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Actigraph as a Device for Estimation of Heat Production of White Leghorn Hens under High Ambient Temperature

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Eight commercial Single Comb White Leghorn hens were used to study the effects of high ambient temperature on behavioral activities and to select a better parameter for the estimation of heat production between activity count and standing time. The hens were kept at ambient temperatures of 25, 29, and 33°C and fed ad libitum. Daily feed intake and heat production decreased with the increase of temperature. Daily total standing time increased significantly with the increase of temperature, specially the increase occurred in the dark periods at 29 and 33°C, and were 247% ($P<0.01$) and 413% ($P<0.01$), respectively, compared to the standing time at 25°C. Heat production per hour decreased significantly ($P<0.01$) in both the light and dark periods with the increase of temperature. On the other hand, the daily activity counts were almost the same at all the temperatures. The levels of activity counts per hour increased significantly ($P<0.01$) during the dark periods at 29 and 33°C in comparison with that of at 25°C. Heat production per activity count decreased significantly ($P<0.01$) with the increase of temperature. The hens changed their behavioral pattern, and minimized heat production when introduced to higher temperatures. From the analysis of variance of the multiple regression equations, the contribution rates of activity counts (counts/h) and standing time (min/h) towards total heat production (kJ/kg$^{0.75}$/h) were 65% and 23%, respectively. Therefore, activity counts give better results in regards to estimating heat production in White Leghorn hens.

Key words : heat production, activity count, standing time, ambient temperature, feed intake

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Introduction

Heat production varied with both ambient temperature and feed intake (Davis *et al.,* 1973 ; Koh and MacLeod, 1999). Usually determined heat increments include the energy expended on the activity of eating as well as the heat produced due to the true calorigenic effect of food (Balnave, 1974). Heat production decreased by 4.8 kJ/kg$^{0.75}$ per day per 1°C increase of temperature, where the range of temperature varied from 12 to 36°C and fed four different feeding levels from 0 to 90 g (Li *et al.,* 1992). Similarly,

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Davis *et al.* (1973) reported that heat production decreased by 4.6 kJ/$kg^{0.75}$ per day per 1℃ increase of temperature in *ad libitum* fed hens in the constant temperature range of 7.2 to 35℃. However, these values were lower than the value of 7.2 kJ/$kg^{0.75}$/d per 1℃ increase in the report of Van Kampen (1974) in fasting hens in the temperature range of 10 to 35℃. The increase of heat production in the fasting hens may be due to the increase of activity. O'Neill *et al.* (1971) estimated the additional activity above starving activity for feathered and defeathered cockerels at maintenance feeding levels. The calculated additional activity of the feathered cockerels decreased with increasing temperature. As shown by Van Kampen (1976 a, b, c), heat production increased after eating, the metabolic rate increased linearly with running speed and the metabolic rate decreased after oviposition, suggesting a change in the pattern of behavior could also alter the metabolic rate. Furthermore, activity and heat production of hens can be depressed by decreasing the light intensity ; the decrease of heat production in the dark may result from the depressed activity and change of posture from standing to sitting (Boshouwers and Nicaise, 1987 ; MacLeod *et al.,* 1988 ; Li *et al.,* 1991 b). Standing with activity increases more heat production rather than quiet standing (Li *et al.,* 1991 a). However, little experimental work has yet to be carried out to quantitatively estimate the heat production of laying hens relative to behavioral activities.

The objectives of the present study was to identify the effects of high ambient temperature on behavioral activities of laying hens and selecting a better parameter for estimating heat production between standing time and activity count.

Materials and Methods

Birds and management

Eight commercial Single Comb White Leghorn hens, with the range of body weights of 1.52～1.62 kg and ages of 25～61 wk were housed individually in cages and fed a standard commercial mash diet (ME 11.9 MJ/kg, CP 17%). Feed and water were provided ad libitum. The hens were fed twice daily at 0900 and 1500 h. Temperature of the poultry house was maintained at 25±1℃. Lighting period was 14 h light : 10 h dark commencing at 0600 h, and was provided by three incandescent bulbs of 60 w. The light intensity in side of the chamber was approximately 40 lux. The hens were trained for approximately 5 wk, habituating them to the respiratory chamber, the Actigraph and the procedures. The experiment was conducted at the three constant temperatures of 25, 29, and 33℃, respectively in the chamber.

