The relationship between udder skin surface temperature and milk production and composition in dairy cattle (Bos taurus Linnaeus, 1758)

Authors: Zaborski, Daniel, Soroko-Dubrovina, Maria, Grzesiak, Wilhelm, Parafiniuk, Mirosław, Modrzejewski, Andrzej, et al.

Source: Canadian Journal of Animal Science, 102(3) : 411-419

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjas-2021-0092

Canadian Journal of Animal Science

Article

The relationship between udder skin surface temperature and milk production and composition in dairy cattle (*Bos taurus* Linnaeus, 1758)

Daniel Zaborski[a], **Maria Soroko-Dubrovina**[b], **Wilhelm Grzesiak**[a], **Mirosław Parafiniuk**[c], **Andrzej Modrzejewski**[d], **Oleh Klym**[e], **Olha Stadnytska**[e], **and Jerzy Wójcik**[a]

[a]Department of Ruminants Science, West Pomeranian University of Technology, 71-270 Szczecin, Poland; [b]Institute of Animal Breeding, Wroclaw University of Environmental and Life Sciences, 51-160 Wroclaw, Poland; [c]Department of Forensic Medicine, Pomeranian Medical University, 70-111 Szczecin, Poland; [d]Clinical Department of General Surgery, Pomeranian Medical University, 71-210 Szczecin, Poland; [e]Institute of Agriculture of the Carpathian Region, 81-115 Obroshyne, Ukraine

Corresponding author: **Daniel Zaborski** (email: daniel.zaborski@zut.edu.pl)

Abstract

The aim of the present study was to determine correlations between udder skin surface temperatures and milk yield and estimated composition in dairy cows. The thermographic images of 34 Polish Holstein–Friesian black-and-white cows were taken in a milking parlor before and after milking. Partial correlation coefficients were calculated between the surface temperatures of the udder hind quarters and milk production traits controlling for age, parity, year, and milking time. Daily milk yield was weakly and nonsignificantly correlated with surface temperatures (r_p ranging from −0.19 to 0.21), except for the mean and maximum temperatures of the left hind quarter after milking ($r_p = 0.40$ and $r_p = 0.38$, respectively). There were significant correlations of skin surface temperature with estimated fat content ($r_p = -0.55$ to 0.48), protein content ($r_p = -0.39$ to 0.42), fat yield ($r_p = -0.42$ to 0.54), and protein yield ($r_p = 0.37$ to 0.54). The estimated somatic cell count was significantly correlated with the minimum temperature ($r_p = -0.54$ to −0.36). The estimated urea content was significantly correlated with the minimum temperature ($r_p = 0.52$). A larger sample size is required in future research to confirm these preliminary results.

Key words: cattle, correlation, mammary gland, milk production traits, thermography

Résumé

Le but de la présente étude était de déterminer les corrélations entre les températures de surface de la peau du pis et le rendement et la composition estimés du lait chez les vaches laitières. Les images thermographiques de 34 vaches Holstein–Friesian black-and-white polonaises ont été prises dans une salle de traite avant et après la traite. Les coefficients de corrélation partielle ont été calculés entre la température de surface du pis de l'arrière-train et les caractéristiques de production de lait, en contrôlant pour l'âge, la parité, l'année et l'heure de traite. Il y avait une corrélation faible et non significative entre le rendement quotidien de lait et les températures de surface (r_p allant de –0,19 à 0,21), sauf pour la température moyenne et maximale de l'arrière-train gauche après la traite ($r_p = 0{,}40$ et $r_p = 0{,}38$, respectivement). Il y avait des corrélations significatives entre la température de surface de la peau avec la teneur estimée en gras ($r_p = -0{,}55$ à 0,48), la teneur en protéines ($r_p = -0{,}39$ à 0,42), le rendement en gras ($r_p = -0{,}42$ à 0,54) et le rendement en protéines ($r_p = 0{,}37$ à 0,54). Il y avait une corrélation significative entre les estimations de numérations de cellules somatiques et les températures minimales ($r_p = -0{,}54$ à –0,36). Il y avait une corrélation significative entre la teneur en urée et la température minimale ($r_p = 0{,}52$). Une plus grande taille d'échantillon est nécessaire pour la recherche future afin de confirmer ces résultats préliminaires. [Traduit par la Rédaction]

Mots-clés : bovins, corrélation, glande mammaire, caractéristiques de production de lait, thermographie

Introduction

Thermal infrared cameras have become increasingly popular in various domains of science and human activity, including veterinary medicine and zootechnics. This is a consequence of an economic factor associated with the steadily decreasing prices of such devices and their rising availability. The advantage of thermography as a measurement method is its noninvasive and noncontact character and the possibility of utilization, e.g., during the dry period in cows (*Bos taurus* Linnaeus, 1758) or before the first calving (Hovinen et al. 2008). Due to the growing availability of thermal cameras, thermography has recently been applied to many areas of dairy cattle farming, e.g., the diagnosis of mastitis, kidney infection, and pneumonia (Hurnik et al. 1984), determination of oestrus onset in Holstein–Friesian cows (Hurnik et al. 1985), hoof health monitoring and identification of joint damage (Unshelm et al. 1992; Nikkhah et al. 2005), observation of inflammatory changes in hot-iron and freeze brand sites (Schwartzkopf-Genswein et al. 1997), analysis of cooling-induced heat stress and general stress in dairy cows (Kimmel et al. 1992; Knizkova et al. 1996; Stewart et al. 2007), evaluation of the effect of natural ventilation on the cows' thermal comfort (Knı´žková et al. 2002), aseptic arthritis diagnosis in Friesian heifers (Cockcroft et al. 2000), detection of viral diarrhea and respiratory diseases (Schaefer et al. 2004, 2007), and pain identification in calves (Stewart et al. 2008). Moreover, infrared thermography has been used in cattle for the investigation of the effect of different vacuum levels and liner types on the change in teat surface temperature (Kunc et al. 1999) and for early mastitis detection (Scott et al. 2000; Colak et al. 2008; Polat et al. 2010).

