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Original Article

An analysis of a herd-based lactation curve reveals the seasonal effect from dairy cows fed under high ambient temperatures

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Abstract

The present investigation was carried out to demonstrate the effect of high ambient temperature (HTa) on lactation performance with herd-based measurement. One large dairy farm in Thailand with more than 300 crossbred Holstein cows milking each month was selected. The meteorological data was recorded once a week during the period of observation. Milking cows (n=90) were observed for a 10-month lactation curve based on their calving seasons: Summer, rainy and winter. The lactation curve was fitted by nonlinear regression using the reduced lactation persistency model. The climatic conditions revealed a high degree of temperature and humidity index (THI). The average THI throughout the year was 84.8 ± 0.5. The THI from summer (86.9 ± 1.0) was significantly higher than that from winter (82.7 ± 0.5, $P<0.05$). An analysis of the average lactation curve revealed that the total 305-day lactation yield (5407 kg) from this farm was higher than the average phenotypic 305-day lactation yield from dairy cows fed in Thailand (4698 kg). Lactation curves from different seasons revealed the potential effect of HTa on mammary gland function. Specifically, the area on the curve of the summer lactation curve was significantly lower than that of the winter curve by16% ($P<0.05$). This effect was apparently from the shortest lactation persistency. In conclusion, dairy cows fed in Thailand were under a high degree of HTa and had compromised lactation performance. Lactation persistency appears to be one of the main phenotypic traits for breed selection for dairy cows fed in the tropical country.

Keywords: Dairy cattle, environmental temperature, heat stress, lactation, season

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Introduction

Based on the Köppen-Geiger climate classification, Thailand is classified into two tropical areas (A) the majority of the north, eastern and central parts of Thailand have savannah (Aw) sub-climatic conditions. Only southern Thailand is classified into the monsoon (Am) sub-climatic condition (Beck *et al.*, 2018). The Aw climatic condition in Thailand is one of prolonged high ambient temperatures (HTa), high relative humidity and rainfall. This area can be divided into three main seasons which are rainy (mid-May to mid-October), winter (mid-October to mid-February) and summer (mid-February to mid-May). Mid-April is considered to be peak summertime in Thailand (Meteorological Department., 2019). At present, it is well accepted that the degree of ambient temperature (Ta) is gradually increasing because of global warming. These conditions not only influence our living quality but also our livestock production, including that of dairy cows.

In Thailand, the majority of dairy farms are small to medium size (10-19 milking cows per herd). In addition, the confinement feeding system in which concentrate and roughage are provided separately is used mostly on dairy farms (Rhone *et al.*, 2008). Many studies from the United States on dairy cows raised in the southeastern area have demonstrated significant economic loss in milk production (West 2003). Similar negative effects from HTa have also been shown in dairy cows raised in tropical areas (Fernandez *et al.*, 2019; Chaiyabutr *et al.*, 2000). Effective temperature, described as the temperature and humidity index (THI), has been shown to be related to milk yield (Bohmanova, *et al.*, 2007). Previously, a THI range of 81-85 has been reported by our group from both dairy cows and goats (Chanchai *et al.*, 2010; Thammacharoen *et al.*, 2014; Nguyen *et al.*, 2019). This THI range suggests that dairy cows and goats fed in Thailand are at a stage of heat stress. However, there is not enough information to support the theory that the capacity of milk synthesis from dairy cows is influenced directly by the HTa from different seasons.

The objectives of this paper were, firstly, to demonstrate the present climatic conditions in the Aw area. Secondly, we hypothesized that the lactation curve is influenced by the season at the level of one herd. This information is of crucial importance in order to set up management strategies for the well-being of dairy cows raised in tropical savannah sub-climatic conditions.

Materials and Methods

Study area and meteorological data: The data was collected on a large commercial dairy farm in Nakornratchasima province, Thailand (latitude 14°32'19.0" N, longitude 102°05'48.4" E). This farm contained more than 300 crossbred Holstein cows (>87.5% Holstein) milking each month. During the study period (from February 2012 to July 2013), milking cows (n=90) were included in the observation based on their calving dates in the three main seasons: March 2012 for summer (n=16), June 2012 for rainy (n=23) and October 2012 for winter (n=51). Because the present investigation aimed to investigate the effect of ambient conditions at the individual farm level, the study population consisted of all lactating cows on farms where information on parity, calving-dates and weekly milk yield was available. In addition, incomplete milk yield information caused by mastitis was excluded from the investigation. The average lactation numbers from summer, rainy and winter cows (3.6 ± 0.4, 3.2± 0.5 and 3.4± 0.3 lactation) were not significantly different. Cows were housed in the free stall barn with the remaining herd. They were fed with concentrate according to production and the roughage and water was provided ad libitum. The observation period for each cow was 10 months after calving in accordance with the normal lactation of dairy cows. Cows were milked two times per day using an automatic milking system that can measure milk volume simultaneously (DeLaval, Tumba, Sweden). The DeLaval milking unit provided the milk production of each cow. Daily milk yields, once per week, from the system were used to calculate the average monthly milk yield from each cow.

