Tropical Animal Health and Production (2024) 56:391
https://doi.org/10.1007/s11250-024-04242-1

REGULAR ARTICLES

Changes in rectal temperature as a means of assessing heat tolerance and sensitivity in chickens

Ricky A. Poku[1] · Ebenezer Agyemang-Duah[1] · Sheila Donkor[1] · Raphael A. Ayizanga[1] · Richard Osei-Amponsah[1] · Romdhane Rekaya[2] · Samuel E. Aggrey[3]

Received: 27 May 2024 / Accepted: 4 November 2024 / Published online: 23 November 2024

Abstract

High ambient temperature and relative humidity significantly affect growth and production performance in poultry. Ability of poultry to regulate their core body temperature relative to the ambient temperature depends on the relative nutrient/energy expenditure in maintenance and performance requirements. We hypothesized that changes in rectal temperature corrected for surface area can be used as a measure of heat tolerance/sensitivity. Rectal temperatures of one hundred mixed sex Ross 308 broiler chickens were measured hourly from 6 AM to 6 PM at 24 days of age. The ambient temperature and relative humidity were also measured hourly for the same 12-h period. Body weights were measured at day 24 and 38 days of age. The temperature-humidity index (THI) increased from 77.5 at 6.00 AM and peaked at 83.5 at 3.00 PM. The average rectal temperature increased from 39.90^{0}C at 6.00 AM to about 41.30^{0}C at 9.00 AM. Thereafter, the average rectal temperature remained constant until 3.00 PM when it began to decline. At 6.00 PM, the rectal temperature had declined to about 40.70 °C. Evaporative heat loss is affected by surface areas and as a result, rectal temperature was corrected for surface area. The change in rectal temperature corrected for surface area was negatively correlated with body weight gain indicating variability in the response of individual chickens exposed to similar THI. This variability was attributed to heat tolerance. It was hypothesized that mismatch between nutrient and energy supply and the partition of nutrient/energy between maintenance of core body temperature and protein synthesis could be reflected on the differences in heat-tolerance and body weight gain in the chicken population. The genetic basis of differences in rectal temperature changes corrected for surface area could be elucidated as a means of developing thermo-tolerant chickens.

Keywords Heat tolerance · Temperature-humidity index · Rectal temperature · Surface area · Growth

Introduction

According to the US National Oceanic and Atmospheric Administration (NOAA), the average global temperatures have increased by about 1^{0}C since 1880. Global temperature is expected to rise by 1.5^{0}C by 2050 and 2–4^{0}C by 2100 (Collins et al. 2013). The year 2023 was the warmest since global records began in 1850 (Lindsey and Dahlman 2020). Climate change significantly affect performance of poultry. Homeotherms (warm-blooded animals) maintain internal core temperature through metabolic and physiological regulations with a range of ambient temperatures often referred to as the thermoneutral zone. For most poultry species, the temperature range (thermoneutral zone) within which heat production and heat loss are equal ranges from 16^{0}C to 22^{0}C. Ambient temperatures outside the thermoneutral zone lead to either cold or heat stress (St. Pierre et al. 2003; Habashy et al. 2017a, b).

The stress response to ambient temperatures outside the thermoneutral zone is a predisposing factor of immunosuppression in broiler chickens (Burkholder et al. 2008; Wasti et al. 2020; Hirakawa et al. 2020). Heat stress (HS) reduces feed intake and growth and impairs feed efficiency.

✉ Richard Osei-Amponsah
ROsei-Amponsah@ug.edu.gh

✉ Samuel E. Aggrey
saggrey@uga.edu

[1] Department of Animal Science, University of Ghana, Legon, Ghana

[2] Department of Animal and Dairy Science, University of Georgia, Athens, GA 30602, Greece

[3] Department of Poultry Science, University of Georgia, Athens, GA 30602, Greece

Impaired feed efficiency with the concomitant reduction in growth causes significant economic losses to producers (St. Pierre et al. 2003; Habashy et al. 2017a, b). Heat stress also increases the stress hormone level of chickens (Wasti et al. 2020) compromising welfare and wellbeing. Additionally, heat stress causes protein oxidation and lipid peroxidation which affects meat quality (Cheng et al. 2018; Habashy et al. 2019).

