Effects of Late Gestation Episodic heat Stress in the Northeastern United States on Holstein Dams and their Calves

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EFFECTS OF LATE GESTATION EPISODIC HEAT STRESS IN THE NORTHEASTERN UNITED STATES ON HOLSTEIN DAMS AND THEIR CALVES

A Thesis Presented

by

Emily Morgan Fread

to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Master of Science
Specializing in Animal Science

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ABSTRACT

Heat stress negatively impacts dry dairy cows in subtropical climates, but impacts in moderate climates are unknown. The objective of this thesis was to determine if dry cows and their calves in Northern NY and VT are impacted by episodic heat stress and varying levels of heat exposure. Another aim of this study was to determine farmers' knowledge of heat stress, heat abatement use, and the need for future research.

Chapter 2 describes a study conducted on a Northern NY farm, where dry cows were housed in moderate heat abatement, meaning fans over a bedded pack or free stalls. Surprisingly, cows had higher reticular temperature and rumination time on hot days. Although not reflected in body temperature or rumination data, these cows were heat-stressed as they stood longer on hot days to dissipate heat. Cows who experienced high amounts of heat stress during the dry period (DP) had a shorter gestation length. Cows who experienced low amounts of heat stress during the DP tended to have higher-quality colostrum than those with moderate heat stress. Cows who experienced high amounts of heat stress during the late DP had lower 21-day milk production. Calves were not statistically affected by in-utero episodic heat stress for the measured variables.

Chapter 3 describes a study conducted on a Northern VT farm, where dry cows were housed on pasture for their early DP and on a bedded pack with access to an outdoor sandlot for their late DP. Similar to the study conducted in Chapter 2, this study indicated that cows ruminated longer on hot days. Unlike in Chapter 2, cows only had higher reticular temperature on hot days when housed on pasture, not when they had the option of shade access of the barn. Cows who experienced high amounts of heat stress during the late dry period tended to have greater weight loss from dry off to calving.

Eight farmers with varying farm sizes and heat abatement use were interviewed regarding their opinions of heat stress and usage of heat abatement, as described in Chapter 4. Overall, all farmers felt their cows were negatively impacted by heat stress, and most had implemented heat abatement strategies on their farms. A prevalent theme of many interviews was farmers’ hesitancy to install sprinklers as a form of heat abatement due to concerns about animal health and water availability.

These studies indicate that dry cows are negatively impacted by episodic heat stress in the Northeast, so heat abatement should be provided during the DP. Farmers in the area believe heat stress negatively affects their cattle and have observed positive impacts of providing heat abatement for their animals.
CITATIONS

Material from this dissertation has been published in the following form:


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LIST OF ABBREVIATIONS

ACUC: animal care and use committee
AHL: accumulated heat load
BGHI: black globe-humidity index
BW: body weight
BCS: body condition score
C: Celcius
CCI: comprehensive climate index
Cm: centimeter
D: day
DHI: dairy herd information
DI: discomfort index
DIM: days in milk
DMI: dry matter intake
DP: dry period
ERHL: effective radiant heat load
ETI: equivalent temperature index
F: Fahrenheit
H: hour
HLI: heat load index
HSP: heat shock protein
IgG: immunoglobulin G
ITSC: index of thermal stress for cows
IRB: institutional review board
Kg: kilogram
L: liter
LS: locomotion score
M: meter
Min: minute
Mo: month
NEFA: non-esterified fatty acids
NRC: national research council
PBMC: peripheral blood mononuclear cells
PROC: procedure
RAD: solar radiation
RH: relative humidity
RT: reticular temperature
S: second
SARA: subacute rumen acidosis
SAS: statistical analysis system
SCC: somatic cell count
SD: standard deviation
SE: standard error
SEM: standard error of the mean
T: temperature
THI: temperature-humidity index
TMR: total mixed ration
VFA: volatile fatty acid
Wk: week
WSPD: wind speed
Yr: year
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CHAPTER 1: LITERATURE REVIEW

1.1. Introduction

As environmental temperatures have increased with climate change, dairy farmers have battled heat stress in cattle, even in moderate climates. Armstrong (1994) defined heat stress as when the effective environmental temperature has surpassed an animal's thermoneutral zone. He further stated that the effective temperature of the environment is influenced by air temperature, relative humidity, air movement, and solar radiation. An animal’s thermoneutral zone is the range in which it can keep a constant body temperature without changing its basal metabolic rate (Shearer et al., 1990). Throughout the literature, heat stress has been determined to affect dairy cattle production, health, and welfare negatively.

1.2. Characterizing heat stress in dairy cattle

1.2.1. Indices to assess environmental conditions as they relate to heat stress in dairy cattle

A list of all indices mentioned in this section can be found in Table 1.

Numerous indices have been developed and evaluated to assess the impacts of heat stress on dairy cattle. The Temperature-Humidity Index (THI) is the most widely used index throughout the published literature. THI accounts for air temperature and humidity, but not other factors such as wind speed or solar radiation, which dairy cattle are more susceptible to on pasture. It is essential to consider the best index to assess heat stress in dairy cattle housed in different environments, as housing conditions can impact heat stress.
The first index to assess heat stress was the Discomfort Index (DI), created by E. C. Thom (1959). The DI was developed to evaluate heat-caused discomfort in humans and accounted for dry-bulb and wet-bulb temperatures. Dry-bulb temperature is representative of the temperature of the air, while wet-bulb temperature takes pressure and humidity into account (NRC, 1971). Following the DI, the Relative Strain Index was the first index developed for animals using environmental conditions, characteristics of the specific animal, and the physiological response to those environmental conditions to differentiate between stress and strain (Lee et al., 1965). Lee et al. (1965) defined stress as external forces that displace homeostasis, and strain as the internal physiological changes in response to that displaced homeostasis.

The National Research Council (NRC; 1971) was the first group to publish the Temperature-Humidity Index, suggesting several different equations using dry and wet bulb temperatures, dew point, and relative humidity. The NRC indicated that more research was needed to determine which was best to use for dairy cattle. The dew point is when air has been cooled enough for condensation to form (NRC, 1971). The widely accepted THI formula used by many recent publications was published by Dikmen et al. (2008). Brugemann et al. (2012) found that averaging hourly THI together for each day is more indicative of heat stress than using daily maximum THI. Historically a THI threshold of 72 has been used to characterize heat stress in Holstein cattle (Igono et al., 1992). A THI threshold of 68 has recently become accepted as when lactating cattle start experiencing heat stress, as metabolic heat loads increase with increased milk production (Zimbelman et al., 2009). Recently, a THI threshold of 77 has been estimated as when dry cows begin
to experience heat stress (Ouellet et al., 2021). The accepted THI threshold that cows begin to experience heat stress has changed over time as dairy animals’ milk synthesis capacity has increased and is impacted by stage of lactation and how the THI formula is used to reflect heat stress.

Several modifications have been made to the THI formula to account for different parameters. St-Pierre et al. (2003) defined three THI formulas to represent the reduction in apparent THI compared to the actual THI in a barn when different levels of heat abatement are utilized (moderate, high, or intense heat abatement). THI was then adjusted for solar radiation and wind speed based upon three studies with beef feedlot cattle (Mader et al., 2006). Mader et al. (2006) found that panting scores were compared with mean daily wind speed, black globe temperature at 15:00 h, and daily relative humidity; panting scores were more correlated to humidity than other variables.

The Black Globe-Humidity Index (BGHI) was developed by Buffington et al. (1981), utilizing black globe and dew point temperature. Black globe temperature is obtained from a temperature sensor housed in a black cap that accounts for solar radiation and radiant heat. Radiant heat includes the heat gained or lost between a cow and various surfaces through radiation, i.e., the exchange between two cows or a cow and a shade structure (Berman and Horovitz, 2012). This index was developed based on a study conducted at the University of Florida, where Holstein cattle were housed on pasture with or without access to shade. Milk production, conception rates, pregnancy rates, rectal temperatures, and respiration rates were collected. Buffington et al. (1981) concluded that the BGHI better predicts heat stress for animals under solar radiation than THI.
The Equivalent Temperature Index (ETI) was developed by Baeta et al. (1987) to incorporate temperature, humidity, and air velocity as a measure of the impacts of heat stress on lactating dairy cattle housed indoors. This index was developed using lactating Holstein cattle exposed to different weather conditions and accounted for milk production, rectal temperature, metabolic heat production rate, respiratory rate, and feed and water intake. It is important to note that for this index to assess heat stress accurately, the temperature must be between 16 and 41°C, relative humidity must be between 40 and 90%, and air velocity must be between 0.5 and 6.5 m/s. ETI results can be broken into several categories: thermoneutral zone (18 – 27°C), caution (27 – 32°C); extreme caution (32 – 38°C), danger (28 – 44°C), and extreme danger (> 44°C).

A Heat Load Index (HLI) was developed by Gaughan et al. (2008) to incorporate black globe temperature, relative humidity, and wind speed when assessing heat stress impacts. HLI utilizes two formulas depending on the level of the black globe temperature (above or below 25°C). These formulas and thresholds were developed using panting scores, respiration rates, and tympanic (ear) temperatures from 13 feedlots. This study provided beef cattle with varying degrees of shade; when shade was present, cattle experienced elevated body temperatures at an HLI of 96. With no shade, the cattle experienced high body temperatures at an HLI of 86. After developing the HLI, the Accumulated Heat Load (AHL) model was created to evaluate the heat load an animal experiences when the HLI is above the threshold at which body temperature begins to increase (Gaughan et al., 2008).
The Comprehensive Climate Index (CCI) was developed by Mader et al. (2010) to reflect heat and cold stress conditions. CCI incorporates several equations to account for ambient temperature, wind speed, relative humidity, and solar radiation. This index was created using the data collected by Gaughan et al. (2008) for the HLI and modeled the relationship between environmental variables and panting scores in warm conditions and environmental variables and DMI in cold conditions. A CCI of 25 is the threshold for mild heat stress, and 40 is extreme heat stress when livestock deaths become more common. More recently, a threshold of a CCI of 20 has been used to classify heat stress (Arias et al., 2021). Researchers found it difficult to establish a threshold for cold stress, as many livestock species are more resistant to cold than heat.

Da Silva et al. (2010) developed the Effective Radiant Heat Load (ERHL) to assess the impact of heat stress on dairy cattle on pasture using solar radiation, black globe temperature, and ambient air temperature. This index was created using cutaneous surface temperature data from Holstein-Guzerath cross-bred dairy cattle in Brazil. The Index of Thermal Stress for Cows (ITSC) was developed by Da Silva et al. (2015) specifically for dairy cattle living in tropical and semi-arid climates, building off ERHL and incorporating wind speed and partial vapor pressure. This index was developed with Holstein dairy cattle in Brazil using rectal temperatures, coat surface temperatures, skin surface evaporation, and air temperatures from breathing. Suggested ranges for this index are as follows: comfort (≤ 150), mild discomfort (151 - 200), discomfort (201 - 250), stress (251 - 350), and warning (≥ 350).
The summer-to-winter ratio was used by Guinn et al. (2019) to look at the effect of heat stress on energy-corrected milk, somatic cell count, fat and protein components of milk, conception rate, heat detection rate, and pregnancy rate throughout different United States regions. To calculate this, Guinn et al. (2019) took a ratio of a specific variable during the summer as the numerator and that same variable during the winter as the denominator. If the ratio is close to 1, this indicates that heat stress has a negligible effect on that particular variable. Using this ratio to compare various variables, Guinn et al. (2019) found that this is a practical tool and that heat stress is more severe in the Southeast and Southern Plains regions of the United States.