Meteorological data at the study area was obtained once a week around 12.00-13.00 using a wet and dry bulb thermometer. Relative humidity (RH) was calculated based on dry and wet bulb temperature differences using the psychrometric chart. The temperature and humidity index (THI) was determined according to Chanchai *et al.*, (2010) as follows:

$$THI = 0.72\ (Twb + Tdb) + 40.6$$

where Tdb and Tdb = wet and dry bulb temperature respectively and was expressed as ˚C

The weekly climatic conditions were used to calculate the monthly data. The climatic conditions of summer (mid-February to mid-June), rainy (mid-June to mid-October) and winter (mid-October to mid-February) were averaged according to the Thai Meteorological Department.

Data collection, measurements and analysis: Milk records were obtained once per week from each cow. Weekly milk yield from each cow was averaged into each of 10 months. The Lactation curve of the average milk yield from each calving season was fitted by nonlinear regression using the reduced lactation persistency model (RLPM; Grossman *et al.* 1999):

$$yt = \frac{Yp}{t1}.t - \frac{Yp}{t1}.Ln\left[\frac{e^{t}+e^{t1}}{1+e^{t1}}\right] + b3.Ln\left[\frac{e^{t}+e^{t1+P}}{1+e^{e1+P}}\right] \quad \text{......................[equation 1]}$$

where yt = yield at time t, t1 = time at transition from increased yield to constant daily yield, yP = level of constant daily yield, b3 = rate of decline in yield from the end of constant daily yield to the end of lactation, and P = persistency of constant daily yield. Based on this model, the total 305-day lactation yield (Y_T) could be calculated based on the simple method of the area under curve of polygons:

$$Y_T = \frac{1}{2}[Y_P(2t_3 - t_1) + b_3\ (P + t_1 - t_3)^2] \quad \text{... ... ... [equation 2]}$$

where t3 = the end of lactation which is 305 for the present investigation.

Statistical analyses: all data was presented as the mean and standard error of measurement (SEM). all variables were checked for Gaussian distribution using the Shapiro-Wilk normality test. Meteorological data and average daily milk yield were analyzed with repeated two-way analysis of variance (ANOVA). The significant main effects of the meteorological data were analyzed subsequently by Dunnette's post-test using the peak Ta of the summer month (April or May) as the control. Likewise, the average daily milk yield from the second month post-partum (M2-PP) was used as the control for Dunnette's post-test. The R^2, residual standard error (RSE) and the Durbin-Watson statistic (D-W) were used to determine the goodness of fit (Grossman *et al.* 1999). The average daily milk yield from the lactation curve during calving month (or different season) and area under lactation curve (AUC) were compared using Bonferroni's post-test. Significance was declared at $P<0.05$.

Results

Climatic conditions: The climatic condition of Nakornratchasrima province, Thailand is tropical savannah (Aw) based on the Köppen-Geiger climate classification. During the study period, the average Ta during summer was significantly higher than that of winter but not for the rainy season ($P<0.05$, Figure 1a). The RH during the rainy season was higher than that of summer and winter ($P<0.05$, Figure 1a). The average THI during winter was lower than that for the summer and rainy seasons ($P<0.05$, Figure 1b). When the present information of climatic conditions was presented by month and analyzed using April as the control HTa, there were significantly higher Ta's from April 2012 than from August, October and December 2012 and January 2013 ($P<0.05$, Figure 2a). Likewise, there were significantly lower RHs from April than from the rainy season: May, June, July, August and September ($P<0.05$, Figure 2a). Finally, only the THI for April was higher than December ($P<0.05$, Figure 2b). When a comparison was made using May as the HTa control, there were significantly higher THIs for May than for January, October, December, and November ($P<0.05$, Figure 2b).

