

Daytime Heat Stress, Thermal Pattern, Hyperthermia and Body Caloric Overload in Tropical Acclimatized Holstein and Jersey Heifers

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Abstract

The influence of daytime tropical heat stress in the summer was studied in Holstein and Jersey heifers already acclimatized to tropical environments to determine their physiological response based on body thermal patterns and respiratory alterations according to psychrometric caloric indicators. Daytime psychrometric elements showed a tropical caloric potential for developing moderate to severe heat stress in dairy cattle. Body temperature and respiratory rate increased in both breeds open and pregnant ($P < 0.01$). Thermal body overload and respiratory works increased from 09 am to 12 md ($P < 0.001$); reaching and sustaining hyperthermia under the highest caloric pressure from 12 md to 03 pm. Rectal temperature increased $+1.5^{\circ}\text{C}$ in open Holstein (OH), $+1.3^{\circ}\text{C}$ in pregnant Holstein (PH), $+0.8^{\circ}\text{C}$ in open jersey (OJ) and $+0.8^{\circ}\text{C}$ in pregnant Jersey (PJ). The lowest heat stress index (HSI) was at 06 am, where OH and PH showed a HIS $+2.25$ and $+2.30$ and OJ and PJ $+2.34$ and $+2.38$. Maximum heat stress occurred at 12 md where OH averaged $+3.28$ and Pregnant Holsteins showed $+3.85$ at 03 pm. Open Jersey (OJ) showed a maximum HSI at 12 md (3.54) and PJ resulted in $+3.89$ at 03 pm. Open and pregnant Jersey heifers were more tolerant to heat stress based on lower body mass, insulation, feed consumption and greater relation between body surface and

metabolic body size for thermolysis. Acclimatization between five and twenty-five months under tropical heat stress allowed Holstein and Jersey heifers to develop thermal tolerance. Middle thermal acclimatization lowered thermal sensitivity, hyperthermia and hyperpnea in Holstein and Jersey heifers in the morning; however, pregnant heifers in both breeds showed higher thermal alteration in the afternoon. Tropical acclimatization at low altitudes could be integrated with environmental improvements and nutritional and health management to reduce influences of severe heat stress and improve physiological comfort and welfare in Holstein and Jersey heifers in the summer. Those combined strategies will reduce daytime thermal and respiratory responses and allow growth, pregnancy and health with lower body heat overload and less hyperthermia.

Keywords

Acclimatization, Dairy Cattle, Heat Stress Index, Rectal Temperature, Summer, Temperature Humidity Index

1. Introduction

The daytime in the tropics during summer represents the highest potential heat stress for dairy cattle because of high environmental temperature (25°C to 42°C) and relative humidity from 85% to 55% [1]. In consequence, temperature humidity index (THI) resulted from moderate to severe potential heat stress [2] without considering the contribution of direct solar radiation, which is another important factor in favor of increasing thermal stress in grazing ruminants in the tropics [3].

The tropical physical environment presents wide variations between night and day hours based on ambient temperature, relative humidity, and potential heat stress risks in dairy breeds [3] and in crossbred dairy cattle [4]. Tropical heat stress promotes thermal, circulatory and respiratory changes in lactating Holstein, Brown Swiss and Crossbred dairy cows; since passive thermolysis is reduced and active thermolysis is increased [3] [5] [6]. Homeotherms gain body heat when Temperature Humidity Index for cattle (THI) is greater than 72, which determines hyperthermy, hyperpnea, reduces passive thermolysis and increases metabolic heat production [5] [7] [8] and therefore, it defines the high caloric body overload state and the thermal heat shock in dairy cattle [3] [6] [9].

Physiological processes such as respiration, blood circulation, heart activity, sweating, panting, ruminal fermentation, urine production, reduction of feed intake and reduced growth rate and milk production in ruminants represent part of the overall adjustments and consequences that combined homeostasis, homeokinesis and homeorrhexis, in order to match with systemic displacements generated by direct and indirect influences of heat stress [10] [11]. Thermoregulation in ruminants under heat stress requires the contribution of sweating [12] [13], hyperventilation [6] [14], reduction of feed intake and increased water

consumption [15]. Some of the main consequences are increased water absorption through gastrointestinal system and reduction of milk production in lactating cows to compensate for water and electrolyte losses in order to maintain ion and water balance based on normothermia and thermal adaptation [16] [17].

Alterations in body temperature and respiratory frequency determine the heat stress index, which was established by Benezra [16]. Nevertheless, caloric body content based on body mass, water and dry matter adjusted by overall caloric capacity can be applied in homeotherms under heat stress to detect the degree of caloric gain and body heat overload [3]. Tolerance of heat stress in dairy cattle modified the physiological thermal responses and reduced milk production changes in lactating dairy cows [18]. The thermoregulatory system is influenced by the hypothalamus-pituitary-adrenal axis; since it participates in the synthesis and release of neurotransmitters and hormones [17], which regulate circulation and blood flow, metabolism and heat production, active thermolysis, ions and water balance, use of nutrient partitioning and behavior of livestock under heat stress [14]. Major effects of heat stress on physiology, production and reproduction require the use of strategies to ameliorate and prevent its negative impacts in dairy cattle [19]. The complex hormonal interplay under heat stress includes epinephrine, norepinephrine, thyroid hormones and aldosterone, leptin, glucocorticoids, somatotrophin and prolactin. These hormones facilitate physiological adjustments as part of the adaptation in livestock under heat stress [9] [10] [17].

Environmental and managing strategies have been proposed and used to mitigate daytime heat stress in dairy cattle [20]-[23]. Those studies must be analyzed in time across the life cycle in dairy cattle and according to reproductive status [24] to separate major sources of variation and consider main adaptations [17] and level of technology and commercial conditions such as in the tropics [25]. Besides, other factors such as the technological level in the dairy farms, economic capacity for improving environmental conditions and degree of heat stress allow for a better thermal comfort and welfare for dairy cattle [10]. Studies of heat stress in lactating dairy cows based on altitude in the tropics showed physiological alterations in body temperature, respiratory rate and cardiac frequency as well as reduction of milk production in crossbreed dairy cows and in European dairy breeds [3].

European bovine breeds are not genetically adapted to tropical environments and the degree of tropical daily heat stress; therefore, when those animals are exposed to high temperature, humidity and direct solar radiation during grazing activities, the thermal balance is altered, producing hyperthermy, hyperpnea, lower appetite, respiratory alkalosis, sweating and reduction of the energy efficiency for production [26]-[28] and reduction of reproductive performance [29]-[32].

One strategy to mitigate heat stress is allowing young animals to grow and develop under thermal stressful tropical conditions accompanied by good nutritional and health practices. This combined technique could help young dairy animals to be acclimatized by developing physiological and systemic accommodations

against heat stress [33] [34]. Once the animals have been exposed to heat stress; physiological performance can be related to daily psychrometric changes to define the degree of response and find out if animals have developed some degree of acclimation and become less sensitive or more tolerant to thermal caloric influences [10] [35]. In the present study, dairy calves were raised from age five to 25 months under tropical heat stress at an altitude of 50 m; but under an appropriate nutritional and feeding program based on nutritional requirements [15] and health care [36] [37].

