Physiological and Behavioral Changes of Water Buffalo in Hot and Cold Systems: Review

Ariadna Yáñez-Pizaña[1], Luis Alberto de la Cruz-Cruz[1], Ariel Tarazona-Morales[2], Patricia Roldan-Santiago[3], G. Ballesteros-Rodea[4], Raym Pineda-Reyes[4] and Héctor Orozco-Gregorio[4,*]

[1]*Escuela de Ciencias de la Salud, Medicina Veterinaria y Zootecnia, Universidad del Valle de México-Coyoacán, Calzada de Tlalpan 04910, CDMX, México*

[2]*Departamento de Producción Animal, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, C.P. 050034, Medellín, Colombia*

[3]*Departamento de Reproducción, Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México, Av. Universidad, Colonia, C.U. C.P. 04510 Ciudad de México, México*

[4]*Facultad de Agronomía y Veterinaria, Universidad Autónoma de San Luis Potosí (UASLP), San Luis Potosí 78321, México*

Abstract: This review's objective is to provide information on the mechanisms that buffaloes express during the thermoregulation process. Generally, the water buffalo is associated with warm and tropical climates. In these systems, the combination of high temperature, relative humidity, and radiation cause different physiological and behavioral changes, particularly during the summer months. Wallowing behavior in water or mud promotes heat dissipation through physical mechanisms, such as conduction, convection, and radiation. Furthermore, the provision of natural or artificial shades contributes to thermoregulation and maintains homeostasis. In production systems in cold climates, the wallowing behavior is inhibited by the water temperature, so it is important to keep the animals protected in stables to avoid the cold winds and rapid drops in temperature, causing increased illness pneumonia and sometimes death. Finally, in cold conditions, the animals require an appropriate diet since the use of energy is distributed mainly for the production of heat. Thus, heat stress and cold stress generates relevant problems in health, welfare, and productivity in water buffaloes. A comprehensive assessment of the severity of the resulting problems associated with thermal stress and specialty in cold stress in water buffaloes is necessary so far, and there's very little information about it in this species.

Keywords: Cold stress, thermal stress, microclimate, behavior, welfare.

1. INTRODUCTION

The domestic buffalo (*Bubalus bubalis*) is a multipurpose species (meat, milk, work) that presents two types (river and swamp) [1]. Water buffalo are well adapted to swamps and areas subject to flooding. Thus, they are most well suited for the marshes of southern Iraq and the Amazon, the tidal plains near Darwin, Australia, the Pontine Marshes in south-central Italy, the Orinoco Basin of Venezuela, and other areas [2]**.** This species evolved by natural selection in hostile environments and was adapting to various environmental factors thanks to its morphological characteristics that allow them to be biologically successful in these environments [3–5].

Although globally, the water buffalo is associated with tropical and subtropical systems [6,7]. They also have an enormous tolerance to cold climates than is commonly assumed; for example, in some places, such as Kandep in Papua, New Guinea, buffaloes are productive at 2,500 m above sea level. While in Nepal, they usually breed up to 2,800 m of altitude or more [8,9]. Likewise, buffaloes have been raised for centuries in countries with a temperate climate such as Italy, Greece, Yugoslavia, Bulgaria, Hungary, Romania and they also remain in the high and snowy plateaus of Turkey and Iran, as well as in Afghanistan and the mountains from northern Pakistan [8]. Most buffaloes in Europe are of the Mediterranean breed, but other river buffaloes (Murrah breed) have been introduced in Bulgaria, Azerbaijan, and Georgia indicating that they have some tolerance to cold [9,10].

However, thermal shocks due to winds and rapid drops in temperature, as well as sudden increases in temperature, relative humidity, and solar radiation, can produce heat stress, increased susceptibility to diseases, and sometimes cause high mortality rates [9,10]. When animals are exposed an environmental challenge, they are likely to respond to them with a variety of related mechanisms including physiological, biochemical, immunological, anatomical, and

*Address correspondence to this author at the Facultad de Agronomía y Veterinaria, Universidad Autónoma de San Luis Potosí (UASLP), Km. 14.5 Carretera San Luis Potosí, Matehuala Ejido Palma de la Cruz CP. 78321 Soledad de Graciano Sánchez, México; Tel: (+52) (444) 852-40-56 al 60; E-mail: hector.orozco@uaslp.mx

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behavioral changes [11,12]. Therefore, the objective of this review is to provide information on the mechanisms that buffalo express during the thermoregulation process. Likewise, relate the effect that thermal stress has, both cold and heat, on the productivity of this species.

2. BUFFALO RESISTANCE TO DIFFERENT CLIMATIC CONDITIONS

Water buffaloes, like cattle, are homeothermic animals because they keep their body temperature relatively constant and endothermic because they use the heat produced by their own metabolism to keep their body temperature constant [13]. For all mammals there is an environmental temperature at which they can maintain their body temperature within normal limits, called a thermoneutral zone that includes the ranges of environmental conditions under which an animal can regulate heat loss with minimal energy expenditure [14,15]. The thermal comfort zone for most farm animals is between 4 and 25 ° C [15]. In the case of buffaloes, there is not much precise data to determine what the comfort temperature is. In this regard, Payne [16] mentions that the optimal climatic conditions for growth and reproduction in buffaloes are: temperatures of 13–18 ° C combined with an average relative humidity of 55–65%, on the other hand, Crudeli [17] estimates that the comfort temperature would be at 21º C. In the case of calves, the thermoneutral zone has been reported to be in a range of 15 to 25 ° C [18] and the lowest critical temperature varies from 9 to 15 ° C at birth and during the two first weeks of life [19]. Therefore, it is important to use clean and dry body covers, hot boxes or warm water baths to prevent cold stress [20].