The lactation curve: The average lactation curve generated from 90 dairy cows revealed the pattern of the lactation curve of dairy cows fed under HTa in Nakornratchasrima province, Thailand. The average daily milk yield from M2-PP was significantly higher than that from M1-PP and from M4-PP to M10-PP. As there was no significance in the average daily milk yield between M2-PP and M3-PP, a comparison of the average daily milk yield using M3-PP as a control was also done. The analysis revealed that the average daily milk yield from M3-PP was also higher than that from M1-PP and from M4-PP to M10-PP (Figure 3a). Using the RLPM and nonlinear regression to fit this lactation (Fig 3a dot line), the estimates of the model parameters and goodness of fit parameters, the estimates total 305-day lactation yield are shown in Table 1. For the average lactation curve, the level of constant daily yield was 21.6 kg, time at transition to constant daily yield was 33 days, the persistency of constant daily yield was 33 days and the rate of decline in yield from the end of constant daily yield (22+33= 55 days) to 305 days was 0.03 kg per day. The R^2 and RSE of the average lactation curve was 0.98 and 0.13, respectively. Autocorrelation analysis using the D-W statistic revealed a positive autocorrelation between the average lactation curve and the predicted curve ($P<0.01$). The total 305-day lactation yield based on the model was 5407 kg.

The lactation curves from different calving months (March, June and October) were used to investigate the effects of the summer, rainy and winter seasons on lactation capacity. The R^2 values from March, June and October lactation curves were 0.91, 0.43, and 0.96, respectively. The RSE from the March and June lactation curves (1.21 and 1.33, respectively) were higher than that from the October lactation curve (0.32). Based on the RLPM and D-W statistic, the autocorrelation of the lactation curve (Table 1) from June ($P<0.05$) and October ($P<0.01$) was also significant. However, the D-W statistic from the March lactation curve revealed that the test for autocorrelation was inconclusive ($P>0.05$) and there was no negative autocorrelation as well. Moreover, the lactation curves from different calving months revealed the effects of the season on the lactation curve in 2 important characters (Figure 3b). Firstly, the average daily milk yields, at M1-PP and at the peak milk yield (M2-PP), were not affected by the different seasons. Secondly, the lactation curve from M3-PP to M10-PP, which included the lactation persistency period, was influenced by the different seasons (Figure 3b). The lactation persistency (Table 1) from dairy cows calving in October (73 days) was maintained longer than that from March (13 days) and from June (20 days). This caused the significantly higher average daily milk yield from the October lactation curve during M4-PP and M5-PP than from March and June ($P<0.05$, Figure 3b). When the cows started lactation in March (M1-PP, summer time), the average daily milk yield started to decline rapidly (from M4-PP). When the cows started lactation in June (M1-PP, rainy season), the high degree of THI from June to October (M1-PP to M5-PP) produced a negative effect on the average daily milk yield as well. The lower degree of THI during November and December increased the average daily milk yield from the June lactation curve. The average daily milk yield from the June and October lactation curves from M6-PP to M9-PP were higher than that from the March lactation curve ($P<0.05$, Figure 3b). At the end of the lactation curve (M10-PP), the average daily milk yield from the June lactation curve was significantly higher than that from the March and October lactation curves ($P<0.05$, Figure 3b).

As the season or THI influenced the lactation curve and because the curve fit using an RLP model revealed a different goodness of fit (Table 1), the 305-day lactation yield that was calculated from the RLP model could not accurately represent the actual milk yield from different seasons. The AUC from each season's lactation curve was used to compare the effects of the season on lactation yield (Figure 4). Calving in the October or winter lactation curves, which had the longest persistency, had significantly more AUC than those form March and June (P<0.05; 16.27%).

