

An Agro-Environmental Approach In Semi-Arid Regions: Development Of A Solar-Powered Embedded System To Mitigate Heat Stress In Dairy Cattle

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Abstract

The climatic environment, particularly heat stress, affects animal welfare and milk production in cows. In semi-arid regions such as the Ghriss Plain (Wilaya of Mascara, Algeria), the frequent rise in the temperature-humidity index (THI) above a critical threshold of 72 in summer causes a significant drop in milk production. This article highlights the design and development of an embedded system. This device allows for real-time monitoring of the position and critical physiological parameters of dairy cows under severe heat stress. The main goal is to rigorously examine the impact of environmental parameters such as temperature and relative humidity, as well as husbandry practices, on dairy performance and animal welfare. Tests conducted on 41 cattle show that the HBT system works well. Based on individual cow data, it takes very precise measurements of body temperature ($37.82^{\circ}\text{C} \pm 0.28$), heart rate ($52.91 \text{ bpm} \pm 3.66$) and instant geolocation accessible via the mobile application "La vache connectée". Solar-powered HBT is an important technological support for dairy farming in environmental engineering. This technology helps anticipate the effects of heat stress, which can impact animal welfare, production, and the resilience of the livestock system in extreme climates.

Keywords: Heat stress, Heliobiotrack (HBT), Precision breeding, Physiological monitoring, Temperature-humidity (THI), Breeding in semi-arid zones, Internet of things (IoT), Environmental engineering.

INTRODUCTION

The integration of digital tools, IoT and AI, in dairy cattle farming has increased work efficiency and farm profitability. These tools are accompanied by automation and herd management or information exploitation. These tools play a key role in increasing productivity, milk quality, traceability and animal welfare (Bonora et al., 2018; Elsayed et al., 2024; Oliveira et al., 2024).

Among these innovations, the combined use of physiological sensors (body temperature, heart rate) and mobile devices promotes early detection of heat stress and physiological imbalances (Karl & Raboisson, 2021; Hanzen et al., 2024). This technical contribution to livestock systems contributes to the responsiveness of interventions, the resilience of livestock farms to climatic hazards, as well as an improvement in milk production. The latter could reach an increase of 10 to 20% (Sissao et al., 2017; Neya et al., 2023; Bouchon et al., 2025).

In this dynamic, we have developed Heliobiotrack (HBT), a sustainable technology that is part of the "connected cow" movement. Powered by solar energy, this solution provides real-time monitoring of the health and behavior of dairy cows. This platform was developed through a co-design approach that aims to strengthen the resilience of livestock systems, on the one hand, and improve zootechnical performance and animal welfare, on the other.

MATERIALS AND METHODS

The objective is to contribute to the evaluation of the influence of certain factors, in particular ambient conditions (temperature and relative humidity) as well as dairy cow herd management practices, on lactation performance in a semi-arid area, in this case the Ghriss plain (Wilaya of Mascara, Algeria), subject to marked thermal stress.

In this context, stables located in the semi-arid plain of Ghriss were the subject of a study aimed at analyzing the

effects of heat stress on the zootechnical performance of dairy cows.

The prognostic value of the temperature-humidity index (THI), which is the main indicator of heat stress, was calculated according to the formula of Johnson et al. (1962).

$$\text{THI} = 1.8 \times T_a - (1 - \text{HR}) \times (T_a - 14.3) + 32$$

With: T_a is the ambient temperature (°C) and RH is the relative humidity (%).

Physiological measurements were performed between mechanical performances each day at 4:30 PM. Rectal temperature (RT) was taken with a veterinary digital thermometer inserted approximately 6 cm for 60 seconds. HR (heart rate) was measured by medical stethoscope for one minute, and RR (respiratory rate) was assessed by counting flank movements over one minute.

Statistical analyses were performed using Excel (version 2017) using a mixed model with repeated measures, to assess the effect of collection month on milk production.

The correlation matrix used is given by the following classical Pearson equation.

Pearson correlation coefficient formula.

The calculation of the Pearson correlation coefficient (r) is done in this way.

$$r = \text{Cov}(X, Y) / (\sigma X * \sigma Y)$$

Or: $\text{Cov}(X, Y)$ is the covariance of variables X and Y .

σX is the standard deviation of the variable X .

σY is the standard deviation of the variable Y .

The HBT, a system composed of sensors to measure an animal's body temperature, heart rate and geolocation, was tested on 41 Belgian cows at different physiological stages; communicated on the mobile application "The Connected Cow".

RESULTS AND DISCUSSION

Heat stress has a direct negative impact on the health, welfare, and production of dairy cattle. It also results in economic losses for farms. It is therefore very important to recognize the associated symptoms early on. In semi-arid regions, heat stress manifests itself as increased breathing, decreased appetite and activity, and a marked reduction in milk production.