Body temperature is a reflection of the balance between heat gain (due to heat absorption from the environment and metabolic activity), nevertheless, thermal stress occurs when the ability to eliminate or gain heat is above or below the body's temperature, during this process there is activation of physiological mechanisms to maintain the thermal balance of the animal's body [10,21]. In hot and dry climates, low humidity determines intense heat loss by evaporation, however, in buffaloes this characteristic is limited by the low number of sweat glands [4]. In addition, dark skin and a poor coat of hair favor greater heat absorption, which together with a smaller amount of sweat glands produce low heat dissipation capacity under these conditions [22,23]. On the other hand, in hot and humid climates, the high humidity combined with diurnal temperature changes, evaporative heat loss is not effective [4]. Therefore, buffaloes resort to other ways to be able to thermoregulate, mainly behavioral changes such as wallowing and adjustment to the investment of time by performing other behaviors [1] (Figure **1A**, **B**). Nevertheless, the condition of the coat of hair (density, condition, etc.) has been shown to be of vital importance for thermoregulation in all bovines in cold climates [10]. Wet tangled layers of hair dramatically reduce an animal's thermoregulatory capacity; therefore a dense layer is important to catch hot air and maintaining body temperature in cold climates [24]. Buffaloes are born with soft fur that thins as they grow in response to weather, housing practices, and exposure to mud and water, as well as genetic factors [10]. Buffalo raised in tropical and subtropical environments are left with little or no fur for adulthood and depend on solar radiation to stay adequately warm. Nevertheless, buffaloes found in colder climates (such as the snowy plateaus of Afghanistan) retain their fur, and this coat serves a vital purpose in keeping the temperature within the optimal range [5].

3. PHYSIOLOGICAL CHANGES DUE TO THE EFFECT OF HEAT STRESS

The adaptability of buffaloes to heat is a complex process that depends on the integrity of various systems such as the respiratory, circulatory, excretory, nervous, endocrine, and enzymatic systems [10,25]. To regulate body temperature, animals need different temperature receptors (thermal sensors), which are located on the skin surface (peripheral receptors), in the preoptic region of the hypothalamus (central receptors) and in other parts of the body (deep receptors), in the abdominal viscera and in or around the large veins of the upper abdomen and thorax [26] (Figure **1**). Skin thermoreceptors have been shown to be polymodal because they not only respond to thermal stimuli, but also respond to different measures to other types of stimuli, such as mechanical and chemical stimuli [27].

The best studied thermoreceptors are those of the skin and consist mainly of neurons classified as Aβ, Aδ (both myelinated) and C (no myelinated). These neurons act as thermal sensors that monitor body temperature, these thermoreceptors allow, in the case of mammals, to discriminate temperatures in the range of -10 ° C (perceived as extremely cold) to 60 ° C (perceived as extremely hot) [27-29] (Figure **1**). Neurons that sense heat project to the midbrain lateral

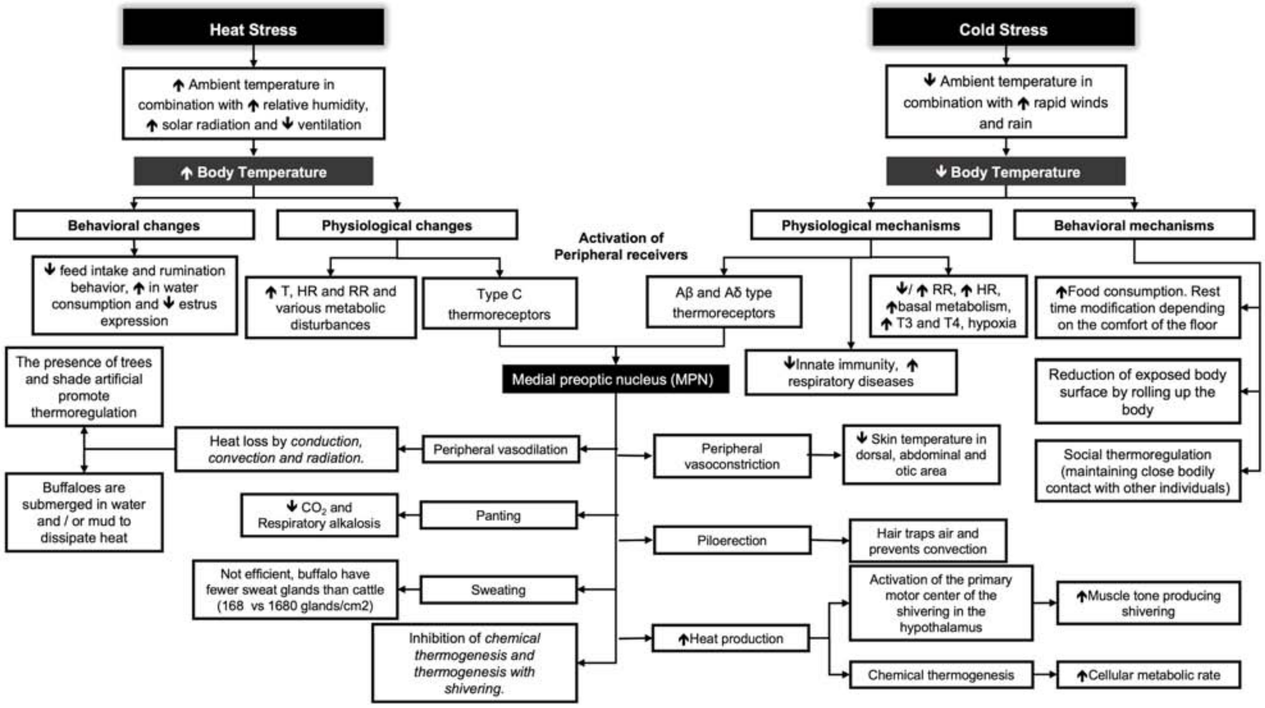

Figure 1: Thermoregulation mechanisms of the water buffalo in hot and cold conditions.

parabrachial nucleus (LPB), specifically to the dorsal LPB subnucleus (DLPB). DLPB neurons are tertiary afferent neurons that in turn project into the preoptic area of the hypothalamus (POA), primarily the medial preoptic nucleus (MPO) [30,31].

Once the information from the internal and external environment in this area (MPO) is integrated, the main mechanism for thermoregulation is the activation of the blood vessels in the skin. These are controlled by sympathetic postganglionic neurons that secrete adrenaline and norepinephrine (adrenergic system), as well as by sympathetic postganglionic neurons that secrete acetylcholine (cholinergic system), responsible for the activation of the sudoriferous glands [14,23]. In particular, buffaloes in hot conditions increase blood volume and flow to the skin's surface to maintain high skin temperature and facilitate heat dissipation by physical mechanisms [4,32] such like radiation, where heat is lost from the body's surface to a cooler object; by convection by heating the air or water around them; by evaporation of respiratory secretions, sweating or saliva, and by conduction to cooler surfaces with which the animal comes in contact, in addition a small amount of heat is also lost with urine and feces [14] (Figure **1**).