Poultry is an integral part of livestock production system in Ghana not only as a source of animal protein but for income generation and employment. In developed countries, poultry is managed in housed temperature-controlled systems. These environmental control systems, though costly, are able to mitigate some of the negative impacts of climate change. However, such sophisticated and costly systems are rare or non-available in developing countries such as Ghana where poultry is directly or partly exposed to the ambient environment.

Chickens exhibit some behavioral changes in response to heat stress. They also increase their exposed surface area by spreading their wings and widening their blood vessels in order to increase heat loss through convection. Chickens have a core body temperature of about 40^0C (Ryder et al. 2004) and lack sweat glands (Hirakawa et al. 2020). Under HS chickens actively lose heat by panting. Heat loss resulting from evaporation of water from the respiratory tract and mouth is effective when the humidity is low to moderate (Ghareeb et al. 2022a). High humidity reduces poultry evaporative heat loss and renders the birds more susceptible to heat stress (Wasti et al. 2020; Onagbesan et al. 2023). Therefore, in production systems where chickens are directly or partially exposed to the ambient environment, thermal stress should be assessed by the temperature-humidity index (THI) and not the ambient temperature alone.

Several management and nutritional strategies have been examined to mitigate HS on broilers with limited and varying success (Akhavan-Salamat and Ghasemi 2016; Wasti et al. 2020; Ariyo et al. 2023; Kwakye et al. 2023). This may be due in part to the lack of comprehensive delineation and understanding of the major biological mechanisms that underlie the role of these strategies. Ultimately, producers have to consider heat tolerant breed types or chicken strains adapted to changing climatic conditions.

Diurnal change in rectal temperature has been used as a measure of heat tolerance in humans (Shvartz et al. 1977), cattle (Turner 1984) and chickens (Chen et al. 2013). Tolerance herein is defined as the ability of an animal to physiologically adjust to high THI exposure and sustain productivity. For a chicken to be heat tolerant, it must adjust its physiology to express minimal change in rectal temperature when exposed to high THI compared to their heat sensitive counterpart that is expected to express high change in rectal temperature.

Bergmann (1847) was the first to posit that there is a relationship between body size and temperature. According to Gillooly et al. (2001), metabolic rate depends on temperature related biological processes and is affected by the rate of biological processes scaled with body size. Therefore, change in rectal temperature will depend on both THI and surface area of the animal. We therefore hypothesize that change in rectal temperature corrected for surface area can be used as a measure of heat tolerance and/or heat sensitivity. The objective of the current study is to assess heat tolerance in broiler chickens exposed to similar THI and how the rectal temperate change corrected for surface area affect growth.

Materials and methods

Five hundred fast feathering Ross308 hatched chicks were reared in a commercial barn with corrugated metal roofing. The sides were constructed with cement blocks up to about 1.2 m from the floor and an inch-square wire mesh netting up to the roof (corrugated metal). The birds were managed according to husbandry protocol provided by Aviagen, Inc. (Aviagen 2020). The birds were raised on the floor with fresh wood shavings. One hundred mix-sexed birds were randomly selected at 24 days of age for the study herein. Birds were exposed to 20 h light (12 h natural day-light and 8 h artificial lighting using led bulbs).

Ambient temperature-humidity index (THI)

The ambient temperature and relative humidity were measured hourly from 06.00 AM to 06.00 PM using Thermo-Hygro Data Logger (−40—80°C; 0%—90%RH). The temperature-humidity index (THI) was calculated using the following formula (Mader et al. 2006).

$$THI = \left(0.8 \times T^0C\right) + [(RH/100) \times (T^0C - 14.4)] + 46.4$$

where T = temperature and RH = relative humidity.

Rectal temperature and body weight

Individual rectal temperatures (RT) were recorded hourly from 6.00 AM to 6.00 PM when the birds were 24 d old. Rectal temperatures were measured to 0.1^0C using digital thermometer (Eurogiant emergency digital thermometer, 2022 model) inserted about 3 cm into the cloaca. Chickens were handled gently by trained personnel to avoid inter-personnel variation. Individual body weights were measured when birds were 24 (BW24) and 38 (BW38) d of age. Body weight gain (BWG) was calculated as BW38-BW24. The maximum RT was reached at 3.00 PM, therefore the change in RT (ΔRT) between 6.00 AM and 3.00 PM was used as a measure of heat tolerance/sensitivity.