Fig 1a

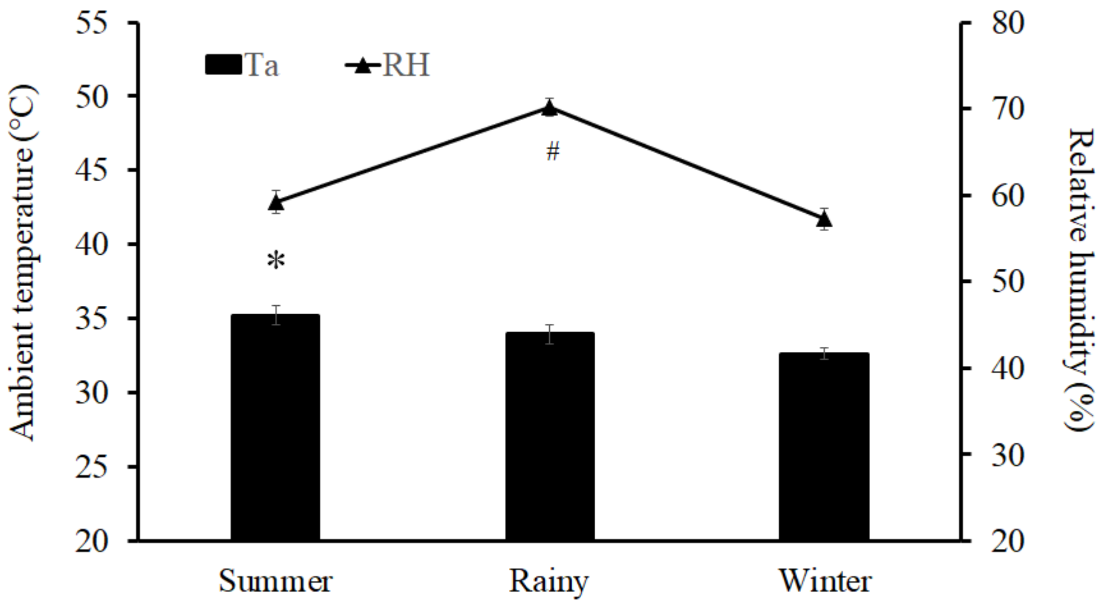

Fig 1b

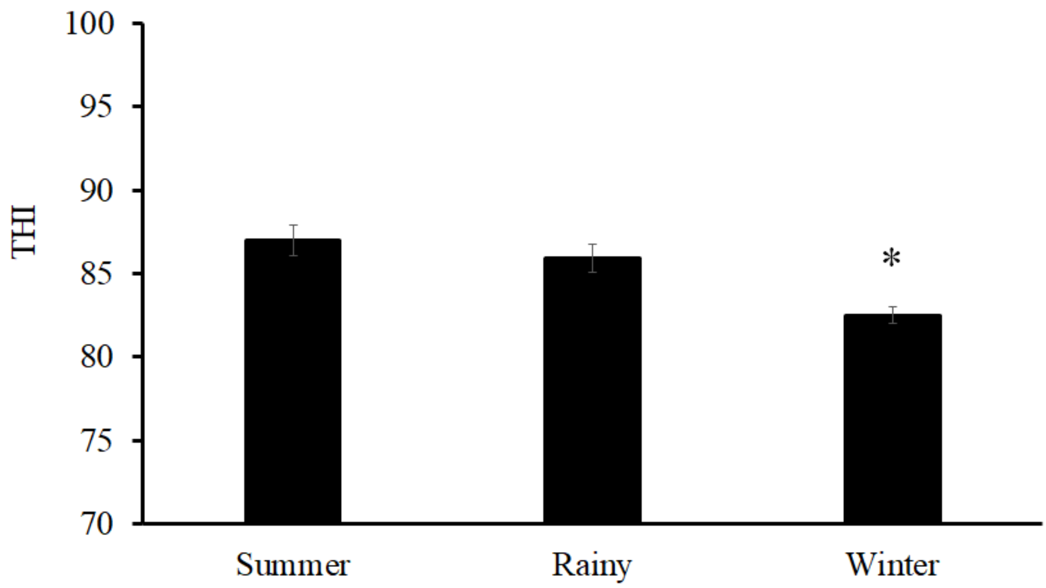

Figure 1 (a) The average ambient temperature (Ta, left axis) and relative humidity (RH, right axis) during summer, rainy and winter seasons. High Ta during summer months was significantly higher than that for winter (*). The RH during the rainy season was significantly higher than that for the summer and winter (#). (b) The average temperature and humidity index (THI) during the summer, rainy, and winter seasons. The THI during summer months was significantly higher than that for winter (*).

