J. Dairy Sci. 101:1–13
https://doi.org/10.3168/jds.2017-13727

Symposium review: The influences of heat stress on bovine mammary gland function[1]

S. Tao,*[2] R. M. Orellana,* X. Weng,* T. N. Marins,* G. E. Dahl,† and J. K. Bernard*
*Department of Animal and Dairy Science, University of Georgia, Tifton 31793
†Department of Animal Sciences, University of Florida, Gainesville 32611

ABSTRACT

Heat stress reduces cow milk yield and results in a significant economic loss for the dairy industry. During lactation, heat stress lowers milk production by 25 to 40% with half of the decrease in milk synthesis resulting from the reduced feed intake. In vitro studies indicate that primary bovine mammary epithelial cells display greater rates of programmed cell death when exposed to high ambient temperatures, which may lead to a decrease in the total number of mammary epithelial cells in the mammary gland, partially explaining the lower milk production of lactating cows under heat stress. The function of mammary cells is also altered by heat stress. In response to heat stress, mammary cells display higher gene expression of heat shock proteins, indicating a need for cytoprotection from protein aggregation and degradation. Further, heat stress results in increased gene expression without altering protein expression of mammary epithelial cell junction proteins, and does not substantially influence the integrity of mammary epithelium. These data suggest that the mammary gland strives to maintain cell-to-cell junction integrity by synthesizing more proteins to compensate for protein losses induced by heat stress. During the dry period, heat stress negatively affects mammary gland development by reducing mammary cell proliferation before parturition, resulting in a dramatic decrease in milk production in the subsequent lactation. In addition to mammary growth, the mammary gland of the heat-stressed dry cow has reduced protein expression of autophagic proteins in the early dry period, suggesting heat stress influences mammary involution. Emerging evidence also indicates that heifers born to cows that experience late-gestation heat stress have lower milk yield during their first lactation, implying that the maternal environment may alter mammary gland development of the offspring. It is not clear if this is due to a direct epigenetic modification of prenatal mammary gland development by maternal heat stress. More research is needed to elucidate the effect of heat stress on mammary gland development and function.
Key words: heat stress, mammary gland, lactation

INTRODUCTION

Thermal stress is defined as "any change in the thermal relation between an organism and its environment which, if uncompensated by temperature regulation, would result in hyper-, or hypothermia" (IUPS Thermal Commission, 2001). Therefore, in this review, heat stress is defined as an environment that skews the balance between heat load and heat dissipation inducing hyperthermia of an animal. Animals display the maximal genetic potential only within their thermoneutral zone, and a heat challenge above an animal's upper critical temperature dramatically alters behavior, health, and productivity. In the livestock industry, heat stress is a primary constraint to efficient production of animal protein and food security (Baumgard and Rhoads, 2013), resulting in economic burdens to producers and raising serious animal welfare concerns (St-Pierre et al., 2003; Rhoads et al., 2013). In the dairy industry, the decrease in milk production in lactating cows caused by heat stress alone results in a $1.2 billion annual loss across the entire US dairy sector (Key et al., 2014). Recent research further indicates that lack of cooling during the dry period could result in a $850 million annual loss to the US dairy industry (Ferreira et al., 2016). Production and economic losses caused by heat stress for the dairy industry are increasing due to global climate change (Key et al., 2014). Therefore, there is a need to further understand the mechanisms through which heat stress exerts negative effects on dairy cattle, to develop appropriate management and nutritional countermeasures.

Heat stress compromises reproduction, productivity, and health of a dairy cow (Kadzere et al., 2002;

Received August 22, 2017.
Accepted November 25, 2017.
[1]Presented as part of the ADSA Lactation Symposium: The New and Old of Mammary Gland Physiology and Milk Synthesis at the ADSA Annual Meeting, Pittsburgh, Pennsylvania, June 2017.
[2]Corresponding author: stao@uga.edu

West, 2003; Hansen, 2013). Among these negative effects, the decreased milk production and increased bulk milk SCC during summer are the most recognized and directly related to mammary gland function. For example, in Georgia dairy farms (Figure 1), milk yield per cow decreased and the test day SCC increased during summer as average ambient temperature-humidity index (**THI**) increased. Although the seasonal pattern of milk production and bulk milk SCC on the farm level is a result of various factors, including reproductive, management, and nutritional programs of a farm, a similar pattern is observed in many regions and is largely attributed to the effects of heat stress on dry and lactating dairy cows (West, 2003; Tao and Dahl, 2013). Thus, this symposium paper will focus primarily on the effect of heat stress on lactation performance and aspects related to mammary gland function of a dairy cow at different stages of the lactation cycle.