Seasonal variation in heat stress.

Climatological studies indicate that heat stress in dairy cows in the Ghriss area materialized from May to August, with temperature-humidity index (THI) values above 72, a threshold considered critical by Johnson (1985). Conversely, from mid-September to December, this indicates that THI values are below this threshold. Therefore, there is no heat stress. (Figure 1) according to Armstrong (1994) and Ouarfli, L., & Chehma, A. (2018), Moderate to high heat stress (average THI: April 72.55; May 77.32; June 81.74) is observed from spring. Severe stress levels are reached during summer, particularly in July (81.74), August (85.49) and mid-September (82.02). However, in the other months, from November to March, there is no heat stress. THI values thus vary between 61.37 and 69.56,

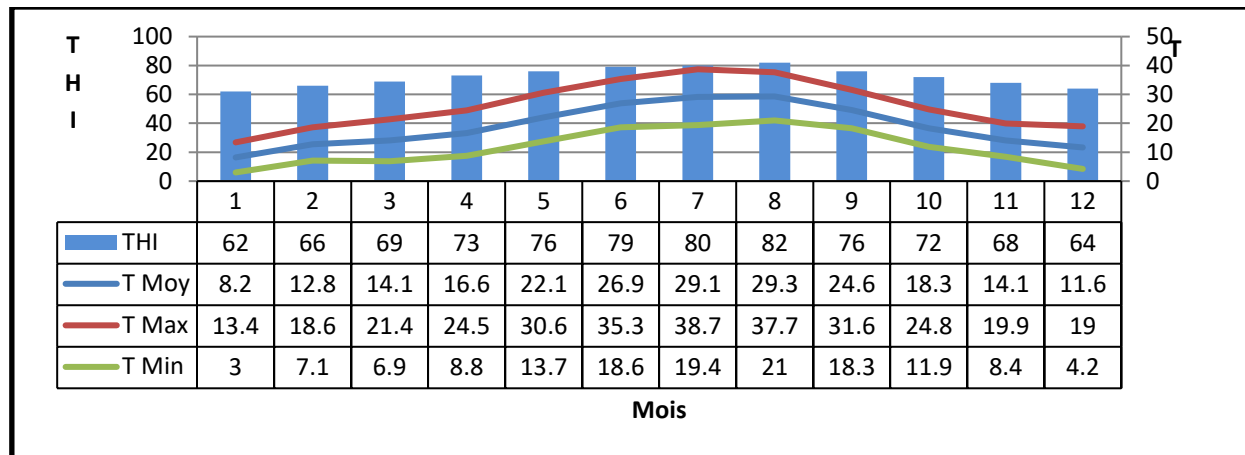


Figure1: Evolution of climatic parameters in the Ghriss plain

Effects of heat stress on milk production.

The temperatures measured in this part of the country indicate a high seasonal variability. In addition, there was moderate to high heat stress which affected the production and reproduction of dairy cows. In accordance with the comments of Bensalem and Bouraoui (2009) and Waubant, J. (2022), these fluctuations are similar to the seasonal variations observed throughout the world. The upper critical temperature for dairy cows is, according to Bonmanova et al. (2007), 25-26 °C, and the critical comfort threshold for THI is 72. In summer, the condition remains generally acceptable, but during spring, the critical threshold is exceeded only on a minority of days (10%). In summer, conditions deteriorate significantly, with temperature peaks increasing to 37 °C and a high average THI of 79.5 which will show strong heat stress (Zoghalmi et al., 2022). These results are also in agreement with the study carried out by Hanzen et al., (2024), Goran et al. (2019) in the Mediterranean region. Johnson (1985) as well as Preez et al. (1990) reported that with a THI greater than 72, there is a clear decrease in milk production, particularly marked by a THI greater than or equal to 76. Furthermore, Molee et al. (2011) noted that a THI greater than 80 has a severe impact on milk production. Vallée et al., (2024) and Bouraoui et al. (2002) observed that an increasing THI results in a decrease in milk production. Thus, if the THI increases from 68 to 78, then milk yield decreases by 21% and dry matter consumption by 9.6%. In addition, a THI greater than 69 results in a milk yield lower by 0.41 kg per unit of THI (Figure 2).

