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REVIEW

Productive and reproductive performance, behavior and physiology of cattle under heat stress conditions

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Abstract This review aimed to detail the main information pertinent to the physiological and behavioral mechanisms evidenced in cattle under heat stress conditions. Brazilian cattle-breeding represents the second largest herd in the world, promoting great impact on the country's exports. Throughout their adaptability, these animals were submitted to different environments, which directly influence productive and reproductive performance, seeking compensatory mechanisms to maintain body homeostasis. Therefore, we can consider that heat stress directly affects the physiological and behavioral responses of cattle subjected to high temperatures. Adaptability of breeds to tropics should be considered of extreme importance in the choice of a productive activity for cattle-breeding and, particularly, in hot environments.

Keywords: bioclimatology, cattle-breeding, physiology

Introduction

The productive chains of meat and milk in Brazil are two profitable segments developed by the second largest cattle herd in the world, with approximately 200 million head (Brazil 2016). However, the animals are submitted to several environments, which directly influence on productive and reproductive performance. Any change in micro or macroclimate that causes heat stress will lead to a consequent decrease in productive efficiency, minimizing economic gains.

In addition, animal production of any breeds and or fitness will depend on their success among the climatic elements. When the climate interferes improperly on homeostasis, the organism feels attacked and consequently produces a physiological response, seeking to restore body temperature and allow the proper use of energy by organism. This physiological response happens until the animal's capacity runs out. From that moment, the animal enters the state called stress. By definition, it is a state manifested by a non-specific syndrome, which consists of changes in the biological system (Muller 1989).

Under heat stress, there will be changes in the physiological variables of the animal, which will seek compensatory mechanisms to maintain body homeostasis, increasing respiratory rate, reduction in energy metabolism leading to a reduction in metabolic heat production and heat dissipation to environment, through radiation, conduction, convection and evaporation (Muller1989; Morais et al 2008). It is known that a tropical country denotes a wide climatic diversity, affecting directly on the livestock activities. Among them, cattle-breeding plays a prominent role, making this review necessary to approach the heat stress effects on cattle, especially in hot environments.

The objective of this review is to contribute in the academic field with pertinent and updated information on the physiological and behavioral mechanisms evidenced in cattle under heat stress conditions.

Water and feed intake

Water and feed intake are basic premises for the survival of any animal. With cattle is no different, when it comes to production these topics gain importance, as it is necessary the availability of water and food in quality, quantity and cost compatible with the desired productivity. Many authors consider, respectively, 3% and 10% as mean values of daily intake of dry matter and water for cattle. Factors such as breed, productive aptitude, productivity and climate affect these proportions (Jimenez Filho 2013, Ali et al 2015).

Valente et al (2015) when working with Nelore and Angus bulls confined in controlled environments demonstrated climate influence on feed intake. These animals were fed corn silage and concentrate, exposed to three environments: thermal comfort (25 °C and THI 72.6),

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low heat stress (29 °C and THI 76.4) and high heat stress (33 °C and THI 81.5). These authors observed the respective average daily dry matter intake: 36.2, 35.4 and 31.6 g/kg body weight for Angus and 29.1, 29.8 and 30.2 g/kg for Nellore breed. A statistically significant reduction was observed in the environment of greater heat stress on the part of the taurine cattle, which did not occur with the zebu cattle. However, the Angus dry matter intake was significantly higher compared to the Nelores in the thermoneutral environment and low heat stress. This may have occurred due to the higher productivity of the Angus, tied to the higher metabolic rate and consequent heat production in an environment with a thermal gradient unfavorable to its dissipation. In this case, there was reduction in feed intake as a way of reduce the metabolic heat production. Jimenez Filho (2013) cites the direct effect of heat on the satiety center in the hypothalamus, reducing dry matter intake, ruminal contractions and production of volatile fatty acids.

Nascimento et al (2014) analyzing the effect of heat waves on feed intake and milk yield in the Minas Gerais triangle (Brazil), observed deleterious effects in both variables studied. While Nejad et al (2015) compared the effect of water restriction during two hours post feed and the free access on daily water and dry matter intake in Holstein dairy cows. This animals showed average live weight of 657 kg, high milk yield, confined in an area with shade available, under heat stress and THI higher than 80. Daily intake averages for the first group of 20.9 kg and 87.9 L and for the second group of 21.8 kg and 90.6 L were observed and showing no statistically significant differences. In this study, the physiological variables that were probably triggered for homeostasis were not evaluated, certainly if the period of water deprivation was greater, the changes could be more drastic.