Bohmanova et al. (2007) suggested that different indices should be used for different climates; for example, more humid climates should use an index emphasizing the relative humidity part of the equation. Other literature indicates that one index can be used universally across climates, as dry bulb temperature predicts increased rectal temperatures during heat stress as effectively as THI (Dikmen et al., 2009). A study by Hammami et al. (2013) suggests that the best index to assess the impacts of heat stress on milk yield and somatic cell score is the adjusted THI index created by Mader et al. (2006). When evaluating the best index to characterize heat stress, the animal's housing conditions must be considered. For animals housed in a free-stall barn, the THI equation reported by Dikmen et al. (2008) is most widely used throughout the literature. The CCI can be used for animals housed on pasture, as it accounts for ambient temperature, wind speed, solar radiation, and relative humidity (Arias et al., 2021). THI adjusted for wind speed and solar radiation can also be used for animals housed on pasture (Mader et al., 2006).
Table 2.1: Summary of indices to assess environmental conditions as they relate to dairy heat stress

<table>
<thead>
<tr>
<th>Index Name</th>
<th>Equation</th>
<th>Abbreviations</th>
<th>Reference</th>
</tr>
</thead>
</table>
| Accumulated Heat Load (AHL)               | \[\text{AHL} = \text{IF} (\text{HLI}_{\text{ACC}} - \text{HLI}_{\text{Lower \ Threshold}})/\text{M}, \text{IF}[\text{HLI}_{\text{ACC}} > \text{HLI}_{\text{Upper \ Threshold}}]/\text{M}, 0],\] | - \text{HLI}_{\text{ACC}}: actual HLI value at a point in time  
- \text{HLI}_{\text{Lower \ Threshold}}: the HLI threshold below which cattle in a particular class will dissipate heat  
- \text{HLI}_{\text{Upper \ Threshold}}: the HLI threshold above which cattle in a particular class will gain heat  
- \text{M}: measures per hour | (Gaughan et al., 2008) |
| Apparent THI w/ high heat abatement       | \[\Delta \text{THI} = -17.6 + (0.36 \times T) + (0.04 \times H)\]            | - \Delta \text{THI}: change in apparent THI  
- \text{T}: ambient temperature (°C)  
- \text{H}: ambient relative humidity (%) | (St-Pierre, 2003) |
| Apparent THI w/ intense heat abatement    | \[\Delta \text{THI} = -11.7 – (0.16 \times T) + (0.18 \times H)\]           | - \Delta \text{THI}: change in apparent THI  
- \text{T}: ambient temperature (°C)  
- \text{H}: ambient relative humidity (%) | (St-Pierre, 2003) |
| Apparent THI w/ moderate heat abatement   | \[\Delta \text{THI} = -11.06 + (0.25 \times T) + (0.02 \times H)\]           | - \Delta \text{THI}: change in apparent THI  
- \text{T}: ambient temperature (°C)  
- \text{H}: ambient relative humidity (%) | (St-Pierre, 2003) |
| Black Globe-Humidity Index (BGHI)         | \[\text{BGHI} = t_{bg} + 0.36t_{dp} + 41.5\]                              | - \text{t}_{bg}: black globe temperature (°C)  
- \text{t}_{dp}: dew point temperature (°C) | (Buffington et al., 1981) |
| Comprehensive Climate Index (CCI)         | \[\text{CCI} = T_a + \text{Eq. [1]} + \text{Eq. [2]} + \text{Eq. [3]}\]     | - \text{T}_a: ambient temperature (°C)  
- \text{RH}: relative humidity (%), decimal form  
- \text{WS}: wind speed (m/s)  
- \text{RAD}: solar radiation (W/m²) | (Mader et al., 2010) |
| Discomfort Index (DI)                     | \[\text{DI} = 0.4 (t_d + t_w) + 15\]                                      | - \text{t}_d: dry-bulb temperature (°F)  
- \text{t}_w: wet-bulb temperature (°F) | (Thom, 1959) |
| Effective Radiant Heat Load (ERHL)        | \[\text{ERHL} = 0.55S + \text{RHL} \times W \times m^{-2}\] Where \text{RHL} = 1.0526h_c(T_g-T_a) + \sigma T_g^4 W \times m^{-2}\] | - \text{S}: solar radiation  
- \text{RHL}: Radiant Heat Load  
- \text{h}_c: convection coefficient of the globe  
- \text{T}_g: black globe temperature (K)  
- \text{T}_a: air temperature (K) | (Da Silva et al., 2010) |
| **Equivalent Temperature Index (ETI)** | \( ETI = 27.88 - 0.456t + 0.01075t^2 - 0.4905h + 0.00088h^2 + 1.1507v - 0.126447v^2 + 0.019876txh - 0.046313txv \) | - T: air temperature (°C)  
- H: relative humidity (%)  
- V: air velocity (m/s)  
(Baeta et al., 1987) |
| **Heat Load Index (HLI)** | \( \text{HLI}_{BG>25} = 8.62 + (0.38 \times RH) + (1.55 \times BG) - (0.5 \times WS) + e^{2.4 - WS} \)  
\( \text{HLI}_{BG<25} = 10.66 + (0.28 \times RH) + (1.3 \times BG) - WS \) | - RH: relative humidity  
- BG: black globe temperature  
- WS: wind speed  
(Gaughan et al., 2008) |
| **Index of Thermal Stress for Cows (ITSC)** | \( \text{ITSC} = 77.1747 + 4.8327t_A - 34.8189U + 1.111U^2 + 118.6981Pv - 14.7956Pv^2 - 0.1059ERHL \) | - T\(_A\): air temperature (°C)  
- U: wind speed (m/s)  
- Pv: air partial vapor pressure  
- ERHL: Effective radiant heat load  
(Da Silva et al., 2015) |
| **Relative Strain Index** | Relative Strain = evaporative cooling required / maximum evaporative cooling possible = \( \frac{[M(I_a + I_{cw}) + 5.55(t_a - 35) + R I_a]}{[7.5 + 2(I_a + I_{cw})]}(44 - p_a) \) | - M: metabolic rate (kcal/m\(^2\), hr)  
- t\(_a\): air temperature (°C)  
- R: net radiant heat load (kcal/m\(^2\), hr)  
- I\(_a\): insulation of air (clo units)  
- Clo: “the thermal resistance which will maintain a difference of 0.18 °C for a heat flow of 1 kcal/m\(^2\), hr”  
- I\(_{cw}\): insulation of coat (clo units at maximum wetness)  
- p\(_a\): vapor pressure of air (mm Hg)  
(Lee, 1965) |
| **Summer to Winter Ratio** | S: \( \frac{\text{Production variable during the summer mo}}{\text{Production variable during the winter mo}} \) | (Guinn et al., 2019) |
| **Temperature Humidity Index (THI)** | \( \text{THI} = 0.4 \times \text{db + wb} - 15 \)  
\( \text{THI} = 0.55 \times \text{db + 0.2 dp} + 17.5 \text{ or} \)  
\( \text{THI} = \text{db} - (0.55 - 0.55 \times \text{rh}) \times (\text{db} - 58) \) | - db: dry bulb temperature of air (°C)  
- wb: wet bulb temperature of air  
- dp: dew point temperature of air  
- rh: relative humidity of air (%)  
(NRC, 1971) |
| **Temperature Humidity Index (THI)** | \( \text{THI} = (1.8 \times T + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T - 26)] \) | - T: dry bulb temperature (°C)  
- RH: relative humidity (%)  
(Dikmen et al., 2008) |
| **THI adjusted for wind speed and solar radiation** | \( \text{THI}_{adj} = [4.51 + \text{THI} - (1.992 \times \text{WSPD}) + (0.0068 \times \text{RAD})] \) | - THI: Temperature Humidity Index  
- WSPD: Wind speed (m/s)  
- RAD: Solar Radiation (W/m\(^2\))  
(Mader et al., 2006) |
1.2.2. Physiological and behavioral responses to heat stress in lactating dairy cattle

The physiological and behavioral responses to heat stress in lactating dairy cattle have been well documented throughout the published literature. Combatting heat stress has become a higher priority for producers, as high-producing dairy cattle are more sensitive to heat stress than low producers (Ibrahim et al., 2006), and environmental temperatures have risen globally due to climate change.

Behavioral Time Budget

As dairy cattle become uncomfortable due to heat stress, their behavior will change, affecting their daily time budget. Standing time will increase, and lying time will decrease when heat stress occurs to increase the surface area available to dissipate heat (Cook et al., 2007; Allen et al., 2015; Nordlund et al., 2019). Specifically, Cook et al. (2007) observed increased standing time in alleys as THI rises above 68. Claw horn lesions are a cause of lameness and are observed at the highest rates at the end of the summer (Cook, 2004), most likely due to increased standing times or increased sub-acute ruminal acidosis (SARA) (Stone, 2004). Increased standing time also puts increased pressure on cows’ hooves, restricting blood flow, leading to lameness (Grandin, 2016). Daily drinking time increases as THI increases (Tapki et al., 2006; Cook et al., 2007), while time spent eating decreases, which is linked to the reduction in dry matter intake (DMI) observed with heat stress (Eslamizad et al., 2015).

Body Temperature and Respiration Rate

Body temperature and respiration rate are measurable variables widely used to assess heat stress in dairy cattle. Rectal, vaginal, tympanic, subcutaneous, and internal
(reticular) temperatures can be used to evaluate the physiological status of the dairy cow. Rectal temperatures are a typical approach but do not monitor the cow's body temperature continuously like other methods. No continuous data recording devices are available to measure rectal temperatures continuously, so they must be done manually. For this reason, rectal temperatures can be biased by human recording error, the thermometer used, and how far the thermometer is placed into the rectum (Burfeind et al., 2010). Conversely, reticular temperatures are highly correlated to rectal temperatures (Bewley et al., 2008) and provide the added benefits of continuous measurement and no human error.

Respiration rate and body temperature will increase with changes in THI at differing rates. Some studies indicate that heat stress affects respiration rate before rectal temperatures (Brown-Brandl et al., 2003). Other studies demonstrate that reticular temperature may be more sensitive to heat stress than respiration rate in standing cows: the reticular temperature increased when the average daily THI threshold reached 65 (Ammer et al., 2016), while respiration rate increased at a THI of 70 in standing cows and 65 in lying cows (Pinto et al., 2020). Rectal temperature and respiration rate will increase within 24 h of the onset of heat stress (Spiers et al., 2004; Bouraoui et al., 2002), rising at least 38°C and 48 breathes per minute, respectively (Li et al., 2020).

Dry Matter Intake and Rumination

It is well known that DMI decreases as THI increases (Bouraoui et al., 2002; Tapki et al., 2006). The hypothalamus responds to heat stress by curbing the appetite of dairy cows (Albright and Alliston, 1971) to decrease metabolic heat production (Bernabucci et al., 2010). The degree of DMI reduction varies at different stages of life. For instance, first lactation animals do not have as severe of a drop in intake as multiparous animals (Holter
et al., 1997). Intake is affected even in temperate climates and will decrease at a THI of 60 (Gorniak et al., 2014). Additionally, there is a lag effect between environmental conditions and DMI. Cows will have decreased intake within 48 h of the onset of heat stress (Spiers et al., 2004), and intake is most affected by the mean ambient air temperature two days prior (West et al., 2003).

