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Effect of temperature-humidity index on productive and reproductive performances of Iranian Holstein cows

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Summary

Calving records from April 1996 to December 2005 comprising 31863 calving events of 1173 dairy cows in a large commercial dairy herd were used to evaluate the effects of heat stress, using temperature-humidity index (THI) on milk yield and composition and reproductive performance of Holstein dairy cows under humid climatic conditions of Rasht in Iran. THI values were grouped into six groups: 30-40 (THI1), 41-50 (THI2), 51-60 (THI3), 61-70 (THI4), 71-80 (THI5) and 81-90 (THI6). Dairy cows in THI6 had lower milk and fat yields than other groups of THI, but cows in THI1 and THI2 had the greatest amounts of milk and fat yields, respectively ($P<0.05$). However, dairy cows in the second group of THI had lower percentages of fat than the sixth group of THI ($P<0.05$). Spring-calved cows had longer days open than cows calved in other seasons ($P<0.05$). Also, summer-calved cows had greater number of services per conception and lower conception rates than cows calved in other seasons ($P<0.05$). Dairy cows within the THI5 which calved in spring and/or calving years 2004-2005 had the longest days open ($P<0.05$). Cows in the second group of THI had the greatest and the lowest number of inseminations and conception rates compared with other groups of THI, respectively. The results of the present study indicated that summer heat stress negatively affected milk yield and composition and reproductive performance of dairy cows. Therefore, application of management interventions to ameliorate the effects of heat load on the performance of dairy cows could be needed in certain periods of the year under the climatic conditions.

Key words: Temperature, Humidity, Reproduction, Cattle

Introduction

Climate condition may exert negative impacts on livestock welfare, performance and health (Nardone *et al*., 2006). Dairy cattle in many subtropical, tropical and semi-arid regions are under the influence of high ambient temperatures and relative humidity for long periods. Under this condition, lactating cows are able to dissipate heat, resulting in heat stress. Consequently, the cow develops several physiological mechanisms for adapting to this stress. These reactions have negative impacts on the physiology of the cow, reproduction and production (Garcia-Ispierto *et al*., 2007). Internal metabolic heat production increased during lactation and this can decrease the tolerance of dairy cows to high ambient temperatures (Chebel *et al*., 2004). Heat stress in dairy cattle can be managed using different approaches such as cooling, shading, and nutrition (Arjomandfar *et al*., 2010).

Many indices have been proposed to measure the level of heat stress. However, their application is restricted by poor availability of data. Most studies on heat stress in livestock have concentrated mainly on temperature and relative humidity (Bouraoui *et al*., 2002) because data on the amount of thermal radiation received by the animal, wind speed, and rainfall are not generally available. On the other hand, temperature and humidity information can usually be obtained from a local meteorological station.

A temperature-humidity index (THI) is a single value depicting the integrated effects of air temperature and humidity associated with the level of heat stress. This index has been developed as a weather safety index to control and decrease heat-stress-related losses (Bohmanova *et al*., 2007). It was indicated that, compared to other indexes, the THI is a practical and useful tool and a standard for many applications in animal biometeorology. THI is extensively used in hot regions all over the world to evaluate the effect of heat stress on dairy cows and is currently used to estimate cooling necessities of dairy cattle in order to improve the efficiency of management strategies to alleviate the negative effects of heat stress. Milk yield reductions of 10 to 40% have been reported for Holstein cows during the summer as compared to the winter. Moreover, heat stress is associated with alterations in milk composition, milk somatic cell counts and mastitis incidences. Heat stress has been associated with deterioration of embryo development and increased embryo loss in cattle (Hansen, 2007). Therefore, the objective of this study was to evaluate the effects of THI on some of the productive and reproductive indices of Iranian Holstein cows.

