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Effect of Temperature-Humidity Index on Thermoregulation Responses of Pesisir Cattle in Different Altitudes

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ABSTRACT

This experiment was designed to study the effect of Temperature Humidity Index (THI) on the thermoregulation responses and the velocity of thermoregulation responses rate of Pesisir cattle raised in lowland (0-300masl) and highland areas (>600masl) in West Sumatra, Indonesia. This study used 8 Pesisir cattle as subjects. Parameters measured were ambient temperature (Ta), relative humidity (RH), and THI, rectal temperature (Tr), skin temperature (Ts), body temperature (Tb), respiration rate (RR), and heart rate (HR). The correlation between THI and thermoregulation responses was analyzed by linear regression analysis. The results showed that the physiological responses of Pesisir cattle were most affected by THI in the lowlands were skin temperature (R2=87.02%), body temperature (R2=73.39%), respiration rate (R2=31.59%), and rectal temperature (R2=30.09%), while in the highlands, body temperature (R2=84.32%), skin temperature (R2=79.57%), rectal temperature (R2=74.95%) and respiration rate (R2=53.91%). The conclusion of the study showed that THI in lowland and highland areas affected body temperature, rectal temperature, skin temperature, and respiration rate but did not affect heart rate. The velocity of the skin temperature rate of Pesisir cattle is higher in the lowland area than in the highland area. The velocity of rectal temperature rate, body temperature rate and respiratory rate of Pesisir cattle raised in highland were higher than in the lowland area.

Key words: Highland, Lowland, Microclimate, Pesisir Cattle, Thermoregulation

INTRODUCTION

West Sumatra is a region with diverse topography, in the form of lowlands and highlands, located on the west coast of the central part of the island of Sumatra (BPS Sumatera Barat 2017). West Sumatra is a tropical rainforest area characterized by high levels of solar radiation, ambient temperature (Ta), and air RH. The main environmental factors that affect animal production are temperature, humidity, solar radiation, and wind (Scholtz et al. 2013; Susanty et al. 2018; Sabre et al. 2020). Heat waves of a few days' duration can reduce animal performance and cause substantial economic losses to the livestock industry (Lees et al. 2019).

A combination of some environmental factors such as ambient temperature (Ta), RH, wind, solar radiation, and rainfall causes heat stress on livestock (Isaksson 2017). Therefore, heat stress is the main factor that limits the growth and production of cattle in this region. The effects of heat stress include reduced productivity, reduced animal welfare, reduced fertility, increased susceptibility to disease, and in extreme cases increased mortality (Godde et al. 2021).

Measuring body temperature is usually used to detect heat stress in livestock. Livestock undergoes heat stress during hot weather, particularly in prolonged high temperatures. Heat stress decreases feed intake, increases RR, and rising water intake (Beatty et al. 2014).

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Increasing rectal temperature and respiratory rate, decreasing dry matter intake, panting, and dropping in productivity are livestock efforts to maintain stable body temperature during heat stress. Reduced dry matter intake and physiological activity alteration can affect the potential of cattle production (Pragna et al. 2017; Ningrat et al. 2020; Pazla et al. 2021; Rastosari et al. 2022). Heat stress causes health problems, reduced productivity and reproductivity rate, and even lead to death (Isaksson 2017; Reswati et al. 2021).

The animals' thermoneutral zone is different because they have different sensitivity to the ambient temperature and relative humidity. The comfort zone of tropical cattle is at a temperature of 22 to 30°C (Gantner et al. 2011). Cows undergo mild stress at ambient temperatures above 27°C (Atrian and Shahryar 2012). Cattle usually can maintain their constant body temperature (i.e., between 38.4°C and 39.0°C), which is essential to preserve biochemical reactions and physiological processes in their body's healthy metabolism (Kiran 2016). Cattle's average body temperature is between 38.3°C to 39.4°C. They need to be in a suitable environment to keep a constant body temperature (Isaksson 2017). Low-producing cattle are more resistant to heat stress than high-producing ones (Gantner et al. 2017). Heat production will increase with increasing body mass, and heat loss will relatively increase the body surface area (Isaksson 2017).