Among the physiological reactions, rectal temperature and respiratory rate have been observed to represent some of the indices for evaluating the degree of heat stress [33]. Mouth breathing or panting are important mechanisms for the dissipation of body heat in animals. Regarding this, Silanikove [34] mentions that measuring the respiration rate seems to be the most accessible and easiest approach to evaluate the degree of heat stress, considering it a low degree of stress when animals present: between 40 to 60 breaths per minute, medium high degree of stress: between 60 to 80, high degree of stress: between 80 to 120, and severe stress: more than 150 breaths per minute in cattle [34]. Experimental studies showed that exposure to acute heat (33–43 ° C, 40–60% RH) in 6-month and 12-month-old buffalo calves caused significant increases in rectal temperature (3.4 and 3.2%) and respiratory rate (495 and 335%, respectively) [35].

In a study conducted in India by Singh *et al*. [36] observed the increase in respiratory rate (19 breaths / minute), and blood flow (5, 15, and 17 units in the dorsal, abdominal, and middle ear areas, respectively) in Murrah buffaloes during the summer (environmental temperature: 45 ° C). Respiratory rate is influenced by ambient temperature, solar radiation, relative humidity, and wind speed. Among these, ambient temperature has been found to be the most influential factor [36].

4. BEHAVIORAL CHANGES DUE TO HEAT STRESS

Animals also use different behavioral mechanisms to resist heat overload. In situations of heat stress, food consumption and rumination behavior decrease despite having higher energy needs. This is because foraging, ingestion, digestion of food and absorption of nutrients are processes that generate heat. Therefore, the reduction in food consumption promote its thermoregulation [13,37]. Heat stress stimulates peripheral heat receptors to transmit suppressing nerve impulses to the appetite center present in the hypothalamus causing a decrease in food consumption [15] (Figure **1**), in this sense, it has been shown that buffaloes voluntarily reduce intake by 9-13% in hot conditions [38]. Likewise, Habeeb *et al*. [39], reported that heat stress conditions of 36 and 32 ° C caused a significant reduction in the daily body weight gain of buffalo calves in 22.6 and 16.5%, respectively, when compared to temperate climatic conditions (18 ° C). Furthermore, exposure to severe heat also suppresses the production of hormone-releasing factors from the hypothalamic centers, causing a decrease in hormonal secretion from the hypophysis and consequently decreases the secretion of thyroid hormones (T3 and T4) [15]. Such changes result in the deterioration of reproduction and production. Against this background, it has been observed that in buffalo calves (6 months old) and adults, exposure to heat (33–43 ° C, 40–60% RH) induced decreases in T3 plasma (35.2%) and T4 (17.5%) [35]. Increasing food intake for milk production also increases metabolic heat production. Therefore, in hot conditions, the most productive animals have more difficulties in dissipating heat, directly affecting milk production compared to less productive animals [40].

Conversely, water consumption can increase up to 40% during summer compared to winter, possibly as a mechanism to replenish water lost through evaporation and to cool the rumen-reticulum complex [12]. India is a tropical country with a hot and humid summer and a winter season. During the summer (May-June), the atmospheric temperature reaches 45 ° C during the day and 30 ° C at night and the photoperiod lasts up to 12-14 hours [41]. During a study conducted in that country, it was found that water consumption in Murrah buffaloes was up to 58% more in summer compared to the winter season where only 16% was recorded, while food consumption was 13% higher in the winter season compared to the summer [42].

Although buffaloes are considered polyestric, they exhibit seasonal variation in estrus expression, conception rate, and calving [7]. There are different climatic factors, which alone or in combination could explain the low productive performance of this species in the summer season. Heat stress causes an increase in prolactin levels, suppressing the secretion of gonadotropins, which triggers an alteration in ovarian steroidogenesis, expression of estrus and decreased conception rate [41,43,44] (Figure **1**).

Conversely, detection of estrus is more frequent in the cold season, since there are changes in hormonal patterns in females [8]. Previous studies carried out in India determined that an humidity temperature index (HTI) of 81 during the summer directly affected the pregnancy rate in Murrah buffaloes since it was only recorded at 25%, while at another time of year with an ITH of 66 it was recorded up to a 59% [7]. Other authors have found similar results, Reddy *et al*. [45] found a low conception rate in April compared to September, where the pregnancy rate was considered high (29 vs. 45%, respectively). Therefore, buffaloes will present better productive results in temperate climates [43]. In this context, García [46] mentions that the impact of heat stress on the female generates a decrease in sexual behavior, a low conception rate, a high embryonic mortality rate and a reduction in reproductive efficiency. In males, high temperatures can reduce libido, which is accompanied by a reduction in testosterone concentrations and ejaculate quality [47].

The use of space is another important thermoregulation mechanism and many animals increase the time they remain resting in the shade or shelters when the environmental temperature is high [1]. One of the behaviors that are modified by ambient heat is the increase in the resting time; the animals maximize the loss of heat from the surface of the body. In grazing systems, when buffaloes have free access to water, in the form of ponds, potholes, or natural pools buffaloes either dive into them or cover their bodies with mud (Figure **2A**, **B**). The mud on the animal's skin helps them to dissipate more heat for a longer time compared to water [12] (Figure **1**). This will allow them to quickly achieve thermal homeostasis due to heat loss through physical methods with a low energy cost [32].

In this context, in a study carried out in southeastern Italy, it was observed that during the summer, the proportion of time heifers spend submerged in water or mud is double that in other seasons [48]. Likewise, Napolitano *et al*. [48] point out that buffaloes spend the hottest hours of the day (10:00 a.m. to 2:00 p.m.) in the shade or submerged in water and that during the summer they spend more time in water ponds (43%) compared with spring and autumn (23 and 24%, respectively). Wallowing behavior can be evaluated from two points of view related to applied ethology; firstly, in relation to the natural behavior of this species to express thermoregulatory behavior and secondly, as protection against ectoparasites [49]. Nevertheless, a recent study found that free grazing buffaloes at Marshes are more susceptible and had a higher overall prevalence of infections than the other feeding types, because water wallowing provide a suitable environment for most of the parasites and their intermediate host to grow and propagate [50]. On the other hand, water buffalo in the Mesopotamian marshlands at Iraq spend 10 -12 h inside the marsh in summer to cool their bodies. Water buffalo graze in the marsh when the water temperature and quality is suitable for swimming and drinking, which means that grazing times during the day differ seasonally [51].