Materials and Methods

Location, data set and animal management

The study was conducted at a large commercial dairy herd in Rasht, Guilan, Iran. Rasht is located between 37°12´ north latitude and 49°39´ east longitude. Calving records from April 1996 to December 2005 comprising 31863 calving events of 1173 Holstein cows were included in the data set. Information for individual calving events, including cow identification, test day milk yield, test day fat yield and fat percentage, successful insemination date, calving date, parity and number of services per conception were included in the data set. Months of birth were grouped into four seasons: April through June (season 1 = spring), July through September (season 2 = summer), October through December (season 3 = fall), and January through March (season 4 = winter). Also, calving years were grouped into five classes: 1996 through 1997 (Y1), 1998 through 1999 (Y2), 2000 through 2001 (Y3), 2002 through 2003 (Y4) and 2004 through 2005 (Y5). First-parity cows represented 30.6%, whereas second- and third-parities accounted for 22.8 and 46.6%, respectively. Days open were considered as the number of days from calving to a successful breeding date. Conception rate was defined as the inverse of the number of services per conception in this study. The herd is under official performance and pedigree recording. Cows are milked three times a day and are fed by total mixed ration and artificial insemination is commonly used in the herd.

Meteorological data

Meteorological data were obtained from the meteorological station of Rasht. Information consisted of daily maximum and minimum temperatures and relative humidities. Monthly THI values for the experimental site were calculated over a 10-year period (1996-2005) using the following formula:

$$\mathrm{THI} = 1.8 \times T_a - (1 - \mathrm{RH}) \times (T_a - 14.3) + 32$$

Where,

T_a: The average ambient temperature in ºC

RH: The average relative humidity as a fraction of the unit

THI values were grouped into six classes: 30-40 (THI1), 41-50 (THI2), 51-60 (THI3), 61-70 (THI4), 71-80 (THI5) and 81-90 (THI6). Summary statistics of environmental conditions during the experimental period are shown in Table 1. THI information at test date was used for the relationship analysis of THI and productive traits. On the other hand, THI information at insemination date was used for the relationship analysis of THI and reproductive traits in this study.

Statistical analysis

Statistical analyses of test day milk yield, milk fat yield, fat percentage of milk, number of services per conception, days open and conception rate were performed using a linear mixed model (Proc Mixed) with the best fitted covariance structure of SAS (2002). The least-squares means were estimated by restricted maximum likelihood (REML) method. The covariance structure used to analyse the productive and reproductive indices of dairy cows was first-order heterogeneous autoregressive structure. Acceptable significant levels were declared at P<0.05. Animal was considered as a random variable in all statistical models.

The final models used to analyse milk and fat yields included the fixed class effects of calving year, calving season, parity, THI and interaction effects of year by THI, season by THI, parity by THI, year by parity and season by parity. The model used in the analysis of fat percentage was similar to the model used in the analysis of milk, but season by parity effect was excluded from the final model. On the other hand, the final model used to analyse days open was similar to the model used in the analysis of milk, but parity by THI effect was excluded from the model. The model used to analyse number of services per conception included the fixed class effects of calving year, calving season, parity, THI and interaction effects of season by THI, year by parity and season by parity. Also, the model used in the analysis of conception rate was similar to the model used in the analysis of number of services per conception, but season by THI interaction effect was excluded from the final model. The regression lines of productive and reproductive traits on THI classes were drawn using the “trendline” option in Microsoft Office Excel 2007. Also, the regression coefficients of days open on number of services per conception or conception rate were estimated using the Reg procedure of SAS (2002).

Results

Least-squares means and their standard errors for the effect of THI on productive and reproductive traits are shown in Table 2. Fall-calved cows had significantly higher milk and fat yields than cows calved in the other seasons and summer-calved cows had higher fat percentage of milk than cows calved in the other seasons. Dairy cows in THI6 had lower milk and fat yields than other classes of THI, but cows in THI1 and THI2 had the greatest amounts of milk and fat yields, respectively (P<0.05). However, dairy cows in the second class of THI had lower percentages of fat than the sixth class of THI (P<0.05). There were significant interaction effects between calving year and parity on milk and fat yields. Also, the interaction of calving season by parity had significant effect on milk and fat yields. In addition, there were significant interaction effects of THI by season, THI by year and THI by parity on milk and fat yields (P<0.05). Therefore, dairy cows within the first class of THI which calved in fall season and or calving year Y5 had the highest milk yield. Also, cows in their third and greater parities and within the first class of THI had the greatest milk yield and multiparous cows could cope better with extreme THI values. On the other hand, dairy cows within the second class of THI which calved in fall season and/or calving year Y5 had the highest fat yield. Further, cows in their third and greater parities and within the second class of THI had the greatest fat yield. There was significant interaction effect between calving year and parity on fat percentage. Dairy cows within the THI4 which calved in summer and/or calving year Y2 had the highest fat percentage of milk. Also, cows in their third and greater parities and within the THI6 had the greatest fat percentage (P<0.05).

