

Heat stress in dairy calves from birth to weaning

Mikolt Bakony and Viktor Jurkovich

Department of Animal Hygiene, Herd Health and Mobile Clinic, University of Veterinary Medicine, Budapest, Hungary

Research Reflection

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Author for correspondence:
Viktor Jurkovich,
Email: jurkovich.viktor@univet.hu

Abstract

This Research Reflection collects current knowledge on the effects of heat stress in dairy calves. Chapters cover the concept of foetal programming, animal-based and environmental indicators of heat stress in the postnatal period, and methods of heat stress abatement. Conclusions for further research about economic efficiency, research methodology and an integrated approach of pre- and postnatal heat stress are also proposed.

Heat stress is one of the main challenges facing the dairy production industry. Physiological and behavioural coping mechanisms of lactating dairy cows are well documented (Polsky and von Keyserlingk, 2017). However, the thermal status of hutch reared calves receives less attention from a scientific (Roland *et al.*, 2016), and even less so from a management standpoint. This research reflection aims to gather current knowledge about the effects of heat stress and the methods of heat alleviation in preweaned Holstein Friesian dairy calves. Biological and environmental indicators of heat stress and methods 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 environment of dry cows can convey an indirect effect of environmental stress and evoke adaptive mechanisms in the calf foetus. Signs of adaptation are present also in the postnatal period, which lead to the concept often called 'foetal programming'. Earlier studies have observed that sensitivity to thermal stress is higher in periods of reproduction and neonatal life, as compared to other phases of the life cycle (Collier *et al.*, 1982). Effects of maternal heat stress on the growing foetus have been extensively studied by researchers at the Calf Unit of the University of Florida (Gainesville, USA). In the past years, the adaptive responses of the foetus have been elucidated in more detail.

Lower birth weight and adult height

Foetal growth is compromised due to hyperthermia-induced placental insufficiency. Reduced placenta size and function limit the maternal-foetal exchange of oxygen and nutrients. Even a few days shortening of gestation length, that often occurs in times of heat stress (Dahl *et al.*, 2016), shortens the period of rapid foetal growth resulting in reduced birth weight. Calves born from dams exposed to heat stress had lower weaning weight than calves from cooled dams. However, pre-weaning weight gain, and body weight in the prepubertal period were not different (Tao *et al.*, 2012; Monteiro *et al.*, 2014). Despite the postpubertal rebound in weight gain, adult height of calves born from heat-stressed dams did not reach that of calves born from dams cooled in the dry period (Monteiro *et al.*, 2014).

Metabolic shift

Heat stress impairs not only the uterine supply of nutrients but also the heat exchange between the dam and the foetus. The foetus has double the metabolic rate as the mother, that is why a narrower temperature gradient can result in foetal hyperthermia. As seen in the sheep model, the foetus can develop adaptive mechanisms at the expense of growth. These include reduced protein accretion in favour of hepatic gluconeogenesis as well as an increased level of catabolic and reduced level of anabolic hormones. The same diet has induced higher insulin concentrations in calves born to heat-stressed dams than those born to cooled cows. The increased insulin response suggests a carryover effect of maternal heat stress (Tao and Dahl, 2013). Calves born from cows not cooled in the dry period showed similar pancreatic insulin sensitivity and systemic insulin clearance at weaning age to that of calves born from cows cooled in the dry period, but a more rapid glucose clearance during both a glucose tolerance test and an insulin challenge (Tao *et al.*, 2014). Dahl *et al.* (2016) concluded that calves experiencing

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heat stress in utero are prone to develop a smaller mature body size and more fat reserves than counterparts in thermoneutrality.

Impaired immune function

In the first 28 d of life, serum IgG concentrations and apparent efficiency of IgG absorption were lower in calves born from heat-stressed dams relative to calves born from cooled dams. Heat stress in late gestation has no evident effect on IgG content of colostrum. It suggests that impaired IgG absorption is presumably due to the deficiency of passive transfer (Tao *et al.*, 2012; Monteiro *et al.*, 2014). However, acute brief heat stress during late gestation did not alter passive antibody transfer capacity in calves (Strong *et al.*, 2015). The proliferation rate of mononuclear cells 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 d of age was similar in both groups. Both humoral immune response and cell-mediated immune function seem to be altered by heat stress.

