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Respiration Rate Predictive Equation and Effective Heat Stress Relief Ways for Hanwoo Steers

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Normalizing respiration rate in heat–stress challenged cattle during summer season is very important. In this study, we investigated the contribution of different thermal factors such as skin temperature, dew–point temperature, solar radiation, dry–bulb temperature and wind speed on its influence to the respiration rate dynamics of 45 Hanwoo steers in 2010. Secondly, the heat insulation efficiencies of the three kinds of roofing materials such as sandwich panel (SP), master panel (MP), and fiber glass reinforced plastic (FRP) were computed by using our newly–developed respiration rate predictive equation for Hanwoo steers. Among the thermal factors, we found out that skin temperature, dew–point temperature and dry bulb temperature mostly influenced respiration rate. Skin temperature was stimulated by increased dry–bulb temperature and solar radiation. Our newly developed respiration rate predictive equation also indicated the positive contribution of wind speed to alleviate heat load of Hanwoo during high ambient temperature, therefore fans should be used for inducing wind speed to 1.0~1.7 m s^{-1} under summer heat stress. Conclusively, sandwich panel could be the most recommendable roofing–type to normalize respiration in heat–challenged Hanwoo steers.

INTRODUCTION

The Korean economy has grown very fast since 1970, which has brought about change in the Korean life–style. Consumption of livestock products such as meat has increased 4.6 times by then, which resulted to higher importation of beef from foreign countries (Kie, 1994). However, cattle production in Korea is continually developed in order to support the rising demand of consumers. This include the raising of the most famous Korean beef cattle breed – Hanwoo (the traditional brown Korean native cattle), regarded as the most expensive and with high quality beef (Kim and Lee, 2003). In order to ensure increased Korean beef production and productivity and reduce production cost, development of improved housing technology aside from better feed management is necessary.

Generally, cattle are remarkable in their ability to cope with environmental stressors and within the limits can adjust physiologically, behaviorally, and immunologically to minimize adverse effects (Hahn, 1999). However, high temperature and humidity, in combination with the solar load and low air movement, can exceed stressor limits with resulting loss of productivity and even death of the animal (Gaughan *et al.*, 2000; Hahn and Mader, 1997; Lefcourt and Adams, 1996; Mader *et al.*, 1999). To improve intensive cattle production, companies and experts in cattle house environment need to plan the house with maximum thermal isolation in order to reduce the negative effects of climate on the production rate.

Environmental modification strategies generally focus on reducing either temperature or solar load, or increasing air movement. The use of shade structures can reduce the solar load by as much as 30% (Bond and Laster, 1975), and has received attention as an effective way of mediating summer heat loads (Bond and Laster, 1975; Brown–Brandl *et al.*, 2001; Paul *et al.*, 1998). One of the main factors that affect incident radiation thermal load in animal housing is the roof, especially due to their material (Silva and Sevegnani, 2001). The roof is the only layer that separates cattle from external environment, as in open–sided cattle houses, the side curtains do not provide efficient insulation. This demonstrates the importance of choosing an adequate roof material (Tinôco, 2001). It is presumed that the skin temperature and radiation heat load are greatly affected by the roofing materials used in the Hanwoo house.

Physiological responses of cattle have been studied intensively and respiration rate has been shown to behave predictably increasing with rising ambient temperature (Hahn *et al.*, 1997; Kibler and Brody, 1949; Morrison and Lofgreen, 1979; Webster, 1973). Respiration rate and core body temperature increase during heat exposure (differences in ambient temperature, 26 versus 40°C (Wise *et al.*, 1988), 20 versus 32°C, (Ominski *et al.*, 2002). The relationship between the respiratory rate of cattle and the thermal factors is differently represented by the breed of cattle (Gaughan *et al.*, 2000). However, the relationship between the respiration rate of Hanwoo and

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the thermal factors, including skin temperature, dry–bulb temperature, dew point temperature, wind speed and solar radiation, has not yet been reported.

In this study, we investigated the relationship between the respiration rate of Hanwoo and thermal factors as mentioned above. Secondly, the performance of the common roofing materials used in South Korea for cattle housing such as fiberglass reinforced plastic (FRP), master panel (MP) and sandwich panel (SP) with regards to its heat insulation efficiency were also investigated by developing a mathematical model for estimating the respiration rate of Hanwoo steers under summer heat stress on the basis of the characterization of the different thermal factors and to recommend effective ways of alleviating heat stress.

MATERIALS AND METHODS

Experimental materials and procedures

A total of 45 Hanwoo steers were used in the present study. The fifteen steers randomly assigned to one of FRP, MP and SP. The thickness of FRP was 2.3 mm. MP consisted of thin metal sheet wherein one side was coated by urethane foam with a thickness of 2 mm. SP consisted of a Styrofoam with thickness of 50 mm between two thin metal sheets.