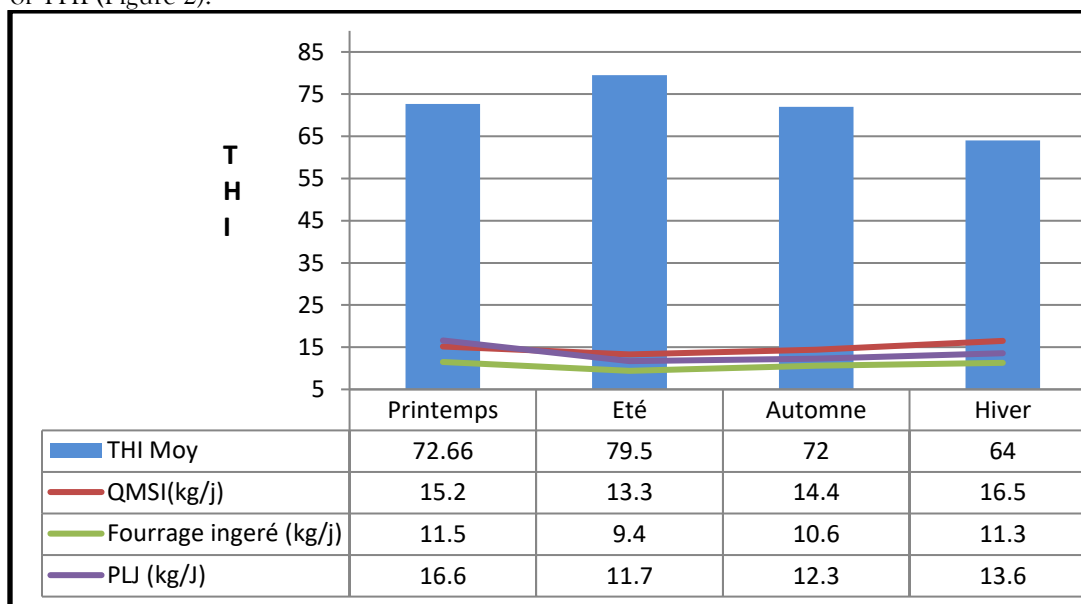


Figure2: Evolution of the monitored parameters according to the season

Physiological parameters and response to heat stress.

Data from the Ghriss region show that milk tonnage per cow exhibits seasonal characteristics. During the summer months, production is much lower than during the rest of the year. Summer yield is 11.7 kg/day, while the spring yield is 16.6 kg/day. According to Rodriguez-Venegas et al. (2023), the average decline was approximately 25.8% (which is a higher decrease). An increase of one (1) unit of THI was detected by this research, representing an evaluation of a total of 7.28 units compared to spring and summer. This average increase was linked to a decline in milk productivity of an increase of 0.64 kg per unit of THI. The studies Morales-Piñeyrúa et al. (2022) and Attia et al. (2022) corroborated these results. This THI then appears as a critical threshold beyond which milk quality begins to deteriorate and the overall efficiency of brass processing plants is reduced. The decline in milk quality results from body temperature and ITI evaluations. Measured rectal temperatures, which vary seasonally between 38.1 and 38.9 °C, are highly correlated with THI. Johnson and colleagues (1963) reported that a slight elevation (38.5-39.5 °C) in rectal temperature was associated with a decrease in feed intake and milk production in dairy cows. It should be noted that West (1999) previously observed a drop in production above 38.9 °C, which is therefore related to high ambient temperatures as shown in Figure 3 and Figure 4.