Measurements

Each hen was placed into the open circuit respiratory chamber one by one and the continuous measurements of heat production were taken for 48 h. Simultaneously, standing time, eating time, and activity counts data of each hen were also measured during the 48 h. During the change of each temperature period, the hens were kept outside the chamber for 4 d to allow adaptation and then again each hen was observed for 48 h at each temperature period. The experiment started at a temperature of 25℃ and then gradually proceeded to higher temperatures of 29, and 33℃. The respiratory chamber was made of transparent plastic sheet with the total capacity of 144 L. The chamber was equipped with a fan on the ceiling, with dry and wet thermocouples on both sides. The chamber was covered by a large covering made of transparent plastic sheet where a heater was set to automatically control the chamber temperature. Heat production per day per hen and hourly change of heat production was measured by indirect calorimetry. Standing and eating behavior was detected via the infra-red beam switches as described by Ito and Mimura (1978), which were set at both the sides of the cage inside the chamber. An Actigraph (Ambulatory Monitoring Inc. 731 Saw Mill River Road, Ardsley, New York, 10502-0609), with a weight of 40 g, length 4.5 cm and width 3.3 cm was used in the present experiment for measuring the total activity as activity counts which are determined by the detection of body movements. Originally this equipment was used as a sensor for detecting three dimensional movements during human sleep. ACT counts may be considered as the absolute value of the movements of a hen. The programming and use of the Actigraph can be compared to that of the Video Cassette Recorder (VCR). One specifies when it will start, how long it will run, and what type of information it will record. The Actigraph collects activity data based on user programmable header information. In the present experiment, the amplifier setting of the Actigraph was 6, filter range was from 0.1 to 3.0 Hz whereas, both the gain and sensitivity threshold were high. The Actigraph, was set on the back of the hens and the data of activity count was recorded every minute. Daily food intake was measured from the difference between the supplied food and remaining uneaten food. Body weights and egg weights were measured daily. Ventilation rate of the chamber was set at approximately 11 L/min and was measured by using a rotameter (Kusano, KG-4 : Sumidaku, Mukoujima 4-26-11, Tokyo, Japan). Oxygen concentration was measured by a paramagnetic O_2 analyzer (Morgan, 500 D : P.K. Morgan Limited, 4 Bloors Lane, Rainham, Kent, ME 8 7 ED, U.K.). During a 1 h period, 50 min were used for the measurements of O_2 in the exhaust air from the chamber and 10 min for inlet air to calculate O_2 consumption from the difference between O_2 concentration and the flow rate. Data of the O_2 concentration (resolution 1/1000%), chamber temperature (resolution 0.1℃), room temperature, standing time and eating time were collected in each minute by a data logger (Advantest, R7430 : Shinjuku-ku, Nishi-Shinjuku 2-4-1, Tokyo, Japan). A NEC/PC-9801 (Minatoku, Shiba 5-7-1, Tokyo, Japan) personal computer was used to process and store the data of the measurements. The measurements were started from 0900 h daily. Before and after the experiment, the whole calorimetry system was checked by calibration by N_2 injection as described by McLean and Tobin, (1987).

Calculations and statistical methods

Heat production was calculated in one min according to McLean and Tobin, (1987) : $HP = 20.5 \times (VO + VC \times dC/dt) \times \Delta O_2$, where HP = heat production (kJ/s) ; VO = air flow rate in STP condition (L/s) ; VC = chamber air volume in STP condition (L) ; dC/dt = changing rate of out let O_2 concentration (%/sec.), ΔO_2 = difference of O_2 concentration between inlet and outlet air of the chamber (%). The results were presented as average values of 1h extrapolated from the 50 min measurements. The average values of activity counts per 1h was calculated from the data of one min. The regressions of the rate of heat production (kJ/kg$^{0.75}$/h) for activity (counts/h), standing time (min/h), and temperature (℃) during the light and dark periods were calculated. The analysis of co-variance of increment of heat production (kJ/kg$^{0.75}$/h) for activity (counts/h) at each temperature was also calculated. The data were the mean value of the 8 birds at all time points. The data of standing time, eating time and activity counts were converted into the square root transformation and then the paired t-test was used to determine the statistical difference between the mean at each time point, whereas one-way analysis of variance was used to test significance between sampling time points. P was two tailed and considered significant if $P<0.05$ or $P<0.01$. Statistical analysis was provided by the Excel-97 (Microsoft Corporation, Shibuyaku, Sasazuka 1-50-1, Tokyo, Japan) data analysis tool box add-in.