Compared with goats, the direct effects of higher temperatures on cattle may be severe, because goats are better able to cope with multiple stressors than cattle (Sejian et al. 2018). Cattle are homoeothermic animals that are always trying to keep their body temperatures in a normal range through thermoregulation. Cattle will increase heat dissipation and heat loss from the body by the process of respiration and sweating, i.e., by increasing RR and HR to maintain the average body temperature to overcome and reduce heat stress (Farooq et al. 2010).

There is no adjustment of the heat production needed to keep the optimal body temperature when animals are raised to a temperature that is in their thermoneutral zone. Body water evaporates all the time to maintain the average body temperature. When the air temperature is below the lower limit of the thermoneutral zone, cows will increase their heat production to keep a stable body temperature. When the air temperature rises, cattle will start to sweat or pant, to lower their body temperature (Isaksson 2017). The thermoneutral zone is the most comfortable condition for animals; therefore, they have the fastest growth rate and achieve the most efficient feed-to-gain ratio in this zone. This thermoneutral zone is variable for each animal. It depends on factors such as species, humidity, time of year, age, acclimation, amount of fat or hair coat insulation, level of production, wind, and other factors (Kerr 2015; Abdoon et al. 2020; Youssif et al. 2020).

Cows maintain normal body temperatures or normothermia by exchanging heat with the external environment (Boehmer et al. 2015). When animals are unable to regulate their body temperature, their body diverts energy reserves to thermoregulatory processes such as decreased or increased heat production during heat stress and cold stress. Thus, these conditions are reducing energy reserves for growth, pregnancy, or lactation (Howard et al. 2014). Increases of 1.5°C and above may exceed limits for normal thermoregulation of cattle and could result in persistent heat stress for these animals in a range of different environments (Lallo et al. 2018; Ranjitkar et al. 2020; Rahimi et al. 2021).

Temperature Humidity Index (THI) is an interaction between temperature and RH, which is a single value representing the combined effects of air, temperature, and humidity. THI is associated with the level of thermal stress. It is widely used to assess the impact of heat stress on animals in tropical areas all over the world (Kohli et al. 2014; Beux et al. 2017; Herbut et al. 2018; Thornton et al. 2021). Heat stress is one of the most critical stressors, but it cannot be indicated only in terms of temperature (Kohli et al. 2014). Livestock raised in an environment with THI ≤74 will feel comfortable, while a climate with THI ≥75 will cause them on heat stress (Hahn 1999).

The present experiment was designed to study the effects of the THI on the thermoregulation responses of Pesisir cattle and the slope rate of those thermoregulation responses in the lowland and highland areas in West Sumatra. The increasing THI values will stimulate thermoregulation responses, such as rising in BT, RR and HR (McDowell et al. 1968). The results of this experiment will be used in determining the appropriate area for raising and developing Pesisir cattle in the highland and lowland areas in West Sumatra, Indonesia. The results of this study can also be a reference for the development of local cattle in countries with tropical climates.

MATERIALS AND METHODS

Ethical Approval

This experiment has referred to research ethics using livestock based on the Republic of Indonesia government law number 41/2014 concerning Animal Science and Health.

Materials

This experiment was conducted in the lowland and highland areas of West Sumatera Province, Indonesia. For lowland observation, the experiment was conducted in Padang City (0-300masl) and for highland observation, the experiment was conducted in BPTU Padang Mengatas, Kabupaten Lima Puluh Kota (>600masl). The materials used in the experiment were 8 Pesisir cattle consisting of 4 head in each area. The experimental Pesisir cattle used were female cattle with the relatively similar ages shown by the replacement of serial teeth by Incisor 2 indicating the ages were around 2-3 years. Feeding system used during the experiment followed the ration and system used by the farmers.

Methods

The variables measured consisted of 2 aspects, i.e., abiotic environment (climatic variable) and thermoregulation aspects of Pesisir cattle. The abiotic environmental aspects were ambient temperature (Ta), relative humidity (RH), and Temperature Humidity Index (THI). Ta and RH parameters were measured using a dry-wet bulb hygrometer (Dry-Wet Bulb Hygrometer, Hisamatsu Model MR-54). The climate variables were used to calculate THI by using the formula of Hahn (1999):

THI = DBT+0, 36 WBT + 41. 2,
where DBT = dry-bulb temperature (ºC), WBT = wet-bulb temperature (ºC).