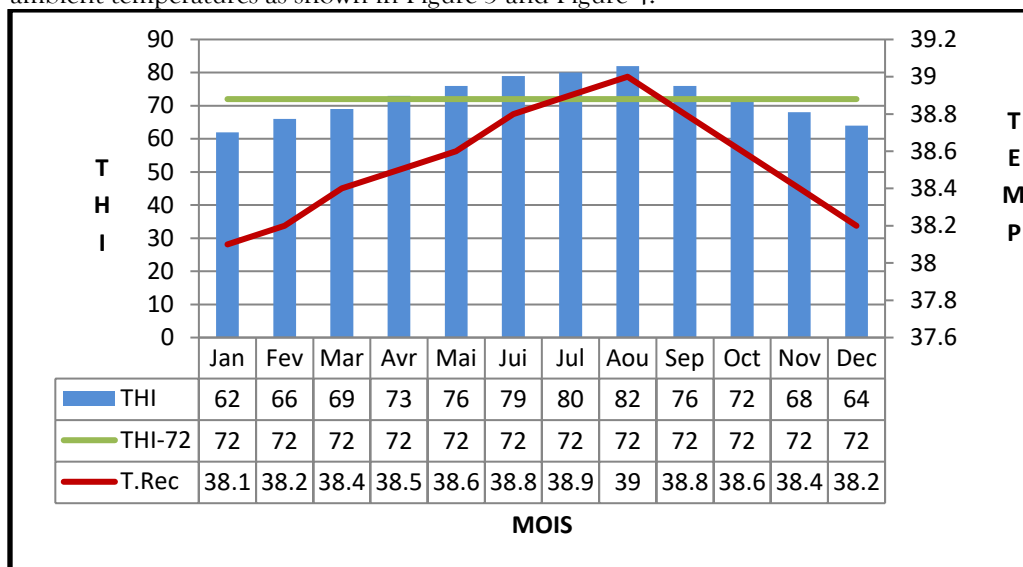


Figure3: Monthly variation of rectal temperature of cows as a function of THI

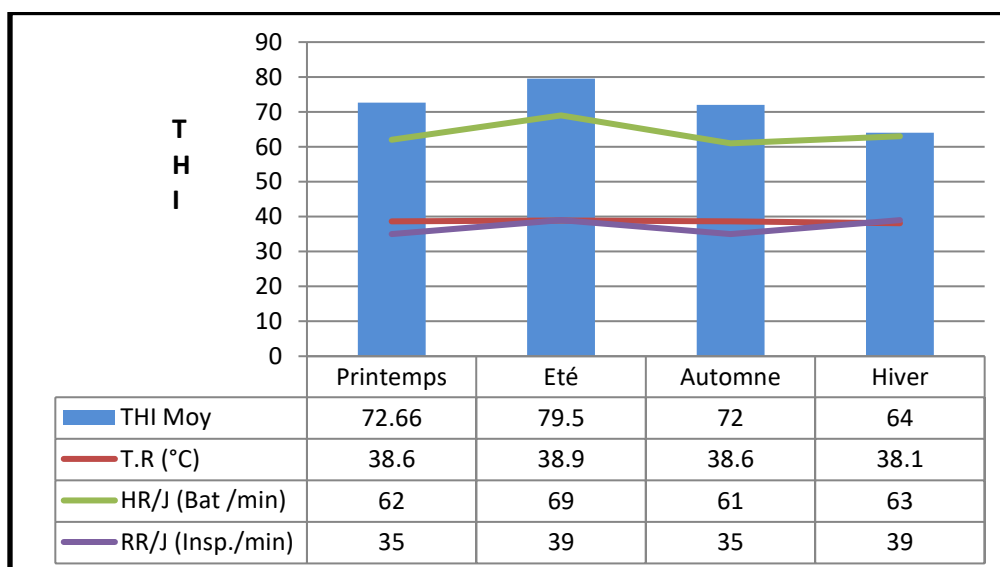


Figure4: Relationship between THI and some physiological parameters.

Presentation of Heliobiotrack (HBT).

Heliobiotrack, or HBT, is a new technology that helps monitor dairy cattle more efficiently on a daily basis. With a compact, self-contained, solar-powered station, farmers can track the health and well-being of their farm animals in real time, reducing operating costs and environmental impact.

This device is connected to the Android app: "The Connected Cow." It will collect data taking into account each cow's temperature, pulse, and GPS in real time. The primary objective is to assist in the rapid identification of an indicator of distress or irregularity in order to manage the herd in a more calm, efficient manner, and adapted to the animals' intrinsic needs.

