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Effect of Environmental Factors on Physiological Responses and Slaughtering Quality of Limpo and Simmental Cattle

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ABSTRACT

Beef cattle, particularly Simmental and Limpo breeds, are strategic commodities in the supply of animal protein, which plays an important role in supporting national food security. The quality of beef is not only determined by management factors at the farm level, but is also influenced by environmental conditions and management practices at slaughterhouses. An unfavorable slaughterhouse environment has the potential to cause physiological stress in livestock prior to slaughter, thereby impacting the quality of the carcass and meat produced. This study aimed to evaluate the effect of slaughterhouse environmental conditions on the physiological response and death rate of Simmental and Limpo beef cattle in Surakarta City. The study was conducted over one month at the Surakarta Animal Health Centre Slaughterhouse using 14 cattle, consisting of 7 Simmental and 7 Limpo. The parameters observed included temperature, humidity, temperature humidity index (THI), heart rate, heart rate frequency (HRF), respiratory rate (RR), and the post-slaughter time to death (PTD). The data obtained were analyzed with Pearson's correlation test using IBM® SPSS Statistics 25.0 for Windows. The results showed that the THI value had a significant correlation with the RR and PTD ($P<0.05$), while no significance was observed in HRF ($P>0.05$). These findings indicate that increased temperature and humidity can worsen physiological stress levels, which ultimately reduces meat quality. Thus, the application of animal welfare principles and good, hygienic, and standardized slaughterhouse environmental management are crucial factors in ensuring livestock quality and supporting the sustainability of national beef production.

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ABSTRAK

Sapi potong, khususnya bangsa Simmental dan Limpo, merupakan komoditas strategis dalam penyediaan protein hewani yang berperan penting dalam mendukung ketahanan pangan nasional. Kualitas daging sapi tidak hanya ditentukan oleh faktor manajemen pemeliharaan di tingkat peternakan, tetapi juga dipengaruhi oleh kondisi lingkungan serta tata kelola di Rumah Potong Hewan (RPH). Lingkungan RPH yang kurang kondusif berpotensi menimbulkan stres fisiologis pada ternak sebelum penyembelihan, sehingga berdampak pada kualitas karkas maupun daging yang dihasilkan. Penelitian ini bertujuan untuk mengevaluasi pengaruh kondisi lingkungan RPH terhadap respons fisiologis serta kecepatan kematian sapi potong bangsa Simmental dan Limpo di Kota Surakarta. Penelitian dilaksanakan selama satu bulan di RPH Puskeswan Surakarta dengan menggunakan 14 ekor sapi, yang terdiri atas 7 ekor Simmental dan 7 ekor Limpo. Parameter yang diamati meliputi suhu, kelembapan, Temperature Humidity Index (THI), frekuensi detak jantung, laju respirasi, serta waktu kematian pasca penyembelihan. Data yang diperoleh dianalisis menggunakan uji korelasi Pearson dengan bantuan perangkat lunak IBM® SPSS Statistics 25.0 for Windows. Hasil penelitian menunjukkan bahwa nilai THI memiliki korelasi signifikan terhadap laju respirasi dan waktu kematian (P<0,05), namun tidak signifikan terhadap frekuensi detak jantung (P>0,05). Temuan ini mengindikasikan bahwa peningkatan suhu dan kelembapan dapat memperburuk tingkat stres fisiologis, yang pada akhirnya menurunkan mutu daging. Dengan demikian, penerapan prinsip kesejahteraan hewan serta pengelolaan lingkungan RPH yang baik, higienis, dan terstandar menjadi faktor krusial dalam menjamin kualitas hasil ternak serta mendukung keberlanjutan produksi daging sapi nasional.

INTRODUCTION

Beef cattle farming plays a crucial role in supporting food security by providing animal protein, including beef (Gustiani & Fahmi, 2022). This is evident from data on global beef cattle demand, which reached 70 million tons in 2019 and is projected to increase to 74 million tons by 2023 (Greenwood, 2021). Lumawir *et al.* (2023) added that the average beef consumption in Indonesia increases by 2% annually. This indicates growing public awareness of the need for animal protein.

In line with this, excellent management is necessary to produce quality beef throughout the entire production chain, from upstream to downstream. One crucial aspect of this process is the application of animal welfare principles (Nurhayati *et al*., 2022). Animal welfare is the relationship between humans and animals and the obligation to treat animals humanely (Khillare & Kaushal, 2021). Animal welfare must be adhered to, including in slaughter houses. Unsatisfactory animal welfare will affect meat quality due to stress in cattle (Nurhayati *et al*., 2022).