Remarks

The key findings of research studies on heat stress in utero bring deserved attention to dry cow management and urge active cooling throughout the nonlactating period. Given that environmental stressors can induce the compensatory hypervascularization of the uterine horn and the alteration of ovarian activity (Collier *et al.*, 1982), further studies are needed to distinguish the maternal and foetal components of hyperthermia-induced intrauterine growth retardation. The metabolic shift in calves heat-stressed in utero makes them prone to preserve energy and acquire less lean tissue. Such a phenomenon is also observed in heat-stressed lactating cows, where increased insulin action is linked to the 'leaky gut' syndrome. It is worth investigating in which ways are the two mechanisms different. A clear distinction between the effects of prenatal and perinatal stress, if possible, would also contribute to improved newborn calf management practices.

Indicators of heat stress in the postnatal period

Just as subtle differences in the uterine environment of cooled and noncooled pregnant cows can induce prolonged effects in the calf foetus, severe heat load experienced after birth may also affect performance in the rearing period. However, the term heat stress is used quite loosely. Accurately assessing the amount of strain environmental conditions impose on dairy calves is challenging. As opposed to dairy cows, no clearly defined thresholds of biological or environmental indicators are commonly accepted for dairy calves that would reliably pinpoint the onset of production losses and thus necessitate cooling interventions. The animal-based indices of assessing thermal status proposed in the literature are discussed below.

Acute stress response parameters

Heart rate variability analysis confirmed that calves exposed to solar radiation had a higher sympathetic tone than shaded calves (Kovács *et al.*, 2018c). Endocrine changes also suggest an increased level of stress due to heat exposure. In a study on pre-weaned calves exposed to heat load, salivary and plasma cortisol concentrations were elevated indicating an increased level of stress (López *et al.*, 2018; Kovács *et al.*, 2019). Plasma concentrations of

thyroid hormones T3 and T4 were lower in heat stress (López *et al.*, 2018).

Behavioural responses

Altered behaviour is the first sign of thermal discomfort. Calves seek shade, change posture, move less during the hottest hours of the day and bunch to provide shade for each other (Roland *et al.*, 2016). Frequency of changing posture is reduced in hot conditions as a sign of discomfort (Kovács *et al.*, 2018a) similarly to cows (Allen *et al.*, 2015). Hutch vs. pen preference or lying vs. standing provides valuable information about the heat-absorbing nature of hutch material or thermal conductive properties of the bedding.

Increased respiratory rates

Increased respiratory frequency promotes evaporative heat loss. Textbooks, publications and online guides describe rates of 20–40 to even 50–70 breaths/min as physiological (Rosenberg, 1979; Piccione *et al.*, 2003). Studies on adaptive responses of calves in neutral/shaded vs. hot/noncooled thermal environments have reported an approx. 50% increase in average respiratory rates as a sign of increased evaporative cooling efforts [from 47 to 53 (de 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)]. Heavier breathing is induced by an increase in ambient and consequently, body surface temperature. The elevation of respiratory frequency thus precedes the rise in core body temperature, which must be taken into account when assessing heat stress status.

Elevated rectal temperature

In thermoneutrality, mammals can maintain their physiological 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 (de 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 hot weather (Broucek *et al.*, 2009), as calves may lose water *via* increased respiration and sweating. As the ambient temperature rises from 0 to 35°C, water intake increases almost 4-fold, from 1.4 l/d to around 4 l/d, in addition to the amount of milk replacer (Quigley, 2001). Making sure each calf is aware that water is available is crucial in preventing dehydration. Moreover, Wiedmeier *et al.* (2005) showed that increased frequency of changing and rinsing water buckets resulted in a higher average daily gain in the preweaning period.

Early mortality

The biological cost of adaptation to prolonged heat exposure can impact calf welfare and the profitability of rearing. High 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 heatwaves can cause excess death of different cattle subpopulations, including dairy calves (Morignat *et al.*, 2014). Research data are, however, inconsistent, as others showed mortality of 1–21 d old Holstein calves to be higher in moderate conditions than in the hot season (Mellado *et al.*, 2014). The term ‘early mortality’ is rather unspecific, though. Death occurring in the preweaning period has multiple causes. Further data on the prevalence of different causes of death could highlight areas that need more attention in periods of hot weather.