The acclimatization to tropical heat stress in Holstein and Jersey heifers may help to reduce sensitivity and improve heat tolerance, which is important in order to reduce the negative effects of thermal stress in physiology [12] [14], reproduction [29] [30] and on milk production [21] [34]. Studies of heat stress have demonstrated negative effects on grazing dairy cows [38], reproductive performance [31] [39], nutritional and metabolic efficiency [40], milk production [29] [41] and productivity of dairy cattle [28] [42]. These results emerged even when animals developed acute and chronic physiological accommodations under heat stress [8] [34].

Heat stress causes negative effects on dairy cattle, affecting physiology, reproduction, nutritional efficiency, milk production and health [29] [31] [43]-[45]. Therefore, physiological performance, production and reproduction in dairy cattle are drastically reduced [35] [46]; lowering productivity and affecting the economy in the dairy farms [42] [47].

All negative consequences are derived in time when animals are not able to maintain normothermia since normal caloric balance is displaced to some level of hyperthermia. As a result, caloric body content increased over the upper biothermal limit [4] [10], which is 38.6°C in normal dairy cattle [37]. The body caloric overload activates and challenges the thermoregulatory and endocrine mechanisms through the central nervous system, which stimulates adrenal glands, metabolic rate, nutrient utilization and metabolic heat production; altering all vital physiological processes [7] [18] and affecting feed intake, milk yield, milk composition and feed efficiency in dairy cows [48].

Dairy cattle are able to regulate body temperature if the ambient temperatures range from 5°C to 25°C [5] [9] [48], but lactating dairy cows maintain their physiology, feed intake and milk production between 4°C to 20°C [7] [49]-[51]. Body metabolism and body heat load increase according to level of milk production [50] and therefore open and pregnant heifers have biothermal advantages. The thermal Neutral Zone (TNZ) is defined when Temperature Humidity Index (THI) for cattle ranges between 68 and 72 for different climates [2] [51].

Other psychrometric elements such as relative humidity, direct solar radiation and shade availability will potentiate the final thermal force and increase the degree of heat stress [2] [5] [12] [41]. Specific conditions which can change the lower and upper critical environmental temperature in dairy cattle are breed and type of crossbred, age, stage of lactation, reproductive status and pregnancy, type of hair coat, hair color, skin pigmentation, altitude from the sea level, type of shade,

climate and milk yield [3] [4] [28] [49].

Feed intake and digestive heat production in dairy animals are some other conditions that must be considered, since about 30% of total energy intake will be released as caloric increment in the rumen [15]. In consequence, as the animal increases feed intake, the gastrointestinal system will release a greater amount of caloric gastrointestinal heat, which also will increase body heat load and determine part of the hyperthermia if the passive and active heat losses are lower than overall body heat gain [3] [5] [7]. However, dairy animals under heat stress will reduce daily feed and dry matter intake as part of the body adjustments [15] [40]. Therefore, feeding and nutritional adjustments and strategies are used to mitigate heat stress in lactating dairy cows [21] [52]-[55].

Main nutritional and feeding strategies for lactating dairy cattle include structural carbohydrate in the diet between 15% to 17%, total protein between 15 to 18% of dry matter; as well as net energy for lactation between 1.62 to 1.72 Mcal/kg dry matter; when daily milk yield ranges from 20 to 33 kg/day [15]. However, nutrient requirements for open and pregnant heifers are lower instead of nutrient requirements for growing, lactating, pregnancy and environmental energetic adjustments [15] [56].

Among minerals, potassium is of particular interest for dairy cattle since it is loosed in milk, feces, sweat, urine and saliva. This mineral is required for maintaining normal heart and renal function, transmission of neuronal impulses, muscle contraction, acid-base balance and body fluids in ruminants [8] [15]. The National Research Council [15] recommended 1.2% to 1.4% of dry matter in order to protect dairy cattle against hypokalemia induced by heat stress; even when we use strategies like shade for lactation dairy cows [54]-[56].

The energy density of dry matter is another important point in ruminants under heat stress; diet contributes to increasing the body's caloric heat load, and therefore, body temperature will increase, defining hyperthermia [7] [33] [49]. Nevertheless, tropical models for feeding dairy cattle are based on forages throughout grazing and they represent a better digestive thermal environment since dry matter and net energy intake are lower than typical diets based on total mixed ration (TMR).

The ability of homeotherms to manage thermal variations depends on total caloric losses by passive and active thermolysis against thermogenesis (metabolism, digestion and muscle activity) plus environmental caloric gain [6]. Dairy cattle dissipate body heat by convection, radiation and conduction based on sensitive heat losses, when body surface temperature is greater than environmental temperature [5] [10]. However, when the environmental temperature is closer to or greater than animal skin temperature, heat loss will depend on sweating, panting and respiratory activity [7] [9] [13]. In addition, active thermolysis is affected by relative humidity, since greater rate of heat flux by evaporation and panting requires low humidity in the air [13] [16] [35].

Maternal heat stress during the early stages of gestation affects early embryo

development and survival, as well as the embryo rate of growing and quality [22] [23] [57]. Sakatani *et al.* [58] showed that embryo survivence is reduced during the first week after fertilization; decreasing conception rate. Ortega *et al.* [59] showed that in vitro exposure of zygotes from 40°C to 40.5°C reduced the proportion of blastocyst stage; which indicates that high uterine thermal environment limited early embryo development based on alterations of cellular functions and related effects [58] [59].

Dairy cattle are altered by heat stress when the ambient temperature is greater than 20°C and relative humidity 100%; however, moderate heat stress will require an environmental temperature from 28°C to 32°C and relative humidity between 20 and 100% [2] [5]. Once the animal is influenced by heat stress, factors such as: environmental temperature (minimum 22°C to 40°C), relative humidity (40 to 100%) and direct solar radiation (250 to 850 Kcal/m² hr) will modify the physiological functions, immunology, metabolic indicators, reproductive and productive performance [39] [41] [45]. According to Fraser *et al.* [37], when the rectal temperature is greater than 39.0°C, thermoregulation will be activated, as well as all physiological adjustments in bovine; and then, signs of negative effects will appear [45] [56]. Therefore, dairy production systems must prevent heat stress by using different strategies to ameliorate the environmental thermal shock [60] [61].

Severe heat stress in dairy cattle is released by active thermolytic mechanisms such as sweating, evaporating, respiratory and panting activities [10] [32] [35]. Besides, animals under hyperthermia lower dry matter intake and grazing activity, but also, will increase water consumption and reduce milk production [12] [40] [41]. Dairy cattle must increase active thermolysis under extreme hot environment [33]; but, environmental heat stress in the tropic is lower and therefore physiological and productive alterations become smaller [1] [11]. However, the strength of tropical thermal stress is enough to produce middle hyperthermia, hyperpnea, salivation, reduce grazing time and lower milk production around 30%; even under some improved strategies to correct the negative effects of tropical summer time [3] [4] [25].

