Quantifying the influence of heat stress on the conception rate of Ghana Sanga cows

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Heat stress as measured by temperature humidity index (THI) negatively impacts cow productivity, but its effect on cows in Ghana has been underexplored. The goal of this study was to investigate the effect of THI during the day of insemination on conception rate of Sanga cows. Artificial insemination records on Sanga cows were obtained from the Amrahia Dairy Farm of Ghana. Daily temperature and relative humidity records were obtained from the Ghana Meteorological Agency weather station in Tema, Ghana. A fixed effect model was fitted with conception rate as the dependent variable and parity of cow, year of insemination and THI on the day of insemination as independent variables. The study revealed a significant ($P \leq 0.05$) effect of THI on conception rate of Sanga cows. The conception rate for cows inseminated on days when THI ranged from 79 to 82 was 82.7% while conception rates for cows inseminated on days when THI ranged from 83 to 85 and 86 to 88 were 76.4% and 54.7%, respectively. A unit increase in THI reduced conception rate significantly ($P \leq 0.05$) by 12% in Sanga cows inseminated when the THI ranged from 79 to 82 but not in THI classes 83 to 85 and 86 to 88, indicating that 79 is the THI threshold at which conception rate in Sanga cows begins to decrease. Heat stress on the day of insemination had an adverse effect on the conception rate of Sanga cows. Heat abatement strategies are needed for improved reproductive performance of Sanga cows.

Keywords: Conception rate, heat stress, insemination, Sanga cows, temperature humidity index

Livestock productivity in tropical environments is adversely affected by the heat stress that characterises such environments. Production losses due to heat stress are estimated to amount to billions of dollars per year, with losses in most tropical regions projected to be far greater than in temperate regions (Thornton et al. 2022). It is thus necessary to quantify the impact of heat stress on tropical livestock to understand its extent and suggest the needed interventional measures.

The Ghanaian Sanga cattle is a cross between a humped Zebu and humpless cattle such as West African Shorthorn or the N'dama (Okantah 1990; Aboagye 2002; Oppong-Anane 2013). It is distributed throughout Ghana and is the predominant breed on the Accra Plains of Ghana where it comprises 79% of the cattle population (Okantah 1990). The Sanga cow is dual-purpose raised for both meat and milk production.

Studies on the reproductive performance of Sanga cows suggest a less than optimum performance attributable to nutritional deficiencies (Sottie et al. 2009; Adjorlolo et al. 2019).However, given the tropical environment in which the Sanga cows are raised, heat stress may be another important factor impacting negatively on the reproductive performance of Sanga cows in Ghana. It has been established that most of West Africa, of which Ghana is a part, experiences moderate heat stress (Rahimi et al. 2020).

Aggrey (1985) demonstrated that cattle raised on the Accra Plains of Ghana experienced heat stress especially in the afternoons and Friesan cattle recorded significantly higher rectal temperatures compared with indigenous breeds. However, Djallonke sheep of Ghana have recently been shown to be under heat stress all day and this might partly be responsible for their lower

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productivity (Abdul-Rahman and AbdulRahim 2018; Abdul-Rahman 2022).

Cattle experience heat stress when a combination of high temperature and humidity overcome their capacity to disperse heat (Das et al. 2016). Under such circumstances, reproductive efficiency declines. The temperature humidity index (THI) combines the effect of environmental (air) temperature and relative humidity to measure the impact of heat stress. THI threshold at which cattle performance declines and the rate of decline of performance after the THI threshold is reached are common parameters used to assess the impact of heat stress on cattle. There is presently, a dearth of knowledge concerning how heat stress affects the reproductive performance of Ghana Sanga cows. Such information will raise awareness about the need to put in place heat abatement strategies for improved reproductive performance of Sanga cows.

The aim of this study was to investigate the effect of heat stress on conception rate of Ghana Sanga cows. The objectives were to determine (1) the relationship between THI and conception rate; (2) the THI threshold at which conception rate of Sanga cows declines and (3) the percentage decline in conception rate per unit change of THI above the THI threshold.