Rumination is an indicator of cow health and comfort, and is affected by many factors including environmental conditions, disease, DMI, diet, calving, age, and estrus. Rumination decreases as temperature increases, especially in high-producing lactating Holstein cows (Tapki et al., 2006; Abeni et al., 2017; Moretti et al., 2017), due to decreased DMI and increased respiration rates (Soriani et al., 2013). Rumination begins to decline at an average daily THI of 52 or higher (Muschner-Simens et al., 2020). It will decrease by 2.2 min per day for every THI unit over a maximum daily THI of 76 (Soriani et al., 2013).

**Immune function and disease**

Heat stress affects the dairy cow's immune system her entire life, starting in the uterus, leading to impacts as a calf, as well as during the dry period (DP) and lactation (Dahl et al., 2020). Diseases such as mastitis and metritis are more prevalent during the summer than in the winter due to increased pathogen survivability and immune system suppression (Tao et al., 2020). Several in vitro studies have illustrated that when heat shock proteins (HSP) are expressed in response to heat stress, they reduce the phagocytic and oxidative burst capacity of dairy peripheral blood mononuclear cells (PBMC) (Lacetera et al., 2006; Lecchi et al. 2016). PBMCs include T and B cells, indicating that heat shock proteins negatively impact both cell-mediated and humoral immune responses in dairy cattle. Toll-like receptors are essential for pathogen recognition by both the innate and
adaptive immune response systems and are less prevalent during heat stress (Dahl et al., 2020). T cells are further impaired in cattle during heat stress because of decreased activity of the interleukin-2 gene, which is responsible for the proliferation of T cells (Benu et al., 2013). Heat stress induces oxidative stress, increasing reactive oxygen species that play a role in suppressing this gene (Pahlavani and Harris, 1998). Because the suppression of the immune system is more likely on hot days, vaccination should be avoided until it is cooler (do Amaral et al., 2011).

The immune system is also affected by “leaky gut” during heat stress in lactating dairy cattle. Essentially, tight gap junctions of the gut epithelium are broken down during this period, allowing toxins within the gut to escape into the bloodstream (Tao et al., 2020) and immune cells to enter the gastrointestinal system (Koch et al., 2019). This type of immune response utilizes large amounts of glucose, which is already depleted during heat stress due to reduced DMI, causing energy stores to be used for the immune system rather than for milk production (Kvidera et al., 2017). Another immunological challenge that lactating dairy cattle face during heat stress is mastitis. Elevated somatic cell count (SCC) in the mammary gland characterizes mastitis, indicating the number of PBMCs deployed to fight off the infection (Becker et al., 2020). During heat stress, somatic cells do not easily move between the mammary gland and the blood, making it more difficult for cows to clear the infection (Elvinger et al., 1992).

*Milk yield and milk components*

Milk yield decreases as THI increases (Igono et al., 1992; Bouraoui et al., 2002; Hill et al., 2015) and is also influenced by wind speed and length of time in the sun (Hill et al., 2015). There is a lag between heat stress and milk yield; some authors contend that
the THI two days prior has the greatest impact (West et al., 2003), whereas others state that it is the THI four days earlier (Bernabucci et al., 2014). A 35-50% reduction in milk yield during heat stress is linked to decreased DMI (Rhoads et al., 2009). Mid-lactation cows have a greater decrease in milk production than early- or late-lactation cows (Johnson et al., 1987). This might be because mid-lactation cows are more dependent upon DMI for milk production, while early- and late-lactation cows mobilize tissue stores for this purpose (Bernabucci et al., 2010).

Breed of cattle plays a role in milk yield and components during heat stress. For example, Jerseys are more heat tolerant than Holsteins. Smith et al. (2013) found that milk production decreased in Jerseys when THI was ≥ 90, much higher than the THI ≥ 79 observed for Holsteins. Holstein's fat percentage was reduced when THI was ≥ 79, while the fat percentage in Jerseys was unaffected.

Milk protein and fat concentrations are lowest in the summer months compared to the winter (Wood, 1970), peaking in January (Salfer et al., 2019). The locational latitude of the dairy farm influences milk protein and fat concentrations, indicating that photoperiod plays a role in annual milk production rhythms (Salfer et al., 2020). Salfer et al. (2020) also found that yearly rhythms of photoperiod can better explain milk, protein, and fat yields than maximum temperatures. Further work needs to be done to separate the impacts of photoperiod and air temperatures, as the longest days typically occur when temperatures are highest, creating a confounding effect (Salfer et al., 2020).

Reproduction
Heat stress negatively impacts the reproductive performance of lactating dairy cattle, affecting the length of estrus (heat), follicular development, and conception rates. Seasonal depression in fertility is due to heat stress and not shifts in natural diurnal patterns. This was determined because fertility can be improved by cooling cows during the summer, and cows who experience heat stress under experimental conditions have reduced fertility (Hansen et al., 1999). When cows are heat-stressed and have elevated body temperatures, cellular function is limited, decreasing the number of viable embryos (Ealy et al., 1995).

Hot climates (75°F at night and between 85 and 95°F during the day) can result in a longer estrous cycle and shorter estrus (Gangwar et al., 1965). Not only does heat stress affect the length of estrus, but it also changes estrus behavior, leading to about 20% more missed heats during the summer (Thatcher et al., 1986). Dairy cattle are 73% more likely to ovulate under thermoneutral conditions than under heat stress. Luteolysis can be delayed for up to nine days in heat-stressed cows, contributing to lower ovulation rates (Wilson et al., 1998). Heat stress up to 40 days before ovulation can affect fertility, as this is the period during which follicles develop to ovulatory size (Hansen et al., 1999).

Conception rate is decreased when the THI is increased on the day of breeding as well as two days before breeding (Ingraham et al., 1974; Ingraham et al., 1976). Recent work has found that conception rate is negatively influenced at a THI threshold of 73, even if the THI only reaches 73 for one hour (Schuller et al., 2014). Conception rates can be improved by cooling cows with sprinklers and fans (Wolfenson et al., 1988).

1.2.3. **Physiological and behavioral responses to heat stress in dry dairy cattle**
Effects of heat stress on lactating dairy cattle have been well established, and more recently, the impacts on dry dairy cattle are being explored. Late gestation dairy cattle are susceptible to heat stress, and many effects carry over into the following lactation, regardless if the heat stress persists. Heat stress has a similar impact on dry cows and lactating cows in that it decreases DMI (Adin et al., 2009; do Amaral et al., 2009), decreases lying time (Karimi et al., 2015), increases body temperature (Fabris et al., 2019), and respiration rate (Toledo et al., 2020). The impacts of heat stress differ in lactating cows and dry cows as the impacts of dry period heat stress on reproduction are unclear. Some studies report no impact on reproduction (Adin et al., 2009; Moore et al., 1992), while others indicate detrimental effects on reproduction (Avendano-Reyes et al., 2010; Thompson et al., 2012). Although dry cows have limited DMI, similar to lactating cows during heat stress, they can still maintain a positive energy balance because they do not have to meet the demands of milk production, and their decrease in DMI is less (Adin et al., 2009; Tao et al., 2011).

*Mammary development and subsequent lactation performance*

Not only does heat stress during lactation reduce milk yield, but heat stress during the DP also does. In Florida, milk production is at its lowest in September, even though the highest temperatures are in July, suggesting that the cows whose DP occurs during the hottest months have lowered milk production in the following lactation (Tao et al., 2013). During lactation, the rate of mammary cell apoptosis is high, and the proliferation rate is low. This is why the DP is essential to maximum milk production; mammary cell proliferation is much higher during the DP than during lactation (Sorensen et al., 2006). Reduced milk yield in the subsequent lactation due to DP heat stress is linked to
compromised mammary gland development during the DP (Tao et al., 2011). One reason for compromised mammary development during the DP due to heat stress may be decreased T4 (thyroid hormone). When cortisol is elevated due to heat stress, it increases norepinephrine and epinephrine levels, leading to reduced thyroid hormones, which are essential for mammary development (Collier et al., 1982).

Providing heat abatement for cows during the DP will compensate for some lost milk production in the subsequent lactation (Collier et al., 1982; Buffington et al., 1983; Fabris et al., 2019). Tao et al. (2011) found that cooling cows with fans and sprinklers during the DP increases mammary cell proliferation rate by 2.3%, allowing for improved milk production. Fabris et al. (2019) demonstrated that cooling cows for their entire DP is crucial, as cooling for the first or last three weeks fails to compensate for lost milk yields. Heat abatement should also be provided for dry cows on pasture, as shade during the last trimester increases milk yield in the subsequent lactation (Buffington et al., 1983; Collier et al., 1982).

*Immune Function*

There is conflicting published information regarding the impact of heat stress during the DP on the immune system. Lacetera et al. (2002) indicated that the immune system might not be as impacted by heat stress during the DP as in lactation. Dry cows had increased respiration rates and rectal temperatures when exposed to mean daily THI values of 75 and nighttime values of 71. These elevated THI values didn’t affect the proliferation of the cell-mediated immune response or IgG concentrations in the colostrum. On the other hand, do Amaral et al. (2010) suggested that increased prolactin due to heat stress during the DP decreases lymphocyte proliferation. Thompson et al. (2014) observed that pathogen
recognition is reduced during heat stress in dry cows because of the impaired expression of toll-like receptors, which play a role in innate and adaptive immunity. Despite conflicting evidence of the impact of heat stress during the DP on the immune system, it can be assumed that it is negatively affected because disease occurrence immediately postpartum increases with DP heat stress (Thompson and Dahl, 2012).

_Gestation_

Heat stress during the DP negatively impacts gestation in a few ways. Heat-stressed ruminants have lower placenta weights at parturition due to decreased cell numbers and smaller placentomes (Early et al., 1991). Contradictory to the smaller placentomes measured by Early et al. (1991), Potadle et al. (2019) observed that heat-stressed dams had increased cotyledon surface area and volume, presumably to deliver adequate nutrients and oxygen to the fetus, despite decreased placental size and blood flow. Dreiling et al. (1991) observed this negative impact on blood flow in pregnant ewes when their body temperature rose 1 °C. Blood flow to the placenta is reduced by 20 to 30% when core body temperature increases due to heat stress (Dreiling et al., 1991). Heat stress also decreases placental hormones, including placental lactogen, which limits fetal growth (Bell et al., 1989; Hossner et al., 1997), and estrone sulfate (Collier et al., 1982), limiting placental function. A higher number of retained placentas are observed during the summer months and are associated with shorter gestation lengths and lowered birth weights following heat stress (Joosten et al., 1987)

1.2.4. **Physiological and behavioral responses to in-utero heat stress**
When considering the effects of heat stress on late gestation dairy cows, it is also essential to consider the calves they are carrying. This is a critical time for fetal growth and development; the greatest fetal growth occurs during the last 60 d of gestation (Bauman et al., 1980). Although it is difficult to measure the impacts of in-utero heat stress while the calf remains in-utero, it is possible to measure the long-term effects once the calf is born.

Effects from birth until weaning

When body temperatures of the dam are elevated during heat stress, the in utero body temperature is also raised (Laburn et al., 2002), causing critical cellular processes for the development of the calf to be altered (Edwards et al., 2003). These high in-utero temperatures have long-term, adverse effects on the productive lives of the offspring.