Variables of thermoregulation in Pesisir cattle measured were rectal temperature (Tr), skin temperature (Ts), respiration rate (RR), and heart rate (HR). Tr and Ts were used to calculate body temperature, by using the formula of McLean et al. (1983b): Tb = 0.86 Tr + 0.14 Ts, where Tr was rectal temperature and Ts was skin temperature (the surface of the body). Tr was measured by inserting a clinical thermometer into the rectum, while Ts was measured by using an infra-red digital thermometer at 4 points of measurements, i.e., shoulder (A), chest (B), upper shank (C), and lower shank (D). The average Ts was calculated based on the modified formula of McLean et al. (1983a):

Ts= 0.25 (A + B) + 0.32 C + 0.18 D.

Respiration rate was measured by using a stopwatch and placing the hand near the nose, and counting the respiration rate for 1 minute. The counting was conducted 3 times and then the results were averaged. Heart rate was counted by using a stethoscope by placing the stethoscope near the axilla bone on the left chest. The heart rate was counted for 1 minute and repeated 3 times, then the results were averaged. The measurements of all variables were conducted 5 times a day, i.e., at 07.00, 10.00, 13.00, 16.00, and 19.00 WIT.

To evaluate the relationship between THI, the interaction between temperature and humidity as an indicator of the comfort zone of environment conditions, and various thermoregulation aspects of cattle, the data were analyzed by using linear regression with Minitab Software in each area, lowland, and highland area.

RESULTS

An illustration of the THI conditions in West Sumatra with different heights can be seen in Fig. 1.THI in the lowlands throughout the day from 07.00am to 07.00pm ranged from 76.2 to 82.3 with an average of 79.96. THI in the highlands throughout the day from 07.00am to 07.00pm ranging from 72.3 to 76.3 with an average of 74.3. The lowest THI throughout the observation period from 07.00am to 07.00pm, in both the lowlands and highlands areas, was found in the morning (07.00am).

THI is directly proportional to ambient temperature. The same phenomenon in ambient temperature is also found in THI. The highest THI value in the lowlands (82.3) occurs at noon at 01.00pm and the highest THI in the highlands (76.3) occurs in the afternoon at 04.00pm. Fig. 1 shows that the lowlands have THI higher than the highlands.

The regression equation to see the effect of THI on the thermoregulation response of Pesisir cattle in the lowlands of West Sumatra can be seen in Fig. 2. Statistical tests showed that the THI in the morning at 07.00am was found to be the same (P>0.05) in both areas. THI was obtained differently from 10am until night (P<0.05) and in general the THI conditions were found to be different (P<0.05) in lowland and highland areas in West Sumatra. The regression equation to see the effect of THI on several thermoregulatory responses of Pesisir cattle in the lowlands of West Sumatra on the graph shows that the physiological values of cattle that are significantly affected by THI are body temperature, rectal temperature, skin temperature, and respiratory frequency (P<0.01), whereas heart rate was not statistically affected by THI (P>0.05). The physiological responses that are most affected by the THI are skin temperature with a coefficient of determination R^2=87.02%, followed by body temperature with a value of R^2=73.39%, respiratory rate with a value of R^2=31.59%, and rectal temperature with a value of R^2=30.09%. An increase in THI of 1 unit will increase skin temperature by 0.86°C, body temperature by 0.20°C, rectal temperature by 0.1°C, and respiratory frequency by 0.69 times minutes-1.

Major changes that occur in environmental climate will be followed by small changes in the four physiological responses. An increase in THI will be followed by an increase in body temperature, skin temperature, rectal temperature, and respiratory rate, and vice versa a decrease in THI will result in a decrease in the four physiological responses, but changes in physiological responses occur in small values. This study shows Pesisir cattle are beef cattle that have adapted to the natural conditions of Indonesia with its tropical climate. Pesisir cattle as native cows from the tropics are able to condition the physiological processes in their bodies in accordance with the changing climate environment.

