy cows in hot regions around the world [8]. The ambient temperature and relative humidity of the environment are used to calculate THI. There are lots of formula combining different environmental factors have been proposed to measure the level of heat stress [9]. The data required to measure THI at farms level in particular at smallholder dairy farms are not available. However, meteorological data from nearby weather station are easily accessible.

Weather station collected environmental parameter records such as temperature, humidity, and other climate-related measurements (e.g., wind speed, dew point, etc.) hourly, provide continuous data over years [10]. These data could be used for calculating the THI which in turn would be useful to assess heat stress effects on dairy farms. Several studies have been conducted to calculate THI from weather station data as an indicator of heat stress, which has identified the thresholds THI level at which dairy cattle production is adversely affected [11]. However, to the best of our knowledge association between THI, calculated using publicly available meteorological records, and milk production has not yet been carried out in Bangladesh. Understanding of heat stress effects on milk production and gross milk composition using publicly available weather station data can provide an opportunity to develop future adaptation strategies against heat stress on dairy cattle performances. This will certainly increase the milk production in Bangladesh, and farmers will be benefited. Considering the above fundamentals, the objective of this study was to predict the intensity of heat stress in terms of THI for 35 years period, to investigate the changes of rectal temperature (RT), milk production and composition in relation to THI, estimated using meteorological data, of dairy cows in a selected area of Bangladesh for five years.

2. Materials and Methods

2.1 Study area and selection of experimental animals

The experiment was conducted in one of the hottest (June) and coolest (January) month of Gazipur district (25°15'0.00" N, 89°30'0.00" E) for a period of five years (2016 to 2020). At each time point of experiment (January and June of each year), 10 crossbred dairy cows from smallholder dairy farmers (having 2-5 cows) were selected. To ensure the homogeneity among the experimental animals there were three selection criteria such as parity (2nd or 3rd), lactation stage (1.5 to 3.0 months after calving), and milk yield (average 7-8 liters/day). The information relevant to selection criteria were evaluated based on owner’s information and phenotypic characteristics. Thus, the total number of animals during the five years long study period was 100.

2.2 Calculation of THI from meteorological data

Meteorological data (air temperature and relative humidity at three-hour interval) during 1986 to 2020 were collected from Bangladesh Metrological Department (BMD). Of the 35 weather stations of BMD throughout the country, the closest weather station (Dhaka) is 36.6 km away from the study area. Based on the distance, the weather station located at Dhaka was more preferable for calculating THI in Gazipur district. Since the weather station records temperature and humidity data at every three-hour interval, the THI value at each recording point for the period of 35 years was first calculated. Then, the three categories of THI, THI^{MAX}, THI^{MEAN} and THI^{MIN} were determined considering the daily maximum, mean and minimum THI values generated from three-hourly recorded temperature and humidity data, respectively. All category THI were calculated using the formula from Kibler (cited in Yousef, [12]); where THI = (Dry bulb temperature) + (0.36×dew point temperature) + 41.2 (temperatures in degrees Celsius). Dew point temperature (Td) was calculated using the following equation of dry-bulb temperature and the relative humidity.

$Td = T - \frac{100-RH}{5}$, where T is dry-bulb temperature and RH is relative humidity

The monthly average THI^{MAX}, THI^{MEAN} and THI^{MIN} value of each year was calculated from the corresponding daily THI values. In order to identify the hottest and coolest month of the year, the monthly average THI^{MEAN} values over the 35 years period was considered. Based on the outcomes, the periodic variation for the hottest and coolest month was examined considering three-hourly calculated THI values of each day for the period of 35 years.

