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— Original Article —

Evaluation of the body surface temperature measured by a two-dimensional radiant thermometer as an indicator of heat stress in dairy cows

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Abstract

To evaluate skin surface temperature measured by a two dimensional radiant thermometer as an indicator of heat stress, a total of 347 surface temperature measurements on the udder and belly were made in Hokkaido and Taiwan dairy herds. The air temperature and temperature-humidity index (THI) in the barns ranged between 9.2 to 32.7 ℃ and 53.6 to 83.5, respectively. The highest surface temperatures on the udder and belly increased with increasing air temperature in the barns ($p<0.01$). However, in barn temperatures below 25 ℃, the variation of the highest surface temperature on the udder and belly of individual cows at the same barn temperature was relatively greater than when the barn temperature was above 25 ℃, and the variance between above and below 25 ℃ was significantly different ($p<0.01$). Similarly, the average values, the individual variations, and the variances of the highest surface temperature were different between THI values above and below 70. These results suggested that most lactating dairy cows in the environment above 25 ℃ or 70 THI have to make an effort to accelerate heat emission from their surface, and are considered to be suffering from mild heat stress in the environment above 25 ℃ or 70 THI.

Key Words: Body surface temperature, Dairy cow, Heat stress, Two-dimensional radiant thermometer

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INTRODUCTION

Thermal environment affects not only animal performance but also health and welfare. High producing dairy cows also produce a large amount of heat, as much as 1.1 to 1.5 kW[3,7]. This means that high producing cows can easily thermo-regulate in a cool environment, but have to emit large amounts of heat to maintain homeothermy in a hot environment. Heat stress forces cows to make thermoregulatory efforts, and affects feed intake, reproduction, milk production, and the endocrine and immune systems [2]. Therefore, the thermal environment has to be evaluated by animal responses.

Many factors influence heat exchange. Dry-bulb temperature is the principal thermal factor, and combinations with other factors such as humidity and wind velocity led to the development of indices for characterizing the thermal environment. Temperature-humidity index (THI) and effective temperature have been used to evaluate the influences of hot environments on dairy cow performance[2,5]. THI is widely used as the basis for livestock weather safety advisories in hot weather. However, it is thought that there are large variations in biological responses resulting from individual differences, acclimatization, breed effects, *etc*.

The body surface temperature reflects heat exchange regulated by blood supply to the skin, and is considered to be a good indicator of the physiological responses of animals to the thermal environment. MCLEAN et al.[6] measured skin surface temperature at four equidistant positions around the trunk of steers by thermocouples to calculate mean skin surface temperature and mean body temperature, and body-heat storage was estimated from these values. In this study, the surface temperature on the udder and belly of lactating dairy cows was measured in a wide range of thermal environments in dairy barns in Hokkaido and Taiwan, and the relationship between the surface temperature and thermal environment was evaluated and is discussed as an indicator of mild heat stress in this paper.

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MATERIALS AND METHODS

A total of 347 measurements of belly and udder surface temperature were taken from lactating Holstein cows. Altogether, 242 measurements were taken from 30 cows housed in a free-stall barn of Rakuno Gakuen University in Hokkaido at 15-20 days interval between June 13th and November 11th. The others were from 15 cows housed in 7 free-stall barns in southern Taiwan every 20 days from June 10th to October 10th and on February 12th and March 10th. Electric fans were used during the hot season in all of these barns. A direct current of air to the cow's trunk from the fan was available in some barns in Taiwan. Surface temperature was measured at noon with a two-dimensional radiant thermometer (Horiba, ii-1064, Kyoto, Japan). The thermometer can measure the surface temperature at 64 spots on a digital photograph from one snapshot measurement. The data is also common to a previous paper[4]. However, individual data was analyzed for detecting heat stress in the present paper, while averages of the highest and lowest temperatures were analyzed to characterize the surface temperature of different portion of the trunk of dairy cows in the previous paper. Air temperature and relative humidity were measured with a data logger (T and D, Ondotori RH TR72, Matsumoto, Japan) at a height of 1.8 m in the central area of the barns. A thermometer with a probe for rectal temperature measurements (Sato Keiki, MC-T103III, Tokyo, Japan) was also used.