The regression equation to see the effect of THI on several physiological responses of Pesisir cattle in highland areas in West Sumatra can be seen in Fig. 3. The physiological values of Pesisir cattle in the highlands of West Sumatra affected by THI are body temperature, rectal temperature, skin temperature, and respiratory frequency (P<0.01), whereas heart rate is not statistically affected by THI (P>0.05). The physiological responses that were most affected by THI were body temperature with a coefficient of determination R^2=84.23%, followed by skin temperature with a value of R^2=79.57%, rectal temperature with a value of R^2=74.95%, and respiratory rate with a value of R^2=53.91%. An increase in THI of 1 unit will increase skin temperature by 0.86°C, body temperature by 0.20°C, rectal temperature by 0.1°C, and respiratory rate by 0.69 times minutes-1.

The same condition in lowland areas also occurs in Pesisir cattle raised in the highlands of West Sumatra. Increased environmental conditions (THI) will be followed by an increase in body temperature, skin temperature, rectal temperature, and respiratory frequency, and vice versa decreases in THI will result in a decrease in all four physiological responses, but changes in small value.

The velocity of the thermoregulatory response rate of Pesisir cattle in the lowlands and highlands in West Sumatra can be seen in Fig. 4. The velocity of the thermoregulatory response rate of Pesisir cattle in both plains in West Sumatra is shown by the slope of straight lines (Fig. 4). The slope of this line is indicated by the value of the regression coefficient in the linear regression for all observed thermoregulation responses (Fig. 3). The research data shows that the regression coefficient of Pesisir cattle skin temperature in the lowland (β_1=0.86) is higher than the regression coefficient of Pesisir cattle skin temperature in the highland (β_1=0.67). This shows that the velocity of the skin temperature rate of Pesisir cattle in a

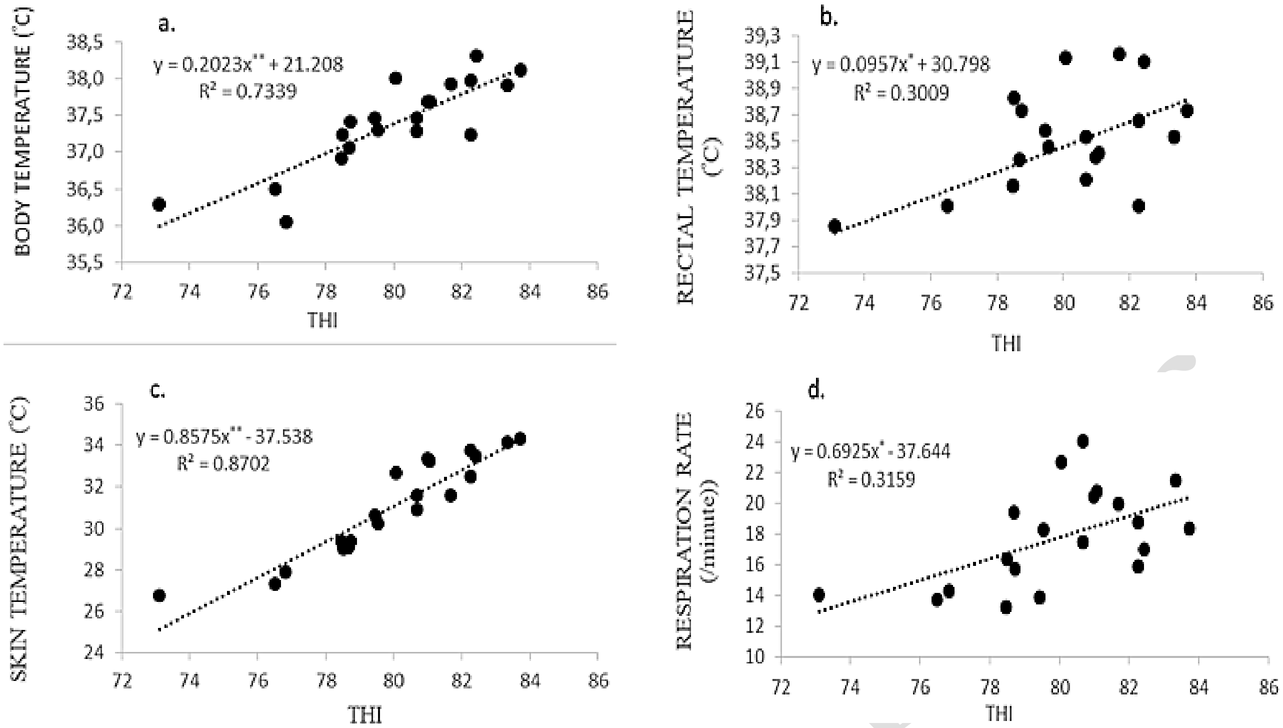

Fig. 1: Temperature humidity index in Lowland (●) and Highland (□) Areas of West Sumatera.