2.3 Sampling procedure and chemical analysis

From 2016 to 2020, ten lactating dairy cows fulfilling the selection criteria were designated for recording milk yield, collecting milk and measuring RT once in a week during the month of January and June throughout the entire study period. Generally, milking is performed two times in a day (morning and afternoon) by the smallholder dairy farmers. Therefore, milk yield from individual cow was recorded at morning and afternoon once in a week. The milk yield was expressed as Kg ECM (Energy corrected milk) using the formula ECM = (milk production × (0.383 × %fat + 0.242 × %protein + 0.7832)/3.1138 as developed by IFCN (International Farm Comparison Network). In order to analyze milk composition, individual milk sample (a daily composite sample from the morning and the afternoon milking) was collected on the same day of milk yield recording. After collection, milk samples were immediately transported to the laboratory maintaining cold chain and stored at 4°C for the analysis of fat, protein and ash contents. Fat and protein content of milk samples were determined by Gerber and Kjeldahl method, respectively as per procedure described by Aggarwala and Sharma [13]. Ash content of milk samples were determined using the protocol described in AOAC [14]. Rectal temperature was measured at 12:00H using a medical digital thermometer.

2.4 Multiple regression analysis

Multiple linear regression is powerful tool to estimate the relationship between two or more independent variables and one dependent variable. The following multiple regression from which was specified in linear function and used to fit the regression between milk production (MP), RT and THI^{MEAN} by ordinary least squares method. The assumption of multiple regression was fulfilled to estimate the unbiased parameters of the regression. The multiple regression was as follows:

Model 1: $MP_{Tt} = \beta_1 + \beta_2 RT_{Tt} + \beta_3 THI_{Tt}$

Where, β_1 = intercept, β_2, β_3 = coefficient for RT_{Tt} and THI_{Tt}, respectively and T is the number of treatment and t is time period.

Similarly simple linear regression was applied to fit the regression between RT and THI^{MEAN} as below:

Model 2: $RT_t = \beta_1 + \beta_2 THI_t$

Where, β_1 = intercept, β_2 = coefficient for THI_t and t is time period.

2.5 Statistical analysis

The THI value was calculated by writing R language on RStudio platform (Version 4.2.2). The THI values generated from the R platform were then inserted into excel sheet (Excel 2016, Microsoft, Redmond, Washington, USA) and were analyzed with the add-in statistical package as per the requirement of the study. The distribution of THI value and skewness through displaying quartiles, median and mean were visualized by constructing boxplot. The correlation between variables and t test were also performed. All significance tests were two-tailed, and $p<0.05$ was considered as significant.

3. Results

3.1 Profile of selected animals

The genotype distribution of 100 crossbred dairy cows selected for the entire study was ½ Holstein-Friesian (HF) ½ Local (45%), ¾ Jersey ¼ Local (20%), ¾ HF ¼ Local (15%), ½ HF ½ Sindhi (10%), ¾ Shahiwal ¼ Local (5%); Unknown (5%). The percent of cows standing in her 2nd and 3rd lactation were 43 and 57, respectively. The average length of lactation stage was 53 days. The average milk yield was 7-8 liters/cow/day. The experimental cows were under subsistence farming system.

3.2 Temporal and periodic variations of THI

The dynamics of three categories of THI values, THI^{MAX}, THI^{MEAN} and THI^{MIN} in different months over the period of 35 years (1986-2020) has been shown in Figure 1. The majority researchers indicated 72 as the upper critical THI value for dairy cattle [8, 9, 15]. In the present study, dairy cows are predicted to face severe heat stress throughout the year when THI^{MAX} was considered. The THI^{MAX} values of each month exceeded the upper critical THI value ranged from 76.97 to 94.97. However, the highest THI^{MAX} value was observed in the month of March, April and May with a range from 86.48 to 94.97 (Figure 1A). In contrary, The THI^{MEAN} values during the month of April to October was surpassed the upper critical THI value with the range of 74.65 to 81.52. As shown in Figure 1B, THI^{MEAN} value in the month of June, July and August was very close which leads to compare the average THI^{MEAN} value of these months. The average THI^{MEAN} value in the month of June, July and August was 79.47±0.73, 79.16±0.36 and 79.34±0.36, respectively. In addition, the THI^{MEAN} value ranged from 78.17 to 81.52 in June, 78.53 to 79.95 in July and 78.61 to 80.03 in August. Thus, the month June was identified as the hottest month in terms of THI^{MEAN} value. Analogously, the average THI^{MEAN} value in the month of January and December was 64.24±1.16 and 66.44±0.95, respectively suggesting January as the coolest month (Figure 1C). As expected, dairy cows are supposed to be in comfort zone throughout the year when THI^{MIN} value was considered. The THI^{MIN} values of each month ranged from 42.66 to 73.61. The highest (71.71±2.28) and lowest (49.68±2.06) average THI^{MIN} value was observed in the month of August and January, respectively (Figure 1C).