However, only a limited number of studies (Schmidt et al. 2004; Kwaśnicki et al. 2007; Perano and Gebremedhin 2015; Byrne et al. 2018; Yang et al. 2018) on the link between the skin surface temperature of different body parts (especially the udder) and milk traits (milk composition, among others) are available in the literature. A rise in udder skin surface temperature may be related to milk yield, as blood flow tends to increase in high-yielding cows. The existence of such relationships could be subsequently used for the development of statistical models predicting the values of these significant traits. Therefore, the aim of the present study was to determine correlations between udder skin surface temperatures measured with an infrared thermographic method and milk yield and estimated composition in dairy cows.

Materials and methods

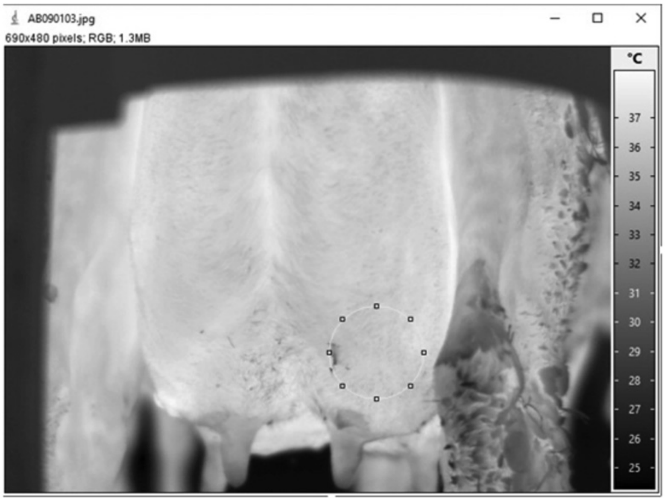
According to the national law, the collection of thermograms during the standard production process (routine milking in a milking parlor) is not classified as experimental work on animals and, therefore, does not require ethics committee approval (Resolution Number 22/2006 of the National Commission for the Ethics of Experiments on Animals, 7 November 2006). A total of 34 Polish Holstein–Friesian black-and-white cows from one farm located in the West Pomerania Province were investigated. They were in their first to fifth lactation [average daily milk yield of 36.44 kg; standard deviation (SD) = 12.22 kg]. Descriptive statistics for the controlling variables (age, parity, year of measurement, and milking time) are shown in Table 1. The cows were housed in freestall barns without access to the pasture but with external pens accessible over the whole year. The stalls were bedded with wood shavings. The animals were milked twice daily (at 03:30 and 13:00) in a herringbone milking parlor (Afimilk Ltd, Kibbutz Afikim, Israel) and fed a total mixed ration. They had unrestricted access to fresh water. The mean 305-day herd milk yield was approximately 11 200 kg. The images were taken in a milking parlor before and after the morning milking in June 2016 as well as the morning and (some photographs) evening milking in August 2017. The animals moved from the waiting area to the milking parlor systematically, and the average waiting time did not exceed 20 min. The udders were cleaned before milking, if necessary. The measurements before milking were taken immediately after the cows took their places in the stalls. The measurements after milking were made almost immediately after the milking process was completed. Due to technical reasons, it was not possible to wait extra time for the animals to rest. All animals included in the study were free of subclinical and clinical mastitis. Mastitis was detected via the California mastitis test. The somatic cell count (SCC) was determined during test days. The thermographic images of the cows' udders were recorded using a VarioCAM HR thermal camera (InfraTec GmbH, Dresden, Germany) with the following parameters: image resolution, 640 × 480 pixels; spectral range, 7.5–14.0 μm; thermal range, −40 to 1200 °C; and detector, uncooled microbolometer. The images were taken at a distance of approximately 1.5–2.0 m from the caudal and lateral aspects of the udder. The emissive angle did not exceed 45°. The distance between the camera and the udder surface was measured using a Vorel 81782 digital ultrasound rangefinder (range 0.91–15 m; Toya S.A., Wroclaw, Poland), whereas the ambient temperature and relative humidity were recorded at a height of approximately 2 m from the ground, away from the direct sources of heat, sunlight, and water, using a WT-150 electronic data logger consisting of a thermometer and a hygrometer (LaCrosse Technology, Strasbourg, France). During the 2016 session, the ambient temperature was 21.3 °C and the relative humidity was 87%. During the 2017 session, the ambient temperature was 23 °C and the relative humidity was 70%. These measurements were carried out to ensure that the conditions were constant during each thermographic session. The effect of session (year and milking time) was subsequently included in the statistical analysis when calculating partial correlation coefficients.

Table 1. The mean and standard deviation (SD) for the continuous controlled variable and the distribution of categorical controlled variables (n = 34).

