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Factors affecting dairy milk production and their associations under practical conditions in Northeastern Thailand

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ABSTRACT

This study investigated factors influencing milk production in terms of quantity (raw milk yield) and quality (%fat, %protein, %lactose, %total solids, and log somatic cell counts (log SCC)) and examined the associations among these traits in the morning (am) and evening (pm) milking sessions. Data were collected from the Herd Health Unit under the supervision of the Livestock Regional Office 3, Northeastern Thailand, during 2022 to 2025. Statistical analyses included analysis of variance (ANOVA) to assess fixed effects, Tukey's Honestly Significant Difference (HSD) test for mean comparisons, and Pearson's correlation analysis. Fixed effects included diurnal difference, groups of temperature-humidity index (THI), milk collecting center types (MCC type), and their interactions. The interaction between diurnal difference and MCC type significantly affected raw milk yield, %fat, % lactose, %total solids, and log SCC ($P < 0.001$). Morning milk yield was highest in dairy cooperatives (10.80 tons; $P < 0.05$), while evening fat percentages were highest in private organizations (4.02%) and dairy cooperatives (3.97%) ($P < 0.05$). Lactose percentages were significantly lower in the university affiliated centers for both morning (4.55%) and evening (4.56%) sessions ($P < 0.05$). Morning total solids were highest in private organizations (12.8%) and dairy cooperatives (12.6%) ($P < 0.05$), and log SCC values were generally higher in the morning across all MCC types. The THI significantly influenced %lactose and %total solids ($P < 0.001$), with THI class A (72 to79.9) exhibiting higher lactose (4.7%) and total solids (12.6%) than other classes ($P < 0.05$). Correlation analyses demonstrated significantly positive associations between the traits in the morning and evening sessions ($r = 0.52$ to 0.79), positive correlations between raw milk yield and milk composition across diurnal differences ($r = -0.05$ to 0.83), negative correlations between milk composition and log SCC ($r = -0.38$ to -0.01), and low positive correlations between raw milk yield and log SCC ($r = 0.08$ to 0.11). These findings demonstrate that milking time, MCC type, and heat stress all contribute to the composition and yield of milk, providing insights for the optimization of dairy management in tropical conditions.

Keywords: Dairy milk yield compositions, Diurnal variation, Somatic cell count, Temperature-humidity index, Tropical dairy production.

INTRODUCTION

Milk production is a critical component of the farm industry, providing essential nutrients for human consumption and serving as a major source of income for smallholder farmers worldwide (World bank, 2025; Adesogan and Dahl, 2020; Tricario *et al*., 2020). The income of dairy farmers depends not only on the quantity of milk produced but also on various milk quality attributes, including fat content, solids-not-fat (SNF), and somatic cell count (SCC), with each quality class corresponding to a specific payment rate (Seangjun and Koonawootrittriron, 2007). In Northeastern Thailand, dairy production faces unique challenges due to environmental stressors, management practices, and herd characteristics that directly influence both milk yield and quality. To incentivize the production of high-quality milk, the Dairy Farming Promotion Organization of Thailand (2015) established payment programs that provide premium rates for milk with higher fat and SNF content, while unacceptable low-quality milk receives a penalty. The levels of base, premium, and penalty rates vary among milk collecting centers (MCCs), which coordinate operations along the dairy value chain. Dairy farmers in the region generally report high satisfaction with the roles of the private organizations and dairy cooperatives in meeting basic needs, ensuring food safety, quality assurance, and fair milk purchasing rates, while satisfaction with credit services is lower (Jitmun *et al*., 2019).

Several factors have been reported to affect milk production, including breed, age, body condition, lactation stage, feeding management, and environmental conditions such as temperature and humidity (Tančin *et al*., 2020; Kheowsri *et al*., 2023; Bednarski *et al*., 2024). Heat stress, in particular, has been shown to reduce milk yield and alter milk composition, including fat, protein, and lactose content (Chen *et al*., 2024; Oliveira *et al*., 2025) as well as affect the SCC, which is an important indicator of udder health (Barlowska *et al*., 2009; Magro *et al*., 2023). Moreover, interactions between farm management practices—such as feeding regimes, type of feed, and milking frequency—and animal-related factors can further modulate milk production outcomes under practical farm conditions. Understanding the associations between milk yield, milk components, and influencing factors is essential for designing effective management strategies that enhance productivity and milk quality.