Studies in Thailand showed that thermoregulatory behavior generated an increase in the grazing time of animals compared to animals that do not have the possibility of expressing this behavior (601 vs. 525 min, respectively) [52]. Likewise, in a study carried out in India by Aggarwal and Singh [21], a higher consumption of food was found (45 vs. 41 kg) and a higher milk production (7.8 vs. 6.9 kg), as well as a lower plasma cortisol concentration. (2.60 vs 4.80 ng / ml) in buffaloes with access to ponds compared to animals that only had water baths. Likewise, Khongdee *et al*. [53] reported lower rectal temperatures (39 vs. 40 ° C), lower plasma cortisol (2.1 vs. 3.3 ng / ml) and a significant reduction in water consumption (29.7 vs. 34.1 L / head / day), accompanied due to an increase in forage consumption (5.8 vs. 6.4 kg / head / day) compared to buffaloes that did not have access to water ponds. Therefore, it has been concluded that the provision of water ponds has beneficial effects on the welfare of water buffaloes, since it allows them to express their thermoregulatory behavior [32,48,54]. In addition, bathing and immersing yourself in water ponds can generate beneficial effects evidenced by a greater number of social interactions (smelling and allogrooming), research (locomotion and exploration) and less inactive behaviors, promoting their welfare [37]. However, in some countries such as Australia, Trinidad and Malaysia, among others, buffaloes are productively efficient without expressing this behavior, as long as this behavior is replaced with the provision

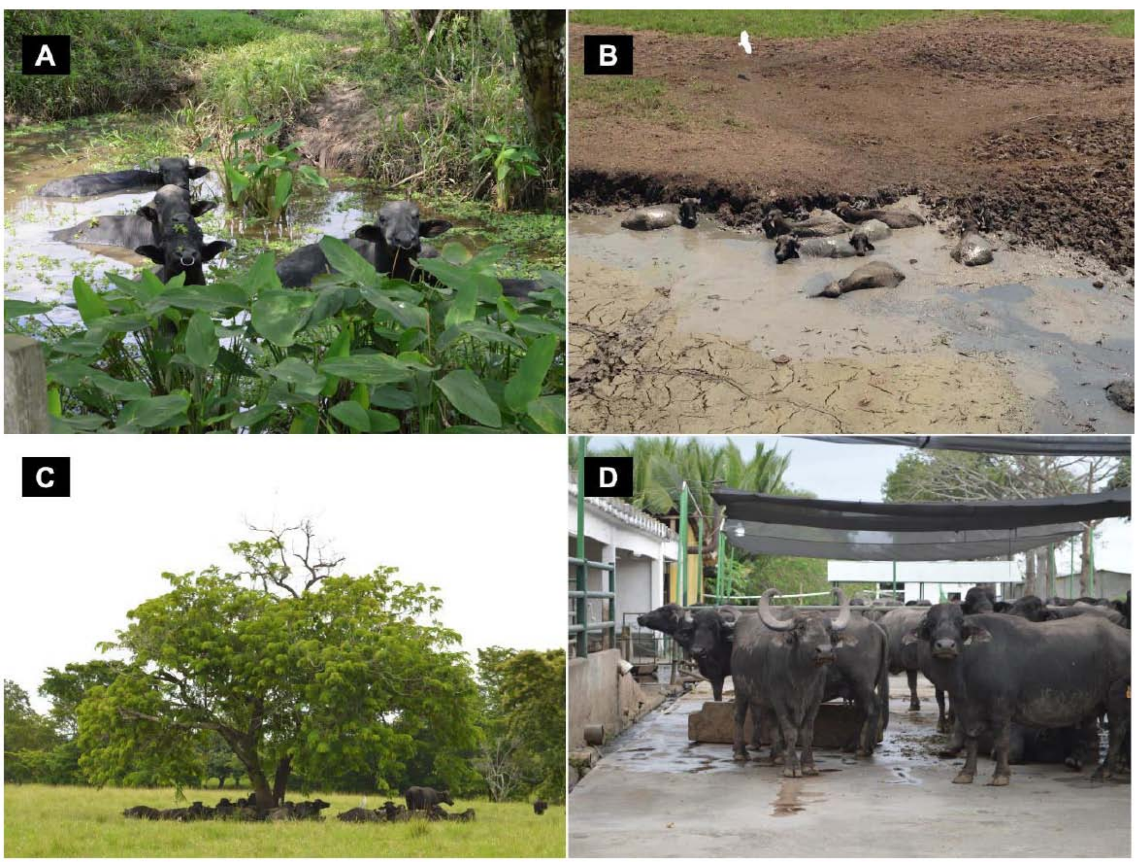

Figure 2: Thermoregulation mechanism in tropical systems. **A**) and **B**) A typical behavior in water buffalo is wallowing and bathing. In summer they spend more time in water ponds; **C**) and **D**) When they do not have water in the production systems, the provision of natural or artificial shade is essential for thermoregulation. Source: Luis A. de la Cruz-Cruz.

of shade and an environment very close to the thermoneutral zone [10,52]. Thus, in the absence of wallowing behavior, buffaloes seek shade to be able to thermoregulate effectively [32] (Figure **2C**, **D**).

In order to reduce the negative effects of tropical livestock farming on animals, studies have been carried out in the Amazon, where different agroforestry, agrosilvopastoral or silvopastoral systems (SPS) have been tested, with good results in raising the water buffalo [55–57] (Figure **3**). SPS are characterized by combining woody perennial plants (trees or shrubs), with herbaceous or fickle (grasses, herbaceous legumes and weeds) and the presence of animals [58,59]. In these areas, the air temperature under the tree tops can be between 2 to 3 ° C lower than that registered directly in the sun [60]. This can provide greater comfort to animals by mitigating the effects of heat stress, thus reducing energy loss due to thermolysis, for example, in a study with cattle, it was found that 71% of the observations of animals kept in SPS showed higher comfort indices, demonstrated with the measurement of heart rate and rectal temperature [61], also in cattle it has been shown that animals raised in SPS systems use energy better by spending less on traveling, increasing profits weight [62].

5. PHYSIOLOGICAL CHANGES DUE TO THE EFFECT OF COLD STRESS

The combination of cold winds, rain and a rapid drop in temperature is associated with hypothermia and respiratory diseases [63,64]. Therefore, it is important to provide facilities that protect animals from sudden changes in temperature (Figure **4A**). Torell *et al*. [65] describe the two etiologies of hypothermia reported in cattle: exposure (gradual) and immersion (acute). Exposure is characterized by a constant loss of body heat in a cold environment through respiration, evaporation, and the lack of an adequate coat of hair, body condition, or weather protection. It can affect all members of a population, but particularly juvenile, elderly, or poor body condition individuals. Immersion involves rapid loss of body heat due to a wet coat of hair in a cold environment. Immersion often occurs after birth or if animals are exposed to rainy and windy conditions [65] (Figure **1**).