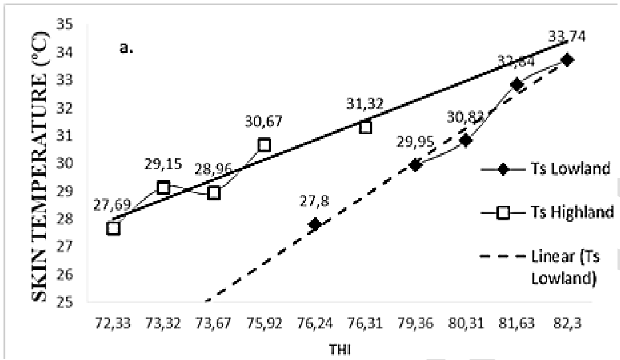

Fig 2: Regression of THI and Thermoregulation Responses of Pesisir Cattle in Lowland Areas in West Sumatera. a. Body Temperature. b. Rectal Temperature. c. Skin Temperature. d. Respiration Rate. **= highly significant (P<0.01); *= significant (P<0.05); ns = non-significant (P>0.05).

lowland which has a slightly hotter climate is higher than the velocity of the skin temperature rate of Pesisir cattle in highland areas with a cool climate. The results showed that skin temperature was strongly influenced by the microclimate of the environment. Pesisir cattle in lowland areas have a velocity of skin temperature rate more sensitive to environmental heat than Pesisir cattle in highland areas. The high temperature of the environment in the lowlands is a trigger for the high velocity of the Pesisir cattle's skin temperature rate.

The results showed that the regression coefficient of the thermoregulatory response body temperature (β_1=0.24), rectal temperature (β_1=0.16), and respiratory rate (β_1=1.1) of Pesisir cattle in the highlands are greater than those in the lowlands (body temperature (β_1=0.20), rectal temperature (β_1=0.09), and respiratory rate (β_1=0.69), meaning the velocity of body temperature rate, rectal temperature rate, and respiratory rate of the Pesisir cattle in the highlands are higher than the velocity of body temperature rate, rectal temperature rate and respiratory rate of cattle in the lowlands.

DISCUSSION

The altitude of an area or region has an impact on the microclimate, especially ambient temperature, and relative humidity, which determine the level of comfort of the environment for livestock indicated by the THI value. Lowland areas had a higher ambient temperature and THI values than the highland area; however, during the daytime period, the humidity in the lowland area was lower than in the highland areas (Fig. 1). THI and ambient temperature in the lowland areas higher than in the highland areas were caused by the high intensity of solar radiation in the lowland areas. The intensity of solar radiation affects long-wave radiation (heat) in an area. Climate elements are controlled by the latitude and the height of the sea level (altitude). Highland areas with altitudes >700masl have a more turbid atmosphere than lowland areas. This condition causes more solar radiation to be absorbed and reflected by the atmosphere so that the intensity of solar radiation received by the earth becomes lower. These conditions result in a cooler ambient temperature in the highland than in the lowland areas.

The climatic conditions seen from the THI value illustrate that the low-lying areas are in the alert zone (hot stress) with an average THI value of 79.96 and the high-altitude areas are in the comfort zone for livestock survival with an average THI value of 72.3. Hahn (1999) stated that a comfortable THI value for livestock ranges from ≤74 and at a value of ≥75 the animal has experienced stress. Pejman and Habib (2012) stated that livestock that is at THI 72-78 will experience mild stress while at THI values 79-88 cattle have experienced moderate stress.