Heat stress is defined by the environmental conditions and its effects will depend on the type of bovine, physiological stage of the dairy cow across its life cycle; therefore, there are many different negative implications among cows, heifers, embryos and fetus. In fact, reproduction is one of the mayor point to be considered in the dairy cow and heifers undergoing heat stress. Some of the major reproductive influences are endocrine and ovarian displacements, embryo survivence and mortality, uterine blood flow in pregnant animals, fetus size, colostrum quality and production [14] [31] [32] [41] [43] [49]. According to Kamano *et al.* [62] and Hansen [63], a major negative effect of heat stress affects early stages of embryo development as it has been shown in embryo transfers at day 8. Embryonic antioxidant protection against heat shock is developed in latest stages of embryo development [64]-[67]. Such short biological adaptation is critical for embryo development and survival; therefore, early stages of embryo development are

more altered by hyperthermia.

Dairy cattle require environmental protection when ambient temperature is greater than 25°C and relative humidity is over 50%; because they will determine a THI greater than 72 units [2]. However, heat stress is going to increase in grazing animals since direct solar radiation will potentiate the THI as described by Mader *et al.* [20]. In addition, as global temperature is increasing, the degree of heat stress is more powerful and therefore dairy cattle will be more affected; reducing reproduction and production [35] [41] [44] [65], fertility [39] and productivity [48] [64] [65]. As consequences, health problems [29] [30] and economic losses will be detected in the dairy farms [28]. Consequently, the degree of heat stress requires the evaluation of environmental parameters, which are related to heat stress in dairy cattle [68] [69].

Many studies have shown evaluations about abatement strategies for confined models used in dairy cattle production; including: nutrition and feeding [19] [38] [40], genetic and selection, management and environmental changes in order to offer a better environment and comfort for dairy cattle [9]. Besides, environmental modifications are considered more convenience based on benefits related to milk production, growth and body weight, diet and nutritional model for lactation, cost of improvements, reproductive performance, time required for adjustments and reduction of potential heat stress [43] [55] [68] [70] toward a better environment, comfort and welfare for dairy cattle [11] [12] in order to improve reproduction, productivity and sustainability [30] [42] [46] [71].

Main strategies to reduce the influences of heat stress and provide a better thermal comfort in dairy animals include the use of shade [71]-[73], water availability and quality, nutritional balance and feeding based on nutrient requirements to maintain health and production [26] [74]; using a confined period in the hottest hours to prevent exposure to direct solar radiation [75] and use shade and fans to ameliorate the strength of heat stress [76]. In fact, a combination of shade, fans and sprinklers in addition to an adequate nutritional balance for energy, protein, minerals and vitamins are accounted to maintain milk production, growth rate and reproductive performance under comfort and welfare in dairy cattle [28] [77].

General strategies to handle heat stress and protect dairy cattle is a very complex scenery; which must include: heat stress relief, feeding care, nutritional condition, hydrations and supplementation, environmental structures and housing, pastures and natural shades, sunshine protection, nutrients availability and water balance [21] [67]. Phenotype and genetic evaluations must be part of those strategies by considering tolerant animals, morphotype and performance of animals based on physiology, reproduction, production, health and longevity [11] [35] [46] [78] [79].

The main objective of this study was to evaluate the influences of daytime psychrometric conditions and moderate to severe heat stress over the physiological thermal patter and body caloric overload in acclimatized open and pregnant Holstein and Jersey heifers to recognize their physiological thermal and respiratory responses and daytime alterations in the summer under a tropical climate without

having special strategies to reduce the impact of daily heat stress; but undergoing an appropriate nutritional and healthy management program in acclimatized dairy heifers.

2. Materials and Methods

2.1. Geographical and Local Description of the Experimental Field

The study was conducted in a small dairy farm for raising heifers located in Campo Alegre, David City, Chiriquí Province, Republic of Panamá; at Latitude 8.44058° (8° 26' 26" North) and Longitude -82.43592° (82° 26' 9" West) and its altitude 50 m. The farm's area was divided into eight pasture blocks fixed with water and plastic feeders to provide nutritional supplements. All paddocks offered a few scattered middle trees, but there were no shaded installations. A stockyard (18 m long × 10 m wide) was fixed in two blocks having 6 pens separated by 2.16 m between animals and between blocks 5.5 m to entry and managed animals classified by breed for physiological evaluation each three hours from 06 am to 06 pm.

2.2. Conditions and Period of Raising Heifers Prior to the Experiment

The environmental conditions around the animals included pastures, dispersed trees, grazing areas, feed, and water recipients. Pasture blocks measured 8120 m² and were divided into two portions, where animals grazed three days by blocks. The pre-experimental period included the time since animals arrived at the new environment in Campo Alegre from December (2019) to March (2021). The experimental evaluation went from February to March (2021), in which daytime thermal environment and animal physiological responses were measured each three hours on one day/week for four weeks to relate daytime thermal trends and respiratory physiology based on heat stress according to psychometric indicators in the humid tropical climate [3] [5] [61] and microclimate around David City [79].

All female calves were weaned at age of 75 days by cutting milk as part of the diet and then animals continued receiving grains, hay, and green forage up to age of five months. Then, animals were moved from the dairy farm from an altitude of 1100 m to a farm located in Campo Alegre, District of David, at an altitude of 50 m. Animals were raised from five to 25 months in this new stressful environment under heat stress until physiological evaluation during summer time.

2.3. Experimental Period, Psychometric and Physiological Indicators

The study was done from February to March 2021, since those months represented the major daily heat stress in the summer of Panamá. The psychometric indicators (ambient temperature, relative humidity, direct solar radiation, enthalpy, wind speed, Temperature Humidity Index (THI) and adjusted THI by direct solar radiation were taken between 06 am and 06 pm each three hours to

register daytime changes. At the mind time, physiological indicators (body temperature and respiratory) were measured each three hours to relate environmental and physiological changes under the influence of heat stress during summer time in the tropical environment based on procedures and integrated strategies to evaluate heat stress in dairy cattle [20] [80]-[82].

2.4. Environment around the Experimental Animals and Thermal Indexes

The psychrometric periods were 06 am, 09 am, 12 md, 03 pm and 06 pm and at the mind time physiological indicators were taken around each daily period from -30 to +30 minutes around the hour set for each period. Environmental indicators come from daily meteorological data provided by the program Weather Clock and satellite assistance for coordinates 8°26'38"N and 82°26'11"W in David City on each day of measurements. The physical environment in the experimental field included the psychrometric parameters [5] [83] plus adjustments by solar radiation and wind speed [2] [23] with modifications indicated by Araúz *et al.* [3] in the tropical climate to define the environmental momentum thermal force for heat stress.

Psychrometric variables were direct solar radiation (Kcal/m² hr), wind speed (m/seg), enthalpy (Kcal/ kg dry air), dry bulb ambient temperature (°C), wet bulb ambient temperature (°C), and temperature humidity Index (% °C) and adjusted THI [5] [20]. Thermal body and respiratory physiological overload work were calculated according to physiological status at 06 am and changes showed each three hours across daytime under heat stress and applications of the standard coefficients were based on psychrometric daily critical point at 12 middle days as described by Araúz *et al.* [3]. The Basic Temperature Humidity Index for bovine was calculated as THI_{bovine} and adjusted THI_{Bovinos} estimated according to Mader *et al.*, [20]. Heat Stress Index (HSI) was calculated according to Benezra [16].

