Managing heat stress in transition cows and calves

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Introduction

Summer heat compromises a lactating cow's performance from different perspectives, including lactation, reproduction and cow health (Fuquay, 1981; Kadzere et al., 2002; West, 2003). Compared with lactating cows, dry cows produce less metabolic heat (West, 2003) and have a higher upper critical temperature (Hahn; 1997). Thus, heat stress management for dry cow is often overlooked, but substantially influences the cow and her offspring's future performance. To avoid the negative impact of heat stress on dry cows and the calves, appropriate cooling should be applied during the entire dry period. This paper will focus on the impact of prepartum heat stress on the cow and her offspring, and treatments are applied during the prepartum period only; after parturition, all animals are managed in the same manner with cooling.

Prepartum heat stress on feed intake and metabolic adaptation

Similar to lactating dairy cows, heat stress decreases dry matter intake (DMI) of dry cows, but to a less extent. Relative to cooled cows (**CL**), the non-cooled heat-stressed (**HS**) cows have ~15% decrease in DMI during the dry period (Table 1). As a result, they gain less body weight during the prepartum period partly due to the slower fetal growth (Tao et al., 2011). In addition to the reduced feed intake, heat stress alters the cows' metabolic responses. Recent studies suggest that, even a 30% decrease in DMI, heat-stressed cows have blunted adipose tissue mobilization in early (Lamp et al., 2015) and mid-lactation (Wheelock et al., 2010), and enhanced the whole body glucose utilization in mid-lactation (Wheelock et al., 2010) compared with pair-fed cows under thermo neutral condition. However, during the dry period, heat stress affects the cow's metabolism differently. Heat stress has no impact on the cow's adipose tissue mobilization (Lamp et al., 2015) or glucose clearance after a glucose tolerance test (Tao et al., 2012) during the dry period, presumably because of a lower energy demand for fetal growth compared with lactating. In contrast, relative to those under thermal neutrality with similar intake, the heat-stressed dry cows have more pronounced protein mobilization perhaps to support the fast fetal growth during late gestation (Lamp et al., 2015). Prepartum cooling improves feed intake before calving, and it has no carryover effects on cow's DMI in early lactation (first 2-3 weeks postpartum) but increases the blood NEFA and BHBA concentrations (do Amaral et al., 2009; Tao et al., 2012) and peripheral tissue insulin resistance (Tao et al., 2012) to support the higher milk production. However, on the other hand, as the lactation advances, prepartum cooled cows will consume more feed relative to non-cooled prepartum cows in order to meet the nutrient demand for higher milk production.

Table 1. Summary of studies on effects of prepartum heat stress (HS) and cooling (CL) on DMI

Duration of the treatment	DMI, kg/d			Reference
	HS	CL	Diff.	
Dry	11.3	12.2	0.9/8%	Adin et al., 2009
Dry	12.0	14.1	2.1/18%	do Amaral et al., 2009
Dry	8.4	9.8	1.4/17%	do Amaral et al., 2011
Dry	8.9	10.6	1.7/19%	Tao et al., 2011
Dry	10.2	11.1	0.9/9%	Tao et al., 2012b
Dry	10.4	12.3	1.9/18%	Thompson et al., 2014b
Average	**10.2**	**11.7**	**1.5/15%**	

Prepartum heat stress on mammary development and following milk production

Late gestation heat stress has profound effects on milk production in the subsequent lactation. When active cooling (such as soakers and fans) is applied during the entire dry period, compared with HS cows, prepartum CL cows produce ~ 4 kg/d (12%) more milk in the next lactation (Table 2). This increase in milk yield by cooling dry cows persists through the entire lactation, indicating an improved mammary function rather than the metabolically related galactopoietic effect (such as bST). On the other hand, when cows are cooled only during the close-up period, the increase in following milk yield is still apparent but lower. From limited studies, relative to HS, the close-up CL cows have ~ 2.2 kg/d (5.8%) increase in milk yield during the next lactation (Table 2). This positive effect of prepartum cooling on following lactational performance attributes to the improved mammary growth during the late gestation. Dry period is characterized by extensive mammary involution during the first couple weeks after dry off and the following mammary growth (Capuco et al., 1997), and heat stress influences both cellular processes. Indeed, HS cows have lower mammary cell proliferation ~2-3 weeks before calving compared with CL (Tao et al., 2011), which is partly due to a lower placental production of estrone-sulfate (Collier et al., 1982). Although often overlooked, mammary involution, including both apoptosis and autophagy, during the early dry period may be important for modulation of following mammary growth and future milk production, and is influenced by environmental heat stress. Indeed, a recent study conducted at the University of Florida finds that the mammary gland of the HS cow has the reduced autophagy during the early dry period compared with CL (Ramirez-Lee et al., 2015). The result from this study suggest that heat stress blunts mammary involution after dry-off, which perhaps negatively affects the following mammary growth and milk production, however, more research is needed to approve this theory. Relative to multiparous cows, prepartum cooling for heifers receives less attention and there are only two publications which compare the lactational responses from prepartum HS and CL heifers (~1 month before calving), and the results are inconsistent (Table 2). More controlled studies are required in this area.

