Heat stress in dairy calves

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Abstract

The current knowledge on the consequences of heat stress in dairy calves is collected in this research reflection. Authors are describing the indicators of heat stress in the prenatal and preweaning period, discuss the term thermoneutral zone and the possible methods for measurements of environmental heat load, and collect the existing techniques to decrease heat load in calves. Based on the recent literature several conclusions for further research are also phrased in relation with economic efficiency, improved methodology and taking into account the effects of maternal heat stress when evaluating calf performance in the preweaning period.

Keywords: dairy calves, heat stress

Heat stress is one of the main challenges facing the dairy industry. Physiological and behavioural coping mechanisms of lactating dairy cows are well documented (Polsky and von Keyserlingk, 2017)□, however, the thermal status of calves kept outdoors from birth to weaning gets less attention from a scientific (Roland et al., 2016)□, and even more so from a management standpoint. The aim of this research reflection is to collect recent literature about the effects of heat stress and the methods of heat alleviation in dairy calves, focusing mainly on Holstein friesian breed in the preweaning period. Current knowledge on animal based and environmental indicators of heat stress and efficiency of heat abatement are discussed and targets of future research are proposed.

Indicators of heat stress in the prenatal period

There is growing evidence that the uterine enviroment of pregnant cows exposed to heat stress in the dry period can convey an indirect effect of environmental stress and evoke adaptive mechanisms in the calf fetus that have prolonged effects in the postnatal period, a concept often called ’fetal programming’. Maternal heat stress effects on the growing fetus have been extensively studied by researchers at the Calf Unit of University of Florida (Gainesville, USA). In the recent years, the research group have focused on elucidating the adaptive responses of the fetus in detail.

Lower birth weight and shorter mature height. Fetal growth is compromised due to hyperthermia-induced placental insufficiency, involving reduced placenta size and impaired vascularization that limits maternal-fetal exchange of oxygen and nutrients. Moreover, even a few days reduction in gestation length, as it is often seen in times of heat stress, shortens the period of rapid fetal growth and thus reduces calf birth weight. Weaning weight of calves from dams exposed to heat stress was lower than that from cooled dams, but pre-weaning weight gain, and weight in the prepubertal period was not different (Tao et al., 2012; Monteiro et al., 2014). Despite the postpubertal rebound in weight gain, mature height of calves born from heat stressed dams does not reach that of calves born from cooled dams (Monteiro et al., 2014).

Metabolic shift. Besides insufficient uterine supply of nutrients, the heat exchange between the dam and the fetus – which has double the metabolic rate as the mother – is also impaired, which can result in fetal hyperthermia. As seen in the sheep model, the fetus might develop adaptive mechanisms like reduced protein accretion in favor of hepatic gluconeogenesis and impaired insulin action at the expense of growth. Calves born to heat stressed dams responded to similar diets with higher circulating insulin concentrations in the first 7 days of life, than calves born to cooled dams (Tao and Dahl, 2013), suggesting a carryover effect of maternal heat stress. Freshly weaned calves born from cows noncooled in the dry period showed similar pancreatic insulin sensitivity and systemic insulin clearance but a more rapid glucose clearance during both a glucose tolerance test and an insulin challenge, than that of calves born form cows cooled in the dry period (Tao et al., 2014). Dahl et al. (2016) concluded that on the basis of evidence from sheep models and the previoulsy mentioned studies on growth rate, calves heat stressed in utero are prone to develop smaller mature body size and greater fat deposition, compared with calves from cooled cows.

Impaired immune function. Lower serum IgG concentrations and apparent efficiency of IgG absorption was observed in calves from heat-stressed dams relative to calves from cooled dams, in the first 28 days of life. Heat stress in late gestation has no apparent effect on IgG content of colostrum, thus impaired IgG absorption is due to deficiency of passive transfer in calves heat stressed in utero (Tao et al., 2012; Monteiro et al., 2014). Monitoring peripheral blood mononuclear cell proliferation until 56 days of age, it was observed that proliferation rate was lower in calves born from heat stressed dams, as compared to the offspring of cooled dams, however, antibody production in an ovalbumin challenge at 28 days of age was similar in both groups.

Indicators of heat stress in the postnatal period. As subtle differences in the uterine environment of cooled and noncooled pregnant cows can induce prolonged effects in the calf fetus, severe heat load experienced after birth may also affect performance in the rearing period. However, the term heat stress is used quite loosely and defining it in the sense of the amount of strain that environmental conditions impose on dairy calves seems challenging. As opposed to dairy cows, no clearly defined thresholds of biological or environmental indicators that necessitate cooling interventions are determined for dairy calves. The animal-based indices of assessing thermal status proposed in the literature are discussed below.