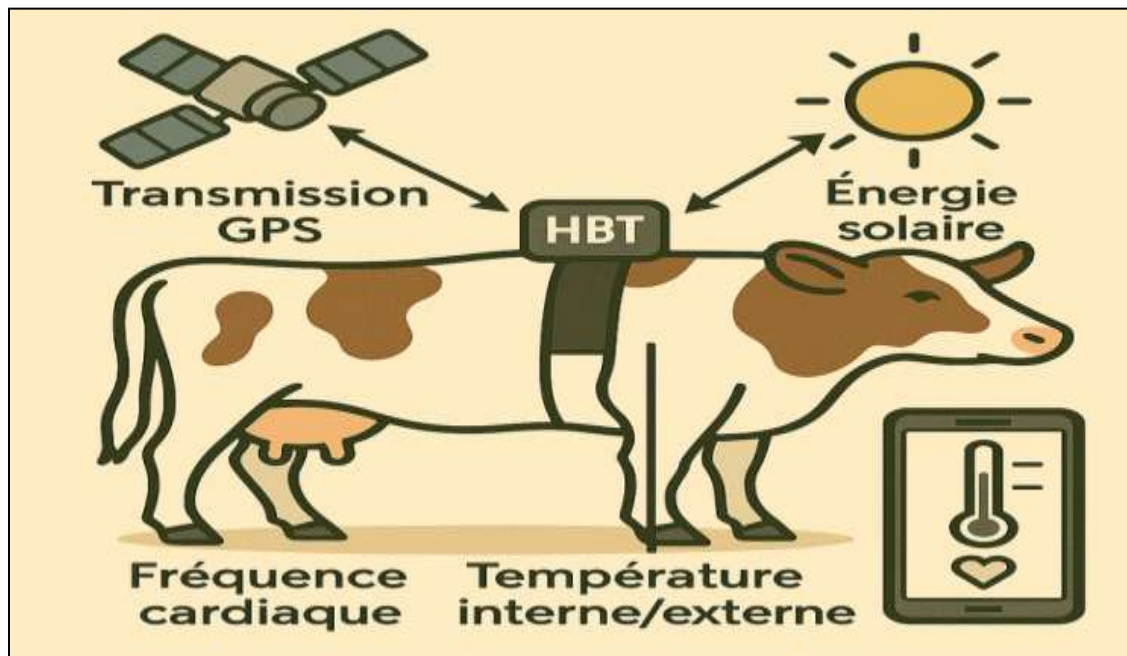
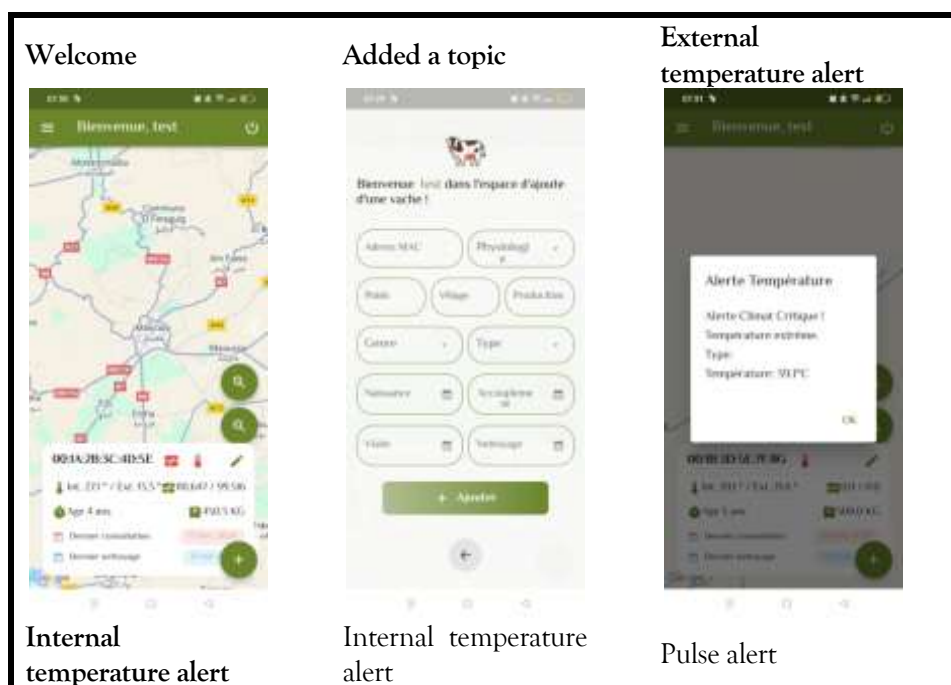