Change in rectal temperature corrected for surface area

Surface area (SA) was estimated using Mitchell (1930) formula, which is a modification of the original empirical formula of Meeh (1879).The formula provided by Mitchell (1930) was $SA = 10 * BW^{0.667}$. However refitting Mitchell's data of measured BW and SA yielded $SA = 8.2054 * BW^{0.7052}$ which was applied on the current data using BW24. Assuming a model without an intercept, $\boldsymbol{y} = \boldsymbol{X}\beta + \boldsymbol{e}$ where $\boldsymbol{y}$ is the vector of measured responses (change in rectal temperature), $\boldsymbol{X}$ is the vector body weights at day 24 (BW24) relating $\boldsymbol{y}$ to the regression coefficient β, and $\boldsymbol{e}$ is the vector of residuals. A least square estimator of the regression coefficient was obtained as $\hat{\beta} = (\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{y}$. Change in rectal temperature adjusted for SA (ΔRT_{SA}) was calculated as $\Delta RT_{SA} = \Delta RT - X\hat{\beta}$. The regression of ΔRT_{SA} on BWG was carried out using PROC REG (SAS, 2018). A regression coefficient was declared to be statistically significant at $P < 0.05$.

Results

The hourly ambient temperature and relative humidity are presented in Fig. 1. The average ambient temperature and relative humidity at 6.00 AM were 27^{0}C and 74%, respectively. The ambient temperature rose steadily to about 33.5^{0}C at 2.00 PM and declined to about 30^{0}C at 6.00 PM. At the same time the relative humidity declined to about 55% at 2.00 PM and increased to about 65% from 4.00 to 6.00PM. The THI index over the course of the day is shown in Fig. 2. The THI index at 6.00 AM was about 77.5, peaked at 83.5 at 3.00 PM, and decreased to about 81.5 at 6 PM.

The average hourly rectal temperatures are presented in Fig. 3. The average rectal temperature for the flock was 39.9 °C at 6.00 AM and gradually rose to about 41.30 °C at 9.00 AM. Hereafter, the rectal temperate stayed relatively constant until after 3.00 PM when it decreased to about 40.70^{0}C at 6.00 PM. The relationship between body weight gain and ΔRT_{SA} is quadratic (Fig. 4) indicating that the chickens with the least change in ΔRT_{SA} gained more weight compared to those with significant changes in ΔRT_{SA}.

Discussion

The current study demonstrates the relationship among THI, the relative response of rectal temperature to THI and growth in broiler chickens. The ambient temperature and