This study aimed to investigate the factors that influence the quantity and quality of dairy milk production in practical farming conditions, and to examine the relationships between dairy milk production traits during morning and evening milking sessions. The findings are expected to provide insights that can support evidence-based interventions to improve milk yield, composition, and overall herd performance in smallholder dairy systems.

MATERIALS AND METHODS

Data Collection

Data were obtained from the Herd Health Unit under the supervision of the Livestock Regional Office 3, Thailand. Monthly records of raw milk yield and composition were collected on two consecutive test days during the morning (am) and evening (pm) milking sessions. The main testing schemes used by the types of MCC included sampling all milking periods within 24-hour test day, which is defined as a diurnal difference (Diurnal). The alternate morning-evening scheme involved a single milking sampled each test day, with milking times alternating between in the morning and evening from test to test. Data were systematically stored in a central database, and compiled from three types of MCC, including 30 private organizations, 21 dairy cooperatives, and 3 university affiliated centers. Personnel from each collection center received standardized training on milk sampling procedures and milk quality assessment protocols in accordance with the guidelines established by the Thai Agricultural Standard (TAS6003-2010) based on the National Bureau of Agricultural Commodity and Food Standards.

The dataset covered the period from January

2022 to May 2025. Information on lactation number and days in milk was not available or recorded during data collection. To account for differences in production scale, herd size was classified into five groups according to the number of animals managed under each milk collecting center (MCC): ≤50, 51–100, 101–500, 501–1,000, and ≥1,001 animals per herd. A preliminary test of independence between herd size and MCC type was conducted using the Chi-square test (x^2) in Jamovi software version 2.5 (The Jamovi Project, 2024). This analysis aimed to determine whether herd size distribution was associated with the MCC type and to ensure that potential confounding effects were appropriately controlled in subsequent statistical models.

Meteorological data, including dry-bulb temperature and relative humidity, were collected for each official test day, with data provided by the Thai Meteorological Department. These climatic variables were subsequently used to calculate the Temperature-Humidity Index (THI) following the equation proposed by the National Research Council (NRC, 1971):

$$THI = 1.8 \times T + 32 - (0.55 - (0.0055 \times RH)) \times (1.8 \times T + 32 - 58)$$

where T was the dry-bulb temperature in degree Celsius (^oC), and RH was relative humidity (%).

The THI was included as a fixed effect in the statistical model. The index was categorized into three classes based on the distribution of the dataset and following the classification proposed by Dimov *et al*. (2020). In this study, the THI was classified into 3 classes: Class A (72.0–79.9), Class B (80.0–89.9), and Class C (90.0–98.9). The mean ± standard deviation and range of THI values were 87.0 ± 4.68 and 75.9–96.4, respectively. This fixed effect was used in place of the month-by-year interaction, which is commonly applied in similar studies (Bohemanova *et al*., 2006; Chen *et al*., 2024; Moore *et al*., 2023).

Milk Analysis

Raw milk collected from smallholder farms was pooled and weighed using a digital scale at the MCCs. The corresponding samples were analyzed for milk quality in compliance with IEC 17025 standards. Prior to routine testing, milk samples were stored in temperature-controlled transport containers and submitted to the Veterinary Research and Development Center, which served as the authorized milk testing laboratory.

Milk composition parameters, including fat, protein, lactose, and total solids, were determined using the mid-infrared spectroscopy method (Fourier-Transformed Infrared Spectroscopy; FTIR, Denmark). The SCC value was measured using a flow cytometry-based technique (Fossomatic FC, Denmark) as described by Kampoosiri *et al*. (2020). All analytical instruments were calibrated and verified using three reference milk samples before each measurement.

Statistical Analysis

Raw milk yield and composition data from both morning and evening milkings were expressed as percentages, and SCC values were multiplied by 1,000 prior to analysis. Data processing was conducted using Microsoft Excel, and statistical analyses were performed with Jamovi software version 2.5 (The jamovi project, 2024). The SCC values were log□ □ -transformed to normalize their distribution.