Figure5:illustration of HBT operation



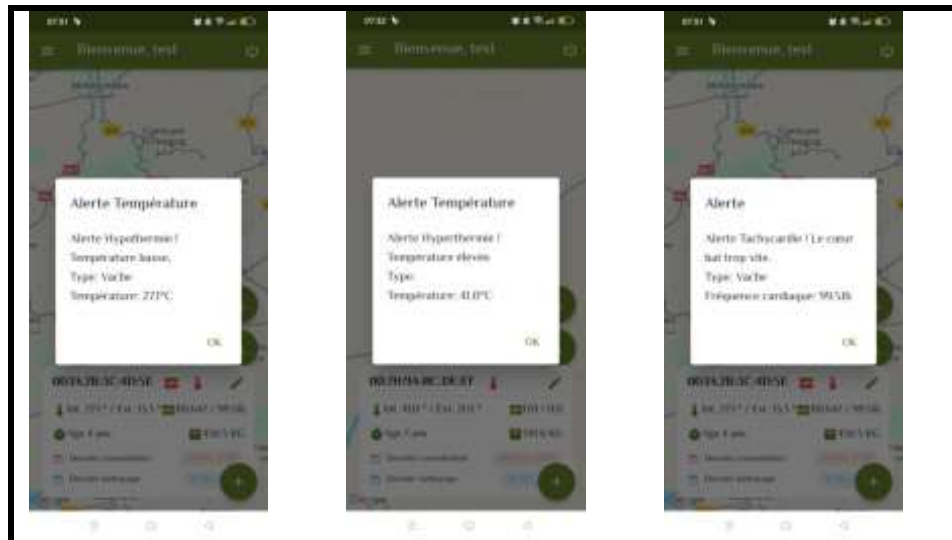


Figure6: Overview of the “connected cow” application

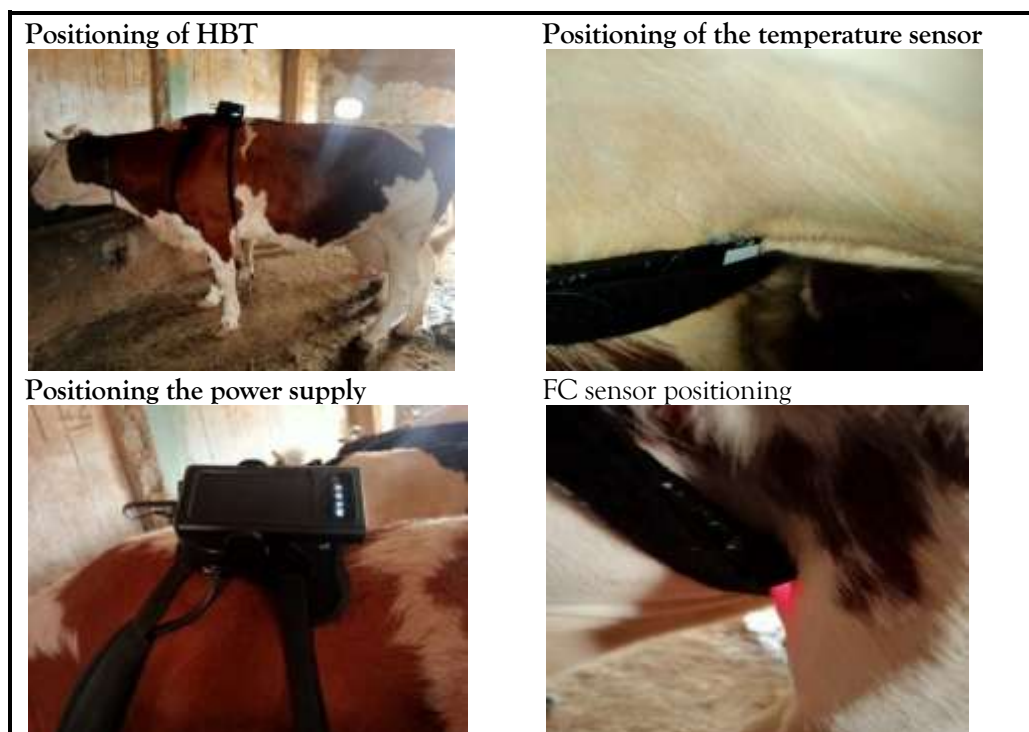


Figure7: the implementation of HBT on a cow

Hbt Test Results

Tests conducted with the HBT device on forty-one cattle, divided according to their stage of gestation, reveal essential physiological information. The first twenty-six subjects include lactating cows and cows in early to mid-gestation (months 1 to 7), while the last fifteen cows are in advanced gestation (months 7 to 9).

Heart rate exhibits fluctuations that are generally correlated with changes in ambient temperature. According to Maillard et al. (2005), a state of nervousness in animals can manifest itself as transient tachycardia, which explains certain irregularities observed on heart rate curves. To ensure reliable measurements on the HBT, it must be positioned correctly, at the level of the thorax just behind the left forelimb (the heart projection area). Improper positioning can result in the recording of erroneous pulses. The mean of the recorded pulse rate was 52.10 ± 0.28 beats per minute (bpm), a remarkably low standard deviation. These results are in agreement with those reported by

Indarjulianto et al. (2022), who indicated that the normal heart rate in cattle is generally between 40 and 80 bpm. This reference range is also confirmed by several physiological studies conducted on healthy cattle such as the studies of Kim et al., (2023), Santos et al., (2021).

Heart rate monitoring.

Continuous pulse monitoring is a good indicator of cattle welfare and metabolic status. A physiological response, likely secondary to stress or cardiovascular disorders, can result in major heart attacks such as tachycardia or bradycardia. These fluctuations indirectly but significantly modify milk production, according to Bernabucci et al. (2014), Rhoads et al. (2009), and Olsson et al. (2001) (Figure 8). The detailed analysis highlights fluctuations in heart rate in response to changes in external temperature. The state of nervousness or thermal stress, as described by Maillard, appears to be linked to these thermal changes. A relative association is observed between external temperature and average heart rate, with a moderate to strong correlation ($r \approx 0.50$). However, a more marked correlation ($r \approx 0.73$) is observed between average body temperature and average heart rate, indicating a more direct physiological relationship between these two parameters.

Body temperature monitoring.

The mean body temperature is 37.82 °C, with a low standard deviation of ± 2.21 °C. This is consistent with the normal value by Indarjulianto et al. (2022) between 37.7 °C and 39.4 °C. The combined sensor used for skin readings can give greater accuracy than conventional probes. But Hillman (2009) mentions that skin readings are always lower than internal readings (rectal or vaginal). (Figure 8, Figure 9).

The researchers found a strong correlation ($r \approx 0.55$) between body temperature and the atmosphere of cattle. These results demonstrate the physiological response of cattle to heat stress. This is consistent with Wang (2022) and Irmawanti et al. (2022).

According to the study Cicogna et al., (2022), heart rate variability can be influenced by factors such as age, gestation, or physical condition. The results obtained in our test (Figure 9) are consistent with these observations, showing heart rate fluctuations closely related to the age of the cows.