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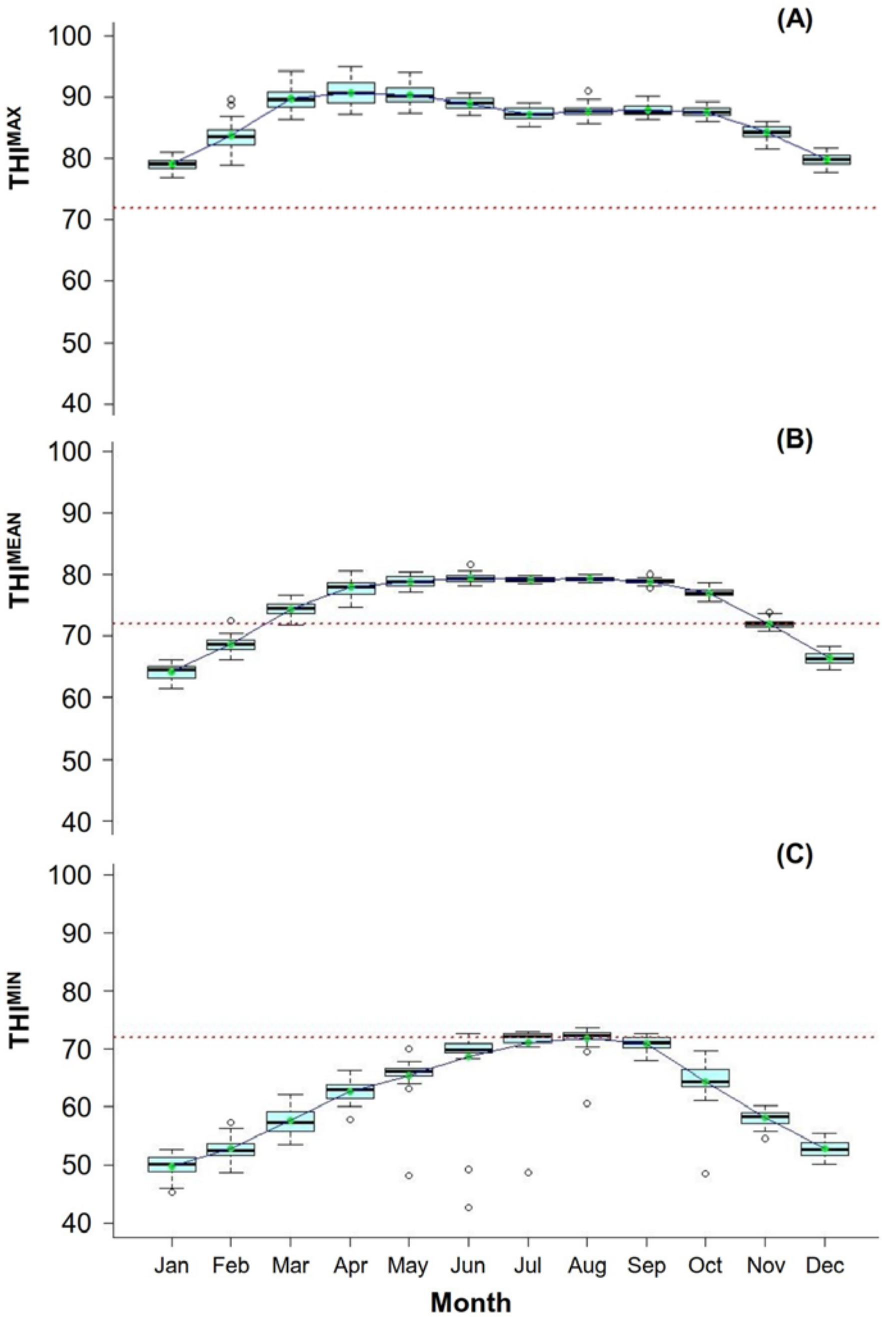

Figure 1. Temporal variation of THI in different months over the 35 years (1986-2020) period. THI^{MAX} (A), THI^{MEAN} (B) and THI^{MIN} (C) are the maximum, mean and minimum daily THI value calculated from three-hourly temperature and humidity data recorded by the weather station. Red colored dotted line indicates upper critical comfort THI level assuming THI ≤72 indicates no stress [15].