Descriptive statistics, including mean, standard deviation (SD), minimum, and maximum values, were calculated. The statistical model was evaluated using the analysis of variance (ANOVA) method with Fisher's F-test. Differences among levels of the fixed effects were determined using Tukey's honestly significant difference. Results are presented as least square means ± standard errors (SE). The statistical model applied was as follows:

$$y_{ijkl} = \mu + Diurnal_i + THI_j + MCC\ type_k + + (Diurnal*THI)_{ij} + (Diurnal*\ MCC\ type)_{ik} + (THI*MCC\ type)_{jk} + (Diurnal*THI*MCC\ type)_{ijk} + e_{ijkl}$$

where

y_{ijkl} = the ijklth observation of each evaluated trait
μ = the overall means
$Diurnal_i$ = the fixed effect of ith diurnal difference; i = morning (am), and evening (pm)
THI_j = the fixed effect of jth temperature-humidity index group; j = 72-79.9, 80-89.9, and 90-98.9
MCC $type_k$ = the fixed effect of kth milk collecting center types; k = private organizations, dairy cooperatives, and university affiliated centers
$(Diurnal*THI)_{ij}$ = the interactions between diurnal and temperature-humidity effects at i*j levels
$(Diurnal*THI)_{ij}$ = the interactions between diurnal and temperature-humidity effects at i*j levels
$(Diurnal*MCC\ type)_{ik}$ = the interaction between diurnal and types of milk collecting center effects at i*k levels
$(THI*MCC\ type)_{jk}$ = the interaction between temperature-humidity and types of milk collecting center effects at j*k levels
$(Diurnal*THI*MCC\ type)_{ijk}$ = the three-interaction among diurnal*temperature-humidity*types of milk collecting center effects at i*j*k levels
e_{ijkl} = random residual errors $e_{ijkl} \sim N(0,\sigma_e^2)$

Pearson's correlation analysis was performed to evaluate the relationships between morning and evening milk yield and composition traits. The significance level of each correlation ($P < 0.05$) was determined using the *corrplot* function in the R package. Correlation coefficients with absolute values ≥ 0.50 were interpreted as strong correlations. A correlation heatmap was generated using the *ggplot2* package in R (R Core Team, 2025).

RESULTS AND DISCUSSION

Descriptive Statistics

The means, standard deviations, minimum, and maximum values of the evaluated traits for both morning and evening milk records are presented in Table 1. The overall mean raw milk yields were 10.40 ± 5.22 tons and 8.13 ± 4.71 tons for morning and evening milking times, respectively. Morning milk yield tended to be higher than that of evening yield. Similarly, the milk composition traits showed minor variations between the two milking periods.

For morning measurements, the mean percentages of fat, protein, lactose, and total solids, as well as the logarithm of SCC (log SCC), were 3.78 ± 0.36%, 3.09 ± 0.19%, 4.65 ± 0.14%, 12.4 ± 0.52%, and 5.37 ± 0.28 cells/mL, respectively. The corresponding evening values were 3.97 ± 0.37%, 3.10 ± 0.21%, 4.64 ± 0.14%, 12.5 ± 0.55%, and 5.40 ± 0.28 cells/mL. Throughout the study period, raw milk yield and composition stayed in the acceptable range according to the Thai Agricultural Standard (TAS6003-2010) on raw cow milk (National Bureau of Agricultural Commodity and Food Standards, 2010).

Table 2 presents the herd size distribution across various types of MCC during this period. The test of independence between herd size and the types of milk collecting center from Chi-square (x^2) test was 19.36 ($P < 0.01$), indicating a significant association between them. Consequently, inclusion of only the types of milk collecting center in the statistical model was deemed appropriate to control for potential confounding effects. In addition, data in each MCCs was totally 972, 839, and 101 records, respectively.

Analysis of Variance and Mean Comparisons

Raw milk yield and composition traits were analyzed to assess the variance of fixed effects. The fixed effects included diurnal variation (Diurnal), groups of THI, types of MCC, their two-way interactions, and a three-way interaction, all of which were incorporated into the statistical model. The results are summarized in Table 3.

The F-test results showed, the fixed effect of MCC type had a highly significant influence on