Reduced feed intake and weight gain

The small number of studies seasonal effects of growth in dairy calves all agree on a 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), rather than consequences of maternal heat stress. Given that dry cow heat abatement is an overlooked area in dairy farming, it is tempting to speculate that prenatal heat stress effects possibly mask postnatal heat stress responses. However, it was shown that postnatal thermal conditions (cooling vs. no cooling) dominate in calf welfare and performance in the preweaning period, irrespective of prenatal thermal status (cooled vs. not cooled dams) (Dado-Senn *et al.*, 2020).

Remarks

Heat stress affects many physiological and production indicators in calves. It is essential to determine which of these is considered valid for defining heat stress. Animal-based indices are the primary measures of animal welfare. Having the primary indicators identified, the physiological thresholds (if not already available) for defining heat stress should be determined. Production indicators are also relevant; however, the authors are of the opinion that importance is only secondary to animal-based indicators. We believe that the principles of animal welfare should prevail and that this will be economical in the long term.

Thermoneutral zone and measurements of environmental heat load

Heat stress abatement of hutch-reared dairy calves is largely ignored in dairy management. However, maintaining constant body temperature in conditions of high ambient temperature, intense solar radiation and high relative humidity is not possible without expending extra energy. Knowing the factors that affect thermoregulation of the calf promotes housing and environmental modifications that could save energy for growth and health.

Thermoneutral zone not clearly defined

There is far more information on the effects of cold on welfare than there is on the upper critical temperature of dairy calves. Several different ambient temperatures were reported as set points of increased evaporative heat dissipation. Gebremedhin *et al.* (1981) observed increased respiration as temperature exceeded 20°C. Other researchers agreed on 26°C as the upper critical temperature of preweaned calves (Spain and Spiers, 1996; Holt, 2014; Collier *et al.*, 2019). Neuwirth *et al.* (1979) observed the first signs of heat stress at 32°C, 60% relative humidity.

Environmental indicators of heat stress

Ambient temperature is accepted to be the sole reliable indicator of the thermal environment of calves in most heat stress studies. In dairy cows, the effect of relative humidity on heat dissipation capacity is well documented, and that knowledge has been incorporated in the temperature-humidity index (THI), the weighted estimator of environmental heat load. It shows a strong correlation to biomarkers of heat stress (Bouraoui *et al.*, 2002; Dikmen and Hansen, 2009; Bernabucci *et al.*, 2010). Attempts have been made to adopt the THI in calf studies (Peña *et al.*, 2016; Manriquez *et al.*, 2018); however, its reliability is limited. Little is known about how relative humidity affects the heat dissipation of dairy calves. THI formulas and thresholds – originally adapted for lactating cattle – do not carry more information than ambient temperature alone.

Quantifying radiant heat

In outdoor conditions, radiant heat and wind speed are determining factors in the operative temperature, that is the temperature perceived by the animal. The THI incorrectly estimates the environmental heat load in hutch reared calves, as it does not incorporate the radiant temperature and airspeed. The use of complex environmental indices was proposed for outdoor measurements by several reports (Gaughan *et al.*, 2008; Mader *et al.*, 2010; Hammami *et al.*, 2013); however, it has not yet been adopted in studies on dairy calves.

Remarks

The environmental thresholds to decide between thermoneutrality or heat stress in dairy calves have not been sufficiently defined. Adequate definitions and limits are needed to judge the real effects of heat stress and to measure the efficiency of heat stress control.

Techniques to decrease heat load in calves

From birth until weaning, most calves are kept outdoors, in individual hutches with small fenced exercise pens. In summer, the microclimate of polyethylene hutches, even if placed under shade, is worse than that of plywood hutches (Lammers *et al.*, 1996; Peña *et al.*, 2016). Rectal temperature and respiration rates were higher in calves housed in plastic hutches as compared to plywood, however, no differences in weight gain or general health status were observed (Lammers *et al.*, 1996; Peña *et al.*, 2016). The practicality of durable and more hygienic plastic and fibreglass hutches make them the most popular type of housing for outdoor reared calves worldwide. Thermal properties of the plastic used during the manufacturing of hutches are improving, however, it is still necessary to reduce heat load and heat absorption of plastic and fibreglass hutches in summer, by means of additional shade (Andrews and Davison, 2002).