In thermoregulatory system, animals need enough time to be in comfort zone for heat dissipation from the body. Therefore, it is very important to know the periodic variation in THI value during the study period. The periodic variation of the hottest (June) and coolest (January) month for 35 years period has been portrayed in Figure 2. During the month of January, the highest (70.23±3.26) average THI value was observed at 15:00H and the lowest value (59.38±3.15) was at 06:00H (Figure 2A). The difference of THI value between these two time points was 10.85 indicating dairy cows get the opportunity to dissipate heat from the body. In contrary during the month of June, the highest (81.05±2.30) average THI value was observed at 15:00H and the lowest value (77.49±1.38) was at 06:00H

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(Figure 2B). The difference of THI value between these two time points was very low (3.56) suggesting dairy cows does not have enough space for heat dissipation. It is noteworthy that the highest THI values always observed at 15:00H in both January and June suggesting a critical time period for dairy cows in the study area.

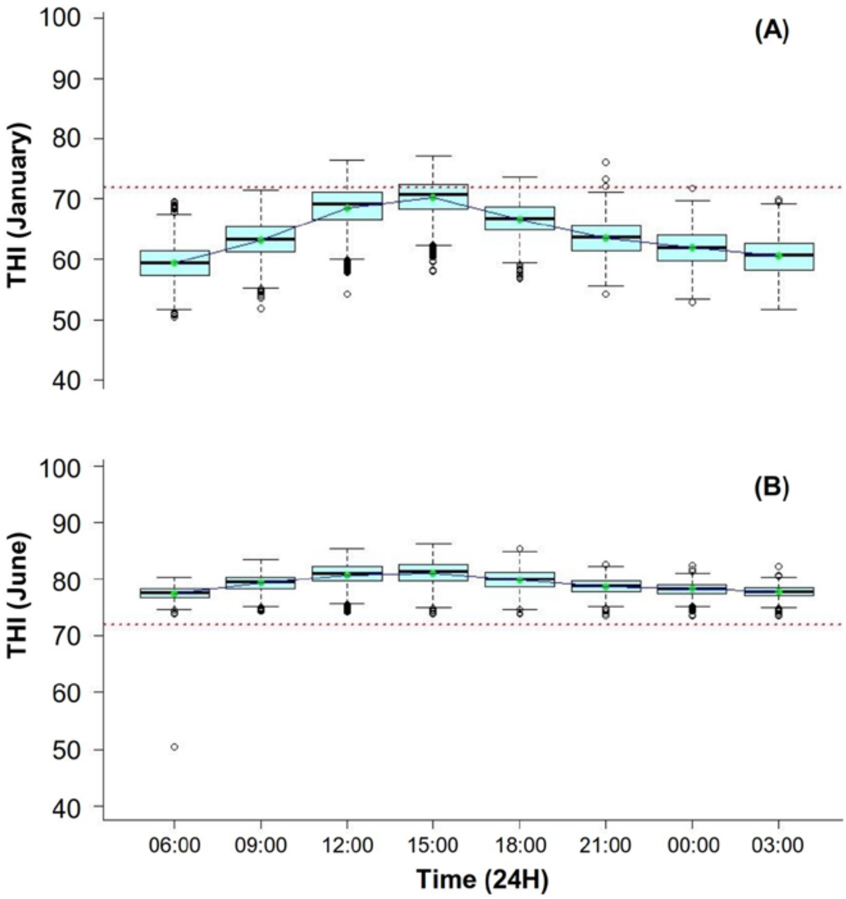

Figure 2. Periodic variation of THI in two different months, the January (A) and June (B) over the 35 years (1986-2020) period. The THI value was calculated using the temperature and humidity data obtained from weather station at every three-hour interval. Red colored dotted line indicates upper critical comfort THI level assuming THI ≤72 indicates no stress [15].