Variable	Mean (±SD)
Age (months)	43.43 (±18.9)
Variant	n
Parity	
Primiparous	19
Multiparous	15
Year	
2016	18
2017	16
Milking time	
Morning	25
Evening	9

Emissivity was set at 0.95. The thermograms were recorded during two sessions (taking place in June 2016 and August 2017) and subjected to computer analysis. After conversion

Fig. 1. A circle with a radius of 50 pixels superimposed on the right hind quarter.



to grayscale, using the IRBIS 3 Professional software (v. 3.1; InfraTec GmbH, Dresden, Germany), an analytical method based on the determination of the udder skin surface temperature (°C) for its individual regions was applied. Using the ImageJ program (v. 1.48; National Institutes of Health, Research Services Branch, Bethesda, MD, USA), a circle with a diameter of 100 pixels was superimposed on the right and left udder hind quarters (Barth 2000; Hovinen et al. 2008; Soroko et al. 2017; Fig. 1).

The following image variables of the udder skin surface temperature were determined: arithmetic mean, SD, minimum, and maximum. The data on daily milk yield (in kg) recorded on the same day as the thermographic measurements were extracted from the database of the herd management software (AfiFarm, v. 4.07; Afimilk Ltd, Kibbutz Afikim, Israel). The data on other milk production traits (fat and protein content, fat and protein yield, lactose and urea content, and SCC) based on test-day records were obtained from the same database. The test-day milk samples were collected during the morning and evening milking. Test days were not specifically designed for the study but were scheduled for the purpose of performance recording. To estimate the values of milk production traits on the day of thermographic measurement, the following formula (used by the national milk recording system to estimate milk composition values) based on two consecutive test-day records (the test-day values recorded before and after the thermographic measurement) was used:

$$y = [(y_{\mathrm{a}} - y_{\mathrm{b}}) / \Delta t] \cdot n_{\mathrm{d}} + y_{\mathrm{b}} \quad (1)$$

where y is the estimated trait value (fat content, protein content, fat yield, protein yield, lactose content, urea content, and SCC) on the day of thermographic measurement, y_{a} is the actual test-day value recorded after the day of thermographic measurement, y_{b} is the actual test-day value recorded before the day of thermographic measurement, Δt is the number of days between the two consecutive test-day records, and n_{d} is the number of days between the test-day record preceding the day of thermographic measurement and the day of thermographic measurement.

Table 2. Means and standard deviations (SD) of the temperature variables in the right and left hind quarters ($n = 34$).

Variable (°C)	Before milking		After milking	
	Mean	SD	Mean	SD
Right hind quarter				
Mean	36.79	0.81	36.63	0.80
SD	0.44	0.18	0.46	0.15
Minimum	34.07	2.78	34.02	2.48
Maximum	37.82	0.66	37.81	0.72
Left hind quarter				
Mean	36.86	0.80	36.49	0.87
SD	0.43	0.14	0.51	0.19
Minimum	34.17	2.26	33.73	2.18
Maximum	37.95	0.65	37.81	0.70

Table 3. Means and standard deviations (SD) of the production variables ($n = 34$).

Variable	Mean	SD
Milk yield (kg)	36.44	12.22
Fat content (%)	3.98	0.58
Fat yield (kg)	1.43	0.41
Protein content (%)	3.27	0.32
Protein yield (kg)	1.18	0.33
Lactose content (%)	4.88	0.17
SCC ($\times 10^3$)	194.81	242.65
Urea content (mg/L)	294.25	36.63

The means and SDs of the temperature and production variables for the right and left hind quarters are presented in Tables 2 and 3, respectively.

Statistical analysis

Partial correlation coefficients were computed to verify the relationships between surface temperature variables and milk production traits (daily milk yield, fat and protein content, fat and protein yield, lactose and urea content, and SCC) controlling for four additional variables (cow's age: continuous variable; cow parity: primiparous or multiparous; thermographic measurement year: 2016 or 2017; and milking time: morning or evening; Table 1). The difference in the skin surface temperature of the left and right hind quarters before and after milking was verified with Student's t test for dependent samples or the Wilcoxon signed-rank test. The effect of additional factors (parity, year, and milking time) on surface temperature, milk yield, and estimated composition was verified using Student's t test for independent samples or the Mann–Whitney U test. Also, Spearman's correlation coefficients between cow's age and the remaining variables (temperature and production traits) were calculated. Statistical significance was declared at $p < 0.05$. All the statistical analyses were carried out using Statistica 13 (Dell Inc., Tulsa, OK, USA) or R (R Core Team 2013, R Foundation for Statistical Computing, Vienna, Austria) software.

Results

The effects of parity, year, and milking time on surface temperature and milk yield and estimated composition are shown in Tables 4 and 5, respectively. Spearman's rank correlation coefficients between age and surface temperature, milk yield, and estimated composition are presented in Tables 6 and 7, respectively. As seen from Table 4, milking time significantly affected all measured temperatures (mean, SD, minimum, and maximum) in both hind quarters. Parity significantly influenced SD in both hind quarters before milking, and the mean, SD, and minimum temperatures in both hind quarters after milking. Year significantly affected SD and minimum temperatures in the right hind quarter before milking, all measured temperatures in the right hind quarter after milking, SD of temperature in the left hind quarter before milking, and the mean, SD, and minimum temperatures in the left hind quarter after milking. Correlations between age and temperatures were mostly weak and statistically nonsignificant (Table 6), except for the SD of temperature in both hind quarters before milking as well as the SD and minimum temperatures in both hind quarters after milking. The effect of parity and year on production traits was significant only for the estimated fat content and protein yield (Table 5), whereas milking time significantly influenced milk yield, estimated fat content and yield, and estimated protein content and yield. The correlation between age and production variables was weak and statistically nonsignificant (Table 7).