Fig 2a

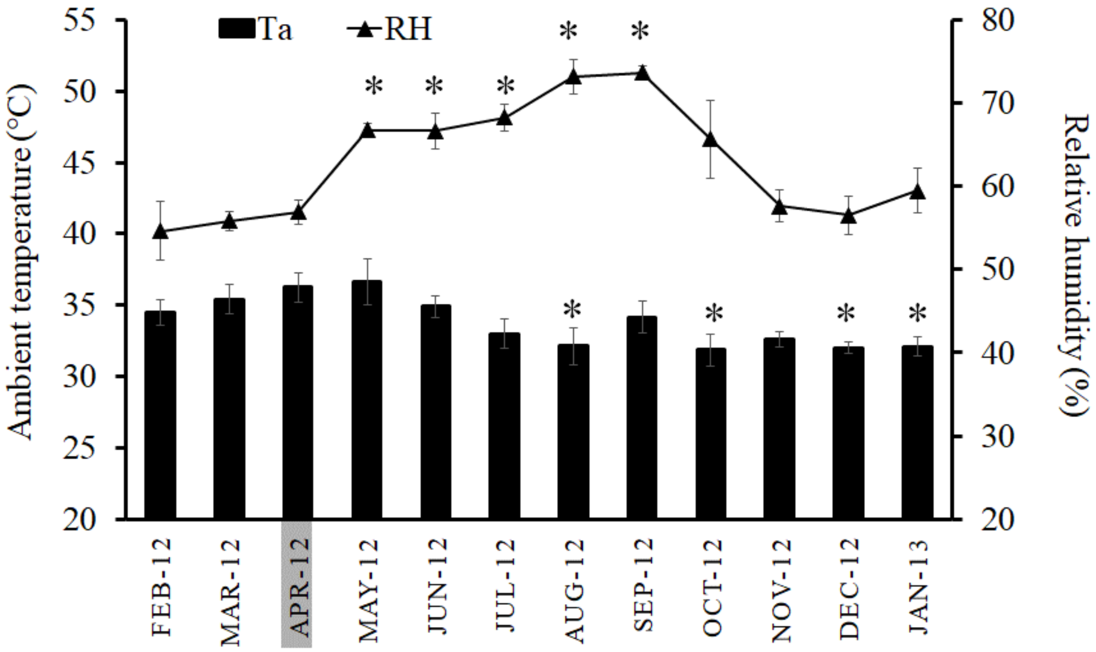

Fig 2b

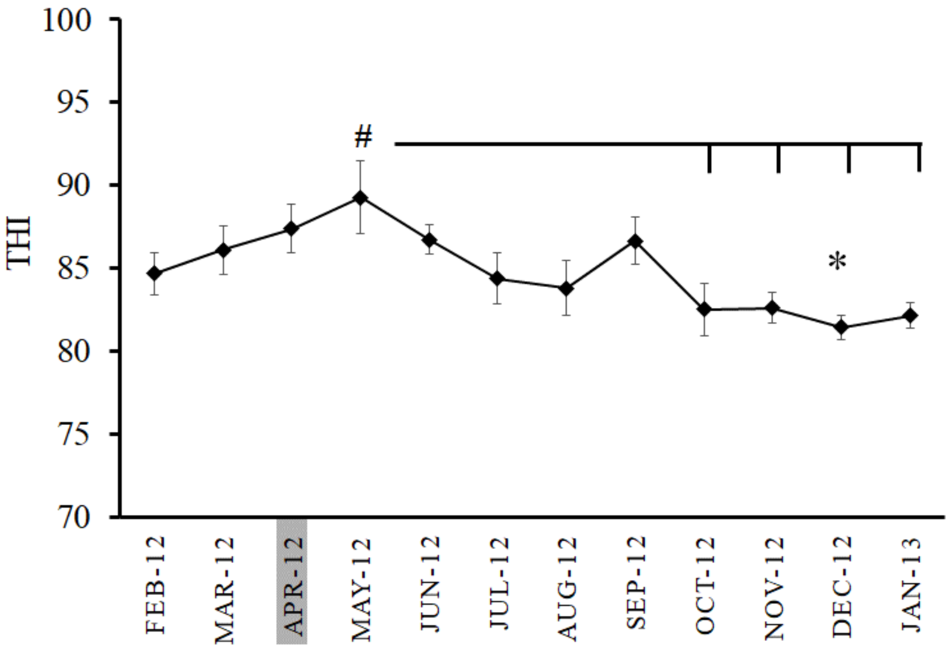

Figure 2 (a) The average ambient temperature (Ta, left axis) and relative humidity (RH, right axis) by month revealed typical high Ta during summer-time and high RH during the rainy season. The asterisks indicate a significantly lower Ta or higher RH using April as the control summer condition ($P<0.05$). (b) The average temperature and humidity index (THI) by month. The asterisk indicates significantly lower THI using April as the control summer condition ($P<0.05$). The THI from the winter months (October 2012 to January 2013) were significantly lower when the highest THI (May) was used as the reference point (#, $P<0.05$).