Table 1. Descriptive Statistics of Evaluated Data from 2022 to 2025

Parameters	Year	n (records)	Mean	SD	Minimum	Maximum
Raw milk yield^{am} (tons)	2022	525	7.16	1.63	4.25	10.10
	2023	511	10.90	5.12	4.15	27.30
	2024	620	12.00	5.35	4.41	21.90
	2025	256	11.20	6.35	4.00	25.00
	0verall	1,912	10.40	5.22	4.00	27.30
Raw milk yield^{pm} (tons)	2022	525	6.12	1.60	4.25	10.00
	2023	511	8.03	4.27	4.13	27.00
	2024	620	12.00	5.34	4.40	22.10
	2025	256	11.20	6.63	4.00	25.20
	0verall	1,912	8.13	4.71	4.00	27.00
% Fat^{am}	2022	525	3.79	0.34	2.55	4.89
	2023	503	3.80	0.37	2.18	4.91
	2024	619	3.79	0.35	2.13	4.82
	2025	256	3.71	0.33	2.47	4.82
	0verall	1,903	3.78	0.36	2.13	4.91
% Fat^{pm}	2022	524	3.97	0.37	2.13	4.97
	2023	503	3.98	0.38	2.19	4.99
	2024	618	3.97	0.60	2.36	4.97
	2025	255	3.90	0.37	2.34	4.97
	0verall	1,900	3.97	0.37	2.13	4.99
% Protein^{am}	2022	525	3.05	0.16	2.56	3.77
	2023	511	3.05	0.16	2.53	3.87
	2024	619	3.12	0.21	2.61	4.07
	2025	256	3.16	0.22	2.74	4.01
	0verall	1,911	3.09	0.19	2.53	4.07
% Protein^{pm}	2022	524	3.07	0.18	2.61	4.03
	2023	510	3.05	0.17	2.06	3.99
	2024	619	3.13	0.22	2.58	4.10
	2025	256	3.17	0.27	2.49	4.09
	0verall	1,909	3.10	0.21	2.06	4.10
% Lactose^{am}	2022	525	4.69	0.14	4.05	5.42
	2023	511	4.60	0.14	3.99	5.10
	2024	619	4.62	0.13	3.79	5.27
	2025	256	4.70	0.12	4.24	5.13
	0verall	1,911	4.65	0.14	3.79	5.42
% Lactose^{pm}	2022	525	4.69	0.14	4.21	5.43
	2023	510	4.60	0.14	3.40	5.10
	2024	619	4.62	0.13	3.89	5.22
	2025	256	4.70	0.12	4.26	5.13
	0verall	1,910	4.64	0.14	3.40	5.22
% Total solid^{am}	2022	525	12.4	0.45	11.1	13.90
	2023	511	12.3	0.52	10.2	13.70
	2024	619	12.4	0.53	10.3	14.00
	2025	256	12.3	0.56	10.7	14.20
	0verall	1,911	12.4	0.52	10.2	14.20
% Total solid^{pm}	2022	525	12.6	0.49	11.0	14.4
	2023	510	12.5	0.52	10.7	13.9
	2024	619	12.6	0.53	10.3	14.1
	2025	256	12.5	0.65	11.0	18.5
	0verall	1,910	12.5	0.55	10.3	18.5
log SCC (cells/mL)^{am}	2022	509	5.40	0.23	3.48	5.85
	2023	439	5.39	0.25	4.23	5.71
	2024	508	5.35	0.31	4.15	5.71
	2025	241	5.31	0.31	4.15	5.69
	0verall	1,697	5.37	0.28	3.48	5.85
log SCC (cells/mL)^{pm}	2022	520	5.43	0.25	4.08	5.89
	2023	433	5.42	0.24	4.36	5.82
	2024	509	5.40	0.31	4.08	5.82
	2025	235	5.33	0.36	4.00	5.81
	0verall	1,697	5.40	0.28	4.00	5.89

n = Total number of monthly records of two daily milking from 3 types of milk collecting center, ^{am} = the measured traits in the morning, ^{pm} = the measured traits in the evening and SD = standard deviation.

Table 2. Different Sizes of Milking Cow Herd Raised by Smallholder Farmers Grouped by Their Respective Milk Collecting Centers During 2022 to 2025.

Herd size	Types of Milk Collecting Center		
(No. of milking cows/herd)	Private Organization	Dairy Cooperative	University Affiliated Center
≥1,001	7	11	-
501-1,000	6	5	1
101-500	13	5	-
51-100	3	-	1
≤50	1	-	1
Total of herds	30	21	3
Total of data recordings	972	839	101

Table 3. Results of Variance Analysis for Milk Yield and Compositions (Statistical Significance of the F-test)

Factors	Traits					
	Raw Milk Yield (tons)	% Fat	% Protein	% Lactose	% Total Solid	log SCC (cells/mL)
Diurnal	<0.001	<0.001	ns	ns	<0.001	<0.001
THI	ns	ns	ns	<0.001	<0.001	ns
MCC type	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Diurnal *THI	ns	ns	ns	ns	ns	ns
Diurnal*MCC type	<0.001	<0.001	ns	<0.001	<0.001	<0.001
THI*MCC type	ns	ns	ns	ns	ns	ns
Diurnal*THI*MCC type	ns	ns	ns	ns	ns	ns

SCC = somatic cell count, Diurnal = diurnal difference, THI = temperature-humidity index, and MCC = milk collecting center, ns = non-significant difference (P > 0.05).

all evaluated traits (P < 0.001). The effect of Diurnal was also significant for raw milk yield, % fat, %total solids, and log-transformed somatic cell count (log SCC) (P < 0.001). The interaction between diurnal and MCC type significantly affected all evaluated traits except protein percentage (P < 0.001).