2.5. Experimental Animals

Six Holstein and six jersey (three pregnant and three none pregnant by breed) were used; which were weighted by scale and special weight tape for dairy breeds described by Araúz [4]. Pregnant Holstein heifers aged 27.3 months and weight 391.3 kg averaging 5.23 ± 0.6 months of gestation and none pregnant age 24.3 months and weight 373.17 kg. Pregnant jersey heifers aged 25.3 ± 0.4 months and weight 282.7 kg and nonpregnant aged 24.3 months and weight 263.7 kg. The body condition score of all animals ranged from 3.25 to 3.50 according to Edmonson *et al.* [84].

2.6. Health, Biology, and Reproductive Status of the Experimental Animals

The health program included vaccination against eight clostridiums each six months by applying 2 ml subcutaneously of Ultrachoice™ 7 to protect animal

against *Clostridium chavoei*, *Clostridium septicum*, *Clostridium haemolyticum*, *Clostridium novyi-Sordellii*, *Clostridium perfringens* Types A & D and Bacterin toxoid. Endoparasites were controlled using anthelmintic drugs (Fenbendazole at 5 mg for every kg body weight or 1 ml for every 20 kg of body weight (BW) every two months). Ectoparasites (Tick and flies) control was done using amitraz at 20.8% by spraying a solution of 1.0 ml at 20.8% diluted in 1 L of Water. Animals also received a subcutaneous injection of 1 ml of iverme for each 50 kg body weight equivalent to 200-mcg ivermectin per kg BW. The biology and reproductive status of the experimental animals are in **Table 1** and **Table 2**. The veterinarian declared all animals healthy across the entire experimental period.

2.7. Feeding and Nutrition of Animals during Summer Time

The feeding program by animal included silage 6.8 kg, molasses 1.13 kg, grain mix 1.81 kg and green forages (*Brachiaria decumbens*). Minerals (50 g by animals) were mixed with the concentrate. The farm used pasture irrigation in all paddocks during summer to ensure an average of 5.2% body weight for forage consumption [47]. The feeding programs for calves and heifers were based on the Nutrient Requirements of Dairy Cattle [15].

2.8. Physiological Parameters, Techniques, and Equipment

Rectal and skin temperature and respiratory frequency from 6:00 AM to 6:00 PM were measured each three hours. Skin temperature was taken using a laser infrared thermometer, NUBEE, Code NUB8380, FDA (USA) Code 1420571-000. Rectal and vaginal temperature was determined using a veterinarian thermometer and stethoscope respiratory auscultation were performed as indicated by Fraser *et al.* [36] [37] and Dukes, and Swenson [85]. Metabolic body size and surface area were estimated as indicated by Curtis [5] and Araúz *et al.* [3]. Blood samples were taken one week before the physiological evaluation by the vacumtainer sampling method [36] and blood analysis was done in a Mindray 3000 Plus Autoanalyzer at the Laboratory of Animal Physiology, Animal Bioclimatology and Dairy Science in the Department of Animal Husbandry, Faculty of Agricultural Sciences in Chiriquí, University of Panamá. Body caloric capacity and body caloric overload in the animals were estimated based on Curtis [5] and Araúz *et al.* [3].

2.9. Experimental Design and Statistical Analysis

The experimental design and data were built according to Gill [24] and Wilcox [86] based on a factorial design. Normal distribution tests were done using the graphic histogram and double quantiles [24]. Statistical analysis was based on three factors (Factorial Design $A_2 \times B_2 \times C_5$); where factor A_i was Breed (a_1 : Holstein and a_2 : Jersey), Factor B_k was reproductive status (b_1 : pregnant and b_2 : open) and Factor C_l was daytime sub-periods (c_1 : 06 am, c_2 : 09 am, c_3 : 12 MD, c_4 : 03 pm, and c_5 : 06 pm) and D_j were animals (j^{mo} : 1, 2, 3 by breed and reproductive status). Overall additive lineal model was

$$Y_{ijkl} = \mu + \alpha_i + \beta_k + (\alpha\beta)_{ik} + \gamma_l + (\alpha\gamma)_{il} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{ikl} + e_{ijk}$$

The analysis of variance, daytime trends, least squares means, regressions and correlations was done in the SAS program [87] according to Gill [24] and Herrera and Barreras [88].

3. Results and Discussion

3.1. Psychrometric Conditions and Degree of Daily Heat Stress in the Summer

Physical environment and major heat stress risks for bovine occurred from 09 am to 03 pm since THI_{bovine} ranged from 79.36 to 86.28. The inclusion of direct solar radiation and wind speed increased THI at 09 am in the morning up to 652.1 W/m²hr at 12 md and then decreased to 202.6 W/m²hr at 03 pm (−68.91%). The caloric content of dry air changed as enthalpy reached at 12 md 100.18 KJ/kg Dry Air and then reduced to 87.8 KJ/kg (−12.36%) around 03 pm (Table 1).

Daily environmental conditions around animals from 09 am to 06 pm showed enough power and caloric potential to develop heat stress in dairy cattle since THI ranged from 79.36 to 90.79. It represented a high physiological risk for ruminants to develop heat stress since the thermal neutral zone demands a THI less than 72 [2] [23] [51]. Animals were influenced by direct solar radiation and therefore adjusted THI ranged from 82.89 to 88.96 between 09 am and 03 pm; resulting in a severe degree of daily heat stress for bovines. In consequence, acute physiological alterations regarding thermoregulatory and respiratory activity, endocrine and metabolic processes are primarily reflected in dairy cattle [14] [41] [44]; which can also affect reproduction [31] [39] [43] [53] [67], health, milk production, biological efficiency and productivity in dairy cattle [21] [22] [34] [48] [49].

The entire physical daytime environment was characterized by psychrometric indicators because homeotherms have an advanced nervous system which can detect thermic pressure and change vital systemic processes [32]. Daytime physical conditions during summer time showed a very high variation from 06 am to 06 pm, where dry bulb temperature, relative humidity, enthalpy and THI indexes indicated the presence of potential severe heat stress for dairy cattle; whose maximum strength occurred around 12 md (Table 1) and it was basically maintained until 06 pm. Dry bulb temperature increased up to 12 md; which resulted in a thermal change +14°C over 25.3°C detected at 06 am (+55.34%). At the mind time, THI increases from 75.14 (06 am) to 90.79 (+20.83%); which indicates the potential thermal environment to develop severe heat stress in bovines. In addition, dry bulb temperature was slowly reduced around 03 pm (−4°C) and at 06 pm (−4.9°C). THI in the afternoon did not change enough to reduce potential heat stress for dairy cattle, since temperature humidity index at 03 and 06 pm averaged 86.28 and 80.83. Therefore, the thermal environment in the morning was lower than afternoon; but daytime heat stress forced body caloric load reaching middle hyperthermia.