3.3 Relationship of THI with milk production and rectal temperature

The THI value represents the effect of environment on animal's ability to dissipate heat from the body. Lactating cows are thought to experience no stress when THI is less than 72 and severe stress when THI exceeds 90 [15]. The relation between THI^{MEAN}, milk production and rectal temperature of crossbred dairy cattle in the month of January and June from 2016 to 2020 was demonstrated in Figure 3. During the five years period, the average THI^{MEAN} value was 17% (0.83 times) higher in June (79.3) than that of January (65.8). With the increase of THI^{MEAN} value average milk production/cow/day was decreased 1.2 folds corresponding to 24.4% in the month of June (6.8 Kg ECM) as compared to January (8.5 Kg ECM). In contrary. the average rectal temperature was 3.3% (0.97 times) higher in June (40°C) than that of January (38.7°C) suggesting rectal temperature is upregulated with the increase of THI^{MEAN} (Figure 3). It should be noteworthy that the relationship trend among THI^{MEAN}, milk production and RT was almost similar in the month of January and June during the five years study period. The data clearly suggests that THI^{MEAN} has a positive relationship with RT but negative relationship with milk production.

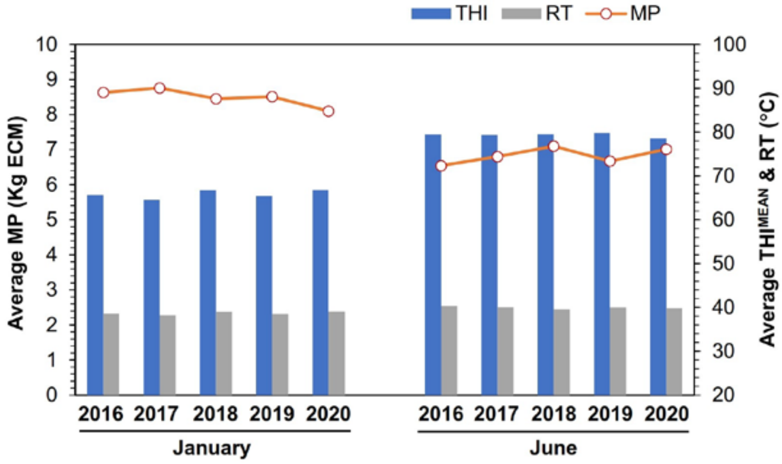

Figure 3. Relationship between THI^{MEAN}, rectal temperature (RT) and milk production (MP) during five years (2016-2020) study period. The milk production data is the average of weekly value (n = 500) obtained from individual dairy cow. THI^{MEAN} is the average THI values generated from test day temperature and humidity recorded by the weather station at every three-hour interval.

3.4 Relationship of THI with milk composition

Hot and humid environment not only affects milk yield but also milk quality. The gross composition of milk (fat, protein and ash) and their association with THI^{MEAN} value for the five years study period has been depicted in Figure 4. The average percentage of fat, protein, and ash content in milk collected during the entire study period were 4.3, 3.6 and 0.6 in January and 3.8, 3.2 and 0.7 in June, respectively representing the reduction of 14.5% fat and 15.2% protein, and the increment of 15.3% ash content. The changes of fat, protein and ash content of milk with the shifting of THI^{MEAN} value between the hottest (June) and coolest month (January) was found statistically significant ($p<0.05$).