Materials and methods

Study area

Artificial insemination records for this study were obtained from the Amrahia Dairy farm of the Ministry of Food and Agriculture of Ghana. The farm is located at Lat 05º 46' N and Long 00º 08' W in the Accra Plains of Ghana (Figure 1). The area has a bimodal rainfall pattern with a major wet season occurring from April to July and a minor wet season occurring from September to November (Obese et al. 2013). The rest of the months constitute the dry seasons. Annual rainfall and temperatures range between 600 mm and 1000 mm and 20°C and 34°C, respectively (Obese et al. 2013).

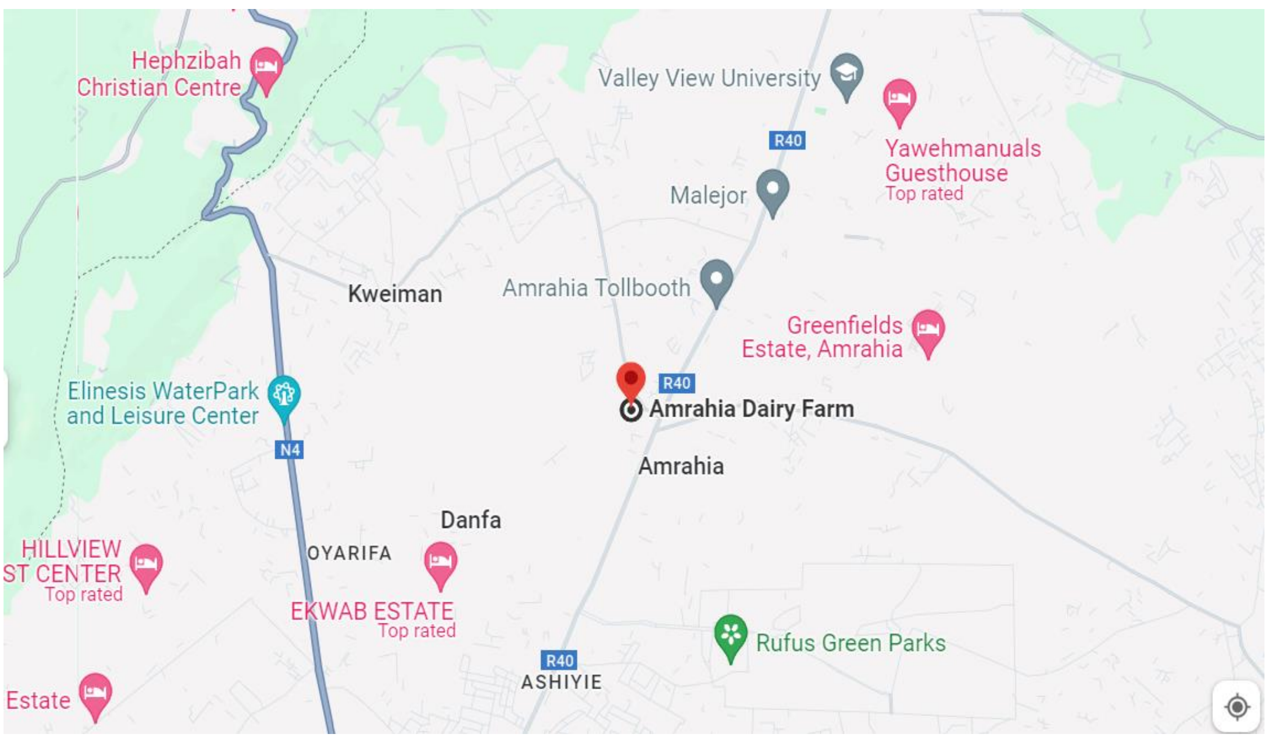

Figure 1: Map showing the location of the Amrahia Dairy Farm of Ghana.
(Source: Google maps)

Data collection and management of animals

Artificial insemination records on 121 Ghana Sanga cows, spanning a period of 7 years (2014-2020), were retrieved from record books of the Amrahia Dairy Farm and entered on an Excel spreadsheet. Management of Sanga cows has been previously described (Obese et al. 2008). Cows used in this study were located on the Amrahia Dairy Farm. Grazing period of Sanga cows was from 08.00 to 15.00h and occurred on natural pasture comprised of *Panicum maximum*, *Stylosanthes haemata* and *Sporobolus pyramidalis.* Animals were not given supplementary feed. Water was provided to the animals ad libitum in the animal house and animals also had twice daily access to water from a dam.