Table 3 indicates the interaction between diurnal variation and types of MCC (Diurnal × MCC type) had a highly significant effect on raw milk yield, %fat, %lactose, %total solids, and log SCC (P < 0.001). Least-squares means and standard errors for these traits are presented in Table 4.

Further examination revealed that the morning raw milk yield in all three types of milk collection centers tended to be higher than the corresponding evening yield. It can be attributed to the fact that morning milking is traditionally the primary milking session in all milk collection centers, as cows experience a longer overnight milking interval and reduced heat stress during the night. These conditions allow greater milk accumulation in the udder, thereby increasing morning milk yield (Bohmanova *et al*., 2006). The dairy cooperative sector exhibited the highest morning yield (10.80 ± 4.78 tons; P < 0.05). In contrast, both morning and evening yields from the university affiliated centers (8.31 ± 2.36 and 5.73 ± 0.54 tons, respectively) were significantly lower than those from other sectors (P < 0.05). The dairy cooperative sector in this study exhibited the highest morning milk yield compared with other sectors, which can be attributed to a combination of farm management scale and milk collection systems. Dairy cooperatives typically collected milk from a large number of small to medium-scale farmers, who delivered the greatest proportion of their milk during the morning milking session. This aggregation effect resulted in a higher total morning milk yield. In addition, cooperatives commonly offered price incentives that encouraged and motivated farmers to deliver milk to cooperative collection centers (Jitmum *et al*., 2019). In contrast, university affiliated centers primarily focused on research

Table 4. Least Square Means ± Standard Errors of the Evaluated Traits Among Interactions Between Diurnal Differences and Types of Milk Collecting Center

Traits/Factors	Types of MCC/ Diurnal difference					
	Private Organization		Dairy Cooperative		University Affiliated Center	
	Morning	Evening	Morning	Evening	Morning	Evening
Raw milk yield (tons)	9.97±3.42[b]	9.61±4.91[b]	10.80±4.78[a]	6.97±2.99[b]	8.31±2.36[c]	5.73±0.54[c]
% Fat	3.80±0.34[b]	4.02±0.37[a]	3.72±0.34[b]	3.97±0.35[a]	3.68±0.41[b]	3.78±0.44[b]
% Protein	3.13±0.20	3.14±0.20	3.06±0.17	3.06±0.19	2.96±0.14	2.97±0.14
% Lactose	4.68±0.14[a]	4.68±0.14[a]	4.63±0.11[a]	4.61±0.12[a]	4.55±0.12[b]	4.56±0.12[b]
% Total solid	12.20±0.50[b]	12.80±0.53[a]	12.10±0.50[b]	12.60±0.49[a]	12.00±0.49[b]	12.10±0.80[b]
log SCC (cells/mL)	5.32±0.30[a]	5.34±0.30[a]	5.43±0.22[b]	5.47±0.24[b]	5.33±0.26[a]	5.43±0.26[b]

[a], [b] and [c] = significant differences at $P < 0.05$ within row.

Table 5. Least Square Means ± Standard Errors of the Evaluated Traits Between Diurnal Differences and THI Classes

Factors	Traits					
	Raw Milk Yield (ton)	% Fat	% Protein	% Lactose	% Total Solid	log SCC (cells/mL)
Diurnal variation						
am	10.13±3.89[a]	3.78±0.35[b]	3.09±0.19	4.65±0.13	12.30±0.52[a]	5.36±0.27[a]
pm	9.61±3.59[b]	3.97±0.37[a]	3.10±0.20	4.64±0.14	12.50±0.56[b]	5.40±0.28[b]
THI classes*						
A	10.96±3.51	3.92±0.39	3.12±0.22	4.70±0.14[a]	12.60±0.57[a]	5.36±0.31
B	9.75±3.50	3.87±0.38	3.09±0.20	4.65±0.13[b]	12.50±0.53[b]	5.38±0.28
C	9.38±3.02	3.86±0.35	3.09±0.21	4.61±0.13[c]	12.40±0.54[c]	5.40±0.27

SCC = somatic cell count, am = the traits measured in the morning., pm = the traits measured in the evening, and THI = temperature-humidity index, [a, b] and [c] = the highly significant differences between rows of the effect ($P < 0.01$). THI classes: class A = 72.0 to 79.9, class B = 80.0 to 89.9, and class C = 90.0 to 98.9

and teaching objectives rather than maximizing milk yield. Although private organizations may employ intensive management practices, their milk was often directly processed or distributed across different collection times, thereby reducing the apparent morning milk volume.