The partial correlation coefficients (controlling for age, parity, year, and milking time) are presented in Table 8. In general, daily milk yield was weakly and nonsignificantly correlated with udder skin surface temperatures (r_p ranging from −0.19 to 0.21 for the SD of temperature and the mean temperature, respectively), except for the mean and maximum temperatures in the left hind quarter after milking (r_p = 0.40 and 0.38, respectively). Significant correlations were observed between estimated fat content and the mean, SD, and maximum temperatures of the right hind quarter after milking (r_p = 0.48, −0.55, and 0.37, respectively), and the SD and minimum temperatures of the left hind quarter after milking (r_p = −0.47 and 0.47, respectively). Estimated fat yield was significantly correlated with the mean and maximum temperatures of the right hind quarter before milking (r_p = 0.42 and 0.39, respectively) and the left hind quarter after milking (r_p = 0.47 and 0.54, respectively), and the SD and minimum temperatures of the right hind quarter after milking (r_p = −0.42 and 0.36, respectively). The estimated protein content was significantly correlated with the SD and minimum temperatures of the left hind quarter after milking (r_p = −0.39 and 0.42, respectively) (Table 8). The estimated protein yield was significantly correlated with the mean and maximum temperatures of the right hind quarter before milking (r_p = 0.38 and 0.37, respectively) and the left hind quarter after milking (r_p = 0.53 and 0.54, respectively).

Moreover, significant correlations were observed between estimated lactose content and the mean and maximum temperatures of the right hind quarter before milking (r_p = 0.40 and 0.41, respectively) and the minimum temperature of the right hind quarter after milking (r_p = 0.44). The estimated SCC was significantly correlated with the minimum temperatures of both hind quarters before milking (r_p = −0.37 and −0.36) and the minimum temperature of the left hind quarter after milking (r_p = −0.54). Finally, a significant correlation was found between the estimated urea content and the minimum temperature of the left hind quarter after milking (r_p = 0.52).

It should also be mentioned that significant differences (Table 9) in the mean temperature of the right hind quarter before and after milking and the mean temperature and SD of temperature of the left hind quarter before and after milking were found.

Discussion

At present, there are only a few studies dealing with the relationship between skin surface temperature and milk yield and composition. Therefore, in the study by Kwaśnicki et al. (2007) on 32 red-and-white cows (a mean lactation milk yield of 6797 kg), significant correlations were found between the skin surface temperature of the hind quarter teat cistern and the contents of urea, lactose, and nonfat solids in milk. In addition, significant correlations between the central ligament surface temperature and the contents of protein and fat in milk were observed. In the cited study, significant relationships between the carpal joint surface temperature and fat content, as well as between the maximum temperature of the oblique body axis and the contents of lactose and nonfat solids on the left side of the body, were also noticed. Finally, Kwaśnicki et al. (2007) found significant correlations between the minimum temperature of the oblique body axis and the contents of fat, dry matter, and SCC on the left and right sides of the body. It should, however, be mentioned that the authors of the cited study did not control for any additional factors, such as age, parity, or the year of the thermographic measurement (2004 and 2005). Moreover, the studied milk yield was determined on the test day of the month during which the thermographic measurements were taken and not on the day of thermographic measurement. Therefore, their results are not directly comparable with ours.

As far as the correlation between SCC and udder skin surface temperature is concerned, Byrne et al. (2018) analyzed 14 Holstein–Friesian cows at the evening milking on a daily basis and found only a weak relationship between the analyzed descriptive temperature parameters and SCS (natural log of SCC; r ranging from −0.16 to 0.19). The absolute partial correlation coefficients obtained in the present study for SCC (significant r_p values ranging from −0.54 to −0.36) were higher than those found by Byrne et al. (2018). It should be mentioned that Byrne et al. (2018) selected cows that had a highly variable SCC in the months preceding the experiment, which means that both healthy and mastitic animals were included in their study, and this could have affected the values of the

Table 4. The effect of parity, year, and milking time on surface temperature ($n = 34$).