Weight of the steers approximately ranged from 450 to 650 kg. They were reared with 5 heads in a pen. The pen size was 5×10 m (stocking density = 10 m^2 $head^{-1}$). The concrete floor of pens was bedded with sawdust of 5 cm in depth. Pens were oriented west/east. Each steer house had two pen lines and an aisle between the two pen lines. Width and eave height of each steer house were 30 m and 5 m, respectively. The feeder and the waterer were located near the two sides of each aisle. The steers were given feed at about 08:00 and 18:00 twice a day and water adlibitum with automatic waterers. Details are shown in Livestock Housing Standard Plan (National Agricultural Cooperative Federation, 2008).

The thermoneutral zone of the Hanwoo steer ranged from 10 to 20°C (Ko *et al*., 2006). Thus, data were collected 14 times when dry–bulb air temperature was at 18, 26, 29, 32 and 35°C from August to October, 2010. Maximum air temperature of a day in South Korea is generally between 2:00~3:00 p.m. In order to ensure linearity of thermal factor changes, the respiration rate (breaths min^{-1}) and skin temperatures (Model Rayngers ST80, Total Temperature Instrumentation, Inc., U.S.A.) of the steers were measured three times a day at 2:00, 2:15 and 2:30 p.m. and the mean value in every sampling time was used as the representative data. Before the experiment, all the steers were identified using ear tags. For each identified steer, respiration rate and skin temperature were recorded. Respiration rates were determined by visual observation of flank movement with a stopwatch for 30 seconds. After measurements of respiration rates, skin temperatures were measured on steers' back and flank at approximately the last rib at a distance of less than 3 m and average was computed. Dry–bulb air temperature (Model TR–72U, T&D corporation, Japan), relative humidity (Model TR–72U, T&D corporation, Japan), solar radiation (Model BabucM, Laboratori Di Strumenta Zione Industriale spa, Italy) and wind speed (Model Testo 416, Testo, Germany) in a pen were measured at 30 min interval from 2:00~2:30 p.m. and then the mean was used as the representative data for analysis in every sampling period.

Statistical analysis

A linear regression model was used to analyze the respiration rate and the other five parameters (steer's skin temperature, dry–bulb temperature, dew point temperature, wind speed, and solar radiation) (SAS, SAS Institute, 2005, USA). The steer weight was not included in the respiratory rate predictive equation, because it lowly contributed to respiration rate changes (Eigenberg *et al*., 2005). When the probability was less than 0.05, the parameters were regarded significant. The relative contribution of each of the variables to respiration rate was determined by calculating the ratio of each standardized regression estimate, squared by the sum of squares from all standardized regression estimates.

RESULTS AND DISCUSSION

Generally, heat stress itself is a function of time, temperature and humidity, because cows rely on water evaporation via sweating and panting to dissipate an excess of heat they have generated metabolically or absorbed from the environment (Cruz *et al*., 2004). It is known that the primary factors that can cause heat stress in cows are high environmental temperatures and high relative humidity (West, 1995). In addition, radiant energy from the sun contributes to stress if cows are not properly shaded (Gwatibaya *et al*., 2007).

Table 1 summarizes the maximum, minimum and mean values of respiration rate, skin temperature, dry bulb temperature, dew point temperature, wind speed and solar radiation, under the three different types of roofing materials (FRP, SP, MP), respectively. The maximum values recorded for respiratory rate was 77.0 breaths min^{-1}, skin temperature 44.7°C, dry bulb temperature 35.0°C, dew point temperature 23.0°C, wind speed 0.8 m s^{-1} and solar radiation 500 W m^{-2}.

Respiration rate provides an easily observed measure of an animal's thermal state and can be valuable physiological parameter in conjunction with additional infor-

Table 1. Maximum, mean and minimum environmental conditions during measurements

Item	Maximum	Mean±SD	Minimum
Respiratory rate (breaths min^{-1})	77.0	45.8±11.9	30.0
Skin temperature (°C)	44.7	33.8±4.7	15.5
Dry–bulb temperature(°C)	35.0	27.0±5.3	17.9
Dew point temperature(°C)	23.0	13.6±5.2	7.0
Wind speed (m s^{-1})	0.8	0.2±0.3	0.0
Solar radiation (W m^{-2})	500	76.3±126.3	1.0

mation, such as ambient temperature (Ta), humidity, radiation heat loads (Garrett *et al.*, 1967; Hahn, 1976), and air velocity (Monteith, 1973). In this study, we calculated the mean respiratory rate of steers in the thermoneutral zone, which was at 33.4 breaths min^{-1} with standard deviation of 2.3 breaths min^{-1}.

$$RR=0.70\ t_s+0.71\ t_{db}+0.66\ t_{dp}-1.26\ V_w+0.004\ r_s-5.83 \quad \text{——— Equation (1)}$$