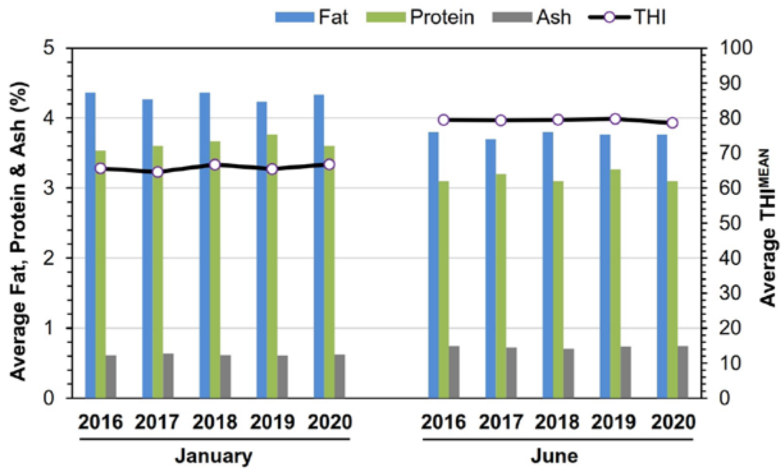

Figure 4. Effect of THI^{MEAN} on milk composition during five years (2016-2020) study period. The milk composition data is the average of weekly value (n = 500) obtained from individual dairy cow. THI^{MEAN} is the average THI values generated from test day temperature and humidity recorded by the weather station at every three-hour interval.

3.5 Multiple regression analysis among milk production, rectal temperature and THI

The regression correlation among THI^{MEAN}, milk production and RT of dairy cows is illustrated in Figure 5. The regression indicates that for each point increase in THI^{MEAN} and

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RT, there was a decrease in milk yield of 0.04 and 1.17 kg ECM, respectively. The regressions of milk yield on THI^{MEAN} and RT were significant ($p<0.01$) with an R^2 value of 0.812 (Figure 5A, B). The regression also indicates each point increase in THI^{MEAN}, there was an increase in RT. The value of this relationship for predictive purposes is relatively low, as depicted by an R^2 value of 0.452 (Figure 5C). The result suggests a negative correlation between milk production and THI^{MEAN}. Milk production and RT also had negative correlation but there was a positive correlation between RT and THI^{MEAN} which was found statistically significant ($p<0.01$).