Spring-calved cows had longer days open than cows calved in other seasons (P<0.05, Table 2). In addition, primiparous cows had longer days open than multiparous cows (P<0.05). The days open of cows within the first, fifth and sixth classes of THI were not significantly different. There were significant interaction effects of year by parity and season by parity on days open (P<0.05). Also, dairy cows within the THI5 which calved in spring and/or calving year Y5 had the longest days open (P<0.05). In addition, there was a positive relationship between milk yield and days open. Summer-calved cows had greater number of services per conception and lower conception rates than cows calved in other seasons (P<0.05, Table 2). Primiparous cows had lower number of services per conception than multiparous cows (P<0.05). In addition, dairy cows within the THI6 had lower number of services per conception than other THI classes (P<0.05). There were significant interaction effects of year by parity and season by parity on number of services per conception (P<0.05). Also, dairy cows within the THI1 which calved in summer had the greatest number of services

Table 1: Environmental conditions during the experimental period of this study

Month	Temperature (ºC)			Relative humidity (%)			THI		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
April	-0.6	35.0	13.5	13.0	100.0	78.7	34.2	79.2	56.2
May	3.8	32.2	17.2	20.0	100.0	81.2	34.2	79.4	62.3
June	10.0	34.2	22.7	20.0	100.0	75.5	34.2	85.2	70.8
July	0.0	35.6	25.0	31.0	100.0	76.4	34.2	86.8	74.4
August	15.2	37.5	26.7	24.0	100.0	75.1	34.2	87.5	76.9
September	13.4	37.2	24.0	32.0	100.0	82.3	34.2	87.1	73.3
October	9.0	37.0	20.0	18.0	100.0	81.9	34.2	82.3	67.0
November	0.2	35.0	15.0	10.0	100.0	83.6	34.2	79.2	58.8
December	-2.8	28.0	9.9	10.0	100.0	82.3	34.2	72.3	50.5
January	-13.6	29.2	7.6	7.0	100.0	83	34.2	74.2	46.7
February	-7.8	29.4	10.0	8.0	100.0	81	34.2	72.4	46.6
March	-2.4	34.6	10.0	10.0	100.0	78.0	34.2	79.4	50.8

Table 2: Least-squares means and their standard errors for the effect of THI on productive and reproductive traits of dairy cows