Calves born to dams without heat abatement during late gestation will have lower birth weights (Collier et al., 1982). The lower weight is due to a few factors: heat stress reduces gestation length, reducing the amount of time the fetus has to grow in-utero; heat stress impairs placenta function, preventing the fetus from receiving adequate nutrients in-utero; and heat stress limits feed intake in the dam, further limiting fetal growth (Tao et al., 2013). Growth rates for in-utero heat-stressed calves remain low until weaning but are not affected from three to seven months (Tao et al., 2012). A more recent study found that heifers born to heat-stressed dams are smaller at one yr of age (Monteiro et al., 2013).

Immune function

In utero heat stress affects newborns' immune systems pre- and postnatally. In pigs, in utero heat stress alters the hypothalamic-pituitary-adrenal axis, altering immune function after birth (Haussmann et al., 2000). Calves exposed to in utero heat stress have
lowered efficiency of IgG absorption (Tao et al., 2012) because of increased apoptotic enterocytes in the jejunum (Ahmed, 2017), the cells responsible for implementing gut closure (Castro-Alonso et al., 2008). Monteiro et al. (2014) observed that this decreased efficiency of absorption is not related to the IgG content of the colostrum but a physiological response to heat stress in the calf.

*In utero* heat stress affects the humoral and cell-mediated response of the calf after birth by decreasing PBMC proliferation (Skibiel et al., 2017) for the first 56 days of life (Tao et al., 2012) and altering B and T cell function (Merlot et al., 2008). Since calves born to heat-stressed dams have lower birth weights, their immune organs, such as the thymus and the spleen, are also smaller, with decreased immune cell numbers, compromising immunity (Ahmed, 2017). *In utero* heat stress may have a lifelong impact on the immune system of dairy animals, as heifers born to heat-stressed dams are more likely to be culled before their first calving (Monteiro et al., 2013; Laporta et al., 2020).

There is conflicting information regarding disease incidence and the survivability of animals in different calving seasons. Some suggest that heifers born during the summer are healthier (Windeyer et al., 2012), while others indicate healthier animals are born in the winter (Svensson et al., 2006).

*Carryover effects: Lactation and fertility*

In-utero heat stress has lasting effects throughout a calf’s life into adulthood. In-utero heat stress also takes a toll on the future reproduction of the offspring. More artificial insemination services to conception are needed (Monteiro et al., 2013), and an average THI $\geq 60$ in the last eight weeks of gestation lowers conception rates (Kipp et al., 2021).
Several meta-analyses suggest calves born to heat-stressed dams will have lowered milk yield during the first lactation (Kipp et al., 2021; Monteiro et al., 2013). A recent meta-analysis indicated that milk yield is reduced in these animals during the first three lactations, and granddaughters of heat-stressed cows have lowered milk production in their first lactation (Laporta et al., 2020). This decreased milk production is due to impaired growth and development of the mammary gland; these offspring simply do not have the same milk synthesis capacity because cell proliferation and cell function is limited (Skibiel et al., 2018). To mitigate some of the lifelong effects of in-utero heat stress, heat mitigation must be provided to dams during the DP. These dams should be supplied with high levels of heat abatement, as calves born to dams provided with evaporative cooling during the last six weeks of gestation produce 19% more milk during lactation and have greater feed efficiency than those born to dams provided with just shade (Dahl et al., 2017).

1.2.5. Metabolic heat production and metabolism during heat stress in dairy cattle

To maintain the demands of milk production, lactating dairy cattle produce a large amount of heat. Dairy cattle have a natural diurnal temperature pattern affected by management practices such as feeding time, milking time, and frequency. The highest body temperatures are observed three hours after feeding (Purwanto et al., 2009), and the lowest is observed after milking (Araki et al., 1984). Cows milked more frequently have higher body temperatures due to higher milk production and metabolic heat production (Kendall et al., 2008). Cows milked in a robotic milking system have free access to milking and choose to be milked more often than cows milked in a traditional parlor twice a day, but less than those being milked three times per day (Wagner-Storch et al., 2003). Cows milked in a robotic milking system produce slightly more than cows milked twice daily in a
traditional parlor. Even though these cows produce slightly more, Galik et al. (2021) showed that they do not experience heat stress effects at a lower THI threshold than cows milked in a traditional parlor. The season may also play a role in circadian body temperatures, as one study measured peak body temperature 4 to 5 h earlier in the day during fall than in summer (Kendall et al., 2009).

Metabolic heat production is higher in high-producing dairy cattle than in dry dairy cattle (Purwanto et al., 1990) because of increased DMI to sustain production (Bauman and Currie, 1980) and increased size and metabolic demands of the mammary gland, liver, heart, and lungs (Smith and Baldwin, 1974). Because metabolic heat is lower in dry dairy cattle, they may have a higher tolerance to heat than lactating dairy cattle (Lamp et al., 2015). Higher body temperatures are observed in lactating cows than in dry cows on hot days (Araki et al., 1984). Lactating dairy cattle have a more remarkable change in rectal temperature (0.91 °C) than dry cows (0.3-0.5 °C) when not provided with heat abatement (Tao et al., 2019).

Heat stress in lactating dairy cattle affects blood metabolite concentrations and causes these animals to enter a negative energy balance (Rhoads et al., 2009). Several pair-feeding studies have been conducted to determine metabolic and production effects of heat stress independent and dependent of DMI (Rhoads et al., 2009; Wheelock et al., 2010). Cows offered a poor-quality diet will mobilize non-esterified fatty acids (NEFAs) to conserve glucose and increase milk production. Heat-stressed dairy cattle have low NEFA concentrations, contributing to lowered milk production measured with heat stress (Wheelock et al., 2010). Low NEFA levels are counterintuitive, as cortisol, epinephrine, and norepinephrine concentrations are elevated during heat stress; these hormones usually
increase NEFA levels (Beede and Collier, 1986). These low NEFA concentrations in heat-stressed animals may be due to increased insulin, which naturally suppresses lipolysis (Wheelock et al., 2010). Lactate increases during heat stress and contributes to low NEFA levels as it binds to adipose receptors, limiting lipolysis (Brooks, 2009).

In addition to its effect on insulin, heat stress also affects somatotropin, thyroid hormones, and prolactin levels. Somatotropin is a hormone partially responsible for partitioning nutrients towards lactation and is decreased during heat stress, partly responsible for lowered milk yield (McGuire et al., 1991). Thyroid hormones are reduced to lower the metabolic heat load (Horwitz, 2001). Prolactin increases during heat stress to improve sweat gland function, even though reduced DMI usually reduces prolactin levels (Roy and Prakash, 2007).

SARA is characterized by low rumen pH and can be caused by several factors during heat stress. With decreased DMI during heat stress comes reduced rumination and therefore decreased buffering agents from saliva traveling to the rumen, lowering pH. Dairy cattle tend to “slug-feed” during heat stress, meaning they eat larger meals less frequently than they usually would, increasing acid production in the rumen (Bernabucci et al., 2010). During heat stress, blood flows away from the gastrointestinal tract and towards the periphery to dissipate heat and protect inner organs. This causes volatile fatty acids (VFAs) to be absorbed less efficiently and increases VFA concentration in the rumen, lowering pH (Bernabucci et al., 2010). When respiration rates increase during heat stress, more CO₂ is lost from the body than usual. The kidney attempts to maintain the HCO₃⁻ (bicarbonate): CO₂ blood ratio by increasing HCO₃⁻. This leads to less HCO₃⁻ being used as buffer in saliva, so this mechanism decreases rumen pH (Kadzer et al. 2002).
1.2.6. Heat acclimation

Several terms describe the physiological changes a dairy cow experiences in response to prolonged heat stress. Acclimation is a phenotypic response to one stressor in an environment, while acclimatization is a phenotypic response to several stressors at one time. Dairy cattle undergo acclimatization, not acclimation, during heat stress because they are exposed to several stressors, including elevated ambient temperatures, humidity, and solar radiation. Adaptation occurs over several generations and involves changes to the species' genome, meaning that an animal’s response will not change when a stressor is removed, unlike with acclimatization (Collier et al., 2019). Acclimatization is a homeorhetic mechanism, meaning set-points of homeostasis are altered to battle heat stress (Collier et al., 2017).

It takes weeks for dairy cattle to undergo the two phases of acclimatization to heat stress: the acute/ short-term and chronic/ long-term phases (Collier et al., 2006). When a dairy cow encounters a stressor such as elevated ambient temperature, afferent neurons receive the signal leading to physiological changes by efferent neurons (Collier et al., 2017). Acute acclimatization involves the first steps of the stress response, beginning minutes after a stressor is presented (Horowitz, 2001). The acute response releases catecholamines and glucocorticoids (Collier et al., 2017), decreasing thyroid hormones (Horowitz, 2001), which decreases the basal metabolic rate by reducing ATP consumption and Na⁺/K⁺ pump syntheses. The dairy cow will further decrease her metabolic heat load during acute acclimatization by reducing DMI and milk yield (Gaughan et al., 2009).

Chronic acclimatization will begin if the stressor persists for more than a few days and is aided by HSPs (Bernabucci et al., 2010). This chronic response increases tissue
sensitivity to the environment by increasing homeostatic hormone receptor populations on cells (Bauman and Curie, 1980). When a dairy cow has become acclimatized to the heat, she will have lower body temperatures, metabolic rate, and increased heat dissipation capabilities at high temperatures (Horowitz, 2001).

1.2.7. Episodic heat stress

Many heat stress studies have been conducted in tropical or sub-tropical environments, such as Florida, where the daily THI stays above 68 for extended periods (Monteiro et al., 2016; Fabris et al., 2019). It is essential to address heat stress in these climates, as these producers battle it year-round; but it is also necessary to think about heat stress in moderate climates, as this is where most cows in the United States are located. California (CA), Wisconsin (WI), and New York (NY) are the three states with the largest cow numbers. WI experiences 39 to 40 heat stress days per year, NY experiences 51 to 66, and CA experiences 69 to 80, with a heat stress day defined as a day where the average daily THI is greater than or equal to 68 (Laporta et al., 2020).

States with lower heat stress days experience hot days episodically instead of continuously, like in warmer regions. This may negatively impact dairy welfare since it takes weeks for dairy cattle to acclimatize to hot weather, and it is rare to have weeks of consistent hot weather in these states. Few studies have focused on episodic heat stress in moderate climates in the United States. Recently, the Miner Institute has determined through several years of research that lactating cows in Northern New York are negatively impacted by heat stress regardless of the heat abatement system (Ballard et al., 2020).

1.3. Cooling mechanisms for dairy cattle
1.3.1 Natural thermoregulation

Dairy cattle are homeotherms, meaning they must maintain a body temperature within a specific range to survive and can do so in a wide range of environmental temperatures. Cows have different critical temperatures, or the temperature range in which they can maintain their body temperature while keeping the basal metabolic rate the same, depending on age, level of production, and body condition. A dry cow’s critical temperature range is between $-14^\circ$ and $25^\circ$ C, while a cow at peak lactation has a critical temperature range between $-25^\circ$ and $25^\circ$ C (Collier et al., 1982). Critical temperatures can be affected by different factors, including the length of time a cow is exposed to a high temperature. When a cow is exposed to high temperatures for an extended period (8 h vs. 1 h), her upper critical temperature is lowered (Zhou et al., 2022).