Table 1. Daytime psychrometric and heat stress indicators in the experimental field during the physiological evaluation in Holstein and Jersey heifers.

Environmental Indicators and Heat Stress in Bovines	Unit	6:00 am	9:00 am	12:00 md	3:00 pm	6:00 pm
Dry Bulb Temperature	°C	25.3	29.5	39.30	35.1	30.2
Wet Bulb Temperature	°C	22.3	21.46	27.61	25.30	22.90
Relative Humidity	%	78	62	52	57	65
Enthalpy	KJ/kg	65.8	70.84	100.18	87.8	65
Direct Solar Radiation	W/m ² hr	0	226.2	652.1	202.6	43.5
Wind Speed	Km/Hr	3.24	4.57	6.51	5.78	4.11
Specific Volume	M ³ /kg da	0.867	0.880	0.919	0.902	0.884
Humidity Ratio	g H ₂ O/kg dry air	0.016	0.016	0.029	0.021	0.017
Water Vapor Pressure	Kpa	2.516	2.558	3.298	3.226	2.792
Saturated Water Vapor Pressure	Kpa	3.226	4.126	7.112	3.226	4.295
Atmospheric Pressure	Kpa	101.33	101.33	101.33	101.33	101.33
Thermal Sequence	°C		+4.2	+9.8	-4.2	-4.9
Added Thermal Changes	°C		+4.2	+14	+9.8	+4.9
Thermal Environmental Overload Index	°C		+1.166	+1.553	+1.387	+1.194
THI-Bovines	°C%	75.14	79.36	90.79	86.28	80.83
Adjusted THIDSRWS †	°C%WM ⁻¹ 2s ⁻¹	79.39	82.89	96.15	88.96	83.36

† (THIDSRWS): Temperature Humidity Index adjusted by Direct Solar Radiation and Wind Speed.

3.2. Physiological Profiles in Holstein and Jersey Heifers

The animal responses against some specific environmental conditions depend on homeostasis, homeokinesis and homeorrhexis as processes that integrate the regulation and physiology in homeotherms [50] [72]. However, chronic and acute adaptations developed as a function of acclimatization contribute to improving physiological and productive performances confirming adaptations and sensitivity in dairy cattle [33] [35] [53]. Therefore, factors such as breed, age, sex, body weight and type of diet can influence how dairy cattle will perform according to psychrometric conditions under heat stress, management and technical practices for growing and production.

First at all, pregnant Holstein and Jersey heifers' weight 381.23 and 272 kg at 25 and 23.33 months and open animals' weight 373.67 and 307 kg at 26 and 25 months. Hemoglobin, erythrocyte, and leukocyte were greater in pregnant animals compared to open Holstein and Jersey heifers because of pregnancy influence. All animals were declared healthy by the veterinarian (**Table 2**).

Table 2. Averaged blood indicators in the experimental animals.

Breed	Reproductive State	TRCV %	HGBN g/100ml	Erythrocytes 10 ⁶ /ml	Leukocytes 10 ³ /ml	OTC ml/100ml
Holstein	Pregnant	30.8	11.5	6.1	8.1	15.36
	Open	30.6	11.2	5.9	7.8	14.60
Jersey	Pregnant	31.0	11.3	6.1	7.6	15.14
	Open	30.9	10.8	6.0	6.7	14.47

TRCV: Total red cell volume; HGBN: Hemoglobin; OTC: Oxygen Transport Capacity.

Table 3. Averaged main biological descriptors of the experimental animals.

Breed		Pregnant Length (m)	Age (m)	Body Weight (kg)	Metabolic Body Weight kg ^{3/4}	Thoracic Perimeters (cm)	Width Skin (mm)
Holstein	Pregnant	5.23 ± 0.60	26.3 ± 0.6	391.3 ± 19.4	87.9 ± 3.3	171.7 ± 4.2	10.5 ± 1.3
	Open	----	24.3 ± 1.5	373.7 ± 11.6	84.9 ± 1.9	164.3 ± 8.1	11.3 ± 0.8
Jersey	Pregnant	5.73 ± 0.4	25.3 ± 0.6	282.7 ± 4.7	66.9 ± 0.9	151.7 ± 2.1	11.0 ± 1.0
	Open	-----	24.3 ± 0.6	263.7 ± 5.9	65.4 ± 1.1	153 ± 4.0	10.9 ± 0.5

Table 4. Biological profiles in Holstein and Jersey heifers one week before the environmental and physiological evaluation under daily heat stress in the tropics.

Biological Indicator	Holstein Pregnant	Holstein Open	Jersey Pregnant	Jersey Open
Age (months)	25	26	23.33	25
Gestation Length (días)	153 ± 23	----	128 ± 15	-----
Body Weight (kg)	381.33	373.67	287.7	263.7
Metabolic Weight (kg ^{3/4})	86.27	84.98	69.86	65.44
Thoracic Perimeter (cm)	170	164.33	151.67	158
Body Surface (M ²)	4.1842	4.1369	3.573	3.403
Hematocrit (%)	30.76	30.57	31.03	31.73
Hemoglobin (gr/100ml)	11.47	10.97	11.30	10.97
Erythrocyte (millions/ml)	6.10	5.97	6.13	6.10
Leukocytes (miles/ml)	8.10	7.87	7.60	6.87
O ₂ Transport Capacity SA 100% (ml/dl)	15.36	14.70	15.14	14.66
Skin Width (mm)	10.5	11.33	10.9	11

The biological indicators included age, body weight and width skin by breed and reproductive status according to reproductive status (**Table 3** and **Table 4**). Body mass is related to metabolic heat production and to surface area [5] [13] [20]; which determines the rate of heat flux by radiation, convection and conduction if skin temperature is greater than ambient temperature [9]. Body heat production and surface area are directly related to body weight; however, thermal body insulation is inverse to body weight [50]. Holstein heifers showed higher body weight and greater body surface area than Jersey animals because of their breed's body weight differences.

3.3. Daytime Biothermal Pattern and Maximum Thermal Alteration under Heat Stress

Caloric body content based on rectal, vaginal and tegumentary temperature changed across daytime ($P < 0.001$) as daytime psychrometric trends and degrees of heat stress occurred as indicated by basic and adjusted THI for bovines. Daytime impact of the environmental heat stress represented a thermal variation of 99.17% in skin temperature, followed by vaginal temperature (66.59%) and rectal temperature (66.59%). It means, the thermoregulatory system is more effective in controlling the endogenous temperature than caloric content in the skin because of the influence of external factors and sweating-evaporating process under heat stress. Other studies showed similar results in grazing dairy cattle under middle and severe heat stress [52] [68]. Rectal temperature was the best thermal indicator based on the level of correlation between body caloric content and daytime thermal changes. The correlations between ambient temperature and rectal temperature in open and pregnant heifers were 0.73 ($P < 0.001$) for both groups and in open and pregnant jersey heifers were 0.87 ($P < 0.01$) and 0.65 ($P < 0.01$). The second best indicator of severe heat stress was the respiratory frequency and daytime temperature in Holstein (open: $r = 0.66$, $P < 0.01$; pregnant $r = 0.84$ $P < 0.01$) and in Jersey (open $r = 0.62$ $P < 0.01$; pregnant $r = 0.66$ $P < 0.01$). There were little differences in the rectal temperature between breeds ($P < 0.01$; **Table 5**); however, major differences occurred from 06 am to 06 pm ($P < 0.001$) and from 06 am to 12 md. Vaginal and skin temperature also showed significant changes across daytime hours ($P < 0.001$). Nevertheless, rectal temperature was the biothermal indicator used to describe body caloric alteration [3] based on correlations between environment temperature and respiratory indicators. Other study [38] found a high relationship between THI and alterations in physiology, blood items and milk production in crossbred dairy cows.