For artificial insemination purposes, oestrus was observed at 6:00 and 18:00 h daily. Cows observed to be on heat (using the "standing heat" method) in the morning were inseminated in the evening of that same day and those observed to be on heat in the evening were inseminated the following morning (Obese et al. 2008).

There were 95 nulliparous cows, and 50 primiparous cows involved in this study. A value of 1 was assigned to cows that conceived within 30 days of insemination and 0 for cows that failed to conceive within 30 days of insemination. Conception within cows was confirmed when cows did not return to heat after 30 days of artificial insemination. When available, milk yield records on cows about a year after artificial insemination were used as further supporting evidence that cows indeed conceived.

Weather records were obtained from the Ghana Meteorological Agency station situated about 23 km from the Amrahia Dairy Farm. Daily maximum and minimum temperatures (^{0}C) and daily minimum and maximum relative humidity (%) were retrieved from the weather records. Daily THI was calculated based on the National Research Council (1971) formula:

$$THI = (1.8 \times Tmax + 32) - [(0.55 - 0.0055 \times RHmin) \times (1.8 \times Tmax - 26.8)]$$

where Tmax is the maximum daily temperature (^{0}C) and RHmin is the minimum daily relative humidity. Maximum daily temperature and minimum daily relative humidity were the most critical values to quantify heat stress in a study involving several types of temperature and humidity values (Ravagnolo et al. 2000).

Statistical analysis

Monthly average conception rates were plotted against monthly average THI values to observe changes in conception rate in relation to THI values across months. THI was classified into three groups, THI1 = 79 - 82, THI2 = 83 - 85 and THI3 = 86 - 88. Cows are exposed to danger at THI values of 79 - 82 while they may be in an emergency at THI values of above 82 (Valtorta et al. 1996).

The R package pwr (R Core Team 2019) was used to calculate the sample size per group given three groups and assuming an effect size of 0.25, a power of 0.8 and a significance level of 0.05. The calculated sample size was 52 individuals per group. The number of cows inseminated when THI ranged from 79 - 82, 83 - 85 and 86 - 88 were 39, 70 and 61, respectively.

A fixed effect model was employed to determine the effect of THI on the day of artificial insemination on conception rate and to determine THI threshold at which conception rate began to decline. The model was as follows:

$$Y_{ijkl} = \mu + THI_i + P_j + Y_k + e_{ijkl}$$

where Y is the conception rate (0 and 1); μ is the overall mean; THI_i effect of the ith THI group; P_j effect of the jth parity of cow; Y_k effect of the kth year of insemination and e is random error. Parities 1 and 2 were combined because of few cows in parity 2. Data from 2019 and 2020 were combined because of few observations in 2020. The years were therefore defined as year 1 (2014), year 2 (2015), year 3 (2016), year 4 (2017), year 5 (2018) and year 6 (2019/2020).

The rate of change of conception rate per unit increase in THI was determined by splitting the data into three subclasses according to the THI group and estimating linear regression coefficients within each THI group in the fixed effect model stated above but treating THI as a continuous variable. The linear model function in R was used to fit the fixed effect model. Comparison of least square means within fixed effects for conception rate were carried out by the cld function of R. The Sidak post hoc test was done to identify differences among least square means.

Results

Description of data

Analysis of records (Table 1) from the weather station revealed that the average temperature was lowest (26.47) for THI1 and highest (29.79) for THI3. Relative humidity ranged from 82.78 to 85.90%. Average THI ranged from 80.90 (THI1) to 86.39 (THI3). Average conception rate per THI group is also indicated in Table 1. Conception rate ranged from 0.58 to 0.77. Conception rate was low at THI3 compared to THI1 and THI2.

Table 1: Mean and standard deviation (SD) of climatic data and conception rate (CR) during the period of this study for the three THI classes

		THI1 79 - 82	THI2 83 - 85	THI3 86 - 88
Temp ^{0}C				
	mean	26.47	28.42	29.79
	SD	0.77	0.76	0.52
RH %				
	mean	85.90	83.05	82.78
	SD	3.23	3.74	2.74
THI				
	mean	80.90	84.16	86.39
	SD	1.00	0.71	0.62
CR				
	mean	0.72	0.77	0.58
	SD	0.45	0.42	0.50

Variation in conception rate across months

To determine whether there was variation in conception rate of Sanga cows across months, the relationship between monthly THI and conception rate was examined (Figure 2). The lowest conception rates were obtained from March to June with conception rates ranging from 0.55 to 0.66 and THI ranging from 82.6 to 85.7. The highest conception rate (0.86) was in October where THI was 83. Thus, prevailing weather conditions in a month influences conception rate in Sanga cows and this was an initial indication that conception rate in Sanga cows might be affected by climatic parameters.