Cold-sensing neurons (Aβ and Aδ) project into the midbrain lateral parabrachial nucleus (LPB), specifically to the lateral and central external subnuclei (LPBla and LPBc). The LPBla and LPBc neurons are tertiary afferent neurons that project in turn to the preoptic area of the hypothalamus (POA), mainly to the medial

Figure 3: Water buffalo in silvopastoral systems in Colombia. Source: Ariel Tarazona-Morales.

preoptic nucleus (MPO) [30,31]. Initially, heat is conserved through peripheral vasoconstriction, which is induced by the contraction of the vascular smooth muscle cells present in the cutaneous arterioles, resulting from the activation of the adrenergic system, causing a temperature gradient in the extremities and reducing the temperature of the skin, so that only a small thermal gradient remains to lose heat by radiation and convection [14] (Figure **1**).

Another mechanism to decrease heat loss is piloerection (erection of the hair of the skin due to the contraction of the small erector muscles of the hair or piloerectors that elevate the hair follicles above the rest of the skin and move it vertically), which generates insulation, the hair traps air and prevents convection, if cooling increases, metabolic heat production is also increased by thermogenesis with or without shivering [14]. In the dorso-medial portion of the posterior hypothalamus and near the wall of the third ventricle is a region designed the primary motor center of the shivering, this center is activated when the body temperature drops, even tenths of a degree, then transmits the signals causing shivering increasing the tone of skeletal muscles and facilitating the activity of the anterior motor neurons, producing shivering (Figure **1**). When the shiver is at its maximum, the body's heat production increases four to five times [14].

Increased sympathetic stimulation or circulating blood norepinephrine and adrenaline levels may induce an immediate increase in cellular metabolic rate. This effect is known as chemical thermogenesis, or shivering thermogenesis, where excess nutrients are oxidized and, consequently, release energy in the form of heat [14]. In this sense, thyroid hormones play an essential role in maintaining the basal metabolic rate. Cooling of the posterior and preoptic hypothalamic region increases the production of thyrotropin-releasing hormone (TRH). This hormone is transported by the portal vein to the adenohypophysis, where it stimulates the secretion of thyrotropin (thyroid stimulating hormone-TSH), this, in turn, stimulates a greater release of triiodothyronine (T3) and thyroxine (T4) by in the thyroid gland, this increase in T3 and T4 increases basal metabolism and promotes thermogenesis [14] (Figure **1**). In this context, it has been found that the T3 level remains at maximum levels in winter, decreasing in spring and reaching the lowest value in summer, both in buffaloes and in Holstein cattle [10]. Likewise, Bhat *et al*. [20] mention high levels of T3 and T4 (2.7 and 55.8 ng / ml, respectively) in Murrah calves at birth in cold climates, these high levels could be due to the effort of the calves to get used to these conditions.

Exposing buffaloes to low ambient temperatures causes a series of drastic changes in biological functions that include alteration in food consumption, efficiency, and utilization [5,10] (Figure **4B**). Calves are relatively sensitive to cold at birth, since the humidity of the fetal fluid added to the surface area, which is relatively greater than that of adults, generates a great loss of heat, which is not compensated by endogenous heat due to the lack of heat production in the absence even of ruminal fermentation [66]. Bhat *et al*. [20] mention that the winter climate in the northern region of India is quite severe due to the low environmental temperature (1-2 ºC), which causes high mortality and a low growth rate in buffalo calves causing losses economic. These same authors observed that the use of infrared lamps in Murrah calves caused a greater weight gain compared to calves that were not fitted with this type of lamps (31.2vs 25.1kg, respectively) [20].

Signs of a mild case of bovine hypothermia (core temperature below 37.8 ° C) include vigorous tremors with increased heart and respiratory rates, the nostrils and extremities will be cold, in severe cases they will be pale due to hypoxia and the reduction of tissue perfusion, in the severe stages of hypothermia, the tremors will stop and muscle stiffness will occur, likewise, the pulse and respiration begin to decrease as body temperature decreases and, at 34.5 ° C, the organs begin to cool and the metabolism of brain neurons is reduced, resulting in death; vital signs will be very difficult to detect if body temperature drops below 30 ° C [64].

6. BEHAVIORAL CHANGES DUE TO COLD STRESS

Water buffalo activities can be divided into two: winter and summer activities. Water buffalo are very sensitive to changes in water temperature, buffalo avoid entering the cool water in winter [51]. It has been observed that animals increase their food consumption when it is cold; this allows them to maintain a higher metabolic rate and, consequently, to increase heat production, which gives them greater tolerance to cold [13] (Figure **3B**). Webster *et al*. [67] mention that the main behavioral responses of cows to cold and wet conditions were reductions in resting and feeding time. Other authors Gonyou *et al*. [68]; Redbo *et al*. [69] and O'Driscoll *et al*. [70] mention that livestock exposed to cold seems to increase or decrease the resting time, in this sense, it has been suggested that the bed surface

Figure 4: Dairy buffaloes in intensive production systems in Quebec, Canada. **A**) Buffalo cows are housed in stables to protect them from sudden changes in temperature in winter; **B**) Water buffalo increase their food consumption to maintain a higher metabolic rate and increase heat production. Source: Luis Roberto Morales.

may be responsible for this difference, if the surface is wet, resting behavior is inhibited.

When there is cold stress, the energy ingested through food can be diverted towards the maintenance of functions for the generation of body heat (Figure **1**). In the Mesopotamian marshlands in the Middle East, local people provide fodder directly to the animals in their yards in winter. Thus, the amount of buffalo milk increases in the winter and trading milk and fodder becomes the dominant economic activity during winter and spring [51]. If food provision is not possible, capacity to produce heat is decreased and can generate various respiratory diseases, diarrhea in young animals, pneumonia and finally death [71]. The minimum critical temperature is defined as the ambient temperature below which the animal has to increase its heat production to prevent its body temperature from falling [41].