The psychrometric changes across daytime were consistent between 09 am and 03 pm, which were the hottest hours and provided the greatest heat stress degree based on THI, adjusted THI and HSI in the animals. Rectal temperature was more influenced by breed and daily sub periods once the degree of heat stress increased toward 12 md with a little recovery in the afternoon in both breeds.

The influence of psychrometric conditions and potential heat stress must

consider the elevation of ambient temperature, the activation of sweating and the increment of respiratory thermolysis in dairy cattle [10] [21] [48] [49]. In addition, high relative humidity interacts with air temperature to increase the degree of heat stress in ruminants [5] [23]. Other physical conditions such as direct solar radiation can increase the degree of heat stress in bovine [66]. However, the strength of heat stress will depend on physiological state [3] [13], dietary energy intake [53], altitude [4] [16], access to nutritional and feeding strategies [8] [19] [77] [81] [82], use of artificial and natural shade [6] [80], wind speed [20], environmental temperature and relative humidity and adjusted temperature humidity index by direct solar radiation and wind speed [2] [20] [75]. Maximum rectal, vaginal and skin temperature occurred around 12 md in both breeds. Rectal temperature alteration in open and pregnant Holstein heifers were +1.5 and +1.3°C from 06 am to 12 md; and open and pregnant Jersey resulted in +0.8 and +1.0°C (Table 6).

Table 5. Analysis of variance for thermal indicators in Holstein and Jersey heifers in the summer time under humid tropical environment.

Source of Variation	DF	Sum Squares Type III and Significance		
		Rectal Temperature (°C)	Vaginal Temperature (°C)	Skin Temperature (°C)
Raza (A)	1	0.6201**	0.0735ns	1.0667*
Reproductive Status (B)	1	0.0375 ^{NS}	0.0001ns	1.0140*
A*B	1	0.1042 ^{NS}	0.0135ns	0.2160ns
Daily Sub Periods (C)	4	2.4535***	1.6764***	2.5305***
A*C	4	0.1835*	1.222ns	0.0696ns
B*C	4	0.1967*	1.1323ns	0.1935ns
A*B*C	4	0.1467 ^{NS}	0.0264ns	0.0473ns
Residual	40	0.0673	0.0538	0.2552
Total Sum Squares	59	14.94	10.0698	10.2067
R ² %		81.96	78.62	57.20
CV%		0.669	0.599	1.71
Mean Squared Error		0.259	0.232	0.505
Overall Mean		38.77	38.71	36.84

Significant differences at 0.1% (***, $P < 0.001$), 1% (**, $P < 0.01$) and 5% (*, $P < 0.05$) and not significant differences at 5% (ns, $P > 0.05$). A: Breeds (Holstein, Jersey) B = Reproductive Status (Open, Pregnant) C (06 am, 09 am, 12 md, 03 pm. and 06 pm).

Table 6. Least squares means for daytime rectal, vaginal and skin temperature in Holstein and Jersey heifers under tropical heat stress.

Breed and Reproductive Status	Daytime Thermal Balance	Daily Hours	Body Thermal Indicators (Temperature)			Respiratory Rate	Heat Stress Index
			Rectal °C	Vaginal °C	Skin °C	Respiratory Frequency rmpm	HSI °C—rmpm
Holstein		06 am	37.7	37.9	36.5	29	2.25
Open		09 am	38.9	38.8	37.6	45	2.97
	+1.5/−0.2 °C	12 md	39.2	39.0	37.6	52	3.28
	DTF 7.5	03 pm	39.1	39.0	36.9	46	3.02
	DTB +1.3	06 pm	39.0	38.8	36.6	39	2.71
Holstein		06 am	38.1	38.1	36.4	30	2.30 (+0.05)
Pregnant		09 am	38.6	38.4	37.0	32	2.40 (+0.57)
	+1.3/−0.1 °C	12 md	39.4	39.2	37.5	58	3.55 (+0.27)
	DTF 13	03 pm	39.3	39.1	37.1	65	3.85 (+0.83)
	DTB +1.2	06 pm	39.3	39.1	36.5	45	2.98 (+0.17)
Jersey		06 am	38.2	38.3	36.2	31	2.34
Open		09 am	38.7	38.6	37.1	45	2.97
	+ 0.8/−0.3 °C	12 md	39.0	38.9	37.6	58	3.54
	DTF 2.7	03 pm	38.8	38.8	37.1	45	2.97
	BTB +0.5	06 pm	38.7	38.8	36.4	24	2.05
Jersey		06 am	38.0	38.1	36.1	32	2.38 (+0.04)
Pregnant		09 am	38.3	38.4	36.4	42	2.83 (−0.14)
	+1.0/−0.1 °C	12 md	39.0	39.0	37.0	60	3.63 (+0.09)
	DTF 10	03 pm	38.9	38.8	36.7	66	3.89 (+0.92)
	DTB +0.9	06 pm	38.9	38.9	36.2	41	2.80 (+0.75)

DFT: Daytime thermal factor; DTB: Daytime thermal balance. °C—rmpm: Celsius degree—respiratory movements per minute.

Daytime thermal factor (DTF) in pregnant Holstein and jersey heifers were 13 and 10 units according to changes in rectal temperature in the morning and recovery of caloric body in the afternoon. Meanwhile, open Holstein and jersey animals showed a DTF of 7.5 and 2.7 units; which lower the daily thermal balance since body caloric overload was smaller. Pregnant animals were more sensible to daily heat stress from 09 am to 12 md because of their greater body weight and thermal insulation. Therefore, pregnant animals showed longer caloric retention and higher hyperthermia; showing also a major caloric overload trough the

afternoon (Table 6, Figure 1 and Figure 2).

Critical environmental conditions reached the highest heat stress degree at 12 md based on daytime and psychrometric properties. Holstein heifers were more sensitive than jersey heifers in the morning between 06 am and 12 md (Figure 1 and Figure 2) as described by the mean (solid lines) and predicted trends (dot sequences). Kinetics of daily rectal temperature in Holstein heifers showed a slight difference between open and pregnant animals before and after 12 md (Figure 1). Pregnant Holstein and Jersey heifers kept higher rectal temperature than open animals in both breeds in the afternoon; which indicates possible negative effects on gestation and fetus [2] [67] [71] [74].