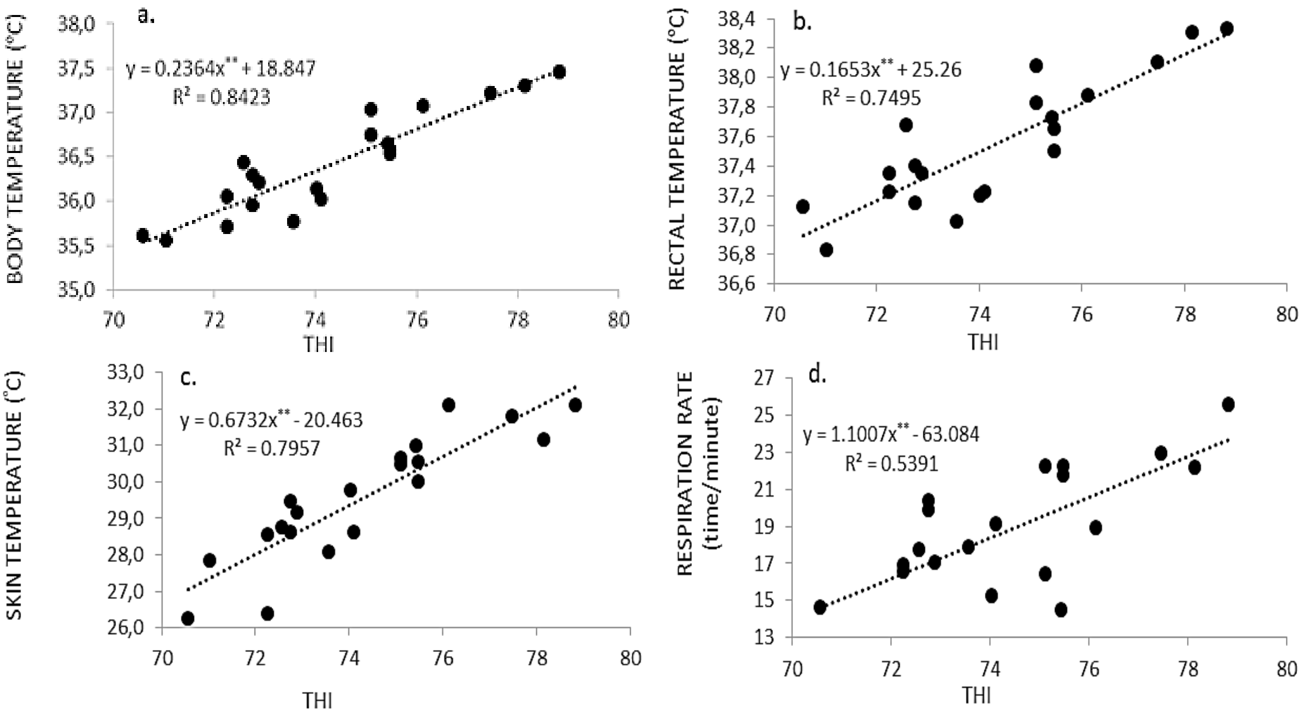

Fig. 3: Regression of THI and Thermoregulation Responses of Pesisir Cattle in Highland Area in West Sumatera. a. Body temperature. b. Rectal temperature. c. Skin temperature. d. Respiration rate. **= highly significant (P<0.01); * = significant (P<0.05); ns = non-significant (P>0.05).