Homeotherms can transfer heat by convection, conduction, radiation, and evaporation. Conduction can occur when a cow is standing or lying still, and heat passes to or from the object they are touching. When cows spend more time standing during heat stress, they decrease the surface area touching a hot surface. Spraying cool water on a cow’s back is a conduction method, as heat is lost from a warm to a cold surface (Shearer et al., 1990).

Convection occurs when a cow starts moving or fans blow air over her back, and the air touching her is replaced by cooler air (Shearer et al., 1990). During heat stress, the increased standing time allows for a greater surface area cooled by convection.

Radiation is not a method that can cool a cow but rather one that will cause a cow to gain heat from the invisible and visible rays of the sun. Even under shade, cows can
experience indirect radiation from sun rays reflecting off the ground and various objects (NRC, 1971).

Evaporation occurs from both respiration and skin areas; cows can dissipate heat through evaporation by both sweating and panting (Gebremedhin et al., 2008). When water evaporates off the skin and is replaced by dry air, the cow can experience some relief from heat stress (Spiers, 2000). Cows will begin to experience more evaporative cooling than conductive or convective cooling when the air temperature is 70°F or higher (Shearer et al., 1990).

1.3.2. Heat abatement strategies

Heat abatement helps reduce the impacts of heat stress on dairy cattle and can be provided in multiple forms, including shade, air, and water. St. Pierre et al. (2003) defined different levels of heat abatement as minimal, moderate, high, and intense in confined housing systems. Minimal heat abatement is described as having enough airflow and ventilation that animals have acceptable air quality but not enough airflow that the animals are being cooled. Moderate heat abatement includes barns equipped with fans, while barns with high heat abatement levels have fans and sprinklers. Intense heat abatement systems use evaporative cooling to decrease the actual THI instead of the apparent THI, like the other heat abatement levels.

Shade

Shade is a basic form of heat abatement that protects cows from harsh solar radiation and can influence their behavior during heat stress. Access to shade decreases aggressive behaviors towards other animals and increases time spent ruminating, grazing,
and resting for animals on pasture (Vizzotto et al., 2015). Even in mild heat stress conditions, shade can lower vaginal temperatures and increase milk production (Kendall et al., 2006). Feed and water must be underneath the frame for cows to receive a shade structure’s full benefits (Buffington et al., 1983).

When installing a shade structure on pasture, it is crucial to consider the structure's costs and the material's capabilities to protect animals from the sun. Shutz et al. (2009) observed that cows will choose to be under a shade structure that provides more protection from solar radiation than one that offers less. Shade structures should be at least 4.3 m off the ground and provide 3.5 to 4.5 m² of shade space per cow. Animals congregating in one area can lead to large amounts of mud, so shade structures should be oriented north-south, allowing the sun to occasionally shine underneath the shade structure, drying the ground (Collier et al., 2006). Corrugated steel or aluminum is a standard shade material that provides more effective shade than other materials at a low cost (Bond et al., 1961).

Air

Before considering fans for cows in confined housing, it must be ensured that barns are adequately ventilated. To accomplish proper natural ventilation, barn roofs should be sloped at 4:12, allowing warm air to rise and exit through the opening of the ridge, which should be 5 to 7.5 cm for every 3 m of building width (Tyson, 2017). Fans can be added to natural ventilation systems to help cool cows during warm weather. Ideally, fans should be located over the stalls, the feed bunk, and the parlor's holding area in free-stall barns. To accomplish the desired airspeed of 2.2 m/s over standing and lying positions, fans should be 2.1 to 2.4 m off the ground and at a 15 to 20° angle (Tyson, 2017).
An alternative to natural ventilation is tunnel ventilation. Barns can be converted from natural ventilation systems during the winter to a tunnel ventilation system during the summer by raising side walls and closing ridge openings. Tunnel ventilation systems have exhaust fans on one end of the barn that pulls fresh air over cows from outlets at the other end of the barn (Tyson, 2017).

Water

Drinking water is crucial for cows because it makes up the majority of milk and is an excellent form of natural heat abatement. That being said, drinking water must be readily available. Because cows drink between 75 and 150 L of water per day, there should be 6.5 to 9 cm of trough length provided per animal, and these troughs should refill at 11 to 19 L/min (Tyson, 2017). Water intake increases by about 50% or 19 to 23 liters per day during heat stress (Jones et al., 1999).

When sprinklers are provided, cows will spend an extra hour eating at the feed bunk on hot days. They will also spend an additional two hours at the feed bunk standing without eating (Chen et al., 2013). While this extra time at the feed bunk may mitigate decreased DMI due to heat stress, it may also increase lameness due to increased standing time. Sprinklers and fans should be used in conjunction as cooling cows with fans and sprinklers will increase milk production by two kg/d compared to just cooling with shade (Igono et al., 1987). More frequent evaporative cooling decreases respiration (Pinto et al., 2019).

1.3.3. Costs of heat stress and heat abatement systems

It has been historically estimated that heat stress costs the dairy industry $897 million annually (St. Pierre et al., 2003). Still, more recently, it is estimated to be much
higher than that, with dry cow heat stress accounting for $810 million in losses (Ferreira et al., 2016). These economic losses are due to many factors, with the most apparent being milk production. St. Pierre et al. (2003) estimated a loss of 139 kg/cow/yr in milk production when lactating cows are not provided with heat abatement. The more recent economic analysis done by Ferreira et al. (2016) estimated that the lack of heat abatement provided to dry cows in New York results in lost milk yields of 387 kg/cow/yr, equating to $75/cow/yr. These economic analyses considered the number of heat stress days per year in each state.

Economic losses from heat stress can be minimized with proper heat mitigation, but producers must consider the costs of heat abatement systems before installing them. Producers must first consider how their cows are currently housed to determine the investment needed to cool them. Building a barn is a much higher start-up cost if cows are on pasture than just adding fans and sprinklers to an existing barn. The prices of utilities and maintenance of equipment such as fans must also be considered. Ferreira et al. (2016) estimated that when it is necessary to build a barn, the payback period would be close to 5 years in California, but only three months if a barn was already in place.

1.4. Objectives and hypothesis

Research conducted by Miner Institute on multiple farms from 2016 to 2019 indicated that lactating dairy cows in northern New York are affected by episodic heat stress, regardless of the heat abatement system in place (Ballard et al., 2020). After understanding the implications of the heat stress research that has been done at the University of Florida regarding dry cows, it became essential to determine if dry cows in the Northeast are affected by episodic heat stress. The first objective of this study was to
assess the occurrence of heat stress in dry cows in the Northeast under minimal and moderate heat abatement through reticular temperature, rumination, and lying time monitoring. The next objective was to determine the physiological and behavioral impacts of cumulative episodic heat stress events on dry cows in the Northeast under minimal and moderate heat abatement. Another aim was to determine the effects of cumulative in-utero episodic heat stress events on calf development with dams in the Northeast under minimal and moderate heat abatement. The final objective of this study was to understand the opinions of dairy farmers in the Northeast regarding heat stress and heat abatement and the use of heat mitigation strategies on farms. We hypothesized that dry cows in the Northeast would be negatively affected by episodic heat stress, regardless of the heat abatement system. It was also hypothesized that more cumulative episodic heat stress events would adversely impact cows throughout the DP. It was hypothesized that calves who experienced more in-utero episodic heat stress events would have impaired growth and development. Finally, it was hypothesized that dairy farmers in the Northeast would have varying opinions regarding the severity of heat stress and that different forms of heat abatement would be employed on farms.
1.5. References


CHAPTER 2: EFFECTS OF LATE GESTATION EPISODIC HEAT STRESS IN NORTHERN NEW YORK ON HOLSTEIN DAMS IN CONFINED HOUSING AND THEIR CALVES

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Heat stress negatively impacts dry dairy cows in subtropical climates, but impacts in moderate climates are unknown. This study aimed to determine if dry cows and their calves in Northern NY are impacted by episodic heat stress and varying levels of heat exposure. During the summer of 2020 and 2021, 170 dry Holstein cows were enrolled 42 d pre-calving. Cows were housed in free stalls or a bedded pack and had fans over feed alleys and lying areas. Temperature (°C) and relative humidity (%) were recorded to calculate the temperature-humidity index (THI) every 10 min. Lying behavior, reticular temperature (RT), and rumination were measured every 1, 2, and 10 min, respectively. Change in BW, body condition score (BCS), and locomotion score (LS) during the dry period (DP) was calculated. Colostrum weight and quality (BRIX) were assessed; total milk yield was calculated for the first 21 DIM. Calf weights and stature measurements were collected at birth and weaning. Calves were blood sampled for serum total protein 48 ± 12 h after birth. To assess the impact of heat events on cows, average median RT, rumination, and lying time were compared between d when the average THI was > 72 (HOT) and ≤ 68 (COOL). To assess cumulative heat exposure, three categories were created retrospectively: low exposure (LOW; THI ≥ 72 for 0-14.9% of DP; n = 59), moderate exposure (MOD; THI ≥ 72 for 15-29.9% of DP; n = 85), and high exposure (HI; THI ≥ 72 for 30-45% of DP; n = 26). Four categories were created retrospectively to assess the impacts of cumulative heat exposure, specifically during early and late DP: LL (n = 100), LH (n = 27), HL (n = 36), HH (n = 7). Low (L) exposure cows experienced THI ≥ 72 for 0-27.5% of early or late DP. High (H) exposure cows experienced THI ≥ 72 for 27.6-55% early or late DP. Heifer calves were assigned to categories corresponding to their dam's
exposure level: low (CL; n = 15), moderate (CM; n = 36), and high (CH; n = 32). Data were summarized 42 d pre-calving and analyzed using PROC MIXED (SAS v 9.4) with the fixed effects of treatment and year and random effect of the cow or calf. On HOT d, cows had 0.19°C greater RT, and 36 minutes longer rumination and standing time than COOL d. LOW cows had 2 d longer gestation and tended to have higher colostrum BRIX than HI and MOD cows, respectively. Cows with high heat exposure during the late DP had a lower 21 d milk yield than cows with low heat exposure during the late DP. As demonstrated by reduced lying time and gestation length, Northern NY dry cows may be impacted by episodic heat stress; high heat exposure during the late DP leads to milk loss in the first 21 d. Calves in our study were not impacted by in-utero episodic heat stress.
2.2. Introduction

The negative impacts of heat stress on lactating cattle have been well documented throughout the published literature (Collier et al., 1982; West et al., 2003; Cook et al., 2007). More recently, the negative impacts of heat stress on dry cows have been explored (Fabris et al., 2019; Laporta et al., 2020). Cows that are heat-stressed during late gestation have impaired mammary development during the dry period (DP), leading to lowered milk production in the subsequent lactation (Tao et al., 2011). When considering the dry cow, one must also consider the calf she is carrying, as this is a crucial time for in-utero development. Florida researchers have observed decreased birth weights and growth rates, compromised passive transfer of immunity (Tao et al., 2012), and lowered milk production in the first three lactations in animals born to heat-stressed dams (Laporta et al., 2020).

Dry dairy cattle experience elevated rectal temperatures during heat stress (Fabris et al., 2019). Although rectal temperatures are a typical measurement of heat stress, reticular temperatures (RT) provide more continuous body temperature monitoring. RT correlates with rectal temperatures ($r = 0.645$) (Bewley et al., 2008) and has no human error.