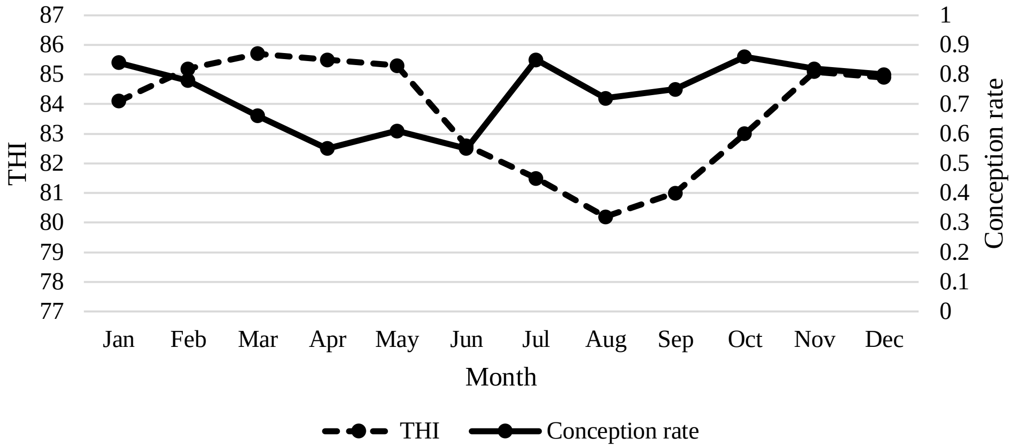

Figure 2: Variation of temperature humidity index (THI) and conception rate across months.

Response of conception rate to THI

To determine whether heat stress adversely affected conception rate of Sanga cows, the effect of THI on the day of insemination on conception was investigated through analysis of variance. THI group had a significant ($P = 0.047$) effect on conception rate and the year of insemination also significantly ($P = 0.002$) influenced conception rate (Table 2). Conception rate in THI1 (79 – 82) (least square mean of 0.827 ± 0.058) was similar ($P > 0.05$) to conception rate in THI2 (83 – 85) (least square mean of 0.764 ± 0.055) (Figure 3). However, conception rates in THI1 and THI2 were significantly ($P < 0.05$) different from conception rate at THI3 (86 - 88) (least square mean of 0.547 ± 0.071). It can therefore before concluded that conception rate in Sanga cows raised on the Accra Plains of Ghana decreased as THI on the day of insemination increased.

Table 2: Analysis of variance showing the effect of the temperature humidity index (THI) class on day of insemination, parity, and year of insemination (year) on conception rate of Sanga cows

	df	Type III SS	F value	P value
THI	2	1.171	3.1149	0.047*
Parity	1	0.616	3.2766	0.072
Year	5	3.811	4.0546	0.002*

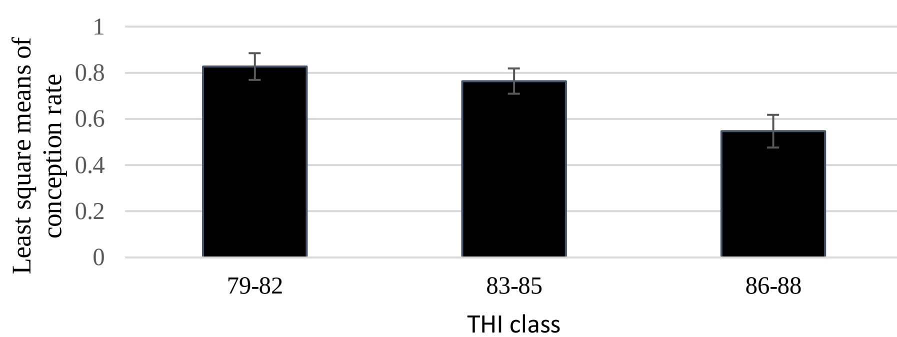

Figure 3: Change in conception rate with increasing THI.