Effect	Class	Trait					
		MY	FY	FP	DO	INS	CR
Year	1	17.25 ± 0.10^{d}	0.52 ± 0.004^{e}	3.15 ± 0.02^{d}	132.38 ± 1.32^{c}	1.96 ± 0.02^{d}	69.30 ± 0.54^{b}
	2	15.81 ± 0.06^{e}	0.56 ± 0.003^{d}	3.67 ± 0.01^{a}	150.48 ± 0.93^{b}	1.89 ± 0.01^{e}	72.12 ± 0.34^{a}
	3	19.11 ± 0.09^{c}	0.62 ± 0.004^{c}	3.40 ± 0.01^{b}	151.55 ± 1.03^{ab}	2.08 ± 0.02^{c}	67.83 ± 1.81^{c}
	4	21.42 ± 0.09^{b}	0.67 ± 0.005^{b}	3.05 ± 0.01^{e}	152.98 ± 1.03^{ab}	2.19 ± 0.02^{b}	65.81 ± 0.41^{d}
	5	24.60 ± 0.11^{a}	0.80 ± 0.005^{a}	3.29 ± 0.01^{c}	154.53 ± 1.35^{a}	2.37 ± 0.02^{a}	62.00 ± 0.49^{e}
Season	1	17.94 ± 0.10^{d}	0.57 ± 0.004^{d}	3.38 ± 0.02^{b}	184.25 ± 1.10^{a}	1.98 ± 0.02^{c}	70.60 ± 0.45^{a}
	2	19.04 ± 0.07^{c}	0.62 ± 0.003^{c}	3.43 ± 0.01^{a}	132.41 ± 0.67^{d}	2.30 ± 0.02^{a}	62.57 ± 1.39^{c}
	3	20.17 ± 0.09^{a}	0.64 ± 0.004^{a}	3.35 ± 0.01^{b}	142.45 ± 0.97^{c}	2.08 ± 0.02^{b}	69.25 ± 0.36^{b}
	4	19.39 ± 0.09^{b}	0.63 ± 0.004^{b}	3.38 ± 0.01^{b}	155.35 ± 1.14^{b}	1.89 ± 0.01^{d}	71.18 ± 0.35^{a}
Parity	1	16.93 ± 0.06^{c}	0.54 ± 0.003^{c}	3.38 ± 0.01^{a}	160.53 ± 0.87^{a}	1.57 ± 0.01^{c}	79.44 ± 1.36^{a}
	2	19.54 ± 0.09^{b}	0.63 ± 0.004^{b}	3.39 ± 0.02^{a}	143.28 ± 0.95^{b}	2.46 ± 0.02^{a}	60.07 ± 0.40^{c}
	> = 3	20.65 ± 0.07^{a}	0.67 ± 0.003^{a}	3.39 ± 0.01^{a}	145.18 ± 0.75^{b}	2.23 ± 0.01^{b}	64.22 ± 0.28^{b}
THI	1	24.05 ± 0.47^{a}	-	-	161.76 ± 5.73^{a}	1.99 ± 0.09^{a}	69.06 ± 2.04^{b}
	2	20.91 ± 0.09^{b}	0.66 ± 0.004^{a}	3.32 ± 0.01^{b}	148.92 ± 0.96^{b}	2.12 ± 0.02^{a}	66.99 ± 0.36^{b}
	3	18.96 ± 0.10^{c}	0.62 ± 0.004^{b}	3.39 ± 0.02^{ab}	146.44 ± 1.14^{b}	2.03 ± 0.02^{a}	68.66 ± 0.43^{b}
	4	18.46 ± 0.08^{c}	0.60 ± 0.003^{b}	3.47 ± 0.01^{a}	148.63 ± 0.90^{b}	2.06 ± 0.02^{a}	68.33 ± 0.35^{b}
	5	18.58 ± 0.08^{c}	0.60 ± 0.004^{b}	3.36 ± 0.01^{b}	152.90 ± 0.99^{ab}	2.09 ± 0.02^{a}	67.71 ± 0.38^{b}
	6	15.19 ± 0.35^{d}	0.50 ± 0.015^{c}	3.48 ± 0.09^{a}	161.66 ± 5.96^{a}	1.82 ± 0.09^{b}	75.30 ± 2.09^{a}

MY: Milk yield, FY: Fat yield, FP: Fat percentage, DO: Days open, INS: Number of services per conception, and CR: Conception rate. [a, b, c, d, e]: Means within a column that do not have a common superscript are significantly different (P<0.05)

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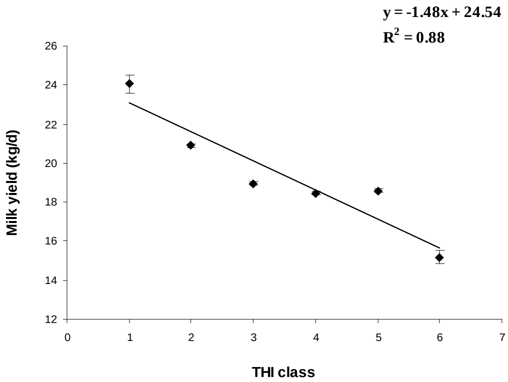
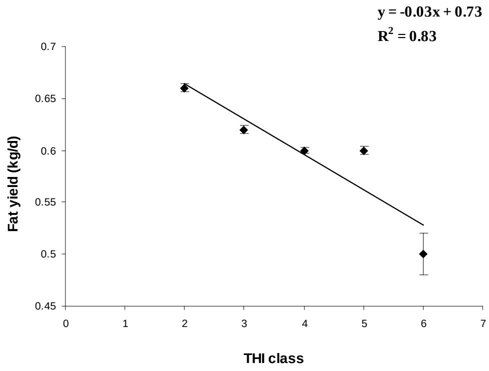
per conception (P<0.05). Primiparous cows had higher conception rates than multiparous cows (P<0.05, Table 2). In addition, dairy cows within the THI6 had higher conception rates than other THI classes (P<0.05). There were significant interaction effects of year by parity and season by parity on conception rate (P<0.05). As shown in Figs. 1a and b, there were linear and negative relationships between THI and milk and fat yields, therefore, cows in their greater classes of THI had lower milk and fat yields than cows in the first class of THI, but there were departures from linearity (P<0.05) between THI and fat percentage of milk, days open, number of services per conception and conception rate of dairy cows (Figs. 1c-f). Cows in the second class of THI had the lowest fat percentage of milk and cows in the sixth class of THI had the greatest percentage of fat. Cows in the third class of THI had the shortest days open compared with other classes of THI. On the other hand, cows in the second class of THI had the greatest and the lowest number of inseminations and conception rates compared with other classes of THI, respectively.