During heat stress, cows stand longer to increase the body surface area available to dissipate heat (Cook et al., 2007). Specifically, dry dairy cattle will stand for over an hour longer when heat-stressed (Karimi et al., 2015), impacting well-being and production. Another physiological parameter indicative of animal well-being affected by heat stress is rumination. Rumination can provide information regarding dairy cattle health and dry matter intake (DMI) and is reduced with heat stress (Moretti et al., 2017).
A temperature-humidity index (THI) value of 68 has become widely accepted as the heat stress threshold for high–producing lactating dairy cattle (Zimbelman et al., 2009). Recently, it has been observed that dry cows do not experience typical signs of heat stress (i.e., increased rectal temperatures and respiration rates) until a THI of 77 (Ouellet et al., 2021). Most published studies regarding heat stress have been conducted in tropical and sub-tropical environments that experience daily THI values above 68 for the entire study (Monteiro et al., 2016; Fabris et al., 2019). Although heat stress is a critical issue in these regions that experience chronic high temperatures, it must also be considered in moderate climates.

Most dairy cows in the United States are located in areas with fewer than 80 heat stress days (daily average THI ≥ 68) per year (Laporta et al., 2020). Cows in these regions experience episodic heat stress, meaning hot days are often interspersed with cool days, and cooler nighttime temperatures regularly occur. It takes weeks for dairy cattle to acclimatize to heat stress (Collier et al., 2006). Acclimatization occurs through homeorhetic mechanisms responding to multiple stressors, including high temperatures and humidity (Collier et al., 2006). These animals experiencing episodic heat stress can never acclimatize, as prolonged heat events are rare in moderate climates. Several years of research indicated that high-producing lactating dairy cows are negatively affected by episodic heat stress in Northern NY, regardless of the heat abatement system (Ballard et al., 2020).

Although the impacts of heat stress on dry cows in subtropical and tropical climates have been researched, little is known about the effects of episodic heat stress on dry cows in moderate temperatures. The first objective of this study was to assess the occurrence of
heat stress in dry cows in Northern NY under moderate heat abatement by monitoring RT, rumination, and resting behavior. The second objective was to determine the physiological and behavioral impacts of cumulative episodic heat stress events on dry cows housed with moderate heat abatement in Northern NY. The final goal was to determine the effects of cumulative in-utero episodic heat stress events on calf development with dams in Northern NY housed with moderate heat abatement. It was hypothesized that dry cows in Northern NY would be negatively impacted by episodic heat stress, despite being housed with moderate heat abatement. It was also predicted that greater levels of cumulative heat exposure would have negative impacts, with similar effects on these animals' calves.

2.3. Material and Methods

A retrospective cohort study was conducted at the Charles Sniffen Dairy Research Center at the William H. Miner Agricultural Research Institute in Chazy, NY, during the summers of 2020 and 2021, in compliance with Miner Institute's Animal Care and Use Committee (ACUC). Between July 7th and September 1st, 2020, 19 primiparous and 31 multiparous Holstein cows were enrolled weekly at dry-off; 60 primiparous and 60 multiparous cows were enrolled between May 4th and August 31st, 2021. A total of 170 cows were enrolled between the two enrollment periods. Cows were excluded from enrollment if they had a locomotion score ≥ 3 at dry-off or were in their fifth lactation or higher. In 2020, primiparous cows and multiparous were dried off at 60 ± 3 d and 54 ± 3 d before their due date, respectively. In 2021, cows were dried off 54 ± 3 d before their due date regardless of lactation number. During both years, cows who were confirmed to be pregnant with twins were dried off 67 ± 3 d before their due date. Due dates were determined to be 280 d after the most recent insemination. Cows were dried off using
SPECTRAMAST DC (Zoetis, Parsippany - Troy Hills, NJ) if SCC was above 200,000 on the last DHI test d or ALBADRY PLUS (Zoetis, Parsippany - Troy Hills, NJ) if SCC was below 200,000.

Cows were housed in sand-bedded free stalls or a bedded pack for their early DP (22 - 42 d pre-calving) and a bedded pack for their late DP (21 d pre-calving). The free-stall housing environment had fans (132 cm; Norbco, Watkins, MN) mounted over stalls and the feed bunk. The bedded pack had smaller fans (91.4 cm; Norbco, Watkins, MN) over the feed bunk and lying area. A new sand-bedded free stall facility was built in 2021 and housed cows during their early DP. It was equipped with NCF 132-cm six-blade panel fans (Norbco, Watkins, MN) and a Genesys Livestock Comfort System (Genesys Energy Systems, Houston, TX) that automatically adjusted fan speed based on wind and air temperature. This system increased fan speed as temperature increased and decreased wind speed (WSPD) if a large draft came through the barn. The Genesys system turned fans on at 19.4°C, and maximum fan speed occurred when the air temperature reached 25°C. The original free stalls and bedded pack were controlled by a Ranco Electronic Temperature Control system (Ranco, Houston, TX) and turned fans on at 19.4°C. These fans were at a constant speed regardless of temperature or outside WSPD. After calving, cows were housed in sand-bedded free stalls with fans over feed alleys and lying areas and were milked three times daily.

2.3.1. Environmental measurements

Air temperature (T) and relative humidity (RH) values were collected every 10-min. These measurements were taken by Kestrel DROP D2AG data loggers (Nielsen-Kellerman Company, Boothwyn, PA) on the bedded pack and HOBO temperature/RH Pro
V2 data loggers (Onset Computer Corporation, Bourne, MA) in the free stalls. T/RH loggers were housed in PVC pipes throughout pens at cow level. These PVC pipes had ventilation holes, allowing adequate airflow for measurements while keeping the loggers out of cow reach. The Temperature Humidity Index (THI) was calculated every 10-min according to Dikmen et al. (2008): \[ \text{THI} = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)] \]. THI data were summarized as hourly and daily averages.

Water temperature was measured in water tanks throughout pens every 15-min using HOBO Water Temperature Pro V2 data loggers (Onset Computer Corporation, Bourne, MA). If pens contained multiple tanks, the water temperature of each tank was averaged as daily values.

WSPD and direction were measured at standing (140 cm) and lying (82 cm) heights in stalls and on the bedded pack once weekly using a Kestrel 5200 Anemometer (Nielsen-Kellerman Company, Boothwyn, PA) mounted on a tripod. WSPD and direction were only measured at standing height (140 cm) in feed alleys, as it was assumed that cows would not be lying in these areas. WSPD was averaged weekly at lying and standing heights in each pen.

2.3.2. Cow measurements

Approximately one week before dry-off, cows were bolused with smaXtec Classic boluses (smaXtec Animal Care GmbH, Graz, Austria) unless they were already bolused from a previous study. Cows enrolled in 2020 received SX1 boluses capable of measuring RT (°C) and activity every 1-min. Cows enrolled in 2021 who did not already have an SX1 bolus received SX2 boluses, capable of measuring RT, activity, and rumination (s/d) every
1-min. Although the smaXtec boluses recorded measurements every min, they presented RT and activity data as 10-min averages. RT data were further summarized as average daily medians. Rumination was also measured with SCR collars (Allflex, Madison, WI) every 2-min in min/d and reported as a 24-hour rolling average every 2 hours. SCR rumination values were summarized as daily averages and were used instead of smaXtec, as data were available for every cow. HOBO Pendant G (Onset Computer Corporation, Bourne, MA) accelerometers measured lying/standing time and bouts every 1-min. These accelerometers were worn on leg bands on the cannon of the back leg and were changed weekly from dry-off until 14 DIM.

A subset of cows (n = 4) was dual-enrolled in another study in 2020 that fed an unknown test product 16 ± 4 d before calving. Another subgroup of cows (n = 72) was dual-enrolled in another study in 2021 and was fed an energy supplement starting at 20 ± 9 d before calving. Cows dual-enrolled in these studies were fed in a Calan Gate System (American Calan, Northwood, NH) for part of their DP, allowing DMI (kg/d) to be measured.

Cows were body condition scored (BCS), locomotion scored (LS), and weighed at dry-off, move to close-up (21 ± 3 d before due date), calving, 14 ± 3 DIM, and 28 ± 3 DIM. BCS was assigned on a 5-point scale, in 0.25 increments, with one being the lowest score and five being the highest (Ferguson et al., 1994) by two trained scorers. LS was assigned on a 5-point scale, where 1 = normal, 2 = mildly lame, 3 = moderately lame, 4 = lame, and 5 = severely lame (Sprecher et al., 1997) by two trained scorers as cows walked on a flat concrete surface. BW were obtained on an Allweigh computerized scale (Allweigh Scale System Inc., Red Deer, AB, Canada).
Gestation length was calculated by subtracting the date of the last insemination from the calving date. Colostrum weights from the first milking were collected using a Rubbermaid Digital Scale (Rubbermaid, Atlanta, GA). Colostrum quality was assessed using a Milwaukee Digital BRIX Refractometer (Milwaukee, Brookfield, WI). Milk weights were obtained at each milking after 1 DIM using a ProVantage Information Management System (Bou-matic, Madison, WI). The first DIM was defined as the first day a cow was eligible to go to the parlor for all three milking. BRIX readings are highly correlated with the IgG concentration of bovine colostrum. A score of 21% is equivalent to 50 g/mL of IgGs, which is the level needed to stimulate the appropriate level of passive transfer of immunity (Quigley et al., 2013).

### 2.3.3. Calf Measurements

Upon birth, calves were weighed on a Brecknell platform scale (Brecknell Scales, Colombia, MD). Calves were blood sampled from the jugular vein 48 ± 12 h after birth to assess serum total protein (TP) levels using a Leica Temperature Compensated Hand-Held Refractometer (Leica Inc., Buffalo, NY). Serum was obtained after centrifugation at 1,300 x g for 20 min. Based on their serum TP level, calves fit into one of four categories that reflect passive transfer of immunity status: excellent (≥ 6.2 g/100 ml), good (5.7 – 6.1 g/100 ml), fair (5.1 – 5.6 g/100 ml), and poor (< 5.1 g/100 ml) (Lombard et al., 2020).

Stature measurements, including body length, heart girth, hip width, hip height, and wither height, were collected 18 ± 6 h after birth. The same stature measurements were collected at weaning (63 ± 12 d) to assess growth rates. Weaning weights were collected using a Salter Brecknell PS500 platform scale (Brecknell Scales, Colombia, MD). ADG
was calculated by dividing the difference between birth and weaning weights by the number of days between collections.

2.3.4. Statistical Analyses

Data were analyzed using SAS (Statistical Analysis System, version 9.4; SAS Institute Inc., Cary, NC). Significance was declared at $P \leq 0.05$, and a tendency was reported at $0.05 < P \leq 0.10$. Shapiro-Wilk and Levene's tests were used to assess all data, except for environmental parameters, for normality and homogeneity of variance, respectively, using the GLM procedure of SAS. Environmental parameters (THI, water temperature, and WSPD) were reported as descriptive statistics (mean ± SD).

Cows were excluded from all analyses if their DP lasted less than 42 d and were excluded from RT, rumination, and resting behavior analyses if they experienced < 5 HOT (average daily THI > 72) d and < 5 COOL (average daily THI ≤ 68) d during their DP. RT, rumination, and lying data were excluded 3 d before calving to account for changes observed due to parturition. Specific d of lying data were excluded if data were absent or if the leg logger had shifted out of place on the leg. Rumination data were excluded for 2 d if a cow was moved into a pen with a Calan Gate System to account for changes in rumination and DMI. Rumination data were also excluded if values were below 200 min/d or were outside of 3 SD for that cow. Cows were excluded from the RT analysis if they had twins. Specific d of RT were excluded if there were missing data.