Fat percentage measured in the morning for all three types of MCC (3.80 ± 0.34%, 3.72 ± 0.34%, and 3.68 ± 0.41%) was significantly lower than the corresponding evening values (4.02 ± 0.37%, 3.97 ± 0.35%, and 3.78 ± 0.44%) ($P < 0.05$). Griinari *et al*. (2001) and Bauman and Griinari (2003) pointed that high milk yield affected milk fat because the volume of milk synthesized increases faster than milk solid synthesis. Consequently, the increased milk volume can dilute milk fat concentration, especially if the energy intake was limiting (Daley *et al.*, 2022). Lactose percentage from the university affiliated centers was notably the lowest in both morning and evening measurements (4.55 ± 0.12% and 4.56 ± 0.12%, respectively) compared with the other centers ($P < 0.05$). Even slight increases in lactose synthesis draw more water into the mammary gland through osmotic regulation, resulting in increased milk yield (Knight, 2019).

The total solids percentage measured in the evening from private organization (12.80 ± 0.53%) and dairy cooperative sectors (12.60 ± 0.49%) was significantly greater than that of the other groups ($P < 0.05$). For SCC, the log SCC values observed in the private organization sector (5.32 ± 0.30 and 5.34 ± 0.30 cells/mL) were significantly lower than those recorded in the dairy cooperative sector (5.43 ± 0.22 and 5.47 ± 0.24 cells/mL), indicating better milk quality (P <

0.05). Dairy management practices in the private sector enabled earlier detection and more effective treatment of mastitis, resulting in lower SCC compared with cooperative systems that aggregated milk from numerous smallholder farms with heterogeneous management practices.

Although the results in Table 3 indicated no significant interaction between diurnal variation and THI groups, significant effects were observed on several evaluated traits when the main factors were considered separately. The result shows in Table 5.

The raw milk yield recorded in the morning (10.13 ± 3.89 tons) was significantly higher than that obtained in the evening (9.61 ± 3.59 tons). Conversely, certain milk components in the evening yield—such as %fat (3.97 ± 0.37%), % total solids (12.50 ± 0.56%), and log SCC (5.40 ± 0.28 cells/mL)—were significantly higher than those measured in the morning (3.78 ± 0.35% of fat, 12.30 ± 0.52% of total solids, and 5.36 ± 0.27 cells/mL of log SCC, respectively). The present study clearly demonstrated that protein and lactose percentages were less affected by diurnal variation compared to other milk components (P >0.05). The pattern of higher morning milk yield accompanied by slightly lower composition compared with evening milk aligns with the findings of Gilbert *et al*. (1972) in the Pennsylvania State University Holstein herd across different lactation stages. According to Forsbäck *et al*. (2010) and Candek-Potokar *et al*. (2006), the primary source of variation in milk components was some biological variations, which was influenced by unequal interval between milkings. A longer milking interval allowed greater accumulation of milk in the mammary gland, resulting in higher milk yield in the morning and lower concentrations of milk solids, particularly milk fat percentage and total solids percentage, due to a dilution effect (Delamaire and Guinard-Flament, 2006). In contrast, Forsbäck *et al.* (2010) reported that during the shorter interval between morning and evening milking, milk fat has less time to accumulate in the udder, leading to differences in fat concentration.