Still on the study conducted by Valente et al (2015) water intake was also evaluated, showing no influence of the environmental conditions on this variable, but revealed a difference between the genetic groups, where Angus breed showed higher water intake in all environments. According to Ali et al (2015), working with dairy cows in a thermoneutral environment, water intake is directly related to dry matter intake, which explains the higher intake in the first two groups of Angus, but this relation was not repeated in the last group. Jimenez Filho (2013), considering the increase of water intake as a response to heat stress due to its direct action on rumen-reticular cooling and as a key element of body thermolysis through sweating and respiratory rate.

Pereyra et al. (2010) studying Holstein cows in the Buenos Aires region during the summer, between 450 and 550 kg live weight in the last third of the lactation cycle. Daily average milk yield of 14 L and these animals grazed in the picket of alfalfa without shade. The number of visits to the drinking fountain, water intake and the number of cows that did so were evaluated. A higher number of visits to the drinking fountain (53.2%) was observed in the warmer period and lower when the temperature and humidity index was milder (2.3%), emphasizing the interference of heat stress in the water intake (Table 1). On the other hand, Nejad et al (2015) cite that the water restriction can optimize the digestion due to the longer time under action of the ruminal microbiota on the food.

Behavior

Among the behavioral changes of cattle under heat stress conditions are those that alter their needs and temporary preferences (Table 1) (Ferreira et al 2014). Adopting strategies that aim to minimize the heat daily production, through the reduction of the water and feed intake, search for shade or decrease of movement (Silva 2013). It is also worth noting the decrease in rumination time, since this process leads to high metabolic heat production. Thus, cattle tend to adjust the rumination period according to the environmental temperature, so they start to do so during the night, in the mild environment, seeking to stay in upright and ruminating for longest time, thus favoring heat exchange with the environment (Malafaia et al 2011).

Another behavioral response during heat stress is the reduction in grazing frequency at warmer times, as well as the amount of feed ingested at end of day, which can decrease up to 30% of consumption. There is a change in the food pattern, whose cattle seek to favor the consumption of daily small portions, selecting food of greater nutritive value during grazing, then grazing during the night period under a lower temperature (Silanikove 1992; Malafaia et al 2011; Vilela et al 2013; Rossarolla 2007).

Animals kept under thermal stress avoid exposure to direct solar radiation seeking out mainly shady places. They seek to explore humid places, isolate themselves from their companions, and move members away in order to increase body surface aiming heat exchange with the convective environment. They can also adopt the routine of being immersed in water, as well as increasing water frequency and intake, mainly during the hottest hours of day (Coimbra et al 2007, Silva et al 2012, Vilela et al 2013).

Oliveira et al (2014) evaluated the amount of short-wave solar radiation willingly tolerated by lactating cows in semi-arid climate. They observed that the frequency of these animals exposed to sun reduced as the radiation level increased. The grazing intensity was more intense at low and moderately low levels and that cows avoided grazing at high and very high radiation levels. The authors also concluded in this study that the critical short-wave solar radiation level that motivates cows to stop grazing and seek shade was between 500 and 700 W m^{-2}. These results demonstrate that

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the intensity of solar radiation directly influences dairy cows behaviors.

Table 1 Changes in productive, reproductive, behavioral and physiological variables of cattle under heat stress conditions.

Variable	Changes	Reference
Water and feed intake	- Reduction of dry matter intake - Increase in water intake	Valente et al (2015); Pereyra et al (2010)
Behavior	- Reducing sun exposure and search for shaded environments - Reduction of movement - Reduction of rumination, ruminar parado - Graze to night - Idleness	Oliveira et al (2014); Silva (2013); Malafaia et al (2011); Vilela et al (2013); Ferreira et al (2014); Titto (2006)
Reproduction and reproductive efficiency	- Reduced fertility (males and females) - Increased internal uterine temperature - Reduction of nutrient availability in the uterus and gestation rate - Embryonic loss - Reduction in semen quality, motility, vigor and number of live spermatozoa - Libido and reproductive performance reduced	Ferro et al (2010); Rensis e Scaramuzzi (2003); Couto (2003); Gabaldi e Wolff (2002); Santiago (2006); Gabaldi (2000)
Rumen physiology	- Factor predisposing to ruminal acidosis	West et al (1987)
Body growth and development	- Fetal growth rhythm is affected - Acquisition of immunity and weaning weight reduced - Welfare reduced, high mortality, weight gain and productive performance compromised	Azevêdo e Alves (2009); Tao et al (2012); Monteiro et al (2014); Roland et al (2016)
Meat and milk production	- Milk production reduced - Productive potential reduced - Longer time to reach ideal weight	Collier et al (2014); Barbosa et al (2004); Rodrigues et al (2010); Scholtz et al (2013); Mitlöhner et al (2001)