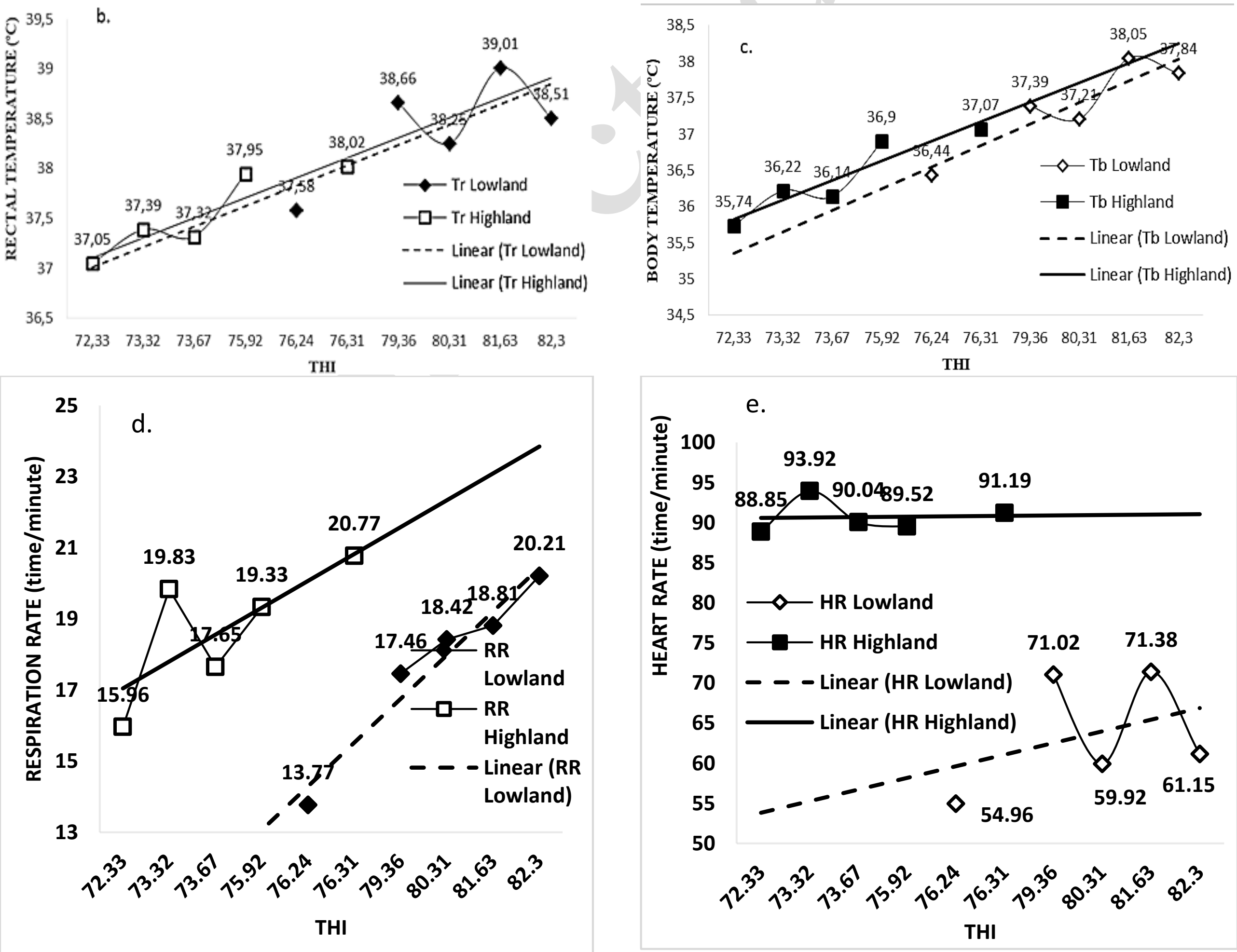

Fig. 4: The Rates of Increase in Thermoregulation Responses of Pesisir Cattle in Lowland (◊) and Highland (■) Areas in West Sumatera. a. Skin temperature. b. Rectal temperature. c. Body temperature. d. Respiration rate. e. Heart rate.

Valente et al. (2015) stated that the THI to estimate heat stress in beef cattle is 72 (moderate), 82 (high) and 94 (extreme) Several studies agree on a THI value of 89 as being the onset of extreme heat stress in several breeds of cattle in temperate regions (Gilbert et al. 2018). While the threshold for severe heat stress onset is in accord with the estimate for tropical cattle (Bos indicus breed) in the study of Valente et al. (2015) was 94. For dairy cattle, Pinto et al. (2020) cited a range of THI from 60 to 72 as the threshold for milk yield losses, while the review of Wang et al. (2018) tabulates "THI thresholds of alert" of between 60 and 78.2 for Holstein cattle across the United States and Europe.