A slaughterhouse is a building or complex of buildings with a specific design used as a place to slaughter animals other than poultry for public consumption (Anggraini *et al*., 2021). Slaughterhouse also plays a crucial role in controlling animal diseases and ensuring public health by providing quality meat (García-Díez *et al*., 2023). As part of the food supply system, slaughterhouses play a crucial role in producing Safe (*Aman*), Healthy (*Sehat*), Whole (*Utuh*), and Halal (*ASUH*) meat products (Dayana *et al*., 2019), including slaughterhouses in Surakarta City. Aditya *et al.* (2022) reported that slaughterhouses in Surakarta have not yet perfectly produced *ASUH* products, which include slaughtering methods, meat packaging, and distribution.

However, the government has established various policies to support cattle slaughter at slaughterhouses that comply with consumer protection principles, including the implementation of *ASUH* management and the HACCP (Hazard Analysis Critical Control Point) approach by identifying critical points in handling and production processes (Anggraini *et al*., 2021). In addition, slaughterhouses must also pay attention to environmental conditions because unsuitable environmental factors can cause stress in cattle before slaughter. This stress will affect the animal's physiological response, such as increased muscle tension and metabolic changes, which can ultimately reduce meat quality. Thus, compliance with *ASUH* standards depends not only on the technical processes of slaughtering and packaging, but also on controlling environmental factors that affect the physiological condition of animals before slaughter.

According to Rinca *et al*. (2022), three factors influence stress levels in cattle at slaughterhouses are environmental conditions, feed quantity, and livestock transportation procedures. Among these three factors, the environment plays a significant role in the comfort and physiological quality of beef cattle. Santoso *et al*. (2023) added that comfortable environmental conditions can support livestock productivity and welfare. These environmental conditions, such as humidity and temperature, must be maintained within ideal limits, namely a maximum of 27°C with a humidity ranging from 65% to 95% for tropical environments. Furthermore, a good temperature humidity index (THI) value ranges from 74.80 to 90.53 (Santoso *et al*., 2023). Environmental conditions that exceed the tolerance threshold can cause discomfort that leads to stress in animals. This stress can be characterized by physiological changes such as increased respiratory rate, heart rate, and rectal temperature (Rinca *et al*., 2022). The fear, pressure, stress and pain experienced by livestock before being slaughtered at the slaughterhouse can also arise due to neglect of aspects of animal welfare (Azzumar & Humaidah, 2024).

Despite the importance of animal welfare principles in slaughterhouse management, studies on the quantitative relationship between the Temperature Humidity Index (THI), physiological responses, and mortality rates of beef cattle in Indonesian slaughterhouses remain limited, particularly in Surakarta. Moreover, research examining the interaction between environmental conditions and physiological parameters of beef cattle, especially in superior breeds such as Limpo and Simmental, is still rare. Therefore, it is essential to conduct further studies focusing on the adaptive responses and physiological performance of superior cattle breeds available in Indonesia to support animal welfare improvement and sustainable beef production under tropical environmental conditions.

In tropical environments, Simmental cattle have an average daily gain (ADG) of 0.85 kg/day (Sholeh *et al*., 2023), while Limpo cattle excel in their ability to adapt to tropical climates (Nugraha *et al*., 2024). In other words, both breeds have the potential to provide quality meat despite differing physiological characteristics and stress tolerance, which can impact meat quality. Furthermore, the impact of THI on the mortality rate of beef cattle has not been widely studied. This is a crucial factor in assessing the level of stress experienced by cattle prior to slaughter. Therefore, this study aims to evaluate the physiological responses and the post-slaughter time to death was chosen as an objective indicator of animal welfare and slaughter efficiency, as it reflects the effectiveness of stunning and bleeding procedures and the degree of physiological stress experienced by animals (EFSA, 2020). Therefore, this study aims to evaluate the physiological responses and *post-slaughter time to death* of Limpo and Simmental cattle to enhance sustainable meat quality in Surakarta City and to provide a scientific basis for improving slaughterhouse management. The findings are expected to contribute to more optimal cattle handling practices and promote the welfare and productivity of superior cattle breeds available in Indonesia.

METHOD

This study was conducted from 6 January to 6 February 2025 at the Surakarta Slaughter House located Surakarta, Central Java, Indonesia (7°33'56" South Latitude, 110°50'22" East Longitude), at an altitude of 91.41 meters above sea level (masl). The ambient temperature at the slaughter house ranged between 25-26°C with a relative humidity of 80-83%.

All animal use protocols were approved by the respective slaughter house (abattoir) authorities for the purpose of conducting exploratory research. The study involved a total of 14 cattle, comprising 7 Limpo (local breed) and 7 Simmental (imported breed) cattle. Selection for slaughter was based on age, with animals ranging from 2.5 to 3 years old.