Parity		First			Second or higher	
Variable	n	Mean (°C)	SD (°C)	n	Mean (°C)	SD (°C)
Right hind quarter before milking						
Mean	19	36.55	0.60	15	37.09	0.95
SD	19	0.52*	0.19	15	0.33	0.09
Minimum	19	33.32	3.00	15	35.01	2.22
Maximum	19	37.70	0.48	15	37.96	0.83
Right hind quarter after milking						
Mean	19	36.34*	0.62	15	36.99	0.88
SD	19	0.53*	0.14	15	0.36	0.10
Minimum	19	33.14*	2.50	15	35.12	2.02
Maximum	19	37.63	0.62	15	38.03	0.79
Left hind quarter before milking						
Mean	19	36.66	0.57	15	37.10	0.99
SD	19	0.50*	0.10	15	0.36	0.14
Minimum	19	33.42	2.37	15	35.12	1.75
Maximum	19	37.85	0.56	15	38.08	0.75
Left hind quarter after milking						
Mean	19	36.12*	0.62	15	36.97	0.93
SD	19	0.63*	0.16	15	0.36	0.10
Minimum	19	32.48*	1.76	15	35.30	1.55
Maximum	19	37.66	0.63	15	38.01	0.77
Year		2016			2017	
Right hind quarter before milking						
Mean	18	36.53	0.62	16	37.07	0.92
SD	18	0.53*	0.19	16	0.34	0.09
Minimum	18	33.23*	3.06	16	35.01	2.14
Maximum	18	37.71	0.49	16	37.94	0.80
Right hind quarter after milking						
Mean	18	36.29*	0.60	16	37.00	0.85
SD	18	0.54*	0.14	16	0.37	0.10
Minimum	18	33.03*	2.53	16	35.12	1.95
Maximum	18	37.57*	0.59	16	38.07	0.78
Left hind quarter before milking						
Mean	18	36.66	0.59	16	37.08	0.96
SD	18	0.50*	0.10	16	0.36	0.14
Minimum	18	33.40	2.44	16	35.03	1.72
Maximum	18	37.85	0.58	16	38.07	0.73
Left hind quarter after milking						
Mean	18	36.09*	0.63	16	36.94	0.90
SD	18	0.63*	0.16	16	0.36	0.10
Minimum	18	32.34*	1.71	16	35.28	1.50
Maximum	18	37.63	0.63	16	38.02	0.74
Milking time		Morning			Evening	
Right hind quarter before milking						
Mean	25	36.44*	0.60	9	37.74	0.50
SD	25	0.49*	0.18	9	0.30	0.07
Minimum	25	33.34*	2.78	9	36.10	1.55
Maximum	25	37.58*	0.51	9	38.49	0.56
Right hind quarter after milking						
Mean	25	36.31*	0.59	9	37.50	0.67
SD	25	0.50*	0.14	9	0.33	0.10
Minimum	25	33.23*	2.35	9	36.20	1.22
Maximum	25	37.58*	0.57	9	38.44	0.74

Table 4. Continued

Parity		First			Second or higher	
Variable	*n*	Mean (°C)	SD (°C)	*n*	Mean (°C)	SD (°C)
Left hind quarter before milking						
Mean	25	36.56*	0.57	9	37.68	0.81
SD	25	0.47*	0.10	9	0.33	0.18
Minimum	25	33.49*	2.10	9	36.04	1.56
Maximum	25	37.75*	0.55	9	38.52	0.59
Left hind quarter after milking						
Mean	25	36.14*	0.62	9	37.47	0.72
SD	25	0.58*	0.17	9	0.31	0.09
Minimum	25	32.79*	1.67	9	36.32	0.93
Maximum	25	37.62*	0.63	9	38.37	0.63

*Differences statistically significant at $p < 0.05$.

Table 5. The effect of parity, year, and milking time on milk yield and composition ($n = 34$).

Parity		First			Second or higher	
Variable	*n*	Mean	SD	*n*	Mean	SD
Milk yield (kg)	19	31.57	5.47	15	42.59	15.52
Fat content (%)	19	4.16*	0.57	15	3.75	0.52
Fat yield (kg)	19	1.31	0.22	15	1.58	0.54
Protein content (%)	19	3.28	0.23	15	3.26	0.42
Protein yield (kg)	19	1.03*	0.15	15	1.36	0.40
Lactose content (%)	19	4.90	0.16	15	4.85	0.19
SCC ($\times 10^3$)	19	175.35	211.58	15	219.45	282.97
Urea content (mg/L)	19	300.00	40.73	15	286.97	30.47
Year		2016			2017	
Milk yield (kg)	18	32.51	3.74	16	40.85	16.53
Fat content (%)	18	4.20*	0.56	16	3.73	0.51
Fat yield (kg)	18	1.33	0.20	16	1.53	0.55
Protein content (%)	18	3.28	0.23	16	3.26	0.41
Protein yield (kg)	18	1.04*	0.14	16	1.32	0.41
Lactose content (%)	18	4.91	0.16	16	4.85	0.19
SCC ($\times 10^3$)	18	163.62	211.26	16	229.89	276.54
Urea content (mg/L)	18	302.60	40.26	16	284.86	30.62
Milking time		Morning			Evening	
Milk yield (kg)	25	30.85*	6.61	9	51.94	10.80
Fat content (%)	25	4.16*	0.55	9	3.48	0.34
Fat yield (kg)	25	1.27*	0.27	9	1.85	0.45
Protein content (%)	25	3.36*	0.30	9	3.02	0.26
Protein yield (kg)	25	1.02*	0.19	9	1.59	0.26
Lactose content (%)	25	4.86	0.18	9	4.92	0.14
SCC ($\times 10^3$)	25	208.69	241.21	9	156.25	257.02
Urea content (mg/L)	25	298.58	38.25	9	282.22	30.44

*Differences statistically significant at $p < 0.05$.

correlation coefficients. In contrast, only nonmastitic cows (at least on the day of thermographic measurement) were included in the present study. The relationship between SCC and udder skin surface temperature is strictly linked to the application of infrared thermography to subclinical mastitis detection, but this issue is beyond the scope of this paper and will not be discussed in detail.

The association between udder skin surface temperature and daily milk yield was also investigated by Yang et al. (2018). In their study on 102 Chinese Holstein cows (from the first to third parity, 76 days in milk on average and the mean morning milk yield of 13.5 kg), the hind quarter skin surface temperature before milking was not significantly correlated with morning milk yield, nor was it significantly influenced by

Table 6. Spearman's correlation coefficients between age and surface temperature ($n = 34$).

