



Invited review: Effects of heat stress on dairy cattle welfare

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ABSTRACT

The effects of high ambient temperatures on production animals, once thought to be limited to tropical areas, has extended into northern latitudes in response to the increasing global temperature. The number of days where the temperature-humidity index (THI) exceeds the comfort threshold (>72) is increasing in the northern United States, Canada, and Europe. Compounded by the increasing number of dairy animals and the intensification of production, heat stress has become one of the most important challenges facing the dairy industry today. The objectives of this review were to present an overview of the effects of heat stress on dairy cattle welfare and highlight important research gaps in the literature. We will also briefly discuss current heat abatement strategies, as well as the sustainability of future heat stress management. Heat stress has negative effects on the health and biological functioning of dairy cows through depressed milk production and reduced reproductive performance. Heat stress can also compromise the affective state of dairy cows by inducing feelings of hunger and thirst, and we have highlighted the need for research efforts to examine the potential relationship between heat stress, frustration, aggression, and pain. Little work has examined how heat stress affects an animal's natural coping behaviors, as well as how the animal's evolutionary adaptations for thermoregulation are managed in modern dairy systems. More research is needed to identify improved comprehensive cow-side measurements that can indicate real-time responses to elevated ambient temperatures and that could be incorporated into heat abatement management decisions.

Key words: well-being, affective state, natural behavior, body temperature, cow

INTRODUCTION

Escalating global temperatures (Schär et al., 2004) combined with global increases in the number of production animals and the intensification of agriculture (Renaudeau et al., 2012), including (but not limited to) that in emerging economies (von Keyserlingk and Hötzel, 2015), has resulted in heat stress becoming an important challenge facing the global dairy industry.

Given that lactating dairy *Bos taurus* cows already have elevated internal heat loads caused by high milk production (Chebel et al., 2004), the effects of accumulating incremental heat are exacerbated when temperature and humidity values increase in the surrounding environment (West, 2003). Not surprisingly, these challenges are greatest in geographic areas where the summer season is long (i.e., southwestern United States, Brazil) and there is a constant presence of radiant solar energy and high humidity, resulting in minimal relief from the heat (Schüller et al., 2014). However, animals housed in northern latitudes (i.e., central Europe, northern United States, Canada) can also experience heat stress, where the summer season is relatively short but warm and there is a minimal decline in overnight temperatures. Heat stress results in total annual economic losses to the US livestock production industry ranging from \$1.69 to 2.36 billion, of which \$900 million is specific to the US dairy industry, stemming from decreased milk production, compromised reproduction, and increased culling (St-Pierre et al., 2003).

Heat stress is defined as the sum of external forces acting on an animal that causes an increase in body temperature and evokes a physiological response (Dikmen and Hansen, 2009). Excessive flow of energy (in the form of unabated heat) into the body, in addition to energy depletion required for lactation and growth (Ferrell and Jenkins, 1985) can lead to deteriorated living conditions, reduced quality of life, and, in extreme cases, death (Mader et al., 2006), unless the animal can activate various adaptive mechanisms to increase the external net energy flow. Documented physiological coping strategies used by dairy cows include increased respiration rate, panting, and sweating, and reduced milk yield and reproductive performance. Behavioral coping strategies include modified drinking and feed

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intake (e.g., increased water intake and shifting feeding times to cooler periods during the day), increased standing time and shade seeking, and decreased activity and movement (De Rensis and Scaramuzzi, 2003; West, 2003; Schütz et al., 2008).