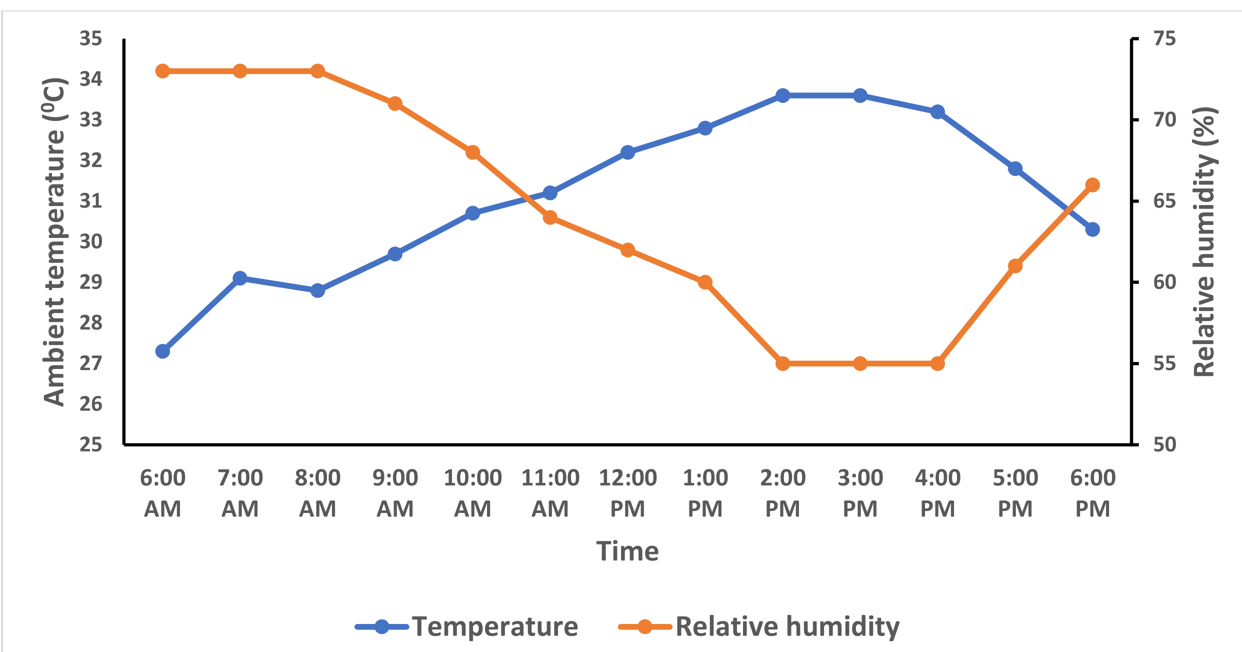

Fig. 1 Hourly ambient temperature and relative humidity

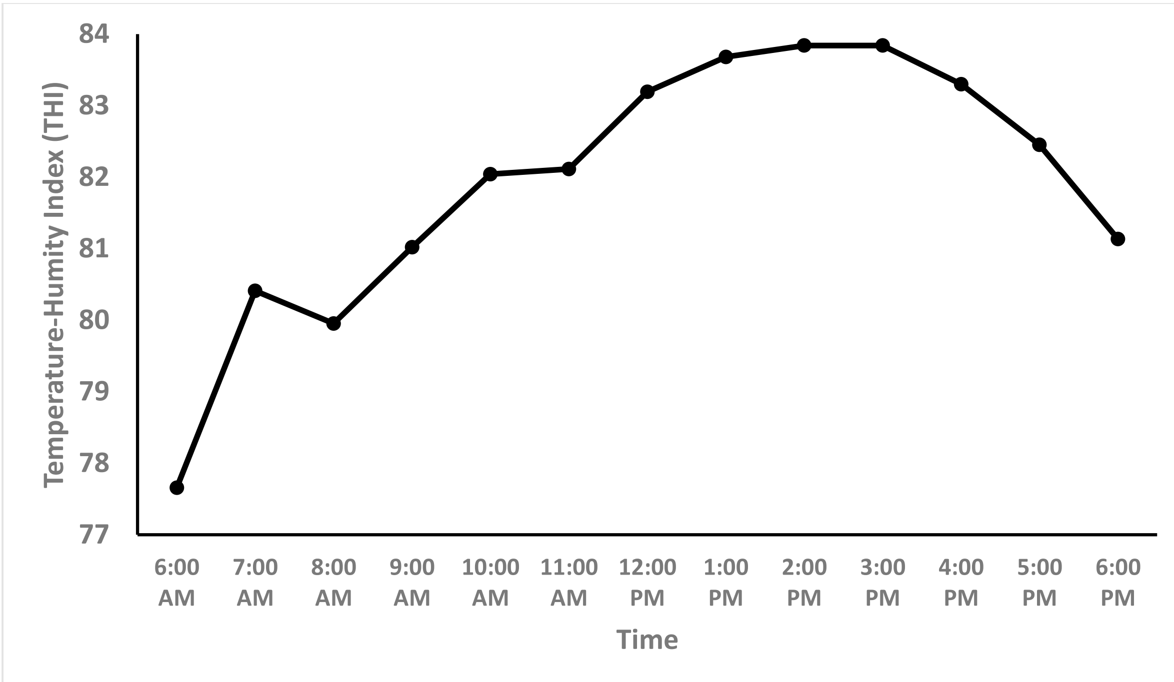

Fig. 2 Hourly temperature-humidity index

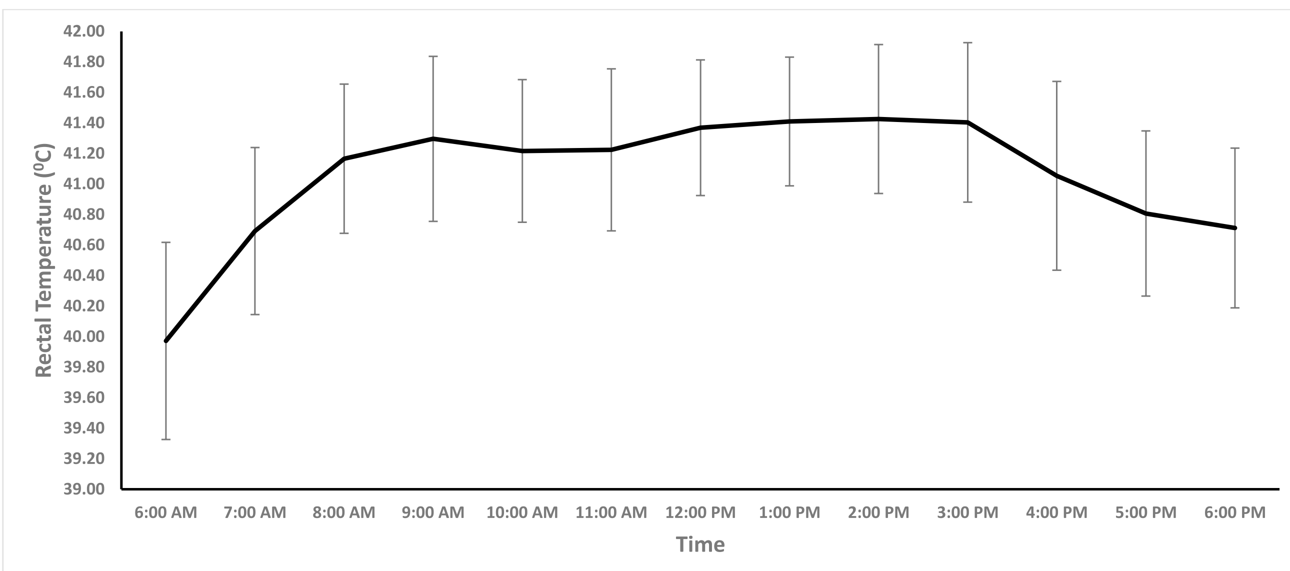

Fig. 3 Rectal temperature response to temperature-humidity index (THI)

relative humidity values showed that, the highest ambient temperature coincided with the lowest relative humidity at 2.00 PM, whereas the highest relative humidity coincided with the lowest ambient temperature at 6.00 PM. Ambient temperature of 27^{0}C for commercial broilers is high enough to cause heat stress. The high relative humidity in