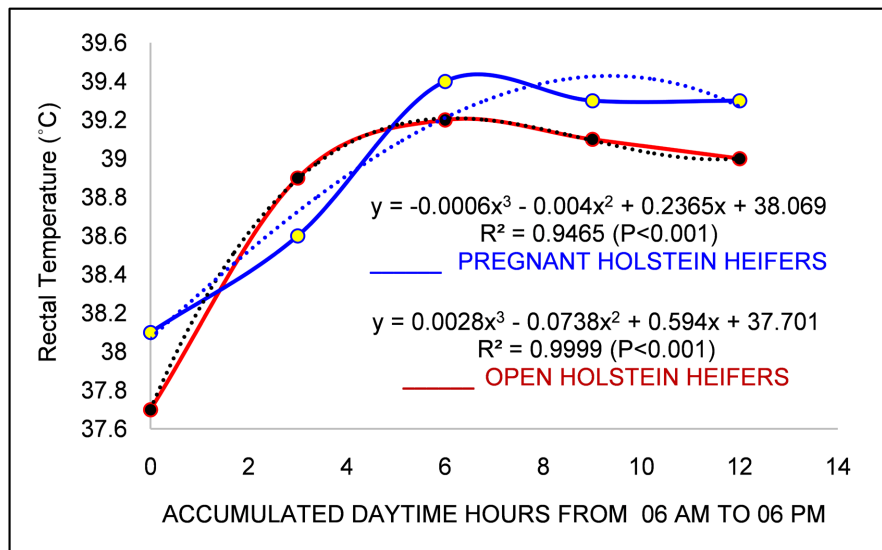


Figure 1. Daytime trends for rectal temperature in open and pregnant Holstein heifers under tropical heat stress.

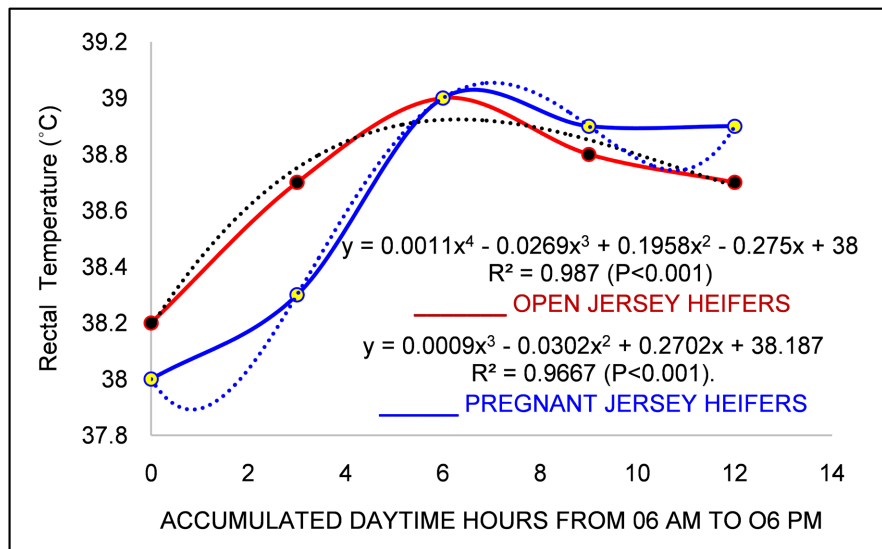


Figure 2. Daytime trends for rectal temperature in open and pregnant jersey heifers under tropical heat stress.

Pregnant animal presented lower thermal reduction in the afternoon as compared to open animals, which indicated a disadvantage for regulation of body temperature under daytime heat stress. The degree of daily caloric pressure was severe as indicated by psychrometric indicators and adjusted THI; therefore, physiological risks were maintaining since endogenous temperature was higher than 1.0°C over 38.6°C, which is the physiological rectal temperature [37].

The process of acclimatization around 20 months in Holstein and Jersey heifers under tropical heat stress benefited both breeds because no animal reached a rectal temperature greater than 39.5°C at critical heat stress degree (12 m: Dry Bulb temperature 39.2°C and RH 52%); even when skin temperature was between 37.0 and 37.6°C. Jersey animals showed lower rectal temperature than Holstein heifers around 12 md since they had smaller body mass, less dry matter intake and less digestive heat production based on their metabolic body size [5] and its predictive dry matter intake [15]. Other advantages of Jersey heifers were less thermal body insulation and less skin surface to gain heat from direct solar radiation. Both breeds were not different on the skin width ($P > 0.05$), but they were different by weight ($P < 0.01$).

Open heifers in both breeds showed a higher rectal temperature in the morning since they had lower body weight and lower surface area. None pregnant heifers presented less body water content and therefore their thermal body capacities were lower [5] [21] [76]. Hence, the exposure to tropical heat stress will produce a greater thermal body load and greater heat shock, at least, across the morning when Dry Bulb Temperatures (DBT) and direct solar radiation are increasing from 06 to 12 md. After comparing pregnant and open acclimatized Holstein and Jersey heifers based on rectal temperature and respiratory activity responses against daytime heat stress in the morning, it was observed that gestation is a process that allowed systemic and body composition adjustments that helped the heifer mother and the calf to have a lower thermal body response under the influence of middle and severe heat stress.

Daytime trends for rectal temperature in Holstein and Jersey heifers showed two phases in open and pregnant animals according to type of thermal response based on body temperature and body heat load; showing a thermal alteration and resulting in a slight hyperthermia. Pregnant Holstein and Jersey heifers showed lower thermal increments than open Holstein and Jersey heifers between 06 am and 12 md. This thermal trend occurred when THI at 06 am, 09 am and 12 md were 75.14, 76.36 and 90.79. However, the major environmental thermal change and pressure occurred between 09 am and 12 md; where, THI increased at the rate of +4.81°C%/hour; reaching the highest environmental heat shock.

The highest THI coincided with the highest rectal temperature in acclimatized pregnant Holstein (39.2°C) and Jersey heifers (39.0°C). The highest body temperature increased at a lower rate in pregnant Holstein and Jersey heifers; since they were heavier and showed a higher caloric heat capacity as described by Araúz *et al.*, [3] [4]. As consequence, pregnant animals maintain a lower change in rectal

temperature in the morning when comparing them to open heifers in both breeds.

Pregnant animals in both breed showed a higher rectal temperature than in open heifers, which was sustained in the afternoon. Thermal overload was influenced by the reproductive status; which indicates that heat stress can affect more in the afternoon because animals developed hyperthermia, hyperpnea and some fatigue trying to maintain normothermia.

Thermolysis is accompanied by skin artery and venous vasodilation, which increases blood irrigation to tegumentary tissues and increases epidermal temperature; which facilitates a greater thermal difference between the environment and the tegumentary surface [5] [85]. This influences caloric heat flux by sensitive and none sensitive heat losses to the environment to maintain thermal balance closer to normothermia under mild or severe heat stress. Water composition in the body is very important for thermolysis, which in ruminants is about 68.5% and ranges from 51% to 81% [51] [52]. The amount and proportion of water and dry matter in the body influence caloric heat capacity and it depends on the specific heat of water (1.0 kcal/kg°C) and the specific heat of dry matter is 0.4 Kcal/kg°C adjusted by total body mass [3] [4]. Therefore, caloric heat capacity and body temperature will determine caloric heat content; as well as body heat overload based on thermal alteration in dairy animals under heat stress [4] [27] [85] and thermolysis [7].