The analysis reveals several notable correlations:

- ✓ There is a relationship between a subject's ambient temperature and their pulse rate.
- ✓ A stronger relationship between body temperature and heart rate ($r \approx 0.73$).
- ✓ Age and other measured variables show a weak negative correlation (r ranging between -0.09 and -0.20), indicating that older animals generally show a reduction in other measured physiological parameters (Figure 9).

These results confirm previous observations by Bun et al (2017), Kim et al (2023), Santos et al (2021), who showed that heat stress simultaneously increased heart rate and body temperature (Figure 10, Figure 11).

The results collected with the HBT instrument provide reliable information on the physiological response of dairy cows to temperature fluctuations. This information is essential for managing and preventing heat stress, which contributes to animal health and productivity.

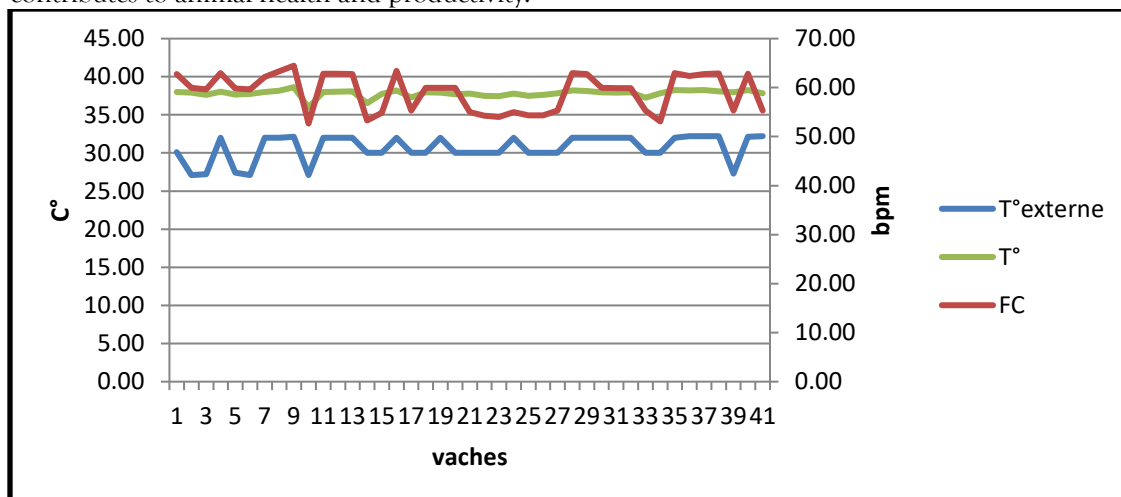


Figure8:graphical representation of the test showing heart rate, temperature and external temperature