the morning hours may hinder evaporative heat loss (Purswell et al., 2013; Wasti et al. 2020). The lowest ambient temperature of 27^{0}C is outside the upper limit of thermoneutral zone, 21^{0}C for commercial broilers. Based on the ambient parameters, these birds are already under heat stress as early as 6.00 AM even though the weather may appear cool. The high humidity in the morning reduces poultry evaporative heat loss and renders the birds more susceptible to heat stress. Therefore,

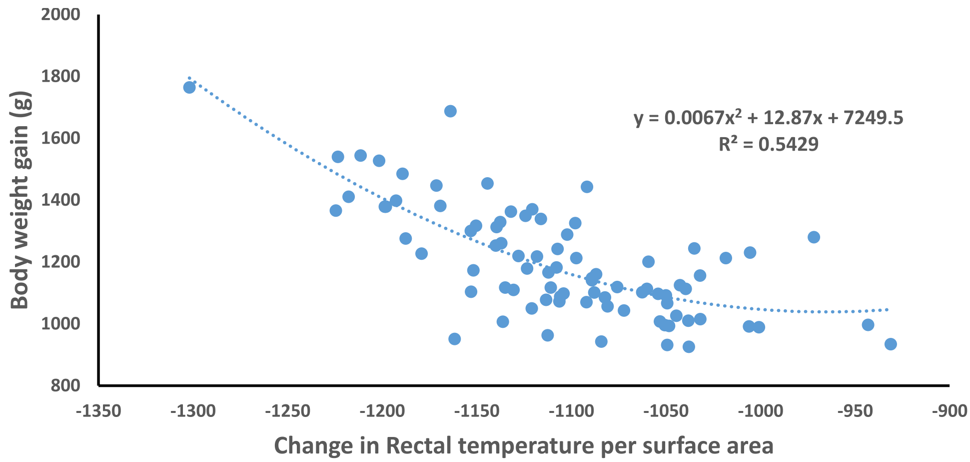

Fig. 4 Relationship between body weight gain and change in rectal temperature adjusted for surface area