Results

Daily feed intake and heat production decreased with the increase of temperature from 25 to 33℃. The highest daily feed intake was 97 g at 25℃ and the lowest was 89 g at 33℃, whereas, the feed intake at 29℃ was 95 g. Similarly, the highest average heat production in the light period was 28.0 kJ/kg$^{0.75}$/h at 25℃, the lowest was 21.8 kJ/kg$^{0.75}$/h at 33℃ and then 26.2 kJ/kg$^{0.75}$/h at 29℃. In the dark period, the average heat production at 25, 29, and 33℃ was 17.0, 18.1, and 15.8 kJ/kg$^{0.75}$/h, respectively. Heat production during the light and dark periods decreased significantly ($P<0.01$) with the increase of temperature (Figure 1). The hens increased their daily standing time at 29 and 33℃ and the increase of standing time especially occurred significantly ($P<0.01$) during the dark period (Figure 1). The daily average level of activity counts were almost the same at all the temperatures, whereas the average level of activity counts per hour in the dark periods differed significantly between the temperatures. Eating behavior was observed only in the light period. In the figure 1, HP (kJ/kg$^{0.75}$/h) and ACT (counts/h) increased in the light period rather than HP (kJ/kg$^{0.75}$/h) and ACT (counts/h) during the dark period, which means that the higher rate of heat production coincided with the higher activity counts. In the dark, standing time at 29℃ and 33℃ were 247% ($P<0.01$) and 413% ($P<0.01$) respectively, compared to the standing time at 25℃. Heat production per 1 min of standing time decreased significantly with the increase of temperature (Figure 2). Similarly, heat production per activity count also decreased significantly ($P<0.01$) with the increase of temperature (Figure 3). Here, the equation is, $Y=bx+a$, where $Y=$ HP (kJ/kg$^{0.75}$/h), $x=$ ACT (counts/h), $b=$ slope (increment of HP) and $a=$ intercept. The multiple regressions of ACT (counts/h), STN (min/h), and Ta (℃) on HP (kJ/kg$^{0.75}$/h) during the light and dark periods were calculated.

The results were as follows :

$$HP=5.84/10^4\times ACT-0.48\times Ta+30.72\ (n=576,\ R^2=0.72^{**},\ SE=\pm 12\%) \quad (1)$$

$$HP=0.18\times STN-0.77\times Ta+37.48\ (n=576,\ R^2=0.44^{**},\ SE=\pm 18\%) \quad (2)$$

$^{**}P<0.01$.