Table 2. Summary of studies on effects of prepartum heat stress (HS) and cooling (CL) on milk production.

Duration of the treatment	Milk production			Reference
	HS	CL	Diff.	
Dry	37.2	40.7	3.5/9%	Wolfenson et al., 1988
Dry	25.4	28.1	2.7/11%	Avendaño-Reyes et al., 2006
Dry	39.3	41.4	2.1/5%	Adin et al., 2009
Dry	26.2	33.7	7.5/29%	do Amaral et al., 2009
Dry	32.2	34.5	2.3/7%	do Amaral et al., 2011
Dry	28.9	33.9	5.0/17%	Tao et al., 2011
Dry	43.2	45.6	2.4/6%	Thompson et al., 2011
Dry	27.7	34.0	6.3/23%	Tao et al., 2012b
Dry	30.2	33.8	3.6/12%	Thompson et al., 2014b
Average	**32.3**	**36.2**	**3.9/12%**	
Close-up	38.7	40.1	1.4/4%	Urdaz et al., 2006
Close-up	32.1	33.5	1.4/4%	Adapted from Wang et al.,2010
Close-up	36.9	38.7	1.8/5%	Adapted from Gomes et al.,2013
Close-up	40.5	44.6	4.1/10%	Karimi et al., 2015
Average	**37.0**	**39.2**	**2.2/6%**	
Late gest.	23.3	25.6	2.3/10%	Adapted from Wang et al.,2010
Late gest.	25.1	25.5	0.4/2%	Adapted from Gomes et al.,2013
Average	**24.2**	**25.6**	**1.4/6%**	

Prepartum heat stress on immune function and disease incidence

Immune dysfunction is well characterized during the transition period and responsible for the increased disease incidence in early lactation. Various studies indicate that prepartum heat stress exaggerates the dysfunctional immune system during late gestation and early lactation. Compared with prepartum CL cows, HS cows have higher blood count of leukocyte but smaller proportion of CD4+ T lymphocyte (Gomes et al., 2014), and weaker proliferative response and TNFα production of peripheral blood lymphocyte when encounter a mitogen in vitro (do Amaral et al., 2010), suggesting a compromised cell-mediated immunity. The humoral immune response is also altered by heat stress during the transition period. After challenged with ovalbumin, the HS cows have a weaker IgG production during the dry period (do Amaral et al., 2011) and early lactation (Gomes et al., 2014) compared with CL. Additionally, the innate immunity, the first line of defense to pathogens in the body, is impaired by prepartum heat stress, evidenced by the lower ability of neutrophils to phagocytize and destroy pathogens of HS relative to CL cows in early lactation (do Amaral et al., 2011).

With the lower immunity during the transition period, it is expected that the prepartum HS cows would experience a higher disease incidence during early lactation. When comparing dry period seasonal effects on the occurrence of health disorders in the first 60 DIM in Florida, Thompson et al. (2012) found that cows dried off in hot months (June, July and August) had higher incidences of mastitis, respiratory problems and retained fetal membranes compared with those dried in cool months (December, January and February). Although confounded with the seasonal effects during early lactation and photoperiod during the dry period, these data may suggest the negative impact of prepartum heat stress on future disease susceptibility. In contrast, results from controlled studies (Santos et al., 2014; Thompson et al., 2014a) suggest that prepartum CL cows have similar incidence of diseases in early lactation but slightly increase in the incidence of metritis in the early lactation. The increase incidence of metritis is unexpected considering the higher immunity of CL compared with HS cows during the transition period, but deserves further investigation.

Prepartum cooling and body temperature

To minimize the negative impact of dry period heat stress, cooling is by far the most efficient approach. Active cooling including sprinklers and fans is widely used to abate heat stress in lactating cows, but not often utilized in dry cow barns, especially for far-off cows. However, supplemental cooling successfully decreased the body temperature of the dry cow results in a significant economic return in improved milk yield as discussed earlier. In a free stall setting, implementation of active cooling effectively reduces dry cow's body temperature by ~ 0.4 °C (0.7 °F; 102.7 vs. 102.0 °F, Table 3) and respiration rate by 21 breath/min (72 vs. 51 breath/min), which are much smaller compared with the difference (~ 1.0 °C) of body temperature between non-cooled and cooled lactating cows but enough to elicit the strong positive influence on following milk production.

Table 3. Summary of studies on effects of prepartum heat stress (HS) and cooling (CL) on physiological parameters.