Another behavior of cattle is idleness (activities that do not include feeding and rumination). There is an increase in idleness time under higher solar radiation. When the animals seek shade and restrict activities during the hottest hours of day, aiming at resting or lying down. Studies indicates that cattle spend more time in upright during rest as an way of seeking to expose a larger body surface to atmosphere to facilitate the heat loss (Ferreira et al 2014; Silva 2013). In a study conducted by Titto (2006), cattle in idleness with heat stress prefer to remain in upright in the hottest hours of day, a position that aid in the heat loss by convection.

Reproduction and reproductive efficiency

The deleterious effects on reproductive function induced by heat stress compromise the fertility of females and males (Table 1) (Ferro et al 2010). High body temperature results in increased uterine temperature, due the blood supply is directed to the body periphery to promote body heat loss, so the blood flow in the uterus is reduced. Consequently, there is a decrease in gestation rate, embryonic loss, and reduced availability of nutrients and hormones due to decreased blood supply to uterus. This makes the reproductive environment unsuitable for the sperm to fertilize the ovule and the embryo development (Santiago 2006; Ferro et al 2010).

In relation to the hormonal levels during heat stress, hypothalamic-pituitary-adrenal (HPA) stimulation with corticotrophin-releasing hormone (CRH) secretion by the hypothalamus stimulates the adrenocorticotropic hormone (ACTH) release by adeno-pituitary and increasing the release of glucocorticoids by the adrenal cortex (Ferro et al 2010; Vianna 2002). HHA axis stimulation changes the

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reproductive functions through the hypothalamic-pituitary-gonadal (HPG) axis, inhibiting the gonadotrophin releasing hormone (GnRH) secretion in the hypothalamus. As a consequence there is a suppression of follicle stimulating hormone (FSH) release and luteinizing hormone (LH) in the adenohypophysis, as also a hormonal imbalance in the gonads, leading to cell sensitivity reduction to the action of FSH and LH (estradiol suppression) (Rensis and Scaramuzzi 2003).

In response to hormonal alterations, there is a formation of less developed ovulatory follicles, due to the decrease in LH concentrations, leading to estradiol secretion reduction by the dominant follicle, causing ovarian dysfunction, reducing the duration and intensity of estrus signs, incidence of silent estrus and corpus luteum formation. Studies have shown that FSH is increased during heat stress due to lower production of plasma inhibin by the dominant follicle (Rensis and Scaramuzzi 2003).

Studies showed that heat stress influence on pregnancy rate in cows with sun exposure and not exposed, observed a pregnancy rate of 51.85% and 70.37% respectively. The main factor responsible for decreasing gestation level in cows under heat stress is embryonic mortality, and thus, the interruption of gestation occurs (Couto 2013).

With regard to heat stress effects on bulls, the following are observed: semen quality reduced; ejaculate concentration reduced; motility, vigor and counting of live spermatozoa decreased. Changes of functions of spermatogenesis and steroidogenesis, leading to testicular degeneration and fibrosis, and as result the sterility, sperm mutation, germinal epithelium degeneration and fertility decline (Gabaldi and Wolf 2002; Santiago 2006).

During periods of high temperatures, males decrease reproductive performance and their libido (Gabaldi 2000). The defects observed in external examination are testicular diameter changes, texture and mass (Ferro et al 2010, Gabaldi and Wolf 2002).

Rumen physiology

The rumen acts as fermentation chamber and is of fundamental importance in ruminant nutrition. Much of the energy consumed by these animals comes from the volatile fatty acids from the action of the saprophyte microbiota on dietary fiber, also serves as a source of protein through surplus microorganisms passage or that have fulfilled their biological cycle to other compartments of digestive tract, where their digestion and absorption occurs.