Increasing airflow

Increasing airspeed could help heat dissipation of the calves. Elevation of the rear side of the hutches is showed to increase airspeed and decrease CO₂ concentration inside the hutch, making it apparently more comfortable for the indwelling calf (44 vs. 58 breaths/min, compared to the control) (Moore *et al.*, 2012). The

specific design of hutches to maximize ventilation – including ridge-top vents and adjustable vent doors – are practical alternatives to labour-intensive manipulation of hutches. The use of fans provide a favourable microclimate (Hill *et al.*, 2011; Dado-Senn *et al.*, 2020), but this is limited to indoor conditions and thus not widespread.

Orientation of hutches

The orientation of calf hutches affected inner microclimate and consequently, the heat load of calves on sunny days (Bakony *et al.*, 2019). Respiration rate was elevated in all four groups, being highest in south-facing hutches (103/min vs. 90/min). Probabilities of a calf lying, being inside the hutch or seeking shade at the time of observation, respectively, were highest in the group of hutches facing south. The level of heat stress in south-facing hutches is attributed to exposure to the most intense solar radiation and the least amount of shade during the day. Individual calf hutches should be positioned to face north or east in the summer period. Oriented alignment of calf hutches could serve as a no-cost measure of improving calf welfare.

Reflective covers

Friend *et al.* (2014) tested different radiant barriers. The silver painting was practically ineffective, while laminates and aluminized plastic covers decreased black globe temperature by 2–4°C in empty hutches. Carter *et al.* (2014) found that reflective covers provided a more favourable inner climate at both low and high ambient THI. Increase in respiration rate and ear canal temperature of the calves, relative to THI, were moderate in insulated hutches. Average daily gain did not differ between calves housed in covered or uncovered hutches. Other studies doubt the advantages of reflective covers. Manriquez *et al.* (2018) found that average THI and ambient temperature were higher (68.6 vs. 67.6, and 23.2 vs. 22.8°C, respectively) in the hutches covered with aluminized plastic material. However, rectal temperature and respiratory rate were not different in control and experimental calves. The authors supposed that reflective covers impede the cooling of the hutch material in the evening hours.

Shading structures

Shading is evidentially more effective in decreasing exposure to solar radiation than reflective covers. Shading reduces the temperature both inside and outside the hutch (Coleman *et al.*, 1996; Spain and Spiers, 1996; Gu *et al.*, 2016; Kovács *et al.*, 2019). Respiratory rate of calves is usually lower under shade (Spain and Spiers, 1996; Gu *et al.*, 2016) and calves spend more time lying in shaded areas (Gu *et al.*, 2016). Shading also provides more comfortable conditions for caretakers in all seasons (Coleman *et al.*, 1996). In practice, greenhouse shade nets (80–85% shade rate) installed at the height of 2 m are one way of providing shade (Coleman *et al.*, 1996; Spain and Spiers, 1996; Kovács *et al.*, 2019). Thatch shading or well-grown trees can also be effective (Kamal *et al.*, 2014). A built roof is a bigger investment for dairy operations; however, it offers protection from precipitation and build-up of radiant heat, while maintaining adequate airflow. Calf mortality rates were observed to drop after installation of a roof (personal observation).

Remarks

Of the techniques used to reduce the heat load, shading is the most effective, however, not widespread. The low-cost measures are flexible but rarely hard-wearing. A permanent solution is, still, a more considerable financial investment that requires proven results on the favourable effects. In the authors' opinion, roof construction is certainly a desirable goal in protecting the calves against solar radiation. Longitudinal studies on the impacts of shading would support the economic feasibility of roof installations.

Nutritional management in heat stress

We have shown that increased energy demands of heat dissipation coupled with reduced starter intake often result in the reduced growth rate of calves in summer months. In support of weight gain, increasing the plane of nutrition or the use of different feed additives are the main strategies for nutritional interventions.

Preference for liquid feed and water

Considering that calves prefer liquid feed over solids in hot weather, a promising approach is to increase the energy content of milk replacer. Increased feeding rate of milk replacer (0.66 kg vs. 0.44 kg dry matter/d, 21% crude protein, 21% fat) increased average daily gain and hip width in calves raised in summer (Hill *et al.*, 2012). An accelerated milk replacer feeding programme (0.66 or 0.77 kg dry matter of milk replacer daily, 26% crude protein, 17% fat) improved energy intake and weight gain in 3–56 d-old calves during summer (Orellana Rivas *et al.*, 2020). Increasing dietary fat content of the milk replacer from 10 to 20% (besides 20% crude protein) yielded higher body weight body size of weaned calves (Blair, 2015). Adding water to dry calf starter was also shown to increase palatability. Starter intake and average daily gain of calves increased when feeding 75 or 50% dry matter vs. 90% dry matter diets (Beiranvand *et al.*, 2016). As mentioned in an earlier chapter, merely the regular provision of fresh, clean water yielded higher weight gain in hutch-reared calves (Wiedmeier *et al.*, 2005).