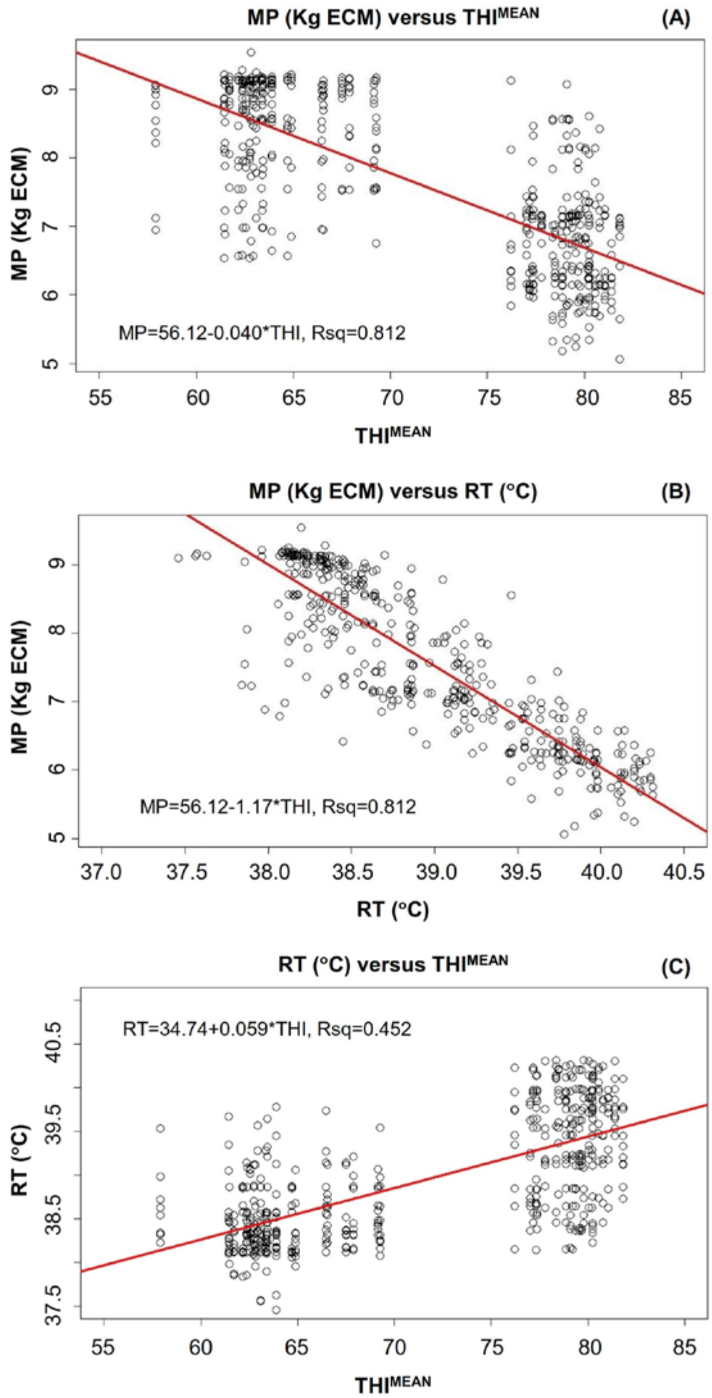

Figure 5. Regression correlation among milk production (MP), rectal temperature (RT) and daily mean temperature humidity index (THI^{MEAN}). The MP and RT data are the weekly value (n = 500)

obtained from each individual dairy cow. THI^{MEAN} is the average THI values generated from test day temperature and humidity recorded by the weather station at every three-hour interval.

4. Discussion

THI is considered as the best indicator to measure heat stress in lactating dairy cows [16]. Ambient temperature and humidity jointly regulate the THI value. In a recent report, it is revealed that monthly mean THI values were the highest in July and the lowest in January for all regions of mainland China. The THI was derived from climate data (1987 to 2016) at 839 meteorological stations [17]. Our study also shows that the highest THI^{MEAN} value was in June and the lowest was in January (Figure 1B).

It is reported that heat stress in dairy cows commences when THI value surpasses 72 [15]. Heat stress adversely affects milk production and its composition in dairy animals with high genetic merit [18]. During the period of heat stress, dairy cows instinctively reduce their feed intake. The reduction of feed intake is likely to increase as weather becomes hotter. Typically, early lactating and high producing cows are more susceptible to heat stress than late lactating or low producing cows [19]. Therefore, decreased milk yield has been suggested as the cumulative effects of heat stress on feed intake, metabolism and the physiology of dairy cattle [20]. Berman [21] estimated that effective environmental heat loads above 35°C activate the stress response systems in lactating dairy cows which in turn reduce feed intake. As a result, negative energy balance is occurred which largely responsible for the decline in milk synthesis [19]. Moreover, maintenance requirements of energy also increased by 30% in heat stressed dairy animal [22]. Therefore, energy intake is not sufficient to meet the daily requirement for milk production.

According to Bouraoui et al., [18], daily THI negatively correlated to milk yield, as increase of THI value from 68 to 78 decreases milk production by 21%. Spiers et al., [23] reported that milk yield decreases by 0.41 kg/cow/day for each THI unit increase of above 69. Brown-Brandl et al.,[24] reported that milk production was clearly related to changes in THI and marked declines occur around 76-78 mean THI in case of temperate dairy breeds. A decrease in milk yield was 0.26 kg/day for each increase in THI. Per unit increase in THI beyond 72, 0.2 kg reduction in milk yield was recorded by West [25]. Further, for every 1°C in air temperature above the thermal neutral zone cause 0.85 kg reduction in feed intake which cause 36% decline in milk production according to Rhoads et al., [26]. Sacido et al.,[27] and Segnalini et al., [28] state that in dairy cows in the conditions of heat stress the production of milk is being decreased by between 10 and 30%. Zheng et al., [29] suggests that heat stress significantly reduces the production of milk. Also, Kadzere et al., [30] point to the fact that at the temperature of 35°C the quantity of milk is reduced by 33%, and at 40°C by 50%. In the present study, milk production decreased 1.2 folds (24.4%) with the increase of THI^{MEAN} value (Figure 3). Thus, our present findings are in agreement with these published results.