The environmental conditions driving heat stress are presented using the temperature-humidity index (**THI**), a calculated index that incorporates the effects of environmental temperature with relative humidity. This unitless index was first introduced by Thom (1959) to describe the effect of ambient temperature on humans but has been adapted to describe thermal conditions that drive heat stress in dairy cattle (De Rensis et al., 2015). The THI is divided into categories that potentially indicate the level of heat stress, but definitions vary between researchers and conditions. Armstrong (1994) used $\text{THI} < 71$ as a thermal comfort zone (assuming the THI does not drop below the thermoneutral conditions of dairy cows, which induces cold stress), 72 to 79 as mild heat stress, 80 to 90 as moderate heat stress, and > 90 as severe heat stress. Comparatively, De Rensis et al. (2015) defined $\text{THI} < 68$ to be outside the thermal danger zone for cows. Mild signs of heat stress are observed at THI of 68 to 74, and a $\text{THI} \geq 75$ will cause drastic decreases in production performance (De Rensis et al., 2015). The THI value is usually the main determinant for management decisions related to heat stress as most meteorological stations close to farms provide this data.

However, the categorical THI values described above (although dependent on the geographic location, as well as cow breed and physical size) can only act as a rough indicator for the effects of heat stress on production measures, in lieu of knowing the animal's internal body temperature. Moreover, calculating environmental heat stress is dependent on which formula is chosen, as THI equations can weight humidity or dry-bulb temperature to account for different environmental conditions (Bohmanova et al., 2007). Wind speed has also been shown to affect environmental temperatures (Mader et al., 2006) and should be included in THI calculations when possible.

Most of the scientific literature on the effects of heat stress on dairy cattle has focused on physiological measures that describe how the animal is interacting with its environment, such as plasma cortisol, heart rate, and respiratory rate (Kadzere et al., 2002). However, physiological measures at best describe the health and biological functioning component of the animal's welfare but fail to address the multidimensional concept of animal welfare that also considers aspects such as mental states (i.e., the absence of pain and frustration), and the ability to live a reasonably natural life (Fraser et al., 1997; Boissy et al., 2007).

Negative feelings such as pain or frustration are increasingly described as suffering (Duncan, 2004). Clearly, when animals lose the ability to control their environment (e.g., a need for water to alleviate dehydration, the need for shade to reduce body temperature), there are associated risks to the animal's welfare that may not necessarily be associated with direct biological functioning. The subjectivity of feelings in animals, including cattle, is difficult to quantify and describe, but scientists have begun to evaluate them using experimental approaches such as preference and motivation testing (Schütz et al., 2008; Charlton et al., 2013; von Keyserlingk et al., 2017) and judgement bias tests (Daros et al., 2014).

A key objective of animal welfare science, as argued by some, is to determine which aspects of natural living are important for animals and how producers can incorporate these needs into best management practices (Fraser et al., 1997). This component of animal welfare has received much debate, as some view natural living to literally mirror the animal's "evolutionary" environment (e.g., grazing on pasture and calves suckling their dam) and how producers can promote their animals to express these behaviors. In contrast, others argue that this interpretation and application of natural living into management practices may negatively affect welfare (e.g., by exposing the animal to diseases, parasites, extreme weather, and predators; Špinka, 2006). Recent research investigating dairy producer attitudes toward animal welfare highlights farmers' concerns for animals' subjective and natural living (Ventura et al., 2015), and ultimately, we see natural living solutions as being a balance of both interpretations so that farm animals can live a "good life."

An essential foundation for welfare science is that different concerns of animal welfare can overlap each other. A lactating cow unable to seek shade on a hot day (natural living) will likely feel uncomfortably hot (affective state) and will experience reduced milk production (poor biological functioning; von Keyserlingk et al., 2009). Most research has addressed welfare issues in a manner where the concern can be subjected to and assessed using scientific investigation through one sphere of animal welfare (i.e., lameness as a component of biological functioning and health; motivation to access pasture as a component of natural living). However, personal values of researchers often dictate the direction of scientific inquiry and may prevent new approaches from being considered and investigated (e.g., lameness as a component of affective states). Unfortunately, heat stress research has followed this same dogma; thus, in this review, we propose new avenues of discussion in an attempt to reframe how we think of heat stress and dairy cattle welfare. For example, for

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