All experimental procedure involving the care and handling of animals were conformed to Rakuno Gakuen University's guidelines.

Highest udder and belly surface temperatures were plotted on air temperature or THI in the barns in scatter diagrams. Equality of variance for the surface temperatures between above and below certain thermal environment was tested by analysis of variance. Differences between means were tested using Welch's test for unequal variances[8]. Correlation coefficients and linear regression equations were computed between surface temperature and each of thermal environments assumed with a common variance[8].

RESULTS AND DISCUSSION

Air temperature, relative humidity and temperature-humidity index (THI) in the barn are shown in Table 1. The average air temperature in Taiwan was about 8 ℃ higher than in Hokkaido. However, the air temperatures during the winter season in Taiwan and during mid summer in Hokkaido were in the ordinary range for Hokkaido and Taiwan, respectively. Relative humidity in Taiwan tended to be higher than in Hokkaido, and was always higher than 60 %. THI in Hokkaido was in the range that is not regarded as causing heat stress, except for one measurement in mid summer. THI in Taiwan was in the stressful range during the entire summer season[1].

Surface temperature of the trunk decreased as the air temperature decreased below 25 ℃, as described in the previous paper[4]. The difference between the highest and the lowest temperature of 64 spots of one snapshot measurement of the udder surface temperature increased with decreasing air temperature. However, the difference between the highest and lowest belly temperature did not increased. The highest surface temperature changed in a different manner from the lowest surface temperature, and may reflect higher blood supply and accelerated heat emission from the surface.

Table 1. Average air temperature(℃), relative humidity(%) and temperature-humidity index(THI) in the barn when surface temperature data were collected

	Hokkaido				Taiwan			
	Mean		SD	Range	Mean		SD	Range
Air temperature	18.0	±	6.7	9.2～31.1	26.1	±	7.1	13.1～32.7
Relative humidity	55.6	±	16.2	35.0～84.0	76.1	±	11.1	60.0～89.0
THI	60.8	±	5.5	53.6～71.3	75.7	±	10.5	55.7～83.5

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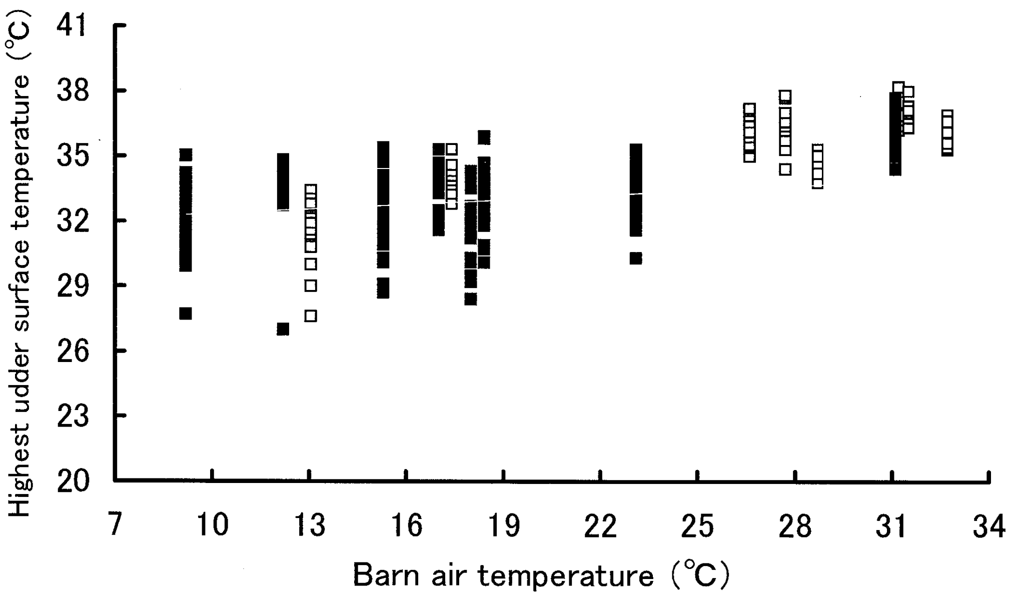

Fig. 1. Relationship between barn ait temperature and highest udder surface temperature.
■ : Data from Hokkaido, □ : Data from Taiwan.