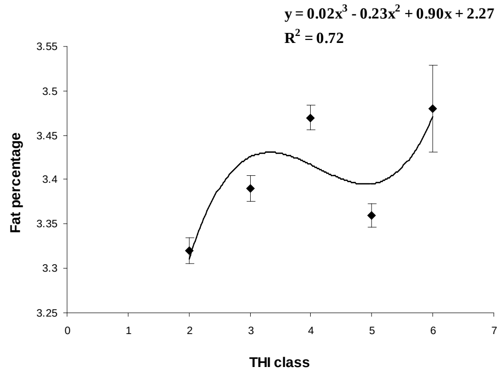
a



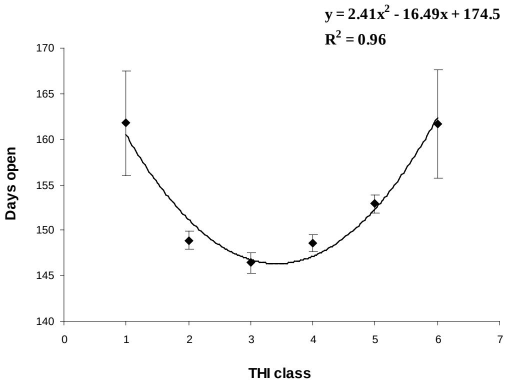
b



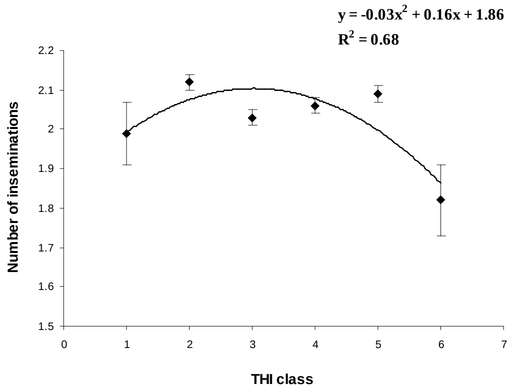
c



d



e



f

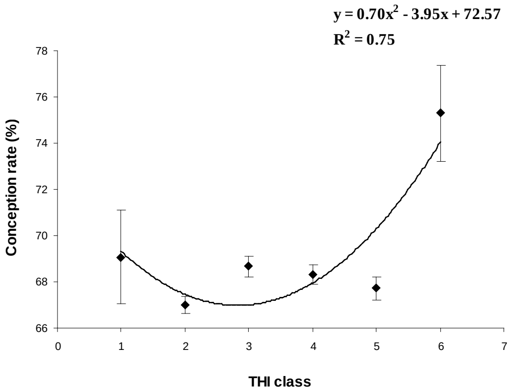


Fig. 1: Association between THI and milk yield (a), fat yield (b), fat percentage (c), days open (d), number of services (e) and conception rate (f) of Holstein dairy cows

Discussion

Consistent with the results of the present study, Bouraoui *et al*. (2002) reported heat stress reduced daily milk yield of cows along with an increase in THI values. The authors concluded that a portion of the negative effects of heat stress on milk production could be explained by decreased nutrient intake and decreased nutrient uptake by the portal drained viscera of the cow. Blood flow shifted to peripheral tissues for cooling purposes may alter nutrient metabolism and contribute to lower milk yield during hot weather. It was demonstrated that glucose disposal was greater in heat-stressed compared to thermal neutral pair-fed cows. The consequence of the reduction of hepatic glucose synthesis, the alteration of glucose turnover and the increased glucose demand for energy need is the lower availability of glucose for mammary gland lactose synthesis. Since, lactose production is the primary osmoregulator and thus determinant of milk yield, reduction of glucose availability leads to the reduction of milk yield (Baumgard and Rhoads, 2007).