The THI had a very significant effect (P<0.01) on body temperature, rectal temperature, skin temperature, and respiratory rate, while the heart rate was not significantly affected by THI (P>0.05) in lowlands (Fig. 2). The thermoregulation response that was mostly influenced by THI was skin temperature with the coefficient of determination R^2=87.02%. In contrast, the thermoregulation response that was the least influenced by the THI was the rectal temperature (R^2=30.09%). Galán et al. (2018) stated that thermoneutral thresholds are usually determined by physiological responses, such as changes to the animal's respiration rate and body temperature, rather than changes to behavior.

Changes in skin temperature, body temperature, rectal Temperature, and respiratory rate due to an increase in 1 unit of THI were 0.86ºC, 0.20ºC, 0.1ºC, and 0.69 times/minute, respectively. The levels of thermoregulation responses found in the present experiment were lower than those reported in the Bos taurus (Finch 1986). These lower thermoregulation responses indicate that Pesisir cattle are tropical beef cattle that have adapted well to tropical climatic conditions. Polsky and Von Keyserlingk (2017) stated that temperate Bos taurus breed tends to be more susceptible than Bos indicus cattle and their crosses which are more adapted to the tropics.

The same phenomena were observed in the influence of THI on the thermoregulation response in the highlands area (Fig. 3). In the highland areas, THI had significant effects (P<0.01) on body temperature, skin temperature, rectal temperature, and respiratory rate, while the heart rate was not affected by the THI (P>0.05). In the highland areas, changes in these thermoregulation responses (body temperature, skin temperature, rectal temperature, and respiratory rate) due to the change in 1 unit of THI were lower than those found in the lowland areas. These data indicate that Pesisir cattle are still able to adapt to the highland environment.

Skin temperature is strongly influenced by THI as a parameter of micro-environmental conditions (Fig. 4). In lowland areas, Pesisir cattle had faster and greater changes or rates of skin temperature response than those raised in highland areas. These results indicate that Pesisir cattle in lowland areas are more sensitive to environmental heat than in highland areas. The higher environmental temperature in the lowland areas is a trigger for the high speed of the response changes in skin temperature in the Pesisir cattle. The velocity of Pesisir cattle's skin temperature rate is high in the lowland as stimulants to activate the sweat glands to maintain body temperature stability.

On the other hand, Pesisir cattle raised in highland areas have higher velocity rectal temperature rate, body temperature rate, and respiratory rate than Pesisir cattle in the lowlands. The velocity in both rectal and body temperature rates due to thermoregulatory responses in Pesisir cattle raised in highland areas is believed to be a stimulus for increased respiratory rates to cope with heat stress. These results indicate that to maintain the balance of the thermoregulation process in the Pesisir cattle raised in highland areas, it will increase the respiratory rate first before the heat dissipation pathway through active sweat. The thermoregulation mechanism is a normal condition in cattle as homoeothermic animals. Finch (1986) and Siregar et al. (2019) state that the control of body temperature is a consequence of animal thermoregulation mechanisms and resistance to heat exchange between cattle bodies and their environments.

Soeharsono (2010) states that cattle that suffer from heat stress will release their body heat quickly so that respiration is encouraged and their breathing frequency increases. Cattle will increase their breathing rate to regulate high body temperature along with increasing ambient temperature in order to maintain physiological balance in the body. Blackshaw and Blackshaw (1994) stated that at high temperatures, the removal of body heat through evaporation is the main mechanism of homeostasis in cattle. This is influenced by humidity, wind speed, and physiological factors such as respiration rate and the amount and activity of sweat glands.

Conclusion

Temperature Humidity Index (THI) in the lowland and highland areas affect body temperature, rectal temperature, skin temperature, and respiration rate. The velocity of skin temperature rate of Pesisir cattle in lowland areas were higher than in highland areas. The velocity of rectal temperature rate, body temperature, and respiratory rate of Pesisir cattle raised in highland areas were higher than in lowland areas.

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Author contributions

Yetmaneli and B. P. Purwanto participated in all stages of the research, namely the research design, the conduct of the experiment, sample analysis, data analysis, writing, and editing of article. R. Priyanto participated in conducting the investigation, W. Manalu was responsible for data analysis. R. Pazla participated in writing and editing the article. All authors participated in writing the article.

Conflicts of Interest Declaration

All authors declare they have no conflicts of interest concerning the work presented in this manuscript.

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