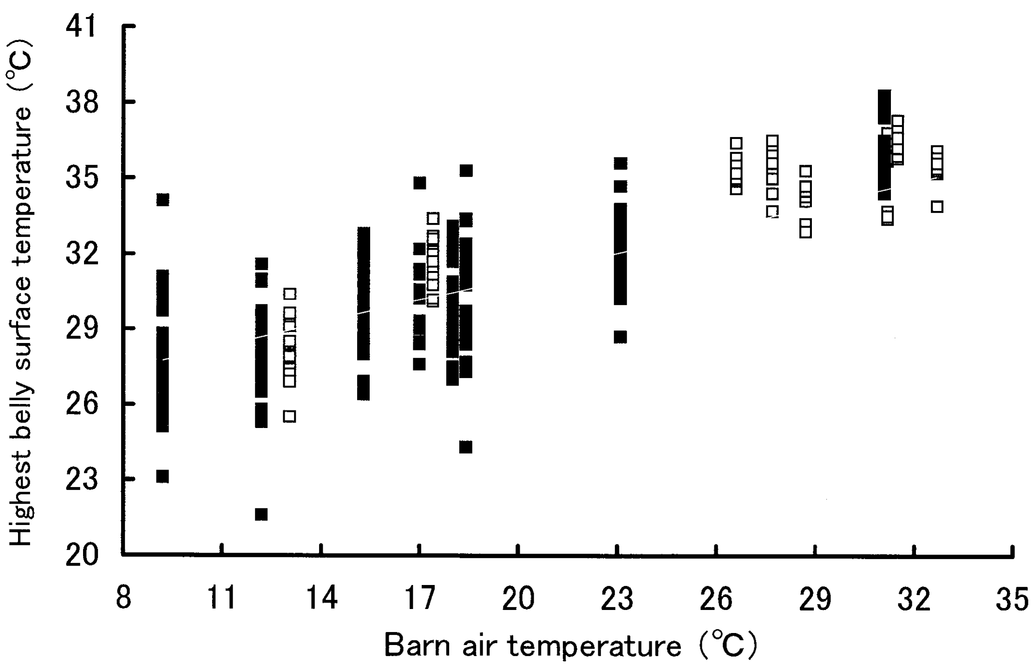

Fig. 2. Relationship between barn air temperature and highest belly surface temperature.
■ : Data from Hokkaido, □ : Data from Taiwan.

The highest surface temperature data on the udder and belly of individual cows was plotted against barn air temperature (Fig. 1 and Fig. 2). There was no apparent distribution difference between the data from Hokkaido and Taiwan, and all data was analyzed together. There were significant correlations between the highest surface temperature and barn air temperature (udder, r = 0.721; belly, r = 0.865). Although the close relationship could be adapted by linear regression, these figures showed different distributions for air temperatures above and below 25 ℃. The correlation coefficient was 0.261 for udder data above 25 ℃ and 0.196 for udder data below 25 ℃. The corresponding correlation coefficients were 0.275 and 0.586, respectively, for belly data. In barn

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temperatures below 25 ℃, the variation of udder surface temperature of individual cows in the same barn temperature was relatively greater than when the barn temperature was above 25 ℃. The results were similar for belly data. The variance of both udder and belly data between above and below 25 ℃ was significantly different ($p<0.01$). The highest mean temperature on the udder and belly above an air temperature of 25 ℃ was significantly higher than those below 25 ℃ (36.09 vs. 32.76 ℃ for udder, 35.53 vs. 29.84 ℃ for belly) as determined by the Welch test. These results suggested that udder and belly data above an air temperature of 25 ℃ belongs to a different population from those below an air temperature of 25 ℃.