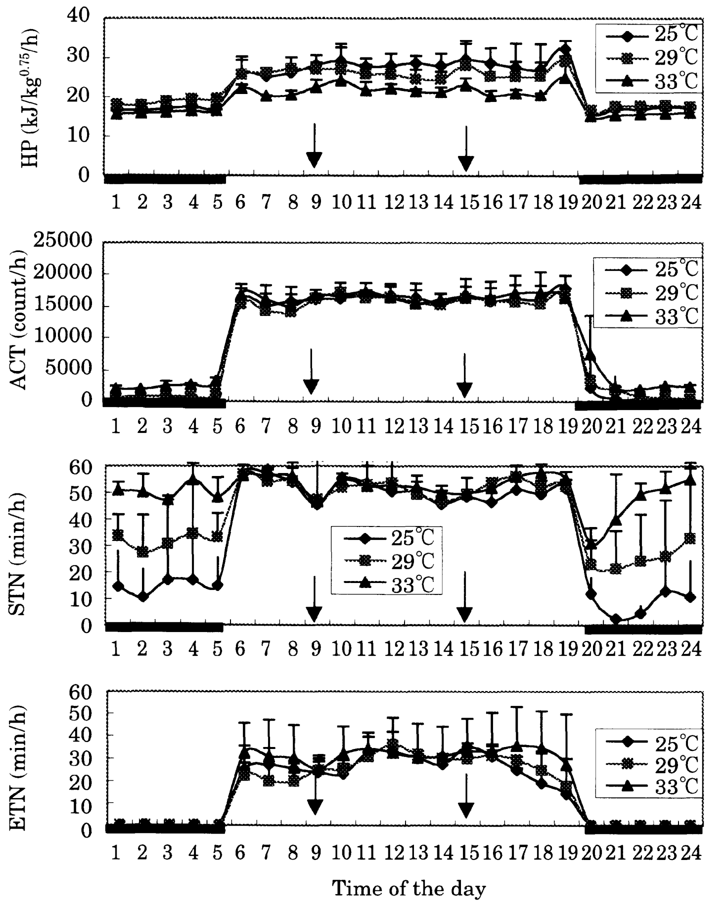

Fig. 1. Changes of heat production (HP), activity count (ACT), standing time (STN) and eating time (ETN) during 24 h at 25, 29, and 33℃. Black bar indicates darkness, arrow indicates feeding time. Each point and vertical bar indicate the mean±SD of 8 hens.

Discussion

The daily feed intake decreased with the increase of temperature. Heat production in the light period was also decreased with the increase of temperature from 25 to 33℃ which is in agreement with the reports of Davis *et al.* (1973) and Li *et al.* (1992) in laying hens. The hens slept most of the time in the dark period and were less active (Karmanova, 1982). Li *et al.* (1991 a) reported that standing had a little effect on heat production in the dark period, where the temperature ranged from 17 to 25℃. In the present experiment, HP decreased significantly during the light and dark periods ($P<0.01$) with the increase of Ta and simultaneously, the hens increased their quiet standing time significantly in the dark periods at 29 and 33℃ where a slight increase of heat production occurred during this time.

Heat production per activity count decreased with the increase of temperature

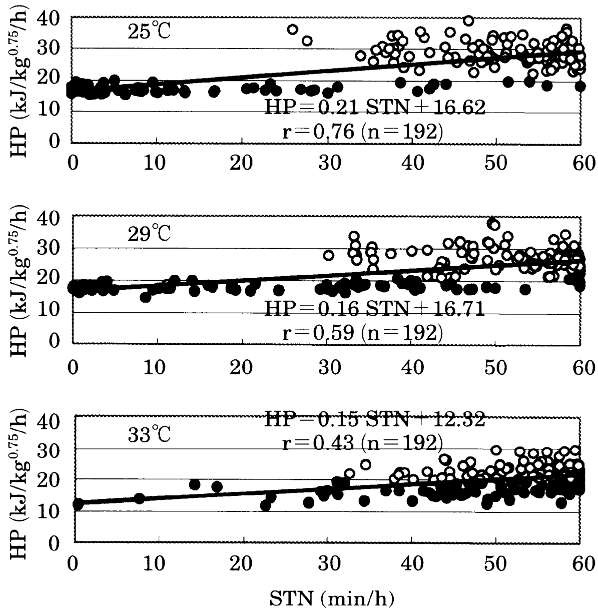

Fig. 2. Relationship between heat production (HP) and standing time (STN) in the light (○) and dark (●) periods during 24 h at 25, 29, and 33℃. Each point indicates the mean value of the measurement of 1 h (n=192).

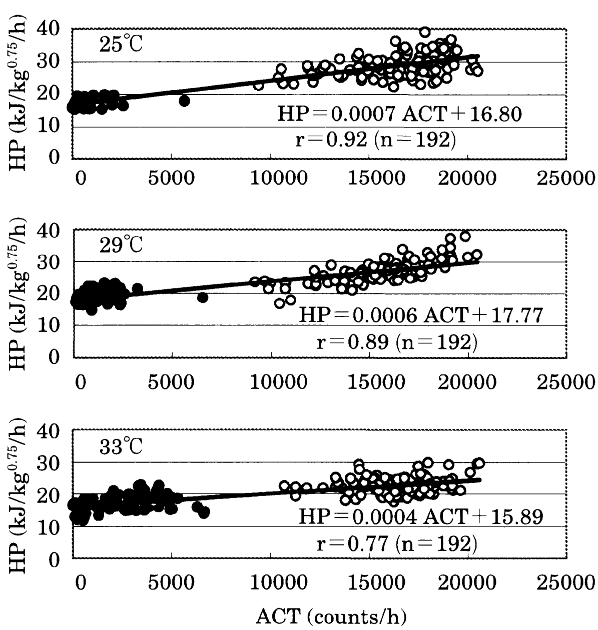

Fig. 3. Relationship between heat production (HP) and activity count (ACT) in the light (○) and dark (●) periods during 24 h at 25, 29, and 33℃. Each point indicates the mean value of the measurement of 1 h (n=192).