To retrospectively assess the impact of heat events on cows, average median RT, rumination, and lying time were compared between HOT and COOL d using the MIXED procedure of SAS with the following model:
\[ Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (RT, rumination, or lying time), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HOT or COOL), \( P_j \) was the fixed effect of yr (2020, 2021), \( SP_{ij} \) was the fixed effect of the interaction between treatment and yr, \( C_k \) was the random effect of cow (\( n = 85, 103, \) or 96), and \( E_{ijk} \) was the residual error.

The last 3 d before calving was removed from DMI data to account for changes due to the upcoming parturition. Cows who did not have at least 3 HOT and 3 COOL d during DMI measurements were excluded. DMI was compared between HOT and COOL d using the MIXED procedure of SAS with the following model:

\[ Y_{ijk} = \mu + S_i + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (DMI), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HOT or COOL), \( C_k \) was the random effect of cow (\( n = 60 \)), and \( E_{ijk} \) was the residual error.

To assess cumulative heat exposure, three categories were created retrospectively: low exposure (LOW; THI ≥ 72 for 0 - 14.9% of DP; \( n = 59 \)), moderate exposure (MOD; THI ≥ 72 for 15 - 29.9% of DP; \( n = 85 \)), and high exposure (HI; THI ≥ 72 for 30 - 45% of DP; \( n = 26 \)). Although these cumulative heat exposure categories focused on the last 42 d of the DP, cows were dry for different lengths of time, so the change in BW, BCS, and LS from dry-off to calving was over a range of days. Average days dry (mean ± SD) were as follows: HI (51.6 ± 5.4 d), MOD (51.7 ± 5.3), and LOW (50.1 ± 4.0 d). Variables had various sample sizes as some were missed; sample sizes are listed in the table footnotes.
BW, BCS, and LS change data were excluded from this analysis if they were more than three SD from the mean. Gestation length data were excluded if the cow had twins. The relationship between these heat exposure categories and gestation length, colostrum quality and quantity, and change in LS, BCS, and BW from dry-off to calving were analyzed using the MIXED procedure of SAS with the following model:

\[ Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (gestation length, colostrum quantity and quality, change in LS, BCS, and BW from dry-off to calving), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HI, MOD, or LOW), \( P_j \) was the fixed effect of yr (2020, 2021), \( SP_{ij} \) was the fixed effect of the interaction between treatment and yr, \( C_k \) was the random effect of cow (\( n = 170, 131, 148, 158, 157, \) and 159), and \( E_{ijk} \) was the residual error. A Tukey's procedure of SAS was used to separate the least square means when there was a significant F-test (\( P \leq 0.05 \)) for one of these variables.

Cows were excluded from the 21 d total milk yield analysis if they had missing values for more than one milking on the first DIM or two consecutive days. Total milk yield for the first 21 DIM was compared between heat exposure categories using the MIXED procedure in SAS (v 9.4) with the following model:

\[ Y_{ijk} = \mu + S_i + M_j + C_k + E_{ijk} \]

where \( Y_{ijk} \) is the dependent variable (21 d milk yield), \( \mu \) is the overall mean, \( S_i \) is the fixed effect of treatment (HI, MOD, or LOW), \( M_j \) is the covariate of 305-day Mature Equivalent milk production, \( C_k \) is the random effect of the cow (\( n = 86 \)), and \( E_{ijk} \) is the residual error.
To assess heat exposure during the early and late DP, four more categories were created: low exposure for early DP and low exposure for late DP (LL; n = 100); low exposure for early DP and high exposure for late DP (LH; n = 27 cows); high exposure for early DP and low exposure for late DP (HL; n = 36); high exposure for early DP and high exposure for late DP (HH; n = 7). Cows with low exposure during their early or late DP experienced THI ≥ 72 for 0-27.5% of that part of their DP, and high exposure cows experienced THI ≥ 72 for 27.6-55% of either early or late DP. Average days dry (mean ± SD) were as follows: LL (51.3 ± 4.9), LH (49.9 ± 4.6), HL (51.1 ± 4.6), HH (52.7 ± 8.7).

The relationship between these early and late DP heat exposure categories and gestation length, colostrum quantity, and quality, changes in LS, BCS, and BW from dry-off to calving, using the MIXED procedure (SAS v 9.4) with the following model:

\[ Y_{ijk} = \mu + F_i + L_j + FL_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (gestation length, colostrum quantity, and quality, change in LS, BCS, and BW from dry-off to calving), \( \mu \) was the overall mean, \( F_i \) was the fixed effect of early DP heat exposure (low or high), \( L_j \) was the fixed effect of late DP heat exposure (low or high), \( FL_{ij} \) was the fixed effect of the interaction between early and late DP heat exposure, \( C_k \) was the random effect of cow (n = 170, 131, 88, 158, 157, and 159), and \( E_{ijk} \) was the residual error. A Tukey's procedure was used to separate the least square means when an F-test was significant (\( P \leq 0.05 \)) for one of these variables.

Total milk yield was compared between early and late heat exposure categories using the MIXED procedure in SAS (v 9.4) with the following model:

\[ Y_{ijk} = \mu + F_i + L_j + FL_{ij} + M_k + C_l + E_{ijkl} \]
where \( Y_{ijk} \) is the dependent variable (21 d milk yield), \( \mu \) is the overall mean, \( F_i \) is the fixed effect of early DP heat exposure (low or high), \( L_j \) is the fixed effect of late DP heat exposure (low or high), \( FL_{ij} \) is the fixed effect of the interaction between early and late DP exposure levels, \( M_k \) is the covariate of 305-day Mature Equivalent milk production, \( C_l \) is the random effect of the cow \((n = 86)\), and \( E_{ijkl} \) is the residual error. A Tukey’s procedure was used to separate the least square means as the F-test was significant \((P \leq 0.05)\).

Calves were assigned to categories corresponding to their dam's heat exposure level: low (CL; \( n=32 \)), moderate (CM; \( n=36 \)), and high (CH; \( n=15 \)). Birth weight data were excluded if the calf had a twin or was outside of three SD from the mean. The relationship between the calf exposure categories and birth weight were assessed using the MIXED procedure of SAS with the following model:

\[
Y_{ijk} = \mu + S_i + G_j + SG_{ij} + C_k + E_{ijk}
\]

where \( Y_{ij} \) was the dependent variable (birth weight), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (CL, CM, or CH), \( G_j \) was the fixed effect of sex (male or female), \( SG_{ij} \) was the fixed effect of the interaction between treatment and sex, \( C_k \) was the random effect of cow \((n = 144)\), and \( E_{ijk} \) was the residual error.

The relationship between heifer calf exposure categories and ADG and serum TP were assessed using the MIXED procedure (SAS v. 9.4) with the following model:

\[
Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk}
\]

where \( Y_{ij} \) was the dependent variable (ADG and serum TP), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (CL, CM, or CH), \( P_j \) was the fixed effect of yr (2020, 2021),
SP\textsubscript{ij} was the fixed effect of the interaction between treatment and yr, C\textsubscript{k} was the random effect of the calf (n = 61 and 68), and E\textsubscript{ijk} was the residual error.

2.4. Results and Discussion

2.4.1. Environmental Conditions

Between the first day of enrollment at dry off until the last calving (July 6\textsuperscript{th} - October 23\textsuperscript{rd}, 2020, and May 4\textsuperscript{th} - October 27\textsuperscript{th}, 2021), there were 13 HOT d in 2020 and 24 in 2021 (Figures 2.1 and 2.2). Most of these HOT d were interspersed with COOL d and nighttime cooling; demonstrating that episodic heat stress is much different than chronic heat stress observed in previous studies conducted at the University of FL, where dry cows were exposed to an environment with THI > 72 for 100\% of their DP (Fabris et al., 2019).

Water tank temperature was greater on HOT d in both the free stalls and bedded pack than on COOL d (Table 2.1) but was still well below the maximum recommended drinking water temperature of 30°C (Beede, 1993). Water temperatures on HOT and COOL d were similar to the warm water temperatures (18.2°C ± 0.4) used in a study to assess the impact of drinking water temperature on RT (Bewley et al., 2007). Cows exhibited a considerable decline in RT when offered cold water (5.1°C ± 0.4); this drop in RT lasted hours longer than the drop observed when cows were offered warm drinking water (Bewley et al., 2007). The current study did not investigate the influence of drinking bouts on RT. Still, if this had been analyzed, it may have provided insight about changes in body temperature due to drinking warm water in moderate climates.
Although fans created higher WSPD on HOT than on COOL d (Table 2.1) in both the free-stalls and bedded pack housing areas, they did not generate enough airflow to meet the recommended 8 kph at standing and lying heights (Tyson, 2017). Fans may need to be added or existing fans repositioned or re-angled to create adequate airflow in dead spots throughout the pens. A study utilizing fans that meet the recommended 8 kph windspeed may be warranted to see the impacts of heat abatement that meets industry standards on dry cows experiencing episodic heat stress.

### 2.4.2. Reticular body temperature

Different sample sizes were used to analyze variables as some samples were missed or some cows did not meet the analysis criteria, which can be found in the statistical analysis and table foot notes. Cows were universally excluded from all analyses if their dry period was less than 42 days, most commonly due to an incorrect breed date record or the birth of twins. On COOL d, cows had 0.19°C greater RT than on HOT d ($P < 0.01$; Table 2.2). Daily average median RT was used so that the decrease in RT from drinking water would not influence results. These results were unexpected and opposite to the RT measured in lactating animals exposed to episodic heat stress (Ballard et al., 2020). These differing results may be because dry cows naturally have a lower metabolic heat load than lactating animals (Purwanto et al., 1990). Blood flows away from the gastrointestinal tract and toward the periphery during heat stress to dissipate heat (Bernabucci et al., 2010), which may further explain why higher RT was observed on COOL d. A recent meta-analysis conducted with dry cows experiencing chronic heat stress indicated that rectal temperature and respiration rate do not increase until a THI of 77 is attained (Ouellet et al.,
It may be that the current study did not include enough consecutive hours of a THI above the threshold to increase reticular temperatures on HOT d.

Evidence suggests that although rectal and RT are highly correlated, they are less correlated during the summer and winter when THI values are more extreme than in spring and fall (Bewley et al., 2008). Bewley et al. (2008) indicated that rectal and reticular temperatures had an r value of about 0.7 during the spring and fall and an r value of 0.58 during the summer. It would have been interesting to measure the impacts of episodic heat stress on rectal temperature to determine its correlation with RT in a moderate climate. If blood flowed away from the gastrointestinal tract towards the periphery on HOT d, rectal temperatures might have been higher than RT.

There was an interesting pattern observed in RT before calving. RT increased about 28 days pre-calving until reaching a peak at about 1 d pre-calving, and then rapidly declined as calving approached (Figure 2.3). The literature suggests a decrease in vaginal and rectal temperature 24 hours before calving (Burfeind et al., 2011), which was observed in the current study. Still, the authors did not report a pattern similar to that observed in the current study at 28 days pre-calving. This reticular temperature pattern was not attributable to a diet change, as a switch from far-off TMR to close-up TMR occurred 21 days before calving.