Time of measurement	Rectal °C	Temperature,		Respiration Breath/min	Rate,		Reference
	HS	CL	Diff.	HS	CL	Diff.	
1400h	39.2	38.8	0.4	---	---	---	Wolfenson et al., 1988
1400h	39.3	39.0	0.3	74	67	7	Avendaño-Reyes et al., 2006
1500h	38.8	38.5	0.3	57	45	12	Adin et al., 2009
1430h	39.2	38.8	0.4	---	---	---	do Amaral et al., 2009
1430h	39.4	39.0	0.4	78	56	22	do Amaral et al., 2011
1430h	39.4	39.0	0.4	78	46	32	Tao et al., 2011
1430h	39.9	39.4	0.5	78	45	33	Thompson et al., 2014b
1430h	39.3	39.0	0.3	69	48	21	Tao et al., 2012b
Average	**39.3**	**38.9**	**0.4**	**72**	**51**	**21**	

Maternal heat stress on calf performance

Fetal growth is at the maximum rate during the late gestation and altered by maternal heat stress. Compared with CL dry cows (~last 45 days of gestation), HS cows give birth to lighter calves (~ 4.7 kg less, Tao and Dahl, 2013). The calves experienced maternal heat stress during late gestation maintain their smaller body weight up to 1 year of age but disappears at the first calving compared with those from CL cows, indicating a possible catch up growth after puberty. In addition to fetal growth, the calves that develop under heat stress conditions in utero have altered metabolism during postnatal period, as they display a greater glucose uptake after a glucose infusion during the pre-weaning period compared with calves cooled during late gestation (Monteiro et al., 2015), suggesting an altered postnatal glucose utilization by maternal heat stress. But, it is still not clear if the altered metabolism persists into the calf's future life and influences her future performance.

The physiological responses of the offspring may also be changed by prenatal heat stress. At birth, calves born to HS cows displayed lower concentrations of stress hormones, such as cortisol (Tao et al., 2012a) and prolactin (Monteiro, Dahl, and Tao, unpublished), compared with those from CL cows, suggesting maternal heat stress physiologically desensitize offspring's stress responses, at least to parturition stress. Interestingly, a recent study (Ahmed et al., 2015) demonstrates that lactating cows born to late gestation heat stressed dams have a better ability to cope with acute heat stress compared with those born to cooled dams, suggesting that the metabolic and/or physiological changes by in utero heat stress favor heat tolerance in progeny at maturity.

In addition to the impairment of fetal growth and altered metabolic and physiological changes, calf's immunity is affected by late gestation maternal heat stress. Passive immune transfer is of importance in a calf's survival and negatively altered by late gestation heat stress. After ingestion of fresh colostrum from their respective dams, calves that experienced maternal heat stress have lower efficiency of IgG absorption (Tao et al., 2012a) and lower total plasma protein and serum IgG concentration during the first month of life compared with calves from CL cows (Tao et al., 2012a). Similarly, when fed the same pooled frozen-thaw colostrum, a reduction in the efficiency of IgG absorption is observed in calves from HS vs. CL cows (Monteiro et al., 2014), indicating that maternal heat stress impairs passive immune transfer regardless of the sources of colostrum. Cellular immunity during the preweaning period is also compromised, such that the peripheral blood mononuclear cells isolated from calves born to HS cows have a lower proliferation rate when encountered a mitogen in vitro compared with those from CL dams (Tao et al., 2012a). Additionally, a recent study (Strong et al., 2015) demonstrated that even a very brief period of exposure to heat stress (one week at three weeks before calving) during the late gestation is sufficient to decrease the gene expression of both *toll-like receptor 2* and *tumor necrosis factor* in the whole blood during the first month of life, suggesting an impairment of the innate immunity.

The maternal heat stress during late gestation may also have a long term impact on offspring's performance. A recent study (Monteiro et al., 2013) analyzed the records of 72 heifers born to late gestation HS or CL dams during the course of five years. After birth all heifers were individually housed in hutches in a sand bedded barn and managed in a similar manner. Heifers born to HS dams had greater morbidity and mortality rates during the preweaning period compared with those born to CL dams. Also, heifers that experienced late gestation maternal heat stress produced an average of 5 kg/d less milk throughout the first 35 weeks of the first lactation. These data suggest that there is a programming effect caused by in utero heat stress that alters the calf's postnatal metabolism, physiology and immunity, in turn affecting the overall production capacity or mammary gland development of heifers.

Conclusions

It is important to recognize the negative impacts of dry period heat stress on the cow and her calf's performance, immunity and metabolism, and the significance of prepartum cooling in transition cow and calf management. A special attention should also be given during the early dry period to ensure a smooth transition from lactating to non-lactating stage.

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