Fig 3a

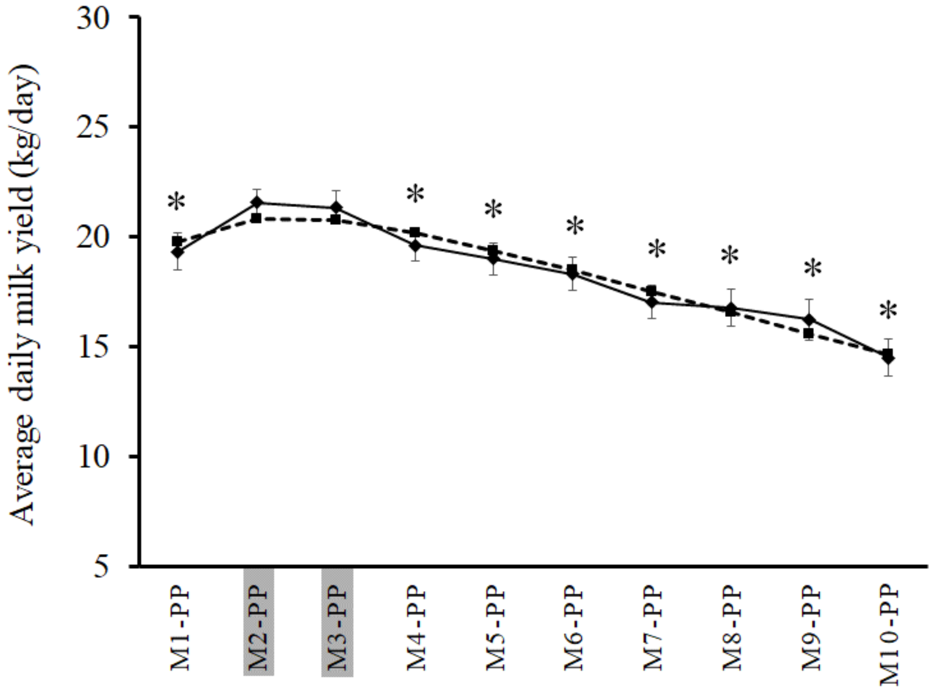

Fig 3b

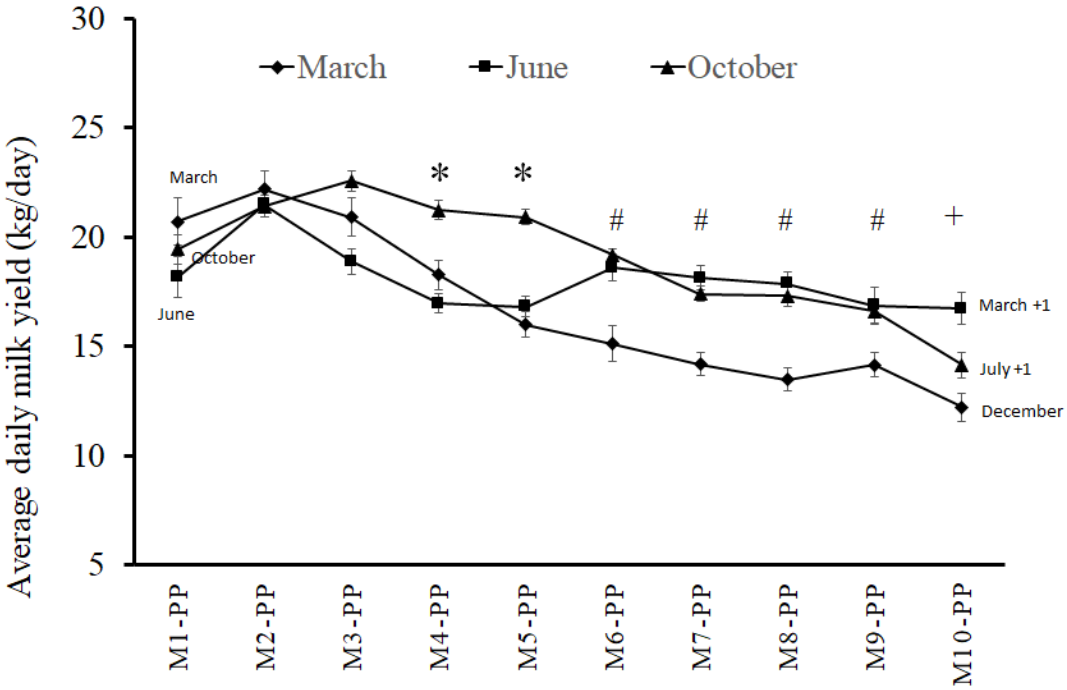

Figure 3 (a) The actual lactation curve (solid line) from one herd. The asterisk indicates a significantly lower milk yield using peak milk yield (M2-PP) as the reference point (P<0.05). The predicted lactation curve was fitted by nonlinear regression through the reduced lactation persistency model (broken line). (b) The actual lactation curve from different calving seasons. The signs reveal significance in milk yields from each lactation month: * between the October curve to March and June curves (P<0.05), # between the June curve to October and March curves (P<0.05), and + between the June curve to March and October curves (P<0.05).