Acute stress response parameters. Heart rate variability analysis of calves exposed to high solar radiation confirmed a higher sympathetic tone on the basis of decreased RMSSD values (Kovács et al., 2018c). Endocrine changes also suggest an increased level of stress due to heat exposure. Elevated salivary and cortisol concentrations were measured in preweaned calves suggest increased level of stress (López et al., 2018; Kovács et al., 2019). Plasma triiodothyronine and tetraiodothyronine concentrations were lower due to heat stress (López et al., 2018). Exposure to 37 °C in 4-6 months-old bull calves for 12h activated heat shock factors and the upregulation of heat shock proteins acting as molecular chaperones assisting in protein folding, factors involved in immune response, and cell cycle inhibition (Srikanth et al., 2017), in accordance with an earlier review on the genes involved in the heat stress response of bovine mammary cells (Collier et al., 2008).

Behavioural responses. Behavioural thermoregulation is the first sign of thermal discomfort: calves seek shade, change posture, align their body away from the sun, reduce locomotion during the hottest hours of the day and bunch to seek shade from other animals, as reviewed by Roland et al., (2016). Frequency of changing posture is reduced in a hot environment as a sign of discomfort (Kovács et al., 2018a)

Increased respiratory rates. Evaporative heat loss is promoted by increased respiratory frequency. Textbooks, publications and online guides describe rates of 20-40 to even 50-70 breaths/min as normal (Rosenberg, 1979; Piccione et al., 2003). Studies on adaptive responses of calves in moderate/shaded vs. hot/noncooled thermal environments have reported a change in the average respiratory rates from 47 to 53 (Lima et al., 2013), from 50-78 to 73-105 (Peña et al., 2016) or from 30-50 to 70-140 (Kovács et al., 2018b). Despite obvious numerical differences in baseline values, a relative increase in respiration rate of approx. 50% was considered a sign of increased efforts of evaporative heat loss in all relevant studies. However, heavier breathing is triggered by an increase in ambient and consequently body surface temperature, preceding an actual rise in core body temperature, which has to be taken into account when assessing heat stress status.

Elevated rectal temperature. To characterize a calf in thermoneutrality, that is maintaining normal body temperature without increased efforts of heat dissipation or heat production, most sources consider 38,5 – 39,1(39,5) °C as the range of healthy body temperature in calves (Rosenberg, 1979; Piccione et al., 2003)□. Consistently, studies on calves exposed to high ambient temperatures report on maximal body temperatures of 39,7 °C (Lima et al., 2013), 40,1 °C (Peña et al., 2016)□, 40,4 °C (Kovács et al., 2018b), and 39,8 °C (Hill et al., 2016).

Water consumption. Water requirement is elevated in the hot periods of the year (Broucek et al., 2009)□, as calves may lose water via increased rate of respiration and sweating. It was shown by a field study that water intake increased almost 4-fold, from 1.4 l/day to around 4 l/day, beside the milk consumption, as the ambient temperature elevated from 0 to 35 °C (Quigley, 2001).

Early mortality. The biological cost of adaptation to prolonged severe heat exposure can impact calf welfare and profitability of rearing. Elevated ambient temperature, especially in calves housed outdoors proved to be a risk factor for early calf mortality in veal calves (Renaud et al., 2018). Extreme heat waves can cause an excess death of different cattle subpopulations, including dairy calves, as it was analyzed by Morignat et al., (2014). The research data are inconsistent, as others (Mellado et al., 2014) showed a higher mortality of day old Holstein calves in moderate conditions, as compared to the hot season.

Weight gain. Only a very few number of studies are available on the effect of season on growth rate in preweaned calves, yet, they are all consistent in the finding of lower average daily weight gain in seasons with higher ambient temperature (Donovan et al., 1998; Broucek et al., 2009; López et al., 2018)□. The reduced growth rate is attributed mainly to reduced starter intake in the hottest periods of the year (Bateman et al., 2012; Holt, 2014).

Thermoneutral zone and measurements of environmental heat load. There is far more information on the lower critical temperature and effects of cold on calf welfare than there is on the upper critical temperature of calves. Spain and Spiers, (1996) observed respiratory rates to be increased at 26 °C, which seems to be accepted in most of the studies as an upper limit of the thermal comfort zone (Holt, 2014)□. Ambient temperature is accepted to be a sole and reliable indicator of thermal environment of calves in most heat stress studies. Attempts have been made, however, to adopt other indices, like the temperature humidity index (THI), which is often used in studies on lactating adult cattle. In dairy cows, much is known about how relative humidity affects evaporative heat loss capacity, and that knowledge is incorporated into the THI, the weighted estimator of heat load. In dairy cows, the THI shows strong correlation to biomarkers of heat stress (Bouraoui et al., 2002; Dikmen and Hansen, 2009; Bernabucci et al., 2010). Peña et al., (2016) used THI for assessing heat load in dairy calves reared in a subtropical climate, however, due to the fact that little is known on how relative humidity affects heat dissipation of dairy calves, and that THI seems oversimplified in outdoor conditions, where most calves are reared, the reliability of a direct adoption of THI formulas and thresholds originally adapted for cattle is limited. In outdoor conditions, where dry bulb temperature does not reflect the enormous heat load of direct solar radiation, the use of complex environmental indices encompassing radiant temperature and wind speed was proposed by several researchers (Gaughan et al., 2008; Mader et al., 2010; Hammami et al., 2013).