The reduction of the exposed body surface when the animal is rolled up also reduces heat loss by convection [14]. Also, social thermoregulation is a behavior that consists of maintaining close body contact with other individuals, so that the surface exposed to the environment decreases. In a way, by keeping very close together, animals acquire the thermal advantages of a very large animal, thus increasing its resistance to cold [13]. Vale [8] recommends that for buffalo kept in cold climates it is necessary to have a shelter that protects animals from rain, snow and strong winds, this can be a simple construction with a roof and three walls, this system It allows buffaloes to graze when the weather permits, it also points out that there should be a feeding area inside the shelter in case there are several days with low temperatures and in this case, a separate warm milking area is recommended (Figure **3A**). He also mentions that it is important to have access to a clean and dry straw bed and, in case the climate is extremely cold for several months with temperatures below 0 ° C (Caucasian or Balkan), it may be necessary to have heated stables [8].

7. CONCLUSIONS

Thermal stress generates significant problems in health, welfare and production in water buffaloes. Buffaloes have little capacity for heat tolerance; therefore, they are more prone to heat stress due to certain anatomical characteristics that make them more susceptible. Exposure to high temperatures in combination with high ambient humidity has negative effects associated with changes in biological functions. These changes have consequences at the behavioral level, in productive and reproductive performance. In cold climates the use of infrared lamps, protective jackets, hot boxes, clean and dry straw bedding, provide a favorable microclimate for calves during the winter in the first days of life. Finally, a comprehensive assessment of the severity of the resulting problems associated with cold weather in water buffalo is necessary as there is so far very little information about it in this species.

DECLARATIONS OF INTEREST

None.

CONTRIBUTORS

All authors must have materially participated in the research and/or article preparation.

REFERENCES

[1] de la Cruz-Cruz LA, Napolitano F, Berdugo-Gutiérrez JA, Tarazona-Morales AM, Toledo L. Comportamiento y bienestar del búfalo de agua. In: Mota RD, Velarde AC, Huertas-Canén S, Cajiao MN, editors. Bienestar animal una visión global en Iberoamérica. 3rd ed. España: Elsevier 2016; pp. 63-76.

[2] Abid H, Fazaa N, Al-Obaidi S, Al-Fartosi K, Radhi Z, Resan H, *et al*. Water buffalo in the Iraqi marshes. In Nature Iraq Status Report 2007. Sulaimani, Kurdistan, Iraq. (Accessed in 1 June 2020). http://www.natureiraq.org/uploads/9/2/7/0/9270858/status_report_buffalothiqar.pdf

[3] Upadhyay RC, Singh SV, Ashutosh. Impact of climate change on livestock. Indian Dairyman 2008; 60: 98-102.

[4] De Rosa G, Grasso F, Pacelli C, Napolitano F, Winckler C. The welfare of dairy buffalo. Ital J Anim Sci 2009; 8: 103-16. https://doi.org/10.4081/ijas.2009.s1.103

[5] Marai I, Habeeb A. Buffaloes reproductive and productive traits as affected by heat stress. Trop Subtrop Agro 2010; 12: 193-217.

[6] Barros DV, Ximenes Silva LK, Lourenco J de B, Almeida da Silva AO, Maciel e Silva AG, Franco IM, *et al*. Evaluation of thermal comfort, physiological, hematological, and seminal features of buffalo bulls in an artificial insemination station in a tropical environment. Trop Anim Health Prod 2015; 47: 805-13. https://doi.org/10.1007/s11250-015-0792-9

[7] Dash S, Chakravarty AK, Sah V, Jamuna V, Behera R, Kashyap N, *et al*. Influence of Temperature and Humidity on Pregnancy Rate of Murrah Buffaloes under Subtropical Climate. Asian-Australas J Anim Sci 2015; 28: 943-50. https://doi.org/10.5713/ajas.14.0825

[8] Vale WG. Effects of environment on buffalo reproduction. Ital J Anim Sci 2007; 6: 130-42. https://doi.org/10.4081/ijas.2007.s2.130

[9] Zava M. Anatomía y Fisiología. In: Zava M, editor. El búfalo doméstico. 1st ed. Argentina: Orientación Gráfica Editora 2011; pp. 39-60.

[10] Marai IFM, Haeeb AAM. Buffalo's biological functions as affected by heat stress - A review. Livest Sci 2010; 127: 89-109. https://doi.org/10.1016/j.livsci.2009.08.001

[11] Lenis-Sanin Y, Zuluaga-Cabrera AM, Tarazona-Morales AM. Adaptive responses to thermal stress in mammals. Rev Med Vet 2016; 31: 121-35. https://doi.org/10.19052/mv.3715

[12] Ratnakaran A, Sejian V, Sanjo J, Shalini V, Bagath M, Krishnan G, *et al*. Behavioral responses to livestock adaptation to heat stress challenges. Asian J Anim Sci 2017; 11: 1-13. https://doi.org/10.3923/ajas.2017.1.13

[13] Manteca X. Conducta de termorregulación y de alimentación. In: Manteca X, editor. Etología Veterinaria. 1st ed. España: Multimédica Ediciones Veterinarias 2009; pp. 75-110.

[14] Klein GB. Termorregulación. In: Klein GB, editor. Cunningham. Fisiología Veterinaria. 5th ed. España: Elsevier 2014; pp. 559-68.

[15] Habeeb A, Gad A, El-Tarabany A, Atta M. Negative effects of heat stress on growth and milk production of farm animals. J Anim Hus Dairy Sci 2018; 2: 1-12.

[16] Hill DH. Cattle and buffalo meat production in the tropic (Intermediate tropical agriculture series). 1st ed. London: Longman Science and Technology 1988.

[17] Crudeli G. Fisiología reproductiva del búfalo. Tec March 2011; 24: 74-81.

[18] Scanes C. Fundamentals of animal science. 1st ed. USA: Delmar Cengage Learning 2011.

[19] Phillips CJC. Principles of Cattle Production (Animal & Veterinary Science). 2nd ed. UK: CABI Publishing 2009.

[20] Bhat S, Kumar P, Kashyap N, Deshmukh B, Dige MS, Bhushan B, *et al*. Effect of heat shock protein 70 polymorphism on thermotolerance in Tharparkar cattle. Vet World 2016; 9: 113-7. https://doi.org/10.14202/vetworld.2016.113-117

[21] Aggarwal A, Singh M. Hormonal changes in heat-stressed Murrah buffaloes under two different cooling systems. Buffalo Bull 2010; 29: 1-6.