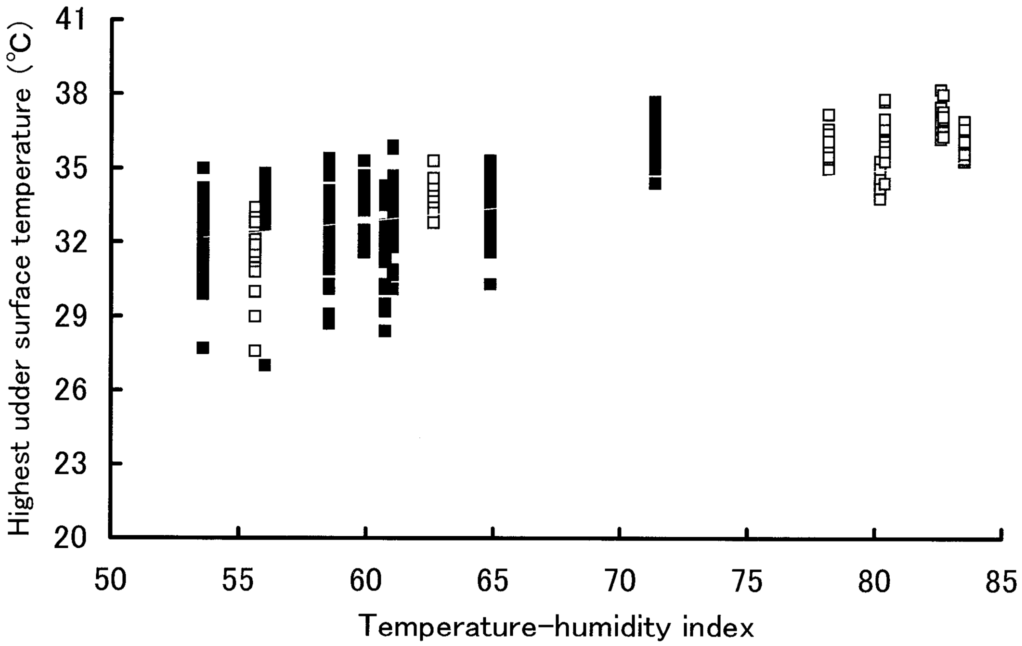

Fig. 3. Relationship between temperature-humidity index and highest udder temperature
■ : Data from Hokkaido, □ : Data from Taiwan.

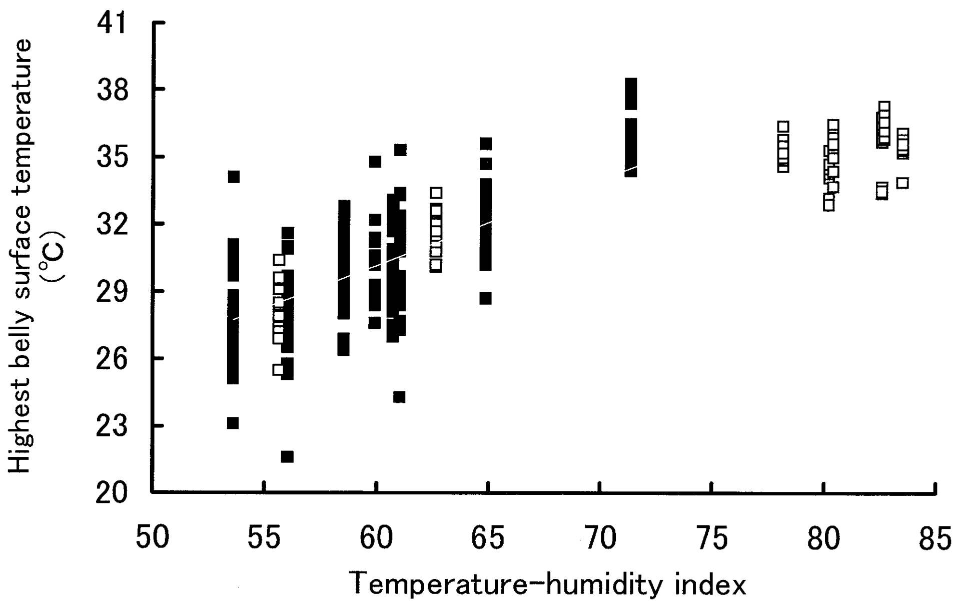

Fig. 4. Relationship between temperature-humidity index and highest belly temperature
■ : Data from Hokkaido □ : Data from Taiwan.