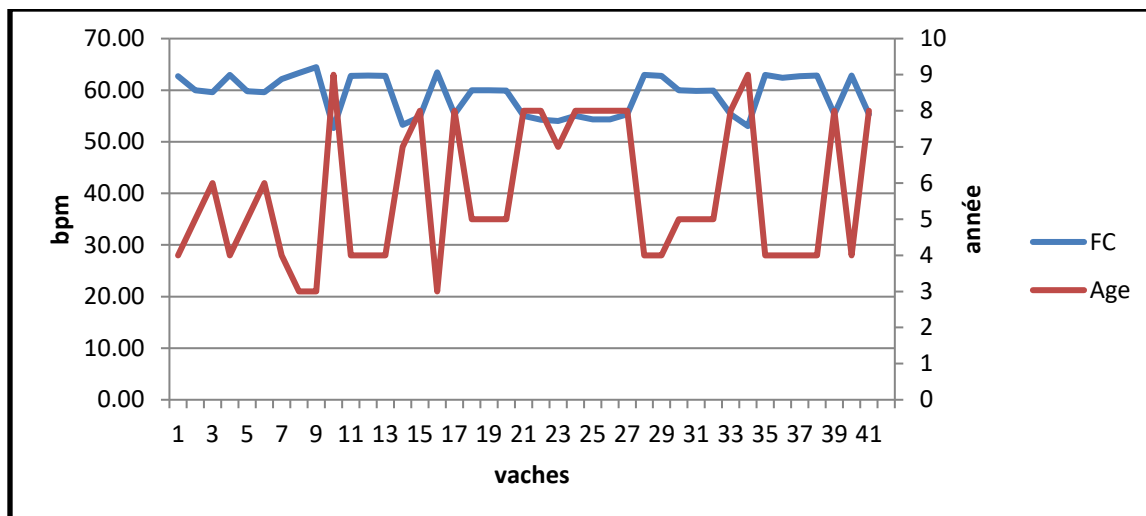


Figure9:graphical representation of pulse recordings with cow age

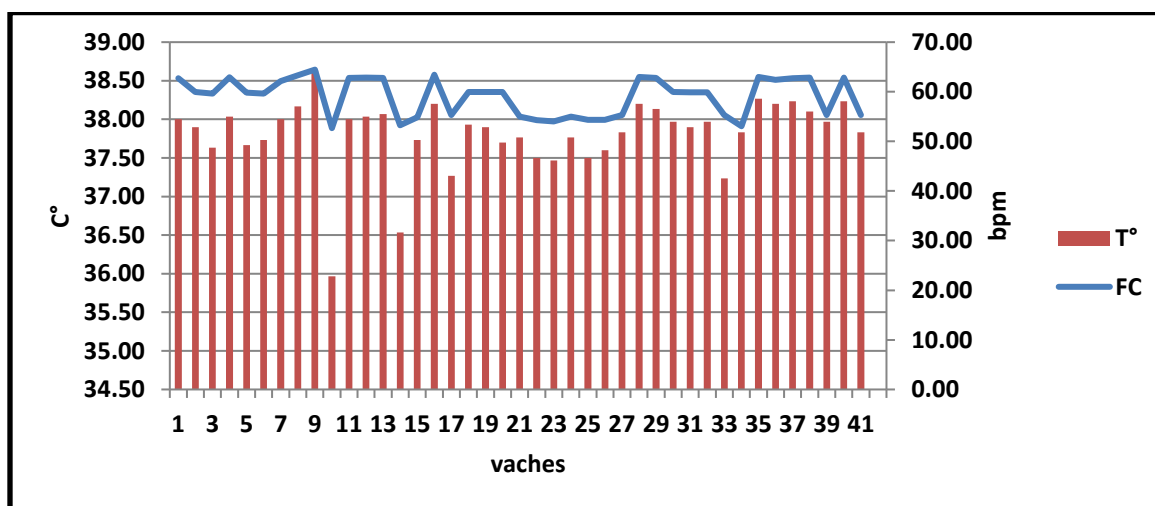


Figure10:representation shows the relationship between heart rate fluctuations and internal temperature

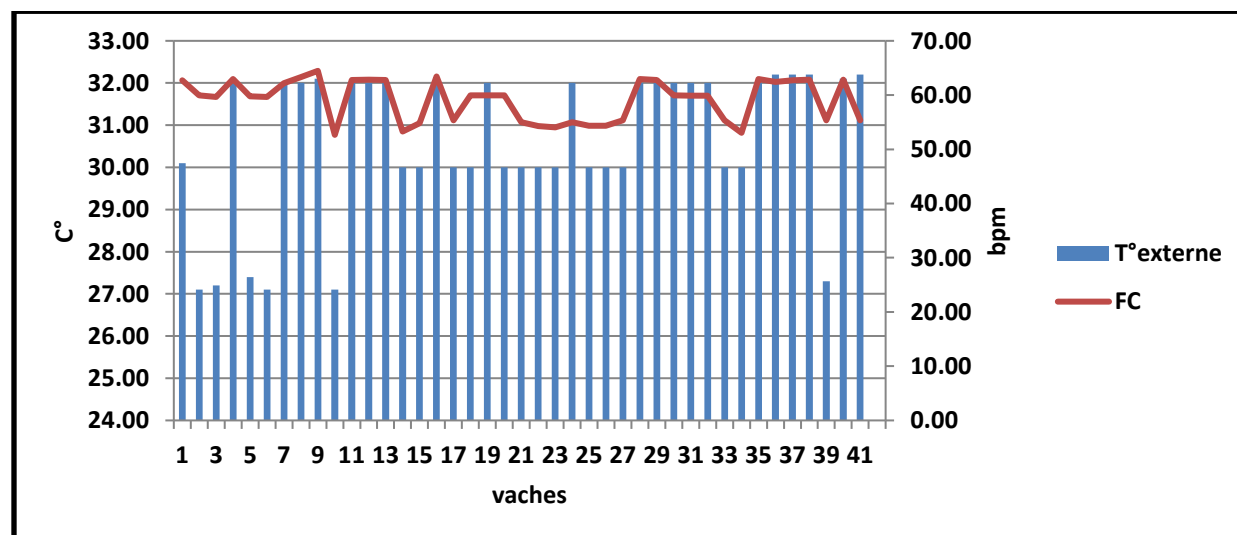


Figure11:representation shows the relationship between heart rate fluctuations and external temperature

CONCLUSION

The design and implementation of the innovative embedded system discussed in this article effectively addresses the significant challenges of tracking the location and biological parameters of dairy cows under heat stress. This device uses advanced sensor technologies, robust wireless connectivity, and real-time data processing intelligence to ensure monitoring. Studies show that there is a reduction in heat stress but also improved animal welfare and an increase in their milk production, thanks to improved farm profitability. The first improvement suggested is the expansion of the system's capabilities with artificial intelligence for early diagnosis of heat risks. This will be of great help to stakeholders in the agricultural sector.

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