[22] Koga A, Chikamune T, Kanai Y, Homma H, Tajima A, Ishikawa N, *et al*. Effects of high environmental temperatures on some physicochemical parameters of blood and heat production in swamp buffaloes and holstein cattle. Anim Sci Technol 1991; 62: 1022-8. https://doi.org/10.2508/chikusan.62.1022

[23] Koga A, Kurata K, Ohata K, Nakajima M, Hirose H, Furukawa R, *et al*. Internal changes of blood compartment and heat distribution in swamp buffaloes under hot conditions: Comparative study of thermo-regulation in buffaloes and friesian cows. Asian-Australas J Anim Sci 1999; 12: 886-90. https://doi.org/10.5713/ajas.1999.886

[24] Schütz KE, Clark KV, Cox NR, Matthews LR, Tucker CB. Responses to short-term exposure to simulated rain and wind by dairy cattle: time budgets, shelter use, body temperature and feed intake. Animal Welf 2010; 19: 375-83.

[25] Das KS, Singh JK, Singh G, Upadhyay RC, Malik R, Oberoi PS. Heat stress alleviation in lactating buffaloes: Effect on physiological response, metabolic hormone, milk production and composition. Indian J Anim Sci 2014; 84: 275-80.

[26] Caballero-Chacón S. Sentido del tacto. In: Caballero-Chacón S, Villa-Godoy A, editors. Fisiología Veterinaria e Introducción a la Fisiología de los Procesos Productivos. 1st ed. México: Universidad Nacional Autónoma de México 2010; pp.113-18.

[27] Schepers RJ, Ringkamp M. Thermoreceptors and thermosensitive afferents. Neurosci Biobehav R 2010; 34: 177-84. https://doi.org/10.1016/j.neubiorev.2009.10.003

[28] Dhaka A, Viswanath V, Patapoutian A. TRP ion channels and temperature sensation. Annu Rev Neurosci 2006; 29: 135-61. https://doi.org/10.1146/annurev.neuro.29.051605.112958

[29] Lumpkin EA, Caterina MJ. Mechanisms of sensory transduction in the skin. Nat 2007; 445: 858-65. https://doi.org/10.1038/nature05662

[30] Romanovsky AA, Almeida MC, Garami A, Steiner AA, Norman MH, Morrison SF, *et al*. The Transient receptor potential vanilloid-1 channel in thermoregulation: a thermosensor it is not. Pharmacol Rev 2009; 61: 228-61. https://doi.org/10.1124/pr.109.001263

[31] Morrison SF, Madden CJ, Tupone D. Central neural regulation of brown adipose tissue thermogenesis and energy expenditure. Cell Metab 2014; 19: 741-56. https://doi.org/10.1016/j.cmet.2014.02.007

[32] Napolitano F, Pacelli C, Grasso F, Braghieri A, De Rosa G. The behaviour and welfare of buffaloes (Bubalus bubalis) in modern dairy enterprises. Animal 2013; 7: 1704-13. https://doi.org/10.1017/S1751731113001109

[33] Verma DN, Lal SN, Singh SP, Om Prakash. Effect of season on biological responses and productivity of buffaloes. Int J Anim Sci 2000; 15: 237-44.

[34] Silanikove N. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest Prod Sci 2000; 67: 1-18. https://doi.org/10.1016/S0301-6226(00)00162-7

[35] Aggarwal A, Upadhyay R. Thermorregulation. In: Aggarwal A, Upadhyay R, editors. Heat stress and animal productivity. 1 st ed. India: Springer Publishing 2013; p. 6. https://doi.org/10.1007/978-81-322-0879-2

[36] Singh A, Rajni D, Kumar Y, Parveen K, Upadhyay R. Physiological changes and blood flow in murrah buffaloes during summer and winter season. J Buffalo Sci 2014; 3: 1-7. https://doi.org/10.6000/1927-520X.2014.03.02.6

[37] Upadhyay R, Chaiyabutr N. Thermal balance in the buffalo species. The buffalo (bubalus bubalis) - Production and Research. 1st ed. Italy: Bentham Science Publishers 2017; pp. 105-44. https://doi.org/10.2174/97816810841761170100008

[38] Savsani H, Padodara R, Bhadaniya A, Kalariya V, Javia B, Ghodasara S, *et al*. impact of climate on feeding, production, and reproduction of animals-A Review. Agric Rev 2015; 36: 26-36. https://doi.org/10.5958/0976-0741.2015.00003.3

[39] Habeeb A, Fatma F, Osman S. Detection of heat adaptability using heat shock proteins and some hormones in Egyptian buffalo calves. Egyptian J Appl Sci 2007; 22: 28-53.

[40] Zava MA. El búfalo doméstico. 1st ed. Argentina: OGE-INTA; 2011.

[41] Kumar S, Kumar P, Harikrishna C, Rani M. Effect of stress on production and reproduction performance of buffaloes- A review. Pharma Innov J 2018; 7: 629-33.

[42] Sharma A, Kundu SS, Tariq H, Mahesh MS, Gautam S, Singh S. Predicting water intake of lactating riverine buffaloes under tropical climate. Livest Sci 2016; 191: 187-90. https://doi.org/10.1016/j.livsci.2016.08.009

[43] Abayawansa WD, Prabhakar S, Singh AK, Brar PS. Effect of climatic changes on reproductive performance of Murrah buffaloes in Punjab: A rertrospective analysis. Indian J Anim Sci 2011; 81: 334-9.

[44] Dash S, Chakravarty AK, Singh A, Behera R, Upadhyay A, Shivahre PR. Determination of critical heat stress zone for fertility traits using temperature humidity index in Murrah buffaloes. Indian J Anim Sci 2014; 84: 1181-4.

[45] Reddy AO, Ramesha KP, Rao MK. Effect of climate on the incidence of oestrus, conception and cycle length in Murrah buffaloes. Indian J Anim Sci 1999; 69: 485-9.

[46] Garcia A. Influência de fatores ambientais sobre as características reprodutivas de búfalos do rio (Bubalus bubalis). Rev Cienc Agr 2006; 45: 1-13.

[47] Andrabi SMH. Factors Affecting the Quality of Cryopreserved Buffalo (Bubalus bubalis) Bull Spermatozoa. Reprod Domest Anim 2009; 44: 552-69. https://doi.org/10.1111/j.1439-0531.2008.01240.x

[48] Napolitano F, Grasso F, Saltalamacchia F, Martiniello P, Bilancione A, Pacelli C, *et al*. Grazing behaviour of buffalo heifers. Ital J Animal Sci 2007; 6: 1256-9. https://doi.org/10.4081/ijas.2007.s2.1256

[49] Bracke MBM. Review of wallowing in pigs: Description of the behaviour and its motivational basis. Appl Anim Behav Sci 2011; 132: 1-13. https://doi.org/10.1016/j.applanim.2011.01.002

[50] Al-Jubury A, Jarullah B, Al-Jassim K, Badran M, Mahmmod Y. Prevalence and diffusion of gastrointestinal parasite infections in swamp water buffalo (Bubalus Bubalis) populations from marshlands of Iraq. J Buffalo Sci 2020; 9: 38-47.