Effect of year of artificial insemination on conception rate

The year within which artificial insemination was done had a significant ($P \leq 0.05$) effect on conception rate of Sanga cows (Table 3). The lowest conception rate occurred in year 2016 and was significantly ($P \leq 0.05$) different from conception rates for years 2015, 2017, 2018 and 2019 (Table 3). The highest conception rate, occurring in year 2015, was only significantly ($P \leq 0.05$) different from the conception rate of year 2016.

Table 3: Least square means (LSM) and standard error (S.E) of conception rate of Sanga cows across years of insemination

Year	Number of cows inseminated	LSM	S.E
2014	10	0.708ab	0.146
2015	21	0.850b	0.096
2016	36	0.404a	0.079
2017	70	0.730b	0.059
2018	35	0.835b	0.080
2019	37	0.749b	0.073

Least square means in a column with different letters differ significantly ($P \leq 0.05$)

Identification of THI threshold and rate of decline of conception rate

A way to quantify the effect of heat stress on reproductive performance of animals is to identify a THI threshold beyond which reproductive performance begins to decline. After THI the threshold is reached, it is expected that reproductive performance of animals would decrease for each unit change in daily THI. To determine the THI threshold and change in conception rate per unit change in THI, regression coefficients, obtained by regressing conception rate on THI, were calculated within THI groups (Table 4). Change in conception rate per unit increase in THI was negative (-0.12) and significant ($P = 0.045$) for THI1 (79 – 82), indicating that for every unit increase in THI, conception rate decreased by 12% after a THI threshold of 79 for Sanga cows inseminated when THI was within the 79 to 82 range. The change in conception rate was negative (-0.07) and not significant ($p = 0.265$) for THI2 (83 – 85) and was positive (0.08) and not significant ($P = 0.545$) for THI3 (86 - 88). There were therefore no THI thresholds for Sanga cows inseminated on days when THI was within 83 to 85 and 86 to 88.

Table 4: Change in conception rate (α) within THI class as a result of heat stress on day of insemination in Sanga cows

	THI1 79 - 82	THI2 83 - 85	THI3 86 - 88
α	-0.12	-0.07	0.08
Standard Error	0.06	0.06	0.13
P-value	0.045	0.265	0.545

Discussion

This study aimed to quantify the effect of heat stress, measured as temperature humidity index (THI) during the day of artificial insemination, on conception rate of Ghana Sanga cows. As the response to heat stress differs among breeds of the same species (Kumar et al. 2018; Srivastava et al. 2021), it is essential to establish temperature humidity thresholds and subsequent rate of decline in reproductive traits specific to Ghana Sanga cows. This study focused on the effect of heat stress on conception rate within 30 days of artificial insemination of Ghana Sanga cows. Conception rate is an important reproductive trait as a reduction in average conception rate increases service life and calving interval resulting in economic losses at the farm level (Jasinski et al. 2023).

The THI range of 79 to 88 recorded for this study indicated that the Sanga cows experienced moderate heat stress based on THI classifications in dairy cattle as no stress (THI < 72), mild stress (THI = 72 - 78), moderate stress (THI = 79 - 88), severe stress (THI 89 - 98) and for THI exceeding 98, animals may die (Armstrong 1994). Studies investigating the effect of heat stress on Djallonke lambs and sheep in Ghana showed that THI values were high as compared to a benchmark for severe to extreme heat (Abdul-Rahman and AbdulRahim 2018). Thus, the prevailing weather conditions in Ghana place animals under heat stress. Indeed, Ghana has been experiencing significant increases in temperature (Antwi-Agyei and Stringer 2021), and the temperature in Ghana is expected to increase on average by 3.9^{0}C by 2080 (Republic of Ghana 2015).

In this study, analysis of month-by-month variation in conception rate and THI revealed that conception rate was lowest from March to June, where the THI ranged from 82.6 (June) to 85.7 (March), providing another layer of evidence that heat stress may have an influence on reproductive performance of Sanga cows and corroborating earlier studies (Kim and Jeong 2019; Bengthay et al. 2020; Temesgen et al. 2022) that warm months are associated with poor reproductive performance in cows.