Vitamins, minerals, yeasts

Trials on the use of different feed additives yielded varying results. Supplementation with fat-soluble and B-vitamins, omega fatty acids and minerals did not provide additional benefit to summer reared calves (Blair, 2015). A combination of vitamins A and E and microelements increased growth performance post-weaning, enhanced immune functions and antioxidant capacity (Bordignon *et al.*, 2019). An exciting approach was adding *Saccharomyces boulardii* to milk replacer to calves between 1–28 d of age (Lee *et al.*, 2019). It resulted in higher dry matter intake and improved gut health during thermoneutrality and higher dry matter intake, but lower rectal temperature and cortisol levels in experimental heat stress than that of untreated controls (Lee *et al.*, 2019). The authors explained the results with the balancing effect of yeast supplementation on intestinal flora that lowered lipopolysaccharide absorption due to the leaky gut syndrome in times of heat stress.

Similarly to dairy cows, the effects of chromium supplementation was also studied in dairy calves. It is known to potentiate insulin action and enhance glucose metabolism. In the study of

Kargar *et al.* (2018), oral supplementation with chromium in a dose of 0.05 mg/kg body weight was associated with greater meal sizes and longer meal durations. The respiratory rates of supplemented calves were lower than that of unsupplemented calves in high ambient temperatures. Overall average daily gain and body weight at weaning was higher in Cr supplemented calves; however, the difference gradually diminished after weaning.

Remarks

Strategies for nutritional alleviation of heat stress are, at present, not numerous in calves, contrary to that in dairy cows. However, results are encouraging, since certain cost-effective adjustments in the feeding regime can promote appetite or provide the extra energy in times of increased maintenance requirements. While, in dairy cows, nutritional interventions can only be secondary to adequate cooling technologies, seasonal adjustments in the feeding protocol are advisable in calf rearing. The physiological chromium requirements of ruminants are not precisely known. Thus the growth-promoting effects of chromium supplementation can partially be due to satisfying by chromium-deficiency of control animals; however, this hypothesis needs further testing. Despite the promising results, trivalent chromium is not authorized as a feed additive in the European Union, based on the scientific opinion of the European Food Safety Authority (EFSA, 2009).

Conclusions for future research

Economic 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 any cooling interventions for dry cows or preweaned calves. Translating the biological cost to financials could convince farm owners to invest in some kind of heat abatement. It could also speed up the much-needed change of thinking in dairy (calf) management, that non-lactating animals require as much attention as lactating animals do.

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. The indices initially developed for indoor conditions, like dry bulb temperature or 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. It necessitates a better understanding of how radiant heat, relative humidity and wind speed contribute to the thermal load of dairy calves.

Integrating the concept of in utero heat stress

Besides dry cow management, heat stress abatement in calf rearing is another overlooked area in dairy management. A longitudinal study involving a larger number of calves could shed light on whether adverse effects of pre- and postnatal heat stress are comparable and whether these effects add up when occurring. It would be interesting to study whether postnatal heat exposure

without maternal heat stress results in the same adaptive metabolic and immune responses as that of the calf foetus. It is also worth investigating whether improved calf management and nutrition strategies could prove useful in mitigating the effects of heat stress on growth and passive transfer of immunoglobulins.

Methodology

Real-time recording of environmental indices (radiant heat, humidity, wind speed) is feasible and could be easily integrated into precision livestock farming technologies (Fournel *et al.*, 2017; Koltes *et al.*, 2018). Automated monitoring of physiological parameters in outdoor kept calves is currently not widely available, due to high costs or limited time of recording (10–14 d for indwelling thermometers). Respiratory rate can only be measured by labour-intensive visual observation. Adaptation of automated methods of measuring breathing rate – designed initially for cattle – would improve reliability and facilitate the determination of upper critical temperatures (Eigenberg *et al.*, 2000; Strutzke *et al.*, 2019).

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