In equation (1), RR is the respiratory rate in breaths/min, t_s is steer's skin temperature in ˚C, t_{db} is the dry–bulb temperature in ˚C, t_{dp} is the dew point temperature in ˚C, V_w is wind speed in m/s, and r_s is solar radiation in W m^{-2}. Equation (1) has a value for the coefficient of determination R^2 of 0.65. In equation (1), steer's skin temperature, dry–bulb temperature and dew point temperature were significant ($p<0.01$), but wind speed and solar radiation were not significant ($p>0.05$). Moreover, based on the equation (1), as wind speed increases, both respiration rate and heat stress decreases. In relation to this, Ko *et al.*(2006) suggested that the effective wind speed for alleviating summer heat stress of Hanwoo steers ranges from 1.0~1.7 m s^{-1}. Our newly developed respiration rate predictive equation indicated also the positive contribution of wind speed to normalize respiration rate of Hanwoo during high ambient temperature therefore fans should be used for inducing wind speed to 1.0~1.7 m s^{-1} under summer heat stress.

The relative contribution of each of the variables in equation (1) is shown in Table 2. Steer's skin temperature, dew point temperature and dry–bulb temperature impacted more to respiration rate, at ca. 37.4, 35.5 and 23.4% respectively, while solar radiation and wind speed only contributed less at ca. 2.1 and 1.7%, respectively.

In terms of the percent relative contribution of each variables to steer's skin temperature, dry–bulb temperature contribution was the highest (ca. 78.7%) followed by solar radiation (ca. 12.9%), dew–point (ca. 7.8%) and wind speed (ca. 0.6%) (Table 3). This finding was also observed from the previous studies that dry–bulb temperature and solar radiation are among the highest contributors of respiration rate dynamics (Eigenberg *et al.*, 2005).

Table 2. Percentage relative contribution of each of the variables to respiration rate

Parameter	Contribution (%)
Steer's skin temperature	37.4
Dry–bulb temperature	23.4
Dew point temperature	35.5
Wind speed	1.7
Solar radiation	2.1

Table 3. Percentage relative contribution of each of the variables to steer's skin temperature

Parameter	Contribution (%)
Dry–bulb temperature	78.7
Dew point temperature	7.8
Wind speed	0.6
Solar radiation	12.9

Table 4. Solar radiation measured at outside of steer houses during the experimental period

	Maximum	Mean±SD	Minimum
Solar radiation (W m^{-2})	905	643±254	240

Table 5. Solar radiation transmission of different roofing materials

	Fiberglass reinforced plastic	Master panel	Master panel
Transmission[1] (%)	29.3	13.1	1.9

[1] The values were measured in steer houses during the experimental period.

Table 4 shows the average solar radiation outside of steer houses during the experimental period that ranged from 240 W m^{-2} (minimum) to 905 Wm^{-2} (maximum). The mean solar radiation was 643±254 W m^{-2} during the entire experimental period.

The kind and layout of facilities can impact the cow's external physical heat load (Spencer, 1995). In this study, we primarily focused on the efficiency of the different roofing materials in terms of percent transmission of solar radiation as shown Table 5. Highest percent solar radiation was transmitted by using FRP at ca. 29.3%, followed by MP (ca. 13%) and SP (ca. 1.9%). Our findings revealed that SP has the best insulation efficiency compared to FRP and MP, which could be due to its structure, material composition and thickness. Our study suggest that thickness of a material is the greatest factor to reduce solar radiation transmission or heat flow, thereby contributing to the reduction of heat transference from the roof to the inside of the building especially during summer period. Secondly, quality of a material can also reduce solar radiation transmission, as from the fact that SP is made of Styrofoam, a well–known thermal insulator (thickness at 50 mm) between two thin metal sheets compared to FRP and MP with thickness at 2.3 and 2.0 mm, respectively.

CONCLUSIONS

Our study investigated the different thermal factors that impacted the respiration rate dynamics of Hanwoo steers. Among these factors, skin temperature, followed by dew point temperature and dry–bulb temperature highly influenced respiration rate. Parameters that impacted the skin temperature were the dry–bulb temperature and solar radiation. Among the three commonly used roofing materials, sandwich panel was the most suitable roofing–type for Hanwoo steers since it showed the highest heat insulation efficiency based on our newly developed respiration rate predictive equation. This equation could be very useful in finding more improved roofing facilities to decrease skin temperature and solar radiation transmission in cattle management during summer season. Our newly developed respiration rate predictive equation indicated also the positive contribution of wind speed to normalize respiration rate of Hanwoo during high ambient temperature therefore fans should be used for inducing wind speed to 1.0~1.7 m s^{-1} under summer heat stress. In conclusion, sandwich panel roof–type could be more recommendable roofing material to alleviate heat load for heat stress–challenged Hanwoo steers.

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