Another important fixed effect identified in this study was the THI groups, which indicates the level of heat stress experienced by dairy cows. The THI had a significant influence on % lactose and %total solids (Table 5). Milk produced under THI class A (72 to 79.9) exhibited the highest values for both traits (P < 0.05). In contrast to the findings of Bohmanova *et al*. (2006), and Moore *et al*. (2023), who reported that milk yield declined at higher THI levels than protein and fat content, the present study observed significant effects of THI on lactose and total solids (P < 0.05). High THI induced heat-stress, which reduced in feed intake and disrupted energy balance, and glucose metabolism (Chen *et al*., 2024). As global temperatures are projected to continue rising in the coming decades, maintaining milk yield and quality will become increasingly challenging. In response, the Thai dairy breeding program has been adapted to address climate change–related challenges by incorporating heat tolerance traits into the national dairy selection index for elite bull selection. Moreover, the heat abatement system such as shades, fans, fog misters, sprinklers were applied to increase efficacy of cooling. As Dimov *et al*. (2020) have mentioned, the severity of heat stress in dairy cows is influenced by multiple factors. The key determinants include ambient temperature and humidity, duration of heat exposure, the extent of nocturnal temperature decline allowing animals to cool, airflow and ventilation conditions, access to drinking water, as well as the animal's size, breed, and coat color.

Correlation Analysis

Based on the above results, a correlation analysis was implemented to examine the association patterns between raw milk yield and composition during diurnal periods and among the measured traits. Figure 1 illustrates the correlation matrix between milk yield and compositional traits for both morning and evening milking sessions.

Correlations between corresponding traits measured in the morning and evening were strongly positive (r = 0.52 to 0.79). The correlation coefficient for raw milk yield between morning and evening measurements was 0.75 (P < 0.001). Similarly, strong positive correlations were observed for milk composition traits between morning and evening samples: %fat (r = 0.52), %protein (r = 0.79), %lactose (r = 0.79), %total solids (r = 0.67), and log somatic cell count (log SCC; r = 0.74), all significant at P < 0.001. The positive correlations between milk yield and quality traits observed between morning and evening milkings was supported by Asher *et al*. (2015), who reported that night milk exhibited superior quality, as indicated by generally lower SCCs compared with morning milk. The authors further noted that night milk is naturally enriched in melatonin, and lipidomic analyses revealed higher levels of certain lipid fractions in night milk than in day milk. In contrast, Teng *et al*. (2021) reported no significant differences in milk fat, protein, lactose, or total solids between day and night milk; however, significant differences were observed in small molecules, metabolites, lipids, as well as hormones and cy-