Variable (°C)	Before milking	After milking
Right hind quarter		
Mean	0.10	0.25
SD	− 0.47*	− 0.52*
Minimum	0.22	0.36*
Maximum	− 0.06	0.14
Left hind quarter		
Mean	− 0.05	0.28
SD	− 0.49*	− 0.69*
Minimum	0.14	0.43*
Maximum	− 0.18	0.02

*Correlation coefficients statistically significant at $p < 0.05$.

Table 7. Spearman's correlation coefficients between age, milk yield, and estimated composition ($n = 34$).

Variable (°C)	r
Milk yield (kg)	0.12
Fat content (%)	− 0.25
Fat yield (kg)	0.09
Protein content (%)	0.09
Protein yield (kg)	0.24
Lactose content (%)	− 0.10
SCC ($\times 10^3$)	0.22
Urea content (mg/L)	− 0.05

milk yield (as analyzed by ANOVA). However, it exhibited a rising trend along with the increase in milk yield, whereas the hind quarter skin surface temperature after milking was both significantly (although moderately) correlated with morning milk yield ($r = 0.31$) and significantly influenced by milk yield (as analyzed by ANOVA).

In another work by Perano and Gebremedhin (2015) on the effect of heat stress on milk production in eight primiparous Holstein cows, a statistically significant correlation was observed between daily milk yield and udder skin surface temperature ($r = 0.53$). It was higher ($r_p = 0.14$–0.40) than that observed in our study for the mean surface temperature when taking into account additional factors. It was also shown (Schmidt et al. 2004) that the udder skin surface temperature in 16 Holstein cows measured with a thermal camera from the rear and lateral sides was higher in animals in the second half of lactation than in cows in the first half of lactation, both before and after milking.

The relationship between skin surface temperature and milk yield and composition has a physiological background. According to Kwaśnicki et al. (2007), thermograms are quantitative reflections of body surface temperature since the amount of energy released from the body is a function of its temperature. Normal body temperature is affected by the metabolic state of the organism. Usually, skin surface temperature is lower than core temperature and influenced by many additional factors (different heat sources, the activity of tissues located under the skin, and heat transfer through conduction, convection, and radiation), apart from the metabolic state. A similar explanation was given by Yang et al. (2018), who indicated that gland cell metabolic activity, blood flow velocity, and mammary gland volume are the main factors responsible for the association between milk production and skin surface temperature. The lack of such a relationship before milking was explained by the cited authors as a result of milk accumulation in the secretory tissue and the cistern of the mammary gland before milking, which could have suppressed blood flow and reduced the metabolic activity of the secretory cells. However, after milking, the mammary gland cells and the vascular system were not influenced by milk accumulation, and the cell metabolic activity as well as blood flow returned to their maximum values. Consequently, cows with a higher mammary metabolic activity showed an increased skin surface temperature than those with a lower metabolic rate. Finally, Perano and Gebremedhin (2015) explained the relationship between udder skin surface temperature and milk yield based on the high vascularity and blood flow rate of the udder, reflecting also the effect of heat stress on the cow's organism.

The association between udder skin surface temperature and milk yield may, in general, be explained by an increased blood flow in high-yielding cows, but these correlations turned out to be statistically nonsignificant in the present study, except for the mean and maximum temperatures of the left hind quarter after milking (perhaps a larger sample size would be required to determine the significance of correlations for the rest of the surface temperatures). However, yields of fat, protein, nonfat solids, and total solids are known to be positively correlated with milk yield (Looper 2020), and the significant correlations between udder skin surface temperature and the estimated fat and protein yields were also positive in the present study (except for the SD of temperature in the right hind quarter after milking). By contrast, selection for milk yield may result in decreased percentages of fat and protein in the total milk composition (Looper 2020), but significant negative correlations in the present study were observed only for the SD of temperature (which shows temperature variation within the measured area), whereas those for the mean, minimum, and maximum temperatures were positive. Significant correlations between skin surface temperature and lactose content may result from the fact that lactose content is known to be positively correlated with milk volume (Looper 2020). Finally, significant correlations between udder skin surface temperature and estimated SCC were negative in our study. In general, the higher the SCC, the higher the temperature, which indicates the presence of clinical or subclinical mastitis. However, only the cows without mastitis on the day of thermographic measurement were included in the present study. Therefore, these preliminary results should be confirmed in a larger sample. A significant difference in the skin surface temperature of the left (mean and SD) and right (mean) hind quarters observed in our study confirmed some earlier reports on this phenomenon found in the literature (Soroko et al. 2017; Yang et al. 2018). However, a detailed analysis of this difference was not the aim of the present work.

Table 8. Partial correlation coefficients between surface temperature variables and milk production traits controlled for age, parity, measurement year, and milking time ($n = 34$).