in production systems where chickens are directly or partially expose to the ambient environment, thermal stress should be assessed by the temperature-humidity index (THI) and not the ambient temperature alone. Chickens experiencing a THI value of 77.5 at 6.00 AM may be under some form of heat stress (Yanagi et al. 2002; Shahzad et al. 2021). The continuous increase in THI values clearly demonstrate that these broiler chickens are under heat stress. This was evidenced by the changes in behavior of these chickens. The birds were mostly laying down with their wings widely opened and panting, all characteristics of heat stress. A study by Ryder et al. (2004) showed that high-pressure misting is effective in reducing heat stress under field conditions. Such strategy could be pursued to reduce some of the negative effects of heat stress.

The birds responded to the changes in THI by regulating their core temperature. In the current study, we used rectal temperature as the response to changes in THI. The average rectal temperature increased by 1.4^{0}C from 6.00 AM to 9.00 AM (38.90–41.3^{0}C) and stayed relatively constant until 3.00 PM when it decreased to about 40.7^{0}C at 6.00 PM. It should be pointed out that the point of decline in the rectal temperature coincided with the maximum THI. The broiler chickens used in the current study were able to maintain their rectal temperature at 41.30^{0}C despite increasing THI. About half of the daily energy expenditure is allocated to maintain a constant core body temperate (Vinales et al. 2019). Additional heat load from increased THI will require more than half of the daily energy expenditures in maintaining a constant core temperature. This invariably means energy needed for immune response (Burkholder et al. 2008; Wasti et al. 2020; Hirakawa et al. 2020), fitness, growth and other physiological functions will be compromised. It has been clearly demonstrated that heat stress reduces feed intake and growth and impair feed efficiency (Habashy et al 2017a, b, 2018, 2019; Ghareeb et al. 2022a, b). Purswell et al. (2012) presented data to show that body weight at 63 days decreased with increasing THI. The individual variability in maintenance of core body temperature and the concomitant changes in body weight may be a function of thermo-tolerance or thermo-sensitivity.

Heat storage is a function of metabolism, work, evaporation, radiation, conduction, and convection (Tansey and Johnson 2015). In the current study, all the chickens were under similar ambient temperature and humidity, and therefore, variability in heat storage may be largely due to chemical reactions occurring within the body to produce heat and evaporative heat loss. Evaporative heat loss depends on the surface area exposed, the THI and convective air currents around the body. Therefore, surface area is expected to reflect the degree of evaporative cooling and consequently the maintenance of core body temperature. Our current findings indicate a negative relationship between changes in rectal temperature corrected for surface area and growth. Additionally, thermoregulation is controlled by several molecular and cellular mechanisms (McAllen et al. 2010; Nakamura 2011). Thus, the molecular regulation of thermo-tolerance and thermo-sensitivity when elucidated could be used to breed thermo-tolerance chickens for heat-stressed endemic regions of the world where sophisticated environmental controlled poultry houses are not available.

Conclusion

The results of the current study show that broiler chickens raised in semi-open houses could be under heat stress at the early hours of the morning. Even though the THI peaked at around 3 PM in the afternoon, the average rectal temperatures stayed constant at 41.3^{0}C from 9.00 AM until 3.00 PM when it began to decrease. The change in rectal temperature corrected for surface area correlated negatively with growth indicating there is variation in the response to THI, which indicates differences in heat tolerance/sensitivity. There could be a relationship between heat tolerance and growth rate, however, this relationship could be non-linear. The difference among thermo-tolerance and thermo-sensitive chickens may partly be due to a mismatch between nutrient and energy supply and the partition of nutrient/energy between maintenance of core body temperature and protein synthesis.

Acknowledgements We would like to acknowledge our colleagues and contributors; Mr. and Mrs Anom of Bethnom Farms who have significantly contributed to this scientific research.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ricky A. Poku, Ebenezer Agyemang-Duah, and Sheila Donkor. The first draft of the manuscript was written by Ricky A. Poku, Ebenezer Agyemang-Duah, Sheila Donkor, Raphael Ayizanga, Romdhane Rekaya, Richard Osei-Amponsah and Samuel E. Aggrey, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data availability Dataset is not publicly available. Data for this study is available from the corresponding author upon request.

Declarations

Ethics approval Not required.

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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