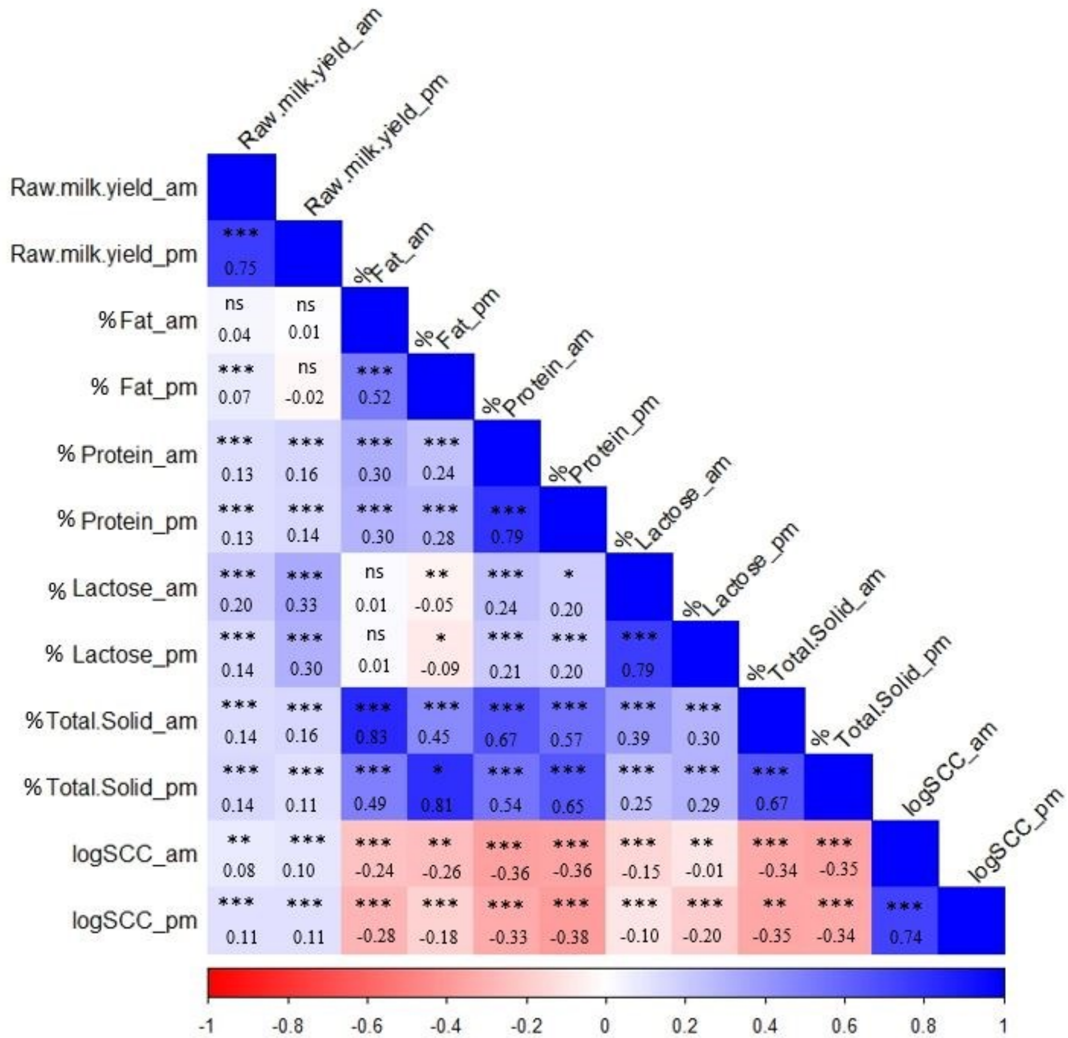

Figure 1. Pearson correlation heatmap illustrating relationships among raw milk yield and compositional parameters from milk samples collected at milk collection centers in northeastern Thailand. The "am" = the traits measured in the morning, "pm" = the traits measured in the evening. ^{ns} = non-significance, * = significant differences based on P < 0.05, ** = significant differences based on P < 0.01, and *** = significant differences based on P < 0.001

tokines (P < 0.05).

There were non-significant correlations were found between raw milk yield and %fat (-0.02 to 0.04), and between lactose and fat percentages in morning samples (0.01). The raw milk yield measured in both the morning and evening sessions was positively and significantly correlated with the %protein, %lactose, %total solids, and log SCC (r = -0.05 to 0.83). These results reflected increased mammary synthetic activity associated with higher milk production. Enhanced lactose synthesis regulated milk volume through osmotic control, thereby linking greater milk yield with increased lactose yield (Knight, 2019). Although increased milk volume may dilute milk fat and protein concentrations, the total daily yields of these components generally increased due to biological homeostasis (Bauman and Griinari, 2003; Walstra *et al.* , 2006).

Milk compositional traits including %fat, % protein, %lactose, and %total solid was significantly and negatively correlated with log SCC (r = -0.38 to -0.01), while low positive correlations between raw milk yield and log SCC (r = 0.08 to 0.11) were observed in this study. The negative correlations among SCC, milk yield, and milk components were consistent with the findings of Ermetin *et al*. (2024), who reported that reduced milk yield was correlated with increased SCC during the late lactation in Turkish Holstein cows, as well as with other studies (Cinar *et al*., 2015; Kul *et al*., 2019). In contrast, Jónás *et al*. (2016) observed positive correlations between SCC and the fat and protein contents of milk. Indicating that udder health remains a major factor of milk quality, a finding that is also reported by Haas *et al*. (2007). Subclinical mastitis or inflammation, indicative of increasing SCCs, can alter mammary gland metabolism and reduce the synthesis of key milk components, thereby negatively affecting both yield and compositional quality (Barlowska *et al*., 2009; Magro *et al.*, 2023).

CONCLUSION

Milk yield and composition were significantly influenced by the interaction among milking time (Diurnal), THI groups, and types of MCC. Morning milking generally produced higher yields, whereas evening milking resulted in a greater fat content. Dairy cooperatives and private organizations significantly outperformed the university affiliated centers in most milk yield, lactose, and total solid percentages because the university affiliated centers was not focused on incentive payment. High heat conditions (THI 90 to 98.9) tended to associate with inferior performance of lactose and total solid contents, indicating that thermal stress had a detrimental effect on milk quality. Positive correlations between milk yield and most compositional traits, except fat percentage, suggested that selection for higher milk yield may lead to a reduction in fat content. Negative correlations between milk components and somatic cell count further confirmed that udder health remained a key determinant of milk quality. Overall, the findings highlighted the combined effects of management system, diurnal variation, and heat stress on milk production and composition, providing valuable insights for optimizing dairy management strategies under tropical field conditions.

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