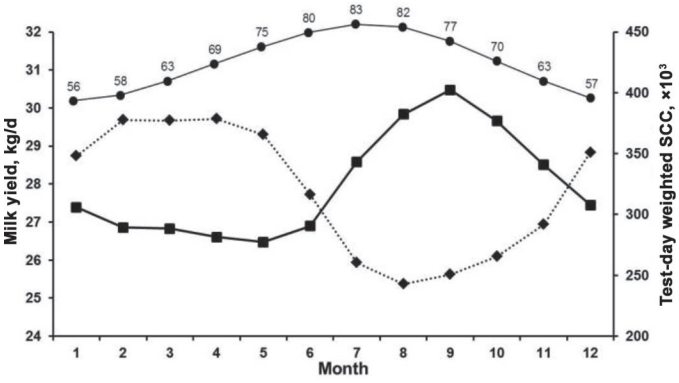

Figure 1. Monthly milk yield [solid diamonds (♦) with a dotted line] and bulk milk SCC [solid square (■) with a solid line] in Georgia (data were extracted from DHIA record of herds in Georgia in 2015, n = 99) and typical ambient temperature-humidity index [solid circle (●) with a solid line] within a year in Georgia.

EFFECTS OF HEAT STRESS DURING THE DRY PERIOD ON MAMMARY GLAND DEVELOPMENT AND LACTATION

The dry period is a nonlactating period between lactations that functions to promote removal of senescent cells within the mammary gland and replenishment of new mammary cells by proliferation before parturition (Capuco et al., 1997, 2001); it is thereby important for maximal milk production in the following lactation. Exposure to environmental cues during this period alters mammary gland development and influences subsequent milk production. For example, cows that experience heat stress during late gestation have a significant reduction in subsequent milk production (Collier et al., 1982; do Amaral et al., 2011; Tao et al., 2011, 2012b). Compared with cows supplemented with evaporative cooling during the entire dry period in summer, those without evaporative cooling have ~4 to 5 kg/d lower milk production during the entire next lactation (Tao and Dahl, 2013), suggesting that heat stress during the dry period alters mammary function before calving. Indeed, relative to cooled cows during the dry period, noncooled cows had lower mammary epithelial cell proliferation at 20 d before expected calving (Tao et al., 2011) but similar mammary gene expression of proteins related to synthesis of milk components in the following lactation (Tao et al., 2013). These data suggest that heat stress during the entire dry period compromises mammary growth during the late dry period without affecting synthetic capacity of mammary epithelial cells during following lactation, leading to lower milk production.

The underlying mechanisms for the reduced mammary growth resulting from heat stress during the dry period are not completely understood. Altered postabsorptive metabolism by heat stress may alter nutrient availability at the mammary gland and influence mammary function and growth. In mid-lactation dairy cows, heat stress enhances glucose uptake by tissues rather than the mammary gland (Wheelock et al., 2010), thereby limiting glucose availability and lactose synthesis in the mammary gland. Similar to lactating cows, heat stress reduces dry cows' DMI but to a lesser extent, likely because overall DMI is lower in dry cows. Relative to cooled cows, noncooled cows had 1 to 1.5 kg/d reduction in DMI before calving (Tao and Dahl. 2013). However, no differences in plasma glucose, nonesterified fatty acids (**NEFA**), BHB, and insulin are observed between cooled and noncooled cows during the dry period (do Amaral et al., 2011; Tao et al., 2012b). Consistently, heat stress had no effect on adipose tissue mobilization (Lamp et al., 2015), NEFA response to an insulin challenge, or glucose clearance after a glucose tolerance test (Tao et al., 2012b) during the dry period, suggesting that the postabsorptive fatty acid and glucose metabolism of the cow are not influenced by heat stress during the dry period at the systemic level. In contrast, relative to those under thermal neutrality with similar DMI, heat-stressed dry cows have more pronounced protein mobilization (Lamp et al., 2015). Whether the enhanced extra-mammary protein degradation affects nutrient availability at the mammary gland and thus its development is not clear. Within the mammary gland, noncooled dry cows had higher gene expression of acetyl CoA carboxylase and fatty acid synthetase relative to cooled cows (Adin et al., 2009). Those data may indicate that the mammary gland of heat-stressed dry cows partitions more energy toward fatty acid synthesis rather than mammary cell prolif-