The lowest conception rate for Ghana Sanga cows obtained for artificial inseminations that occurred in days when THI was between 86 to 88 as compared to conception rates for days when THI was between 79 to 82 and 83 to 85, provided some evidence that heat stress adversely affected conception rate of Ghana Sanga cows. The observation that increasing THI adversely influenced conception rate in the Ghana Sanga cows involved in this study aligns with the results of other authors (Morton et al. 2007; García-Ispierto et al. 2007; Djelailia et al. 2020; Rolando et al. 2022) who reported that THI increment significantly affected conception rate in other breeds of cow.

THI thresholds and subsequent decline in both production and reproductive traits have been used extensively as indicators of the impact of heat stress on cows (Ekine-Dzivenu et al. 2020; Ratchamak et al. 2021; Niyonzima et al. 2022; Nishisozu et al. 2023). In this study, the THI threshold of 79, for Sanga cows inseminated when THI ranged from 79 - 82, and a significant decline ($P \leq 0.05$) in conception rate for every unit increase in THI after the THI threshold in Sanga cows indicated that Sanga cows became sensitive to heat stress starting at THI of 79. It is worth emphasising that this THI threshold should be considered only for conception rate in Sanga cows, under the conditions of this study, and not any other reproductive and productive traits. In other words, Sanga cows may show a decline in other traits at different THI thresholds. The absence of both a THI threshold, and an accompanying significant decline in conception rate for Sanga cows inseminated on days when THI ranged from 83 to 85 and 86 to 88 could be due to the animals getting acclimatised to the heat stress (Ekine-Dzivenu et al. 2020). The THI threshold of 79 obtained in this present study for Ghana Sanga cows conception rate is the same THI threshold beyond which milk, fat and protein content decrease in some cattle breeds (Kekana et al. 2018; Ma et al. 2019).

The decline in conception rate after a THI threshold of 79 in this study corroborates previous studies that reported decline in reproductive performance of cows after THI threshold is reached (Djelailia et al. 2020; Rolando et al. 2022). Differences in the actual percentage change (12% decline in conception rate after THI threshold of 79) in the present study compared to previous studies (Djelailia et al. 2020; Nishisozu et al. 2023) could be partly due to differences in how different breeds respond to heat stress and the extent of heat stress.

In this study, the decline in conception rate on the day of artificial insemination as THI increased could be due to several physiological factors. Impairment of sperm transport to the oviduct because of heat stress on the day of breeding (Morton et al. 2007), induction of heat shock during fertilisation (Orgal et al. 2011) and disrupting of the antipolyspermy system in oocytes as a result of heat stress (Sakatani et al. 2015) are among the reasons heat stress reduces conception rate on the day of artificial insemination. Significant differences among years of artificial insemination for conception rate may be due to differences in feed availability, weather conditions, prevailing health conditions and management of the cows across years. An outbreak of foot and mouth disease and contagious bovine pleuropneumonia in the year 2016 led to reduced productive and reproductive performance of cows on the Amrahia Dairy Farm (S.T. Dzanku and S. Quansah, personal communication, June 14, 2024), and this explains the low conception rate in Sanga cows in the year 2016.

This study has revealed that heat stress, especially on the day of artificial insemination adversely influences conception rate in Ghana Sanga cows. Both short and long-term measures can be implemented to reduce the impact of heat stress on performance of Ghana Sanga cows. In the short term, provision of adequate shade and cool, clean drinking water for the cows is a necessity. Nutritional interventions such as increasing the dietary concentration of specific vitamins, minerals and antioxidants have been shown to improve cow performance under conditions of heat stress (Negrón-Pérez et al. 2019) and such interventions could be implemented for the Sanga cows prior to, during and after insemination. In the long term, genetic selection for Sanga cows with high tolerance of heat stress can be undertaken as within breed genetic variation of heat tolerance in cows is appreciable (Nguyen et al. 2016; Ravagnolo et al. 2000).The combination of physical changes to the environment, nutritional interventions and genetic manipulation will lead to improved reproductive performance of Sanga cows in Ghana.

Conclusion

Heat stress on the day of insemination had adverse effects on conception rate of Sanga cows raised on the Accra Plains of Ghana with a decline in conception rate starting at THI of 79. Knowledge of the THI at the time of breeding is thus crucial in enhancing conception rate in Sanga cows. Heat abatement strategies especially around the time of breeding are required to improve the reproductive performance of Ghana Sanga cows.

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