from 25 to 33℃ (Figure 3). Similarly, heat production per min of standing time also decreased with the increase of temperature (Figure 2). Van Kampen *et al.* (1979) reported that in chickens, heat production decreased with increasing temperature and electromyogram amplitude declined with increasing temperature up to 27.5℃ in the light and 22.3℃ in the dark, and was higher in the light than in the dark. In pigeons, electromyograms from the pectoral muscle showed a considerable increase of electrical activity in the cold which increased pectoral temperature and the increased pectoral muscle temperature reflects an elevated heat production (Steen and Enger, 1957). Heat production decreased with the increase of Ta due to the change in frequency of the tone muscle activity which was not detected by the Actigraph, as the filter range was set from 0.1 to 3.0 Hz. Heat production is directly related to feed intake and feed intake is affected by the Ta. In the present experiment, the daily feed intake decreased with the increase of Ta and the daily HP also decreased with the increase of Ta, but the daily ACT counts at all the varying Ta were almost the same. Therefore, it can be suggested that the HP per activity count of White Leghorn hen may decrease with the increase of temperature.

Standing with different activities increases activity counts, which increases heat production rather than quiet standing and sitting, even though the time period of standing is same. In the present experiment, the hens increased their standing time significantly ($P<0.01$) in the dark at 29 and 33℃ in comparison with that of 25℃ and rested in quiet standing position with minimal heat production. This behavior was possibly to facilitate heat dissipation from the body. Panting in the dark at 33℃ was observed which may have had an influence on the slight increase of activity counts during this time. The levels of heat production during the light and dark periods decreased significantly with the increase of temperature, which agrees with the results of Li *et al.* (1992), where they reported that the maintenance energy requirements may decline with an increase of temperature. This may be possible due to the changing behavioral patterns at high ambient temperatures. In the present experiment, the decrease of heat production per 1℃ increase of temperature per day was 11.5 $kJ/kg^{0.75}$ (equation 1). On the contrary, in the reports of Li *et al.* (1992) and Davis *et al.* (1973) the decrease of heat production per 1℃ increase of temperature per day was very low. Because, the results of simple regression equations presented by them may have included the effect of activities on HP which may have suppressed the decreasing rate of heat production per 1℃ increase of temperature. Li *et al.* (1992) have presented the data of only 9 h during the light period and on the basis of this data of the short period, calculated a hypothetical result per day, which may not be the real decreasing rate of heat production per 1℃ increase of temperature, as behavioral activities in the high ambient temperature is different in the dark period compared to the light periods. On the contrary, in the multiple regression equation of the present experiment, heat production per 1℃ increase of temperature and heat production per activity count were calculated separately and hence, estimating heat production by the Actigraph may be a more accurate method.

From the results of the analysis of variance of multiple regression equations, the contribution rates of activity and standing on heat production were 65% and 23%, respectively. The regression equations (Figure 3) between activity and heat production under different temperatures were subjected to the analysis of co-variance, where the decline of the equations decreased significantly ($P < 0.01$) with the increase of temperature, but the intercepts of 25 and 29℃ did not differ significantly, maybe due to the same level of feed intake. The correlation coefficient (r) of the simple regression equations (Figure 2) between heat production and standing time ($r^2 = 0.18$ to 0.58) was smaller than that between heat production and activity ($r^2 = 0.59$ to 0.85) in different temperatures (Figure 3). Besides, in the multiple regression equations the correlation coefficient (R) of heat production and standing time was also smaller than that of heat production and activity. The variation of the correlation coefficient maybe due to the fact that the hens increased their quiet standing time significantly ($P < 0.01$) in the dark at higher temperature, and rested in a quiet standing position with minimal heat production rather than sitting. The amount of standing with body movements increased heat production rather than the same amount of standing without body movements. On the contrary, increasing body movements coincided with the increasing activity counts, resulting in increased heat production.

In conclusion, the present study suggests a better understanding of estimating heat production by the application of activity count method rather than the standing time in laying hens.

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