A type of housing systems were utilized for both Simmental and Limpo cattle which were kept in a double-row stall system arranged tail-to-tail. The slaughtering process was conducted in two distinct areas. Non-stunning slaughter was applied to the local Limpo cattle because they are easier to handle during slaughter, while stunning prior to slaughter was implemented for Simmental cattle using a restraining box.

Data collection was conducted daily from 01.00 AM to 06.00 AM. The parameters recorded included temperature (T), relative humidity (RH), heart rate frequency (HRF), respiratory rate (RR), and the post-slaughter time to death (PTD). T and RH data were collected using a thermohygrometer, with observations taken daily at 01.00 AM. The data were then calculated to measure temperature-humidity index (THI) with formula of $THI = (1.8 \times T + 32) – [(0.55 – 0.0055 \times RH) \times (1.8 \times T – 26)]$ (T in °C, RH in %; categories followed (Gopar *et al*., 2020). HRF was measured based on modified method of Hermawansyah *et al*., (2024) by palpating the coccygeal artery at the base of the tail, counting the pulse beats for one minute. This measurement was repeated three times, and the average HRF was calculated. RR was determined with modified method of Sulistyowati *et al*. (2019) by using two methods: (1) counting the number of breath placing the back of the hand in front of the animal's nostrils for one minute, or (2) visually observing the rise and fall of the abdominal cavity over a one-minute period. Both methods were repeated three times, and the average RR was calculated. The PTD was measured using modified method of Sambodo *et al*. (2023). A stopwatch starts immediately after the incision. Indicators of death included the absence of the corneal reflex, cessation of respiratory movements observed in the thoracic and abdominal cavities, and the assessment of blood flow characteristics such as rhythm and intensity.

Data were analysed using descriptive statistics to obtain mean values, standard deviations, minimum, and maximum values, and Pearson's correlation test was performed in IBM® SPSS Statistics 25.0 for Windows to determine the strength of the relationship between independent and dependent variables at a significance level of 5%. The relationship between variables X (T, RH, and THI) and variables Y (HRF, RR, and PTD) can be either positive or negative. The decision criteria are as follows: 1) if the significance value is <0.05, the variables are considered to be correlated; 2) if the significance value is >0.05, the variables are not correlated. If the significance value is exactly 0.05, the Pearson correlation test can be compared to the critical r value (r-table) with the following criteria: 1) if the Pearson correlation test result > r-table, there is a significant relationship; 2) if the Pearson correlation test result < r-table, there is no significant relationship. The guidelines for interpreting the degree of correlation are as follows:

Table 1. Pearson Correlation Guidelines

Coefficient Interval	Relationship Strength
0.00 – 0.199	Very weak
0.20 – 0.399	Weak
0.40 – 0.599	Moderate
0.60 – 0.799	Strong
0.80 - 1.000	Very strong

Source: Jabnabillah & Margina (2022)

RESULT AND DISCUSSION

Table 2. Results of Correlation Analysis

Item	THI	HRF	RR	PTD
THI	0	0.890	0.022	0.008
HRF	0.890	0	0.880	0.049
RR	0.022	0.880	0	0.008
PTD	0.008	0.049	0.008	0

*The correlation is significant at a P-value < 0.05

Table 3. Physiological Responses of both Simmental and Limpo Cattle

Cattle	THI	HRF (beats/minute)	RR (beats/minute)	PTD (minute)
Simmental	75.75±1.15	37.00±7.34	34.85±5.11	3.56±0.45
Limpo	76.55±0.82	34.57±5.56	36.71±2.98	3.43±0.39

Temperature Humidity Index

The results of the study (Table 2) indicate that there is no significant correlation (P>0.05) between THI and HRF. These results are inconsistent with Hermawansyah *et al.* (2024), who stated that increases in respiratory rate, heart rate, and rectal temperature in cattle can be caused by high barn temperatures. Conversely, this study shows a significant correlation (P<0.05) between THI and RR and PTD, indicating that as THI increases, respiratory rate increases and the PTD of cattle becomes longer. This finding aligns with Rinca *et al.* (2022), who reported that increased body temperature or heat stress can affect the physiological status of livestock. Furthermore, Yan *et al.* (2021) reported an increase in respiratory rate in cattle when THI was in the thermoneutral to moderate stress category. High THI can stimulate the thermoregulatory system through increased respiration to release body heat.

Based on the research results, THI was at the alert status (Table 3), indicating that Limpo and Simmental cattle were suspected to be experiencing moderate stress. Unfortunately, the findings did not show a significant correlation with increased HRF (Table 2). Nugraha *et al.* (2024) stated that differences in heart rate are due to physical activity and heat stress, where higher environmental temperatures increase heart rate frequency. Furthermore, a significant effect on the PTD may occur due to an increase in physiological responses, as reported by Nurhayati *et al.* (2022), who noted an increase in blood flow time in cattle experiencing stress.