The body temperature of cows can be measured in various ways of which RT is considered as one of the best methods. In production practice, RT is often used as a sensitive index to determine whether a cow has reached thermal balance [31] and to determine the influence of the thermal environment on growth, lactation, and reproduction in dairy cows [32]. A study by Xue et al., [33] showed that RT increased from 37.8°C to 38.5°C when the THI value rose from 45 to 72, representing increases in THI and RT of 60% and 1.8%, respectively. However, when THI rose from 72 to 79, RT increased from 38.5°C to 39.35°C, representing increases in THI and RT of 9.7% and 2.2%, respectively. In the present study, when average THI^{MEAN} value increase from 65.8 in January to 79.3 in June, the average RT increases from 38.7 to 40°C, representing increases in THI^{MEAN} and RT of 18% and 3.33%, respectively (Figure 3). Our findings are closely related to the study carried out by Xue et al., [33]. According to Xu et al., [34] RT had significant effect on milk yield. They suggested that the average daily milk yield decreased 1.26 kg with per unit increase of RT. Our finding is comparable to Xu et al., [34] results where milk production decrease 1.17 Kg ECM for each unit increment of RT (Figure 5B). Liu et al., [35] showed that RT was significantly higher during heat stress than during non-heat stress periods and that for each unit increase in the THI value, the RT of dairy cows increased by 0.1062°C, 0.0739°C, and 0.0847°C during early, mid and late lactation, respectively. In our study, RT increases 0.059°C for each unit increment of THI^{MEAN} that match to the above findings (Figure 5C).

Hot and humid environment affects not only milk yield but also milk quality. It has been proposed that the depressed fat levels in heat stressed dairy cows could be attributed to the decrease in forage intake which may result in an inadequate fiber level in the diet to maintain normal rumen functions [18]. The reduction in milk protein seems to be attributed to the restricted feed intake as well [36]. In the current study, with the increase of THI^{MEAN} value both the protein and fat content of milk decreased significantly (Figure 4). Our findings are in agreement with Rodriquez et al., [37] and Knapp and Grummer [38] who reported a decrease milk protein with increase THI. Bouraoui et al., [18] also observed lower milk fat and milk protein in the summer season. When THI value goes beyond 72, milk fat and protein content declines. The results regarding milk protein and fat content is agreed with the findings of Zheng et al.,[29] who reported that heat stress significantly reduces the percentage of milk fat and proteins. Sacido et al., [27] and Segnalini et al., [28] also reported significant decrease in milk fat and protein content with the increase of THI. Ozrenk and Inci [39] also reported that milk fat, protein and total solids percentages in cow milk were highest during the winter and the lowest during the summer.

Ash content of milk follow the opposite trend of fat and protein content. The average ash content increase from 0.62% in January to 0.73% in June during the five years long study period (Figure 4). Reyad et al., [40] revealed higher mineral content in milk of HF crossbred cows during lower THI period and lower minerals content in higher THI period. This finding is in accordance with our present study. Higher minerals content in milk during higher THI period might be due to declining the milk yield and increasing the concentration of minerals in milk as a consequence of heat stress.

5. Conclusions

In conclusion, our results demonstrate that the THI value calculated from publicly available meteorological station data could be a useful approach for assessing the impact of heat stress on dairy cattle production in Gazipur district of Bangladesh. Based on the 35 years meteorological data, June and January were portrayed as the hottest and coolest month of the year, respectively which had a good correlation with milk production and composition. As air temperature have been rising due to global warming, analysis of dairy cattle performance using environmental parameters could be an important tool to enable farmers for taking corrective measures.

Author Contributions: Conceptualization, M.M.R and A.S.M.S.; methodology, M.M.R and A.S.M.S.; formal analysis, M.D.H., M.A.S., S.A. and S.A.M.H; investigation, M.D.H., M.U.H., S.Ah. and M.M.I.; writing—original draft preparation, M.M.R and M.D.H.; writing—review and editing, M.M.R, A.S.M.S. and S.A.M.H; supervision, M.M.R; project administration, M.M.R and M.D.H.; funding acquisition, M.M.R and M.D.H. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to gratefully acknowledge the financial support from Research Management Wing of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh (to M.D.H.) and Krishi Gobeshona Foundation, Bangladesh (to M.M.R.).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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