The negative slopes of the regression lines of milk and fat yields on THI indicate that milk and fat production decrease as THI increases. The drop in daily milk production in our study (1.48 kg per day) was considerably higher than the 0.32 kg per day per cow reported by Bouraoui *et al*. (2002). A large part of the variation in daily milk yield could therefore be attributed to heat stress. Similar to our results, Bouraoui *et al*. (2002) observed significant reduction in milk fat yield, but contrary to the current results, they reported summer-calved cows had a greater fat percentage of milk than spring-calved cows. The reason for the discrepancy between our results and other reports may be due to the differences in experimental conditions.

The longest interval from parturition to the next conception in spring is probably due to the delay in the breeding of dairy cows in the summer months (because of the heat stress, lower conception rate and poorer condition of nutrition). Days open is an intermediate factor and is influenced by several factors such as voluntary waiting period, estrus detection rate, and conception rate. Similar to the current results, Silvia *et al*. (2002) reported days open was least in cows that calved in the summer. The number of days open is typically shortest in cows that calve in the summer since they will enter the breeding herd in the fall and have the longest interval to conceive before heat stress becomes a factor again in the summer.

The regression line of days open on number of services per conception was positive ($b=2.56$, $P<0.01$). But, the regression line of days open on the conception rate was negative ($b=-0.08$, $P<0.01$). These regressions indicated that for each point increase in the number of services per conception and conception rate, there were increases and decreases in days open of dairy cows, respectively. Consistent with current results, Ghavi Hossein-Zadeh and Ardalan (2011) reported a negative correlation between days open and conception rate of dairy cows in Iran. Positive phenotypic correlations were found between days open and number of services per conception by Dematawewa and Berger (1998), because both traits were indicators of loss of fertility. Similar to the results of this study, Nabenishi *et al*. (2011) concluded that the conception rate of dairy cows decreased during the summer season. Heat stress may reduce the fertility of dairy cows in summer by poor expression of oestrus due to a reduced estradiol secretion from the dominant follicle developed in a low luteinizing hormone environment (De Rensis and Scaramuzzi, 2003). Also, semen concentration, number of spermatozoa and motile cells per ejaculate of bulls are lower in summer than in winter and spring. It has been reported that heat stress during the summer season may change the follicular microenvironment of highly productive dairy cows at an earlier stage postpartum, compromising the oocyte’s developmental competence and granulosa cell quality (Shehab-El-Deen *et al*., 2010). Therefore, it is postulated that the reduced conception rate during the summer season in this study may have been caused by an elevated body temperature during oocyte maturation.

Similar to the current results, Goshu *et al*. (2007) reported number of services per conception tended to increase significantly with parity number. Also, consistent with our results, Chebel *et al*. (2004) reported multiparous cows were less likely to conceive than primiparous cows. This result might be partially explained by the higher incidence of postparturient diseases compared to primiparous cows. Diseases during the early postpartum period are known to affect reproductive performance of lactating dairy cows. Therefore, it is possible that older cows experienced lower conception rates because they were at a higher risk for periparturient problems known to affect fertility.

The results of the present study indicated that summer heat stress and or increase in THI significantly decreased milk and fat yields in lactating dairy cows managed under humid climatic conditions of Rasht. There were linear relationships between THI and milk and fat yields, but there were non-linear associations between THI and fat percentage of milk, days open, number of services per conception and conception rate of dairy cows. On the other hand, seasonal effects on reproduction and fertility were noticeable, which indicates that management interventions to ameliorate the effects of heat load on reproductive performance of dairy cows could be necessary in certain periods of the year under the climatic conditions of the present study.

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