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The highest surface temperature on the udder and belly of individual cows is plotted against temperature-humidity index (THI) in Fig. 3 and Fig. 4, respectively. The correlation coefficient was 0.769 for udder data and 0.831 for belly data. When these data sets were divided between above and below 70 THI, the correlation coefficient reduced to 0.126 and 0.238 for udder data above and below 70 THI, and 0.181 and 0.609 for belly data above and below 70 THI, respectively. The analysis of variance showed that data points above 70 THI had a different variance from data points below 70 THI ($p<0.01$). The mean highest temperature on the udder and belly above 70 THI was significantly higher than those below 70 THI (36.11 vs. 33.19 ℃ for udder, 35.36 vs. 30.57 ℃ for belly) as determined by the Welch test. These results suggested that udder and belly data above 70 THI belong to different population from that below 70 THI.

The variation in the surface temperature of individual cows indicated that the extent of the blood supply to the skin differed, and less variation at higher surface temperature indicated that most cows supplied blood continuously to the skin to accelerate heat emission from their surface. It was therefore suggested that the border between different variances was the border between zones below and above mild heat stress. The border points of the barn air temperature and THI in the present study were 25 ℃ and 70 THI, respectively. It is known that milk production is influenced slightly in the temperature range of 21 to 27 ℃, and is reduced considerably above 27 ℃. Dairy cow performance and conception rate is negatively influenced when THI is higher than 70[1,2]. The results in the present study were consistent with these previous findings.

There was no significant correlation between rectal temperature and barn air temperature or THI. However, rectal temperature of cows in barns above 26 ℃ or 77 THI was above 38 ℃, and significantly higher ($p<0.01$) than that of the cows in barns below 26 ℃ or 77 THI.

In the present study, the highest surface temperature on the udder and belly was distributed in a different manner between air temperatures above and below 25℃ and THI values above and below 70. These results suggested that most cows supply blood to the skin surface, and the surface temperature reaches a plateau in the environment above 25 ℃ or 70 THI. It was confirmed that cows in temperatures higher than 25 ℃ or THI higher than 70 suffered from mild heat stress.

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温熱環境と泌乳牛の体表温度との関係からみた暑熱環境の評価

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要　約

暑熱環境下では乳牛の体表面からの熱放散が活発化し、体表温は上昇するはずである。この現象を利用して暑熱環境を評価することが目的である。北海道と台湾南部の泌乳牛延べ 347 頭の乳房と腹部の体表面温度を二次元放射温度計にて計測した。測定時の牛舎内の気温は 9.2ー32.7℃、相対湿度は 35.0ー89.0%の範囲であった。乳牛個体の乳房と腹部の体表温の最高温度をプロットすると、牛舎内気温の上昇または THI 値の上昇につれて乳房および腹部の体表温の最高温度は高くなり、有意な相関が認められた（p<0.01）。しかし、体表温の分布は気温 25℃あるいは THI 値 70 を境に、それ以上と以下において異なり、それぞれの領域における相関係数は小さくなった。乳房と腹部の体表温の最高温度の個体差は、25℃以上の気温あるいは THI 値 70 以上の暑熱環境においては、25℃以下あるいは THI 値 70 以下におけるより小さく、それぞれの分散は有意に異なった（p<0.01）。これは、25℃以上あるいは THI 値 70 以上の暑熱環境の下では泌乳牛の大部分は体表面からの放熱を高水準に維持する必要があり、体表温は高い値で斉一となることを示し、泌乳牛は上記の境界において軽度の暑熱ストレスに曝されるものと考えられた。

キーワード：体表面温度，乳牛，暑熱ストレス，二次元放射温度計

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