Table 1 Model parameters[1], model residual standard error (RSE), Durbin-Watson statistic (D-W), and estimates of total 305-day lactation yield

	Averaged lactation curve (LC)	March LC	June LC	October LC
y_P, kg	21.56	21.68	19.61	21.99
t_1, day	33.41	31.11	32.27	33.94
b3, kg/day	-0.03	-0.04	-0.01	-0.04
P, day	33	13	20	73
R^2	0.98	0.91	0.43	0.96
RSE	0.13	1.21	1.33	0.32
D-W	0.409**	1.071	0.646*	0.372**
Y_T[2], kg	5407	4924	5286	5609

[1] equation [1] and [2] equation [2].
y_P = level of constant daily yield, t_1 = time at transition from increased yield to constant daily yield, b3 = rate of decline in daily yield from the end of constant daily yield to the end of lactation, P = persistency of constant daily yield, Y_T = total 305-day lactation yield
* Positive autocorrelation at *P*<0.05
** Positive autocorrelation at *P*<0.01

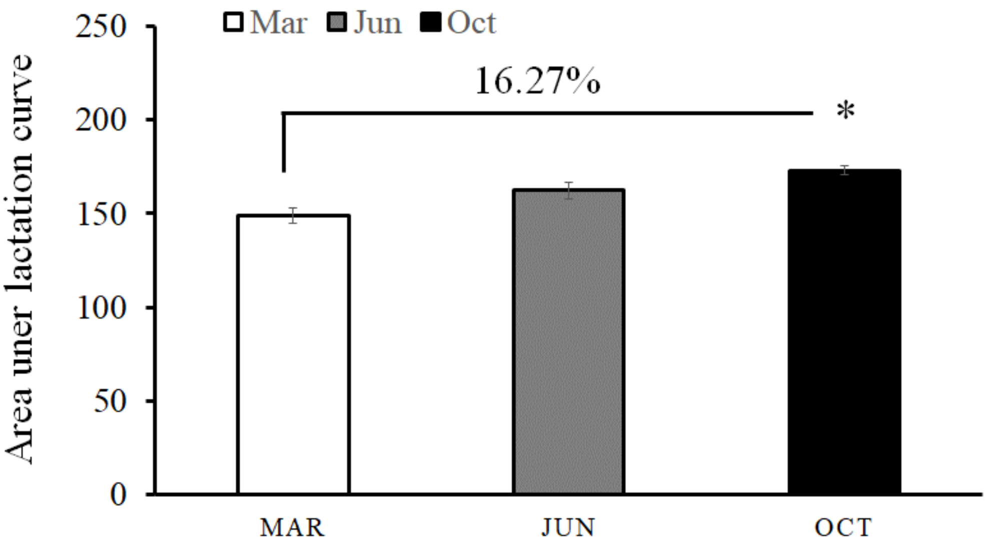

Figure 4 Area under the curve (AUC) of the lactation curve from different seasons. The asterisk indicates the summer AUC was significantly lower than the winter AUC, (*P*< 0.05).

Discussion

The data reported here revealed the effect of HTa on the lactation capacity from dairy cows fed under tropical conditions. In Thailand, the ambient conditions of a tropical savannah climate were first demonstrated to be associated with lactation performance. Under this climatic condition, HTa influenced mainly the persistency of the lactation curve. The shorter persistency from cows that started lactation in the summer months (March) made 16.3% lower AUC than in the winter months.

According to the Köppen-Geiger climate classification, the present study area represented the majority part of climatic conditions of Thailand which are tropical savannah sub-climatic conditions (Aw, Beck *et al.*, 2018). High Ta and RH made the THI throughout the year higher than 80 (mean THI = 84.8±0.5) which is much more than the critical value of 72 (Hahn. 1999; Bernabucci *et al.*, 2014; Bohmanova *et al.*, 2007). The degree of HTa from the present investigation was more than that reported previously from the incident of livestock deaths in North America and in Italy (Hahn. 1999; Vitali *et al.*, 2009). In tropical regions, there are four countries, including Puerto Rico (75.0), Thailand (75.5), the Dominican Republic (76.2), Guyana (77.2) and Malaysia (78.7) that have THI above 72 for the whole year (12 months; Johnson. 1989). It should be noted here that from those four tropical countries, only Thailand has a savannah sub-climatic condition. The rest are rainforest (f) or have monsoon (m) sub-climatic conditions (Beck *et al.* 2018). To our knowledge, this is updated information on the year-round climatic conditions from Thailand since 1989. The present climatic condition and previous reports indicate two important areas of information that may influence animal dairy farming in the tropical region. Firstly, the Ta and THI from the present investigation was much higher than that reported 30 years ago. This is probably due mainly to the effect of global warming. Secondly, dairy animals raised in this region are confronted with a high degree of HTa throughout the year. The later information suggests that under the HTa of the present conditions the acclimatization process is an important mechanism conducting animal production and survival.