West et al (1987) cite heat stress as a predisposing factor to development of rumen acidosis in cattle and its consequences (laminitis, low milk fat, etc.) (Table 1). This occurs due to fact that pulmonary hyperventilation as a form of heat dissipation, reduces the blood concentration of CO_2, leading the body to promote the renal excretion of HCO_3 ions to avoid a metabolic alkalosis, maintaining an adequate relationship between HCO_3 and CO_2.

These authors emphasize that this mechanism decreases the amount of bicarbonate to be used in saliva as a rumen buffer in the rumen, also stressing that severe heat stress causes the animals to drool and lose more saliva and consequently the buffering power. In addition, reduction in feed intake showed by Cardoso et al (2016) also contributes to this, because rumination works as a stimulant of saliva production.

Beede and Collier (1986) affirm that it is necessary to supplement Na2CO3 in diets of animals that are being submitted to high levels of heat stress, serving as buffer agent in the ruminal environment, besides the induction of acetogenic agents able to balance the cation-anionic relation in the blood.

Body growth and development

According to Azevêdo and Alves (2009), fetal growth rhythm, at birth, before and after weaning, can be affected by temperature, relative humidity, wind speed and thermal radiation, which can lead to heat stress condition. Because these conditions affect feed intake, energy availability for production and maintenance functions is compromised (Table 1).

Tao et al (2012) evaluated heat stress effects on last forty-five days of gestation on the growth and immune function of calves and concluded that this condition negatively affected these variables from birth to calf weaning. Monteiro et al (2014) observed that heat stress during the last six weeks of gestation adversely affects the ability of calves to acquire passive immunity, regardless of whether or not colostrum is received. These authors also observed that calves weighed less from birth to sixty days of life than non-stressed calves. Therefore, it is clear that there is heat stress influence on growth and development of calves, mainly in relation to weight and immunity acquisition.

According to Roland et al (2016), heat stress on calves negatively affects the animal welfare condition, besides causing direct losses due to mortality and indirect costs due to reduction in weight gain, productive performance and long-term survival. In this way, heat stress interferes in the growth and development of calves, affecting their productive performance throughout the life.

Meat and milk production

Heat stress causes losses in milk production, since feed intake is reduced, with consequent decrease in metabolizable energy intake, and interference on physiological variables occurs as a way of maintaining thermoregulation (Barbosa et al 2004; Collier et al 2006, Rodrigues et al 2010). According to Baccari Júnior (2001) the reduction in feed intake increases according to the intensity of heat stress. Being exposed to a thermally stressful environment, the center of the appetite located in the hypothalamus is inhibited, resulting from the corporal hyperthermia.

Collier et al (2006) verified a lower rectal temperature of 0.5 °C and a lower respiratory rate of 28 breaths/min in dairy cows maintained in shaded environments compared to animals in unshaded environments. This resulted in a 10% higher milk production in those cows with shade access, proving greater efficiency in the milk production of animals in thermal comfort. These results corroborate with that observed by Martello et al (2004), who showed to decrease in rectal temperature and respiratory rate, as well as superior milk production in Dutch cows kept in climatized environments.

Most of the heat stress effects on dairy cattle are also observed in beef cattle (St-Pierre et al 2003), mainly due to reduced feed intake and feed conversion (Brown-Brandl et al 2006). It is known that environments characterized by high temperatures and humidity reduce the productive potential of the animals (Scholtz et al 2013).

Mitlöhner et al (2001) compared heat stress impact on confined heifers and mitigation by shade or nebulization. These authors observed that animals kept in shade achieved the desired weight faster, as well as animals kept in an unshaded environment presented physiological responses to heat stress such as increased respiratory rate and negatively affected productivity (Table 1).

Final considerations

Following this explanation, it is clear that there is interference of heat stress on cattle and their physiology. This should be considered in regions such as the Brazilian semiarid, where the challenge of animal productivity is practically constant, taking into account the adverse climatic condition. In order for cattle-breeding to be practiced efficiently, reaching the expected productive levels, production systems and breeds adapted to each purpose, as well as the adaptation of the animals to region's climate.

In this way, it is necessary to have an integration between the animal and their environment, adding a better nutritional and reproductive efficiency, providing the economic viability of productive system.

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