Techniques to decrease heat load in calves. Most calves are kept in individual hutches with a small outdoor area during the preweaning period, where they are exposed to solar radiation. Polyethylene hutches – even if placed under shade – provide a slightly worse microclimate for the indwelling calf in summer than conventional plywood hutches (Lammers et al., 1996; Peña et al., 2016). Rectal temperature and respiration rates were lower in calves housed in plywood hutches as compared to plastic ones, however, no differences in weight gain or general health status were observed when comparing the two housing systems (Lammers et al., 1996; Peña et al., 2016). Practicality of durable and more hygienic plastic hutches won over, making them the most popular type of housing for outdoor reared calves worldwide. Thermal properties of plastic used during the manufacturing of hutches are improving, however it is still necessary to reduce heat load and/or heat absorption of plastic hutches.

Increasing air flow. Increasing air speed could help heat dissipation of the calves, thus better ventilation may be useful. Elevation of the back side of the hutches is showed to increase airspeed, decrease CO_2 concentration within the hutch, and therefore decrease respiration rate of the calves (44 vs 58 compared to the control) (Moore et al., 2012).

Reflective covers. Friend et al. (2014) tested differenc reflective materials in their study. Reflective painting was almost ineffective, while aluminized plastic covers were successful in decreasing black globe temperature by 2-4 °C in empty hutches. Carter et al. (2014) found that rate of increase of interior hutch temperature relative to ambient temperature was lower in insulated hutches indicating they were warmer at low THI and cooler at high THI. Increase in respiration rate and ear canal temperature of the calves, relative to THI, were moderated in insulated hutches. Average daily gain did not differ between the groups. The advantages of reflective covers are not clear enough. Manriquez et al. (2018) found that THI and ambient temperature are somewhat higher (68.6 vs. 67.6, and 23.2 vs. 22.8 °C, respectively) in the hutches covered with aluminized plastic material. The rectal temperature and respiratory rate were not different in the control and experimental calves. Authors supposed that hutches covered with plastic can not cool down in the evening hours.

Shading structures. Shading seems to be more effective in decreasing exposure to solar radiation, since the results are more consistent in decreasing ambient temperature in the hutch or in the outdoor area under the shade (Coleman et al., 1996; Spain and Spiers, 1996; Gu et al., 2016; Kovács et al., 2019). Respiratory rate of calves are usually found to be lower under the shade (Spain and Spiers, 1996; Gu et al., 2016). The comfort behaviour of calves (though buffalo) was also different, since the calves spent more time lying under the shade material (Gu et al., 2016). A very positive side effect of shading is that workers mentioned that they were more comfortable working under the shade (Coleman et al., 1996). The shading material is usually an agricultural net material with 80-85% solar radiation blockage placed around 2 m above the calf pen (Coleman et al., 1996; Spain and Spiers, 1996; Kovács et al., 2019). Other materials such as thatch shading roof or well grown tree can also be effective (Kamal et al., 2014).

Conclusions for future research.

Economical efficiency. Despite the growing body of evidence of adverse effects of heat stress on dairy calves from as early as the prenatal period, most dairy operations carry on without the least of cooling interventions for dry cows or preweaned calves. Economic quantification of the biological cost of heat stress and analysis of cost-efficiency of cooling technologies could make the results of costly state-of-the-art research methodology practically relevant and more convincing to decision makers, that might speed up the slow progression of paradigm shift in dairy calf management, namely that non-producing animals also require attention.

Understanding the basics. Scarce literature on the upper end of the thermoneutral zone warns that there is room for improvement in understanding thermal requirements and heat dissipation capacities of dairy calves. Indices originally developed for indoor environment, like dry bulb temperature or different formulas of the temperature humidity index can be misleading when assessing the thermal environment of outdoor reared calves. Upper critical thresholds should be formulated in a manner that suits the housing environment of calves. This necessitates a better understanding of how radiant heat, relative humidy and wind speed contribute to thermal load of dairy calves.

Integrating the concept of in utero heat stress. Considering that besides dry cow management, calf rearing is another overlooked area in dairy management, it is worth investigating if we should separate the phenomenon of in utero heat stress from preweaning heat stress, or the two are necessarily intertwined. It would be interesting to study whether postnatal heat exposure without maternal heat stress results in the same adaptive metabolic and immune responses in the young calf as it is observed in the calf fetus. It is also worth investigating whether modified calf management strategies and nutrition in hot conditions could prove useful in mitigating the effects of retarded growth and impaired passive transfer of immunoglobulins in calves at risk.

Methodology. Real-time recording of environmental indices (radiant heat, humidity, wind speed) is feasible and could be easily integrated into precision livestock farming technologies, given that critical thresholds are known (Fournel et al., 2017; Koltes et al., 2018). Automated monitoring of physiological parameters in outdoor kept calves are currently not widely available, due to high costs or a limited time of recording (10-14 days for indwelling thermometers). Respiratory rate can only be measured by labour-intensive visual observation. Development of automated measurement of respiratory rate would improve measurement reliability and facilitate determination of upper critical temperatures.

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