Variable (°C)	Milk yield (kg)	Fat content (%)	Fat yield (kg)	Protein content (%)	Protein yield (kg)	Lactose content (%)	SCC (×10^3)	Urea content (mg/L)
Right hind quarter before milking								
Mean	0.14	0.35	0.42*	0.00	0.38*	0.40*	− 0.33	0.03
SD	0.10	− 0.30	− 0.12	− 0.21	− 0.11	− 0.04	0.31	0.00
Minimum	− 0.04	0.15	0.15	0.22	0.21	0.08	− 0.37*	− 0.01
Maximum	0.14	0.28	0.39*	0.02	0.37*	0.41*	− 0.32	0.20
Right hind quarter after milking								
Mean	0.21	0.48*	0.34	0.02	0.35	0.24	− 0.25	0.12
SD	− 0.19	− 0.55*	− 0.42*	0.05	− 0.08	− 0.23	0.21	− 0.30
Minimum	0.13	0.31	0.36*	0.06	0.24	0.44*	− 0.28	0.06
Maximum	0.07	0.37*	0.23	0.09	0.27	0.21	− 0.20	0.11
Left hind quarter before milking								
Mean	0.18	0.11	0.31	− 0.12	0.26	0.22	− 0.23	− 0.05
SD	0.06	− 0.06	− 0.06	− 0.06	0.03	− 0.07	0.20	− 0.06
Minimum	− 0.17	0.17	− 0.03	0.08	− 0.12	0.04	− 0.36*	0.04
Maximum	0.18	0.14	0.29	− 0.16	0.18	0.20	− 0.36	0.11
Left hind quarter after milking								
Mean	0.40*	0.21	0.47*	0.02	0.53*	0.17	− 0.19	0.02
SD	0.18	− 0.47*	0.08	− 0.39*	0.29	0.14	0.15	− 0.24
Minimum	− 0.06	0.47*	0.28	0.42*	0.09	0.24	− 0.54*	0.52*
Maximum	0.38*	0.18	0.54*	− 0.08	0.54*	0.29	− 0.22	0.05

*Statistically significant at $p < 0.05$.

Table 9. Surface temperature before and after milking ($n = 34$).

Variable (°C)	Before milking		After milking	
	Mean	SD	Mean	SD
Right hind quarter				
Mean	36.79*	0.81	36.63	0.80
SD	0.44	0.18	0.46	0.15
Minimum	34.07	2.78	34.02	2.48
Maximum	37.82	0.66	37.81	0.72
Left hind quarter				
Mean	36.86*	0.80	36.49	0.87
SD	0.43*	0.14	0.51	0.19
Minimum	34.17	2.26	33.73	2.18
Maximum	37.95	0.65	37.81	0.70

*Statistically significant at $p < 0.05$.

Some limitations of the present study should also be mentioned. First, only the surface temperature of the hind quarters was measured, whereas milk production and composition were determined for the combination of four udder quarters. However, due to technical reasons, the measurement of the skin surface temperature of the fore quarters was practically impossible. Moreover, Colak et al. (2008) found no significant difference in udder skin surface temperature between the front and hind quarters. In addition, the same approach as in our study was recently used by Yang et al. (2018) in their paper on the effect of milk yield on udder skin surface temperature. Second, to obtain more reliable results when controlling for additional variables (age, parity, year, and milking time), a much larger sample size is required, and only then could the studied sample be divided into several homogeneous groups in terms of the abovementioned factors. However, it should be emphasized that some earlier studies on the same subject did not control for additional factors either, and that the present study has a preliminary character and the results should be confirmed in a larger sample in the future. Third, the udders were washed if required before milking, which could have affected the measured surface temperatures, but this procedure was inevitable under production conditions.

In conclusion, the present study revealed rather weak and nonsignificant partial correlations between udder skin surface temperature and milk yield (taking into account cow's age, parity, year, and milking time), except for the mean and maximum temperatures of the left hind quarter after milking. However, significant partial correlations were observed between surface temperatures and estimated milk composition determined based on test-day records. Additionally, significant partial correlations between the abovementioned temperatures and estimated SCC were found. A larger sample size is required in future research to confirm the preliminary results obtained in the present study.

Acknowledgements

We would like to thank the Board of OHZ Lubiana for providing the data needed for the statistical analyses presented in this study.

Article information

History dates

Received: 17 September 2021
Accepted: 21 February 2022
Accepted manuscript online: 4 March 2022
Version of record online: 8 July 2022

Copyright

Data availability

The data underpinning this work are publicly unavailable.

Author information

Competing interests

The authors have declared that no competing interests exist.

Funding information

The authors declare no specific funding for this work.

References

Barth, K. 2000. Basic investigations to evaluate a highly sensitive infrared-thermograph-technique to detect udder inflammation in cows. Milchwissenschaft, **55**: 607–609.

Byrne, D.T., Berry, D.P., Esmonde, H., and McHugh, N. 2018. Investigation of the relationship between udder quarter somatic cell count and udder skin surface temperature of dairy cows measured by infrared thermography. J. Anim. Sci. **96**: 4458–4470. doi:10.1093/jas/sky281.

Cockcroft, P.D., Henson, F.M.D., and Parker, C. 2000. Thermography of a septic metatarsophalangeal joint in a heifer. Vet. Rec. **146**: 258–260. doi:10.1136/vr.146.9.258.

Colak, A., Polat, B., Okumus, Z., Kaya, M., Yanmaz, L.E., and Hayirli, A. 2008. Short communication: early detection of mastitis using infrared thermography in dairy cows. J. Dairy Sci. **91**: 4244–4248. doi:10.3168/jds.2008-1258.

Hovinen, M., Siivonen, J., Taponen, S., Hänninen, L., Pastell, M., Aisla, A.-M., and Pyörälä, S. 2008. Detection of clinical mastitis with the help of a thermal camera. J. Dairy Sci. **91**: 4592–4598. doi:10.3168/jds.2008-1218.

Hurnik, J.F., De Boer, S., and Webster, A.B. 1984. Detection of health disorders in dairy cattle utilizing a thermal infrared scanning technique. Can. J. Anim. Sci. **64**: 1071–1073. doi:10.4141/cjas84-124.

Hurnik, J.F., Webster, A.B., and DeBoer, S. 1985. An investigation of skin temperature differentials in relation to estrus in dairy cattle using a thermal infrared scanning technique. J. Anim. Sci. **61**: 1095–1102. doi:10.2527/jas1985.6151095x.