The average lactation curve from the present investigation represents the production performance of dairy cows fed under HTa conditions from one large commercial dairy farm in Northeastern Thailand. The curve fitted well with an RLP model and allowed the prediction of a total lactation yield (305-day basis). The predicted total 305-day lactation yield from the present investigation (5407 kg) was higher than the average phenotypic trait of 305-day lactation yield from 1993 to 2013 (3244 to 4698 kg, 48 kg/year), reported by the Department of Livestock Development (DLD), Thailand (Buaban. 2018). However, the phenotypic traits of 305-day lactation yield from the present investigation and from the DLD reports were much lower than the 305-day lactation yield of 2017 reported by USDA:AIPL (12,750 kg, 112 kg/year; USDA:AIPL, 2019). Genetic backgrounds and selection programs are the major contributing factor for the differences in lactation yield between Thailand and US Holsteins. In addition to genetic processes, the effect of HTa may influence the phenotypic traits of lactation yield in two ways. Firstly, HTa may suppress the mechanism of genetic progression during the course of a breeding program (Carabano *et al*., 2017). Secondly, HTa may influence milk synthesis in part through the acclimatization processes. The present investigation aimed to show evidence of the later HTa effects from the tropical zone and to emphasize that dairy cows fed under HTa need adjustment to achieve optimum lactation capacity and animal well-being.

The lactation curves from cows calving from different seasons revealed the effects of HTa on milk synthesis mainly on lactation persistency. As expected, the shortest persistency was the March or summer lactation curve. The persistency of the rainy lactation curve (June) was compromised by the low Ta of winter during late lactation. In addition, the rapid decline of the lactation curve in the rainy season during M4PP-M5PP (Fig3b) apparently corresponded with the increase in THI during this period. The goodness of fit for the present lactation curves was in agreement with previous reports where the typical lactations could be predicted using an RLP model. However, an RLP model could not accurately predict non-typical lactations that are influenced by season (Olori *et al*., 1999). Thus, we used the calculated AUC to compare the potential effects of seasons on the lactation curve. The AUC data revealed a significantly lower lactation proficiency with 16.3% less in the summer than in winter. Similar results for the effect of HTa on lactation proficiency were reported previously from Central American, European and Asian countries (Bernabucci *et al*., 2014; Bohmanova *et al*., 2007; Bouraoui *et al*., 2002; Igono *et al*., 1992; Javed *et al*., 2004; Ray *et al*., 1992; Tekerli *et al*., 2000). According to the broken-stick function for milk yield and THI relationship (Bernabucci *et al*., 2014; Bohmanova *et al*., 2007), the present THI levels were at the second phase of the regression model where milk yield linearly declines with the increasing degree of THI. This means that any alleviated strategic decrease in THI or improvement in the tolerance could increase milk yield. We demonstrated previously that increasing evaporative heat dissipation by evaporative cooling, but not misty fan cooling, could improve milk yield from cows fed under similar conditions (Igono *et al*., 1985; Suadsong *et al*., 2008; Chanchai *et al*., 2010). Moreover, under the HTa conditions of tropical areas, the persistency of lactation could be rescued by somatotropin supplementation. Specifically, the effects of somatotropin supplementation in increasing milk yield under HTa was mediated by increased mammary blood flow and nutrient uptake (Chaiyabutr *et al*., 2007). This evidence indicates that the effect of HTa on the capacity of the mammary glands is reversible and supports in part the idea that mammary glands acclimatize to HTa conditions. It should be noted here that the present investigation aimed at uncovering the effect of HTa at the level of one herd. This main question forced us to recognize the drawbacks of sample size limitation. However, it was clear from the results that the herd level HTa has a significant effect on lactation pattern. Taken together, it is undeniable that dairy cows fed in Aw countries are in the stages of heat stress. Acclimatization mechanisms through a decrease in lactation capacity is common. Both physical (Igono *et al*., 1985; Suadsong *et al*., 2008; Chanchai *et al*., 2010) and nutritional (Nguyen *et al*., 2019) modifications are essential means for dairy cow management in tropical countries.

In conclusion, by demonstrating the lactation curves in relation to the climatic conditions or seasons in Thailand, we conclude that dairy cows are raised under a permanently high degree of HTa or THI. The different lactation curves indicate the adaptation of mammary gland function as part of HTa acclimatization. In this range of high degrees of THI, it is possible to improve lactation performance by promoting heat dissipation. Both physical and nutritional strategies should be considered to alleviate the negative effects of HTa and to promote animal well-being.

Conflict of interests: No conflict of interest, financial or otherwise, is declared by the authors.

Statement of animal rights: The manuscript does not contain clinical studies or animal experiments.

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