[51] Fazaa NA, Dunn JC, Whittingham MJ. Evaluation of the ecosystem services of the central marsh in Southern Iraq. Baghdad Sci J 2018; 15: 369-80. https://doi.org/10.21123/bsj.15.4.369-380

[52] Somparn P, Gibb M, Vajrabukka C. Wallowing behaviour of swamp buffalo (Bubalus bubalis) heifers under continuous stocking during the summer in Northeastern Thailand. Buffalo J 2006; 1: 11-24.

[53] Khongdee T, Sripoon S, Vajrabukka C. The effects of high temperature and roof modification on physiological responses of swamp buffalo (Bubalus bubalis) in the tropics. Int J Biometeorol 2013; 57: 349-54. https://doi.org/10.1007/s00484-012-0557-3

[54] De Rosa G, Grasso F, Braghieri A, Bilancione A, Di Francia A, Napolitano F. Behavior and milk production of buffalo cows as affected by housing system. J Dairy Sci 2009; 92: 907-12. https://doi.org/10.3168/jds.2008-1157

[55] Castro AC, Lourenco-Junior JB, dos Santos NFA, Monteiro EMM, de Aviz MAB, Garcia AR. Sistema silvipastoril na Amazônia: ferramenta para elevar o desempenho produtivo de búfalos. Cien Rural 2008; 38: 2395-402. https://doi.org/10.1590/S0103-84782008000800050

[56] Joele MRSP, Lourenco LFH, Lourenco Junior JB, Araujo GS, Budel JCC, Garcia AR. Meat quality of buffaloes finished in traditional or silvopastoral system in the Brazilian Eastern Amazon. J Sci Food Agric 2017; 97: 1740-5. https://doi.org/10.1002/jsfa.7922

[57] da Silva JAR, de Araújo AA, Lourenço-Júnior JB, dos Santos NFA, Garcia AR, de Souza NB. Conforto térmico de búfalas em sistema silvipastoril na Amazônia Oriental. Pesq Agropec Bras 2011; 46: 1364-71. https://doi.org/10.1590/S0100-204X2011001000033

[58] Esperschuetz J, Balaine N, Clough T, Bulman S, Dickinson NM, Horswell J, *et al.* The potential of L. scoparium, K. robusta and P. radiata to mitigate N-losses in silvopastural systems. Environ Pollut 2017; 225: 12-9. https://doi.org/10.1016/j.envpol.2017.03.042

[59] Murgueitio E, Barahona R, Chará J, Flores M, Mauricio R, Molina J. The intensive silvopastoral systems in Latin America sustainable alternative to face climatic change in animal husbandry. Cuba Cienc Agríc 2015; 49: 541-54.

[60] Moraes-Júnior RJ, Garcia RA, dos Santos NFA, Nahúm BS, Lourenco-Junior B, de Aaraújo CV, *et al.* Conforto ambiental de bezerros bubalinos (*Bubalus bubalis* Linnaeus, 1758) em sistemas silvipastoris na Amazônia Oriental. Acta Amazon 2010; 40: 629-40. https://doi.org/10.1590/S0044-59672010000400001

[61] Garcia AR, Matos LB, Lourenco-Júnior JB, Nahúm BS, de Araújo CV, Santos AX. Variáveis fisiológicas de búfalas leiteiras criadas sob sombreamento em sistemas silvipastoris. Pesq Agropec Bras 2011; 46:1409-14. https://doi.org/10.1590/S0100-204X2011001000039

[62] Tarazona-Morales AM, Ceballos MC, Correa-Londoño G, Cuartas-Cardona CA, Naranjo Ramírez JF, Paranhos da Costa MJR. Welfare of cattle kept in intensive silvopastoral systems: A case report. Rev Bras Zootec 2017; 46: 478-88. https://doi.org/10.1590/s1806-92902017000600002

[63] Ahmad S, Tariq M. Heat stress management in water buffaloes: a review. In: Romero F, editor. Proceedings of the 9th World Buffalo Congress; 2010: Buenos Aires, Argentina: Facultad de Ciencias Veterinarias de la Universidad Nacional del Nordeste (UNNE) 2010; pp. 297-310.

[64] Khounsy S, Nampanya S, Inthavong P, Yang M, Khamboungheung B, Avery M, *et al.* Significant mortality of large ruminants due to hypothermia in northern and central Lao PDR. Trop Anim Health Prod 2012; 44: 835-42. https://doi.org/10.1007/s11250-011-9975-1

[65] Torell R, Kvasnicka B, Bruce B. Care of hypothermic (cold stressed) newborn beef cows. Available online: thecattlesite [serial on the internet]. 2008 Feb 29; [cited 2020 march 15]. Available from: https://www.unce.unr.edu/publications/files/ag/other/cl788.pdf

[66] Collier RJ, Beede DK, Thatcher WW, Israel LA, Wilcox CJ. Influences of environment and its modification on dairy animal health and production. J Dairy Sci 1982; 65: 2213-27. https://doi.org/10.3168/jds.S0022-0302(82)82484-3

[67] Webster JR, Stewart M, Rogers AR, Verkerk GA. Assessment of welfare from physiological and behavioural responses of New Zealand dairy cows exposed to cold and wet conditions. Animal Welf 2008; 17: 19-26.

[68] Gonyou H, Christopherson R, Young B. Effects of cold temperature and winter conditions on some aspects of behavior of feedlot cattle. Appl Anim Ethol 1979; 5: 113-24. https://doi.org/10.1016/0304-3762(79)90083-X

[69] Redbo I, Ehrlemark A, Redbo-Torstensson P. Behavioural responses to climatic demands of dairy heifers housed outdoors. Can J Anim Sci 2001; 81: 9-15. https://doi.org/10.4141/A00-071

[70] O'Driscoll K, Boyle L, Hanlon A. The effect of breed and housing system on dairy cow feeding and lying behaviour. Appl Anim Behav Sci 2009; 116: 156-62. https://doi.org/10.1016/j.applanim.2008.08.003

[71] Yung B. Ruminat cold stress: effect on production. J Anim Sci 1983; 57: 1601-7. https://doi.org/10.2527/jas1983.5761601x

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