Physiological Responses

The results of the study (Table 2) show no significant correlation (P>0.05) neither between THI and HRF, nor between HRF and RR. This indicates that an increase in THI does not affect HRF, and an increase in HRF is not directly related to RR. This occurence is likely due to effective physiological compensation mechanisms of both Simmental and Limpo, allowing them to maintain cardiovascular stability despite the environmental THI being at an alert level. To support these, both HRF and RR (Table 3) remained within the normal physiological range based on Indarjulianto *et al.* (2022), suggesting that both breeds were still able to maintain cardiovascular stability. However, this finding differs from Hermawansyah *et al.* (2024), who reported that an increase in heart rate is associated with an increase in RR as a mechanism for heat dissipation. Additionally, other studies have noted that increased heart rate can also be caused by high environmental temperatures, increased feed intake, and poor handling during transportation and unloading (Hermawansyah *et al.*, 2024; Suprayogi *et al.*, 2019). This finding is likely due to the livestock still being able to cope with heat stress effectively.

Furthermore, the research results (Table 2) show a significant correlation between RR and THI as well as RR and PTD (P<0.05). This indicates that higher THI increases RR and slows down the PTD. Unfortunately, to date, there have been no studies with findings similar to these findings. Nurhayati *et al.* (2022) reported that increased blood drainage time is caused by stress factors. Stress can occur due to increased physiological responses in livestock.

Respiratory rate can serve as an indicator of stress in livestock, which may potentially affect meat quality (Nurhayati *et al*., 2022). Stress increases respiratory rate, triggered by high environmental temperatures, and heart rate also increases as livestock respond to stress due to elevated cortisol levels as a stress response. This can cause meat colour to darken and reduce meat pH (Anwar, 2021).

Post-Slaughter Time To Death (PTD)

The results of the study (Table 2) show a significant relationship between the PTD and THI, HRF, and RR (P<0.05). This indicates that the higher the THI, the higher the RR and HRF. Furthermore, this will slow down the PTD of cattle. However, there are no similar findings reporting a relationship between the speed of death and THI, heart rate, and respiratory rate. The speed of death of cattle after slaughter can affect physiological responses. According to Nurhayati *et al.* (2022), death can be considered a unified and interconnected process, where the brainstem ceases to function, and respiration stops. The heart, however, will continue to function until electrical activity disruptions prevent rhythmic contractions of the heart chambers.

Furthermore, Wibowo *et al.* (2021) reported that stress in cattle affects the pH of the meat. This can occur due to the conversion of muscle glycogen into lactic acid during slaughter. Normally, the pH of beef ranges from 5.4 to 5.8. Furthermore, stress in slaughter cattle has the potential to reduce carcass quality, such as Dark Firm Dry (DFD) (Azzumar & Humaidah, 2024). Based on the result of the study, the average time of death for Simmental and Limpo cattle was 3.49 minutes, which is 11.30% longer than the normal range. According to Tsalitsah (2022), the range of time of death for cattle slaughtered by stunning is 2.13–3.14 minutes. The speed of animal death affects meat quality through post-slaughter biochemical changes. After death, respiration ceases, and anaerobic glycolysis produces lactic acid, lowering muscle pH below 5.5–5.8. This pH decrease triggers the rigor mortis phase, where the muscles become stiff and water-binding capacity decreases, affecting meat tenderness and colour (Hidayat *et al*., 2015). Thus, it can be inferred that the speed of death in cattle will affect meat quality.

CONCLUSION AND RECOMMENDATIONS

This study shows that the Temperature Humidity Index (THI) has a significant effect on increasing the RR and PTD of Limpo and Simmental cattle. These findings emphasize the importance of consistently applying animal welfare principles in slaughterhouses, such as regulating the temperature of the slaughterhouse environment and managing the slaughter process to minimise stress on livestock. If left unaddressed, physiological stress caused by the environment can prolong the time to death and potentially reduce carcass quality, such as a decrease in pH and the potential formation of DFD (Dark, Firm, Dry) meat.

CONTRIBUTIONS STATEMENTS

The authors contributed to the research and manuscript preparation as follows: AAY and RKS conceptualized the study. Data curation was performed by MRM and YMA. Formal analysis was conducted by NP and WS. The methodology was developed collaboratively by RKS, AAY, and MRM, with AAY also responsible for software implementation. Validation was undertaken by WS and NP, while AAY and MRM led the investigation. The original draft of the manuscript was prepared by RKS, MRM, and NP, with AAY responsible for review and editing. All authors have read and approved the final version of the manuscript.

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