3.4. Hyperthermia, Daytime Heat Overload and Thermal Correlations

The body temperature is one of the clinical signs used to recognize a healthy state in the homeotherms in animal production. However, this physiological indicator of body heat could be used to indicate the degree of daytime alteration in animals under heat stress, according to production, grazing and locomotion under solar influences and stressful managing practices [4] [82].

Body temperature alteration across daytime in the none pregnant Holstein heifers showed the highest temperature overload averaging +1.35°C every three hours, followed by pregnant Holstein heifers averaging +1.05°C. Jersey animals showed the lowest thermal alteration; resulting +0.60°C and pregnant heifers +0.78°C. It seems that higher body mass represents an advantage because of greater water content and caloric capacity. However, once the heat stress increased in the daytime hours, weightier heifers were less efficient in maintaining normothermia because of greater body insulation, heat production, feed intake and greater surface area for solar radiation; which limited thermolysis, increased body heat retention, potentiated thermal alteration and developed higher moderate hyperthermia than jersey heifers.

Smaller heifers presented a better chance to maintain the thermal balance closer to normal temperature in comparison to heavier animals. The highest alteration of body temperature occurred at 12 md (open Holstein +1.5°C and pregnant Holstein +1.3°C), which is a relative alteration of 3.89 and 3.41% based on rectal temperature at 06 am. Hyperthermia was smaller in jersey heifers than in Holstein

animals. Open jersey showed the maximum thermal body alteration at 12 md (+0.8°C) and pregnant animals +1.0°C; which corresponded to 2.09 and 2.63% over the physiological temperature taken at 06 am.

Body heat overload in dairy cattle under heat stress could be expressed in a short moment since caloric balance is dynamic according to sensitive and none sensitive mechanisms and ways for caloric energy flux [4] [5] [7]. In the present study, thermal body alteration showed the thermal stage of body heat overload, since rectal temperature was greater than 38.6°C; indicated as the upper normal body temperature for bovines [4] [33] [52]. The body caloric capacities in pregnant and open Holstein heifers were 293.07 and 306.43 kcal/°C and maximum overload heat alterations were 293.07 and 459.65 kcal according to maximum body temperature alteration. Pregnant and open jersey heifers showed a body caloric capacity of 235.21 and 216.23 Kcal/°C and maximum caloric overload alteration were 211.68 and 129.74 kcal. Hyperthermia can be a different thermal condition in heifers according to their weight, reproductive status, physiological capacity to perform thermolysis and environmental caloric conditions. Alteration of body temperature demonstrated that acclimatized Holstein heifers were more sensitive to heat stress based on their capacity to maintain normothermia. Jersey heifers presented lower body thermal displacement; corresponding to 57.41% in none pregnant animals (Jersey vs Holstein) and 73.81% of thermal alteration in pregnant Holstein and Jersey.

The changes in daytime body temperature and THI across daytime behaved in parallelisms in both breeds and reproductive status according to the increasing heat stress degree. The correlations between rectal temperature and THI in open and pregnant Holstein heifers were 0.72 ($P < 0.01$) and 0.74 ($P < 0.01$). At the mind time, open and pregnant Jersey heifers showed a correlation 0.86 ($P < 0.01$) and 0.67 ($P < 0.01$). It means that rectal temperature increased as THI increased until 12 md. Both rectal temperature and THI showed curvilinear trends across daytime hours; however, rectal temperature in pregnant Holstein and Jersey stayed with little reduction in the afternoon, because hyperthermia was higher than in open Holstein and Jersey heifers.

This study demonstrated that acclimatization in Holstein and Jersey heifers helped them to develop chronic systemic accommodation and become less heat sensitive to severe heat stress since body thermal temperature was not greater than 39.4°C under the highest caloric pressure. It represents a good physiological point to mitigate somehow the influence of heat stress in the tropics. In addition, acclimatization could be combined with other strategies as proposed by Beede and Collier [19], West [8], Baumgard *et al.* [9] and Gupta *et al.* [27], in order to mitigate the negative influences on dairy cattle, even under the tropics. Finally, strategies including nutrition, feeding, environmental physical improvements (shade, forced ventilation), reproductive control and management are useful to reduce and/or prevent exposure of animals to direct solar radiation in order to maintain normal body temperature in dairy cattle and provide comfort and welfare under

any condition related to heat stress. Nevertheless, better results will be observed if all those strategies are accompanied by acclimatization and systemic adaptations in dairy animals such as in pregnant and open Holstein and Jersey heifers under heat stress in the summer of tropical environment.

4. Conclusions

Daytime hours in the tropical climate at low altitude presented changes in the psychrometric elements such as ambient temperature, relative humidity, enthalpy and direct solar radiation, THI and adjusted THI; which guarantee daily severe heat stress for dairy cattle during summer time.

The critical hours for developing heat stress were detected around midday, but ranged about six hours from 09 am to 03 pm based on environmental characterization and physiological alterations in rectal temperature and respiratory rate; which was confirmed by the temperature humidity Index and heat stress index in the animals when overall thermolysis was not enough to maintain normothermia under severe daily heat stress and then moderate hyperthermia and hyperpnea were developed in both breeds and reproductive status.

The degree of physiological alterations in Holstein and Jersey heifers occurred from middle to severe heat stress trough daytime in the summer, but Holstein animals were more affected than Jersey based on body temperature and respiratory rate. The Jersey heifers showed fewer thermal alterations and lower hyperthermy than in Holstein animals.

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Bioethic, Biosecurity and Animal Welfare

Animals were treated in this experiment under normal management techniques and all activities were planned to guarantee nutrition, health, vaccination and prevention of clostridia diseases, parasite control, applications of drugs, use of individual and sterile injection needles, recommended dosages as laboratory instructions adjusted by weight and physiological evaluations were done carefully and without stress. Health status of animals was checked and followed by Dr David Berroa, which is a licensed veterinarian in Panama, whose professional veterinarian ID is 336 for Veterinary Medicine and Animal Husbandry.

Authors' Contributions

EEAS: Planned and conducted the experiment, defined the feeding program for calves and heifers, gave technical support for raising calves and heifers, directed building pens, measured the psychrometric, thermal and respiratory indicators, built data matrix, developed statistical analysis, wrote the manuscript and introduce adjustments in the article. ERVE participated in the experiment measuring part of physiological and psychrometric parameters and managing animals. The health program was established and supervise by Dr David Berroa P., who is a veterinarian certified in Panamá with a professional ID number 336. BGMA, RGMM, GAC and DBP: Reviewed the manuscript and made important observations and critical scientific corrections in order to improve the scientific content and presentation of the final manuscript.

Conflicts of Interest

All authors read and approved the final manuscript. The authors also declared no conflicts of interest in this article.

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