Kimmel, E., Arkin, H., and Berman, A. 1992. Evaporative cooling of cattle: transport phenomena and thermovision[online]. *In* Paper presented at the 1992 International Summer Meeting sponsored by the American Society of Agricultural Engineers, 21–24 June 1992, Charlotte, NC. Availablefrom http://agris.fao.org/agris-search/search.do?recordID=US19950101604[accessed 10 October 2015].

Knizkova, I., Kunc, P., Knizek, J., and Novy, Z. 1996. Evaluation of evaporative cooling on the changes of cattle surface body temperatures with use of thermovision. Zivocisna Vyroba, **41**: 433–439.

Knı´žková, I., Kunc, P., Koubková, M., Flusser, J., and Dolezal, O. 2002. Evaluation of naturally ventilated dairy barn management by a thermographic method. Livest. Prod. Sci. **77**: 349–353. doi:10.1016/S0301-6226(02)00062-3.

Kunc, P., Knizkova, I., and Koubkova, M. 1999. The influence of milking with different vacuum and different design of liner on the change of teat surface temperature. Czech J. Anim. Sci. **44**: 131–134.

Kwaśnicki, R., Dobicki, A., Zachwieja, A., and Nowakowski, P. 2007. Interrelationship between thermal imaging data and dairy traits in red-and-white cows. Biotechnol. Anim. Husb. **23**: 277–282. doi: 10.2298/BAH0701277K

Looper, M. 2020. Factors affecting milk composition of lactating cows[online]. Agric. Nat. Resour. **FSA4014**: 1–6.

Nikkhah, A., Plaizier, J.C., Einarson, M.S., Berry, R.J., Scott, S.L., and Kennedy, A.D. 2005. Short communication: infrared thermography and visual examination of hooves of dairy cows in two stages of lactation. J. Dairy Sci. **88**: 2749–2753. doi:10.3168/jds.S0022-0302(05)72954-4.

Perano, K.M., and Gebremedhin, K.G. 2015. Use of udder skin temperature as a heat stress indicator in lactating dairy cattle. *In* 2015 American Society of Agricultural and Biological Engineers Annual International Meeting, Paper No. 152190863. New Orleans, LA. doi:10.13031/aim.20152190863.

Polat, B., Colak, A., Cengiz, M., Yanmaz, L.E., Oral, H., Bastan, A., et al. 2010. Sensitivity and specificity of infrared thermography in detection of subclinical mastitis in dairy cows. J. Dairy Sci. **93**: 3525–3532. doi:10.3168/jds.2009-2807.

Schaefer, A.L., Cook, N., Tessaro, S.V., Deregt, D., Desroches, G., Dubeski, P.L., et al. 2004. Early detection and prediction of infection using infrared thermography. Can. J. Anim. Sci. **84**: 73–80. doi:10.4141/A02-104.

Schaefer, A.L., Cook, N.J., Church, J.S., Basarab, J., Perry, B., Miller, C., and Tong, A.K.W. 2007. The use of infrared thermography as an early indicator of bovine respiratory disease complex in calves. Res. Vet. Sci. **83**: 376–384. doi:10.1016/j.rvsc.2007.01.008.

Schmidt, S., Bowers, S., Dickerson, T., Graves, K., and Willard, S. 2004. Assessments of udder temperature gradients pre- and post-milking relative to milk production in Holstein cows as determined by digital infrared thermography. J. Anim. Sci. **82**: 460–461.

Schwartzkopf-Genswein, K.S., Stookey, J.M., and Welford, R. 1997. Behavior of cattle during hot-iron and freeze branding and the effects on subsequent handling ease. J. Anim. Sci. **75**: 2064–2072. doi:10.2527/1997.7582064x.

Scott, S.L., Schaefer, A.L., Tong, A.K.W., and Lacasse, P. 2000. Use of infrared thermography for early detection of mastitis in dairy cows. Can. J. Anim. Sci. **80**: 764–765.

Soroko, M., Zaborski, D., Grzesiak, W., Parafiniuk, M., and Modrzejewski, A. 2017. Changes in udder skin surface temperature of dairy cows caused by machine milking. Folia Pomeranae Univ. Technol. Stetin. **334**: 163–174. doi:10.21005/AAPZ2017.42.2.15.

Stewart, M., Webster, J.R., Verkerk, G.A., Schaefer, A.L., Colyn, J.J., and Stafford, K.J. 2007. Non-invasive measurement of stress in dairy cows using infrared thermography. Physiol. Behav. **92**: 520–525. doi:10.1016/j.physbeh.2007.04.034.

Stewart, M., Stafford, K.J., Dowling, S.K., Schaefer, A.L., and Webster, J.R. 2008. Eye temperature and heart rate variability of calves disbudded with or without local anaesthetic. Physiol. Behav. **93**: 789–797. doi:10.1016/j.physbeh.2007.11.044.

Unshelm, J., Reinhart, E., and Platz, S. 1992. Untersuchungen uber das Erfassen haltungsbedingter Schaden beim Rind mit Hilfe der Infrarottthermometrie. Tierärztl. Umsch. **47**: 516–521.

Yang, C., Li, G., Zhang, X., and Gu, X. 2018. Udder skin surface temperature variation pre- and post-milking in dairy cows as determined by infrared thermography. J. Dairy Res. **85**: 201–203. doi:10.1017/S0022029918000213.