2.4.3. Resting behavior

On HOT d, cows stood ($P < 0.01$) for 36 min longer compared to COOL d (Table 2.2). Resting behavior was similar to other studies (Karimi et al., 2015) and indicated that cows were heat-stressed as they stood longer on HOT d to dissipate heat. No difference
(mean ± SEM) was measured in the occurrence of lying bouts (10.9 ± 0.2) between HOT and COOL d (Table 2.2), similar to the results that Nordlund et al. (2019) found in lactating cows under heat stress. This indicates that lying bouts were shorter in duration on HOT d.

2.4.4. Rumination behavior and dry matter intake

On HOT d, cows ruminated ($P < 0.01$) for 36 more min compared to COOL d (Table 2.2). These results differ from previous studies regarding heat stress in dry cows (Maia et al., 2020) and lactating cows (Tapki et al., 2006; Abeni et al., 2017; Moretti et al., 2017), which all observed a decrease in rumination due to heat stress. Unlike the moderate climate here, these studies were conducted in environments with consistently high THI and may not reflect the impact of episodic heat stress on rumination. There was a significant treatment by year ($P < 0.01$) interaction for rumination, with a greater difference in rumination on HOT and COOL d in 2020 than in 2021; this may be influenced by the small sample size in 2020.

Unlike other studies that found a decrease in DMI in dry cows due to heat stress (Adin et al., 2009; do Amaral et al., 2009), no difference in DMI (15.9 ± 0.2 kg/d; Table 2.2) between HOT and COOL d was measured in the current study. Interestingly, DMI did not change on HOT d similarly to rumination, as these are often related. This increase in rumination also contradicts studies showing that lying time and rumination are linked (Schirmann et al., 2012). Since the current study observed increased lying time on HOT d, it would be assumed that cows would also have greater rumination, but this was not the case.

2.4.5. Body weight, body condition score, and locomotion score
No difference was observed in BW change (2.2 ± 2.6 kg), BCS change (0.04 ± 0.02), or LS change (0.4 ± 0.05) between dry-off and calving between LOW, MOD, and HI groups (Table 2.3) or LL, LH, HL, and HH groups (Table 2.4). Increased standing time typically increases lameness (Grandin, 2016), which contradicts the stable LS between dry-off and calving observed in this study, despite the increased standing time measured on HOT d. Although cows stood longer on HOT d, they did spend a portion of their DP on a bedded pack, which is better for lameness prevention than free-stall housing (Bran et al., 2019).

BW change from dry-off to calving differed from Fabris et al. (2019), who observed a greater loss in body weight in animals that were heat-stressed for their entire DP. Because DMI remained stable through episodic heat stress, it may have allowed cows to have similar changes in BW and BCS across treatment groups.

2.4.6. Lactation performance, colostrum quality, and quantity

No difference was observed in colostrum weight (6 ± 0.3 kg) or 21-d milk yield (917 ± 11.8 kg) between the LOW, MOD, and HI groups (Table 2.3). No difference in colostrum weight or BRIX was measured between LL, LH, HL, and HH groups (Table 2.4). Several studies suggest similar results of consistent colostrum quantity despite chronic heat stress exposure (Tao et al., 2012; Dado-Senn et al., 2021).

LOW cows tended to have higher colostrum BRIX than MOD cows ($P = 0.07$; Table 2.3), but interestingly, they did not significantly differ from the HI group. There is contradicting literature regarding the impacts of chronic heat stress during late gestation on the IgG content of colostrum. Some report lowered IgG content (Nardone et al., 1997),
while others report no difference despite chronic heat stress exposure (Lacetera et al., 2002).

There was no significant difference in 21-d milk production among HI, MOD, and LOW groups, but the LOW cows had the greatest production numerically. A power analysis was conducted, revealing that this study was underpowered for this variable, with a power value of 0.465. The power analysis estimated that 91 more cows would be needed to make this difference significant.

Cows who experienced high levels of heat stress, specifically during their late DP produced less milk during the first 21 DIM than cows that experienced low amounts of heat stress during their late DP ($P < 0.05$; Table 2.4). There was no effect of heat exposure levels during the early DP on milk yield, which differed from Fabris et al. (2017), who observed that heat stress at any point during the DP tended to decrease milk production during the first 21 DIM. Tao et al. (2011) observed that cows had a lower mammary epithelial cell proliferation rate 20 days before calving (during the late DP) when exposed to chronic heat stress. It would be helpful to know the impacts of heat stress on mammary cell proliferation rates during the early DP; mammary cell proliferation is typically measured through mammary biopsies (Tao et al., 2011). This would help determine whether or not they reflect the lack of change in milk production due to early DP episodic heat stress observed in the current study.

2.4.7. Gestation length, calf immunity, and growth

Compared to LOW cows, HI cows tended to have about 2 d shorter gestation ($P = 0.06$; Table 2.3), but no difference ($276.5 \pm 0.3$ d) was measured between LL, LH, HL,
and HH groups (Table 2.4). This was slightly different from Fabris et al. (2019), who found that heat stress at any point during the DP reduced gestation length. They discovered that gestation length was decreased by differing amounts based on when heat stress occurred during the DP, with the lowest gestation lengths in cows that were heat-stressed during their early DP and cooled during their late DP. A power analysis was conducted for gestation length. It was estimated that only one more cow would be needed to make the difference between the HI and LOW groups significant.

No difference was observed in birth weights (43.8 ± 0.4 kg), ADG (0.98 ± 0.02 kg/d), or serum TP (6.3 ± 0.08) (Tables 2.5 and 2.6) between CL, CM, and CH groups. This contradicts Florida research that observed lower birth weights, ADG, and serum IgG (Laporta et al., 2017) in calves who experienced chronic in-utero heat stress. There may not have been an impact of episodic in-utero heat stress in this study as the dam's body temperature decreased on HOT d. Hence, calves never experienced elevated in-utero temperatures. It was surprising that CH calves did not have lower birth weights since their dams tended to have a shorter gestation length than the other animals. It may have been relevant to measure placenta weights and hormones to see if they were impacted by episodic in-utero heat stress, as Florida research (Laporta et al., 2017) has suggested that these factors are negatively affected by in-utero heat stress.

2.5. Conclusions

Although RT and rumination data may indicate otherwise, dry dairy cows were negatively impacted by episodic heat stress, as observed in reduced lying time and gestation length. Late DP episodic heat stress may be more detrimental than early DP episodic heat stress, as high amounts of episodic heat stress during the late DP led to
reduced 21 d milk yield. Although dry dairy cows were affected by episodic heat stress in NY, it seems to be lesser than the impacts of chronic heat stress in subtropical climates like FL. Based on the results of this study, calves are not impacted by in-utero late gestation episodic heat stress. In the future, it would be interesting to look at placenta weights and see if they remained constant despite episodic heat stress, corresponding with the lack of impacts on calves.
2.6. References


### 2.7. Tables and figures

**Table 2.1.** Average wind speed (kph) and water temperature (°C) in free stall and bedded pack housing areas on **HOT** and **COOL** d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Housing location</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free stalls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HOT(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing height</td>
<td>5.8 ± 3.5(^3)</td>
<td>1.9 ± 2.4</td>
<td>6.1 ± 2.9</td>
<td>2.9 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>Lying height</td>
<td>4.8 ± 4.2</td>
<td>1.6 ± 1.9</td>
<td>5.0 ± 2.7</td>
<td>2.3 ± 2.4</td>
<td></td>
</tr>
<tr>
<td>Water temperature, °C</td>
<td>19.1 ± 2.1</td>
<td>15.8 ± 2.4</td>
<td>19.1 ± 1.4</td>
<td>17.8 ± 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bedded pack</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HOT(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COOL(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)HOT – d where the average daily THI > 72.

\(^2\)COOL – d where the average daily THI ≤ 68.

\(^3\)Mean ± SD.
Table 2.2. Least squares means of reticular temperature, lying time, lying bouts, rumination time, and dry matter intake of dry Holstein cows on COOL and HOT d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>COOL</th>
<th>HOT</th>
<th>SEM</th>
<th>Treatment (T)</th>
<th>Year (Y)</th>
<th>T x Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>85</td>
<td>39.6</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>&lt; 0.01</td>
<td>0.77</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>2020</td>
<td>11</td>
<td>39.7</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>74</td>
<td>39.5</td>
<td>39.5</td>
<td>&lt; 0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying time, min/d</td>
<td>96</td>
<td>823</td>
<td>787</td>
<td>14</td>
<td>&lt; 0.01</td>
<td>0.63</td>
<td>0.19</td>
</tr>
<tr>
<td>2020</td>
<td>11</td>
<td>826</td>
<td>775</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>85</td>
<td>821</td>
<td>799</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying bouts</td>
<td>96</td>
<td>10.5</td>
<td>10.3</td>
<td>0.4</td>
<td>0.53</td>
<td>0.09</td>
<td>0.01</td>
</tr>
<tr>
<td>2020</td>
<td>11</td>
<td>10.5</td>
<td>9.2</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>85</td>
<td>10.5</td>
<td>11.3</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>103</td>
<td>556</td>
<td>592</td>
<td>6</td>
<td>&lt; 0.01</td>
<td>0.6</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>2020</td>
<td>14</td>
<td>543</td>
<td>610</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>89</td>
<td>569</td>
<td>574</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter intake, kg/d</td>
<td>60</td>
<td>16.1</td>
<td>15.8</td>
<td>0.3</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\)Treatment: COOL – average daily THI ≤ 68; HOT – average daily THI > 72.
Table 2.3. Least squares means of gestation length, colostrum yield, colostrum quality, 21 d milk yield, change in LS, BCS, and BW from dry-off to calving in Holstein cows exposed to varying degrees of heat stress throughout the DP.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>P-values</th>
<th>SEM</th>
<th>Treatment (T)</th>
<th>Year (Y)</th>
<th>T x Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>MOD</td>
<td>LOW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gestation length(^2), d</td>
<td>275.1(^a)</td>
<td>276.6(^ab)</td>
<td>277.3(^b)</td>
<td>0.6</td>
<td>0.06</td>
<td>0.93</td>
</tr>
<tr>
<td>Colostrum yield(^3), kg</td>
<td>5.5</td>
<td>5.9</td>
<td>6.3</td>
<td>0.6</td>
<td>0.68</td>
<td>0.19</td>
</tr>
<tr>
<td>Colostrum quality(^4), % solids</td>
<td>24.9(^yx)</td>
<td>23.4(^x)</td>
<td>25.3(^y)</td>
<td>0.7</td>
<td>0.08</td>
<td>0.29</td>
</tr>
<tr>
<td>Total milk yield for 21 DIM(^5), kg</td>
<td>886</td>
<td>912</td>
<td>949</td>
<td>19</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>Δ LS(^6)</td>
<td>0.48</td>
<td>0.25</td>
<td>0.27</td>
<td>0.09</td>
<td>0.24</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Δ BCS(^7)</td>
<td>0.08</td>
<td>0.03</td>
<td>0.02</td>
<td>0.03</td>
<td>0.44</td>
<td>0.04</td>
</tr>
<tr>
<td>Δ BW(^8), kg</td>
<td>7.5</td>
<td>-1.8</td>
<td>-0.9</td>
<td>5.6</td>
<td>0.51</td>
<td>0.38</td>
</tr>
</tbody>
</table>

\(^a\)Means within a row with different superscripts are significantly different (\(P \leq 0.05\))

\(^x\)Means within a row with different superscripts have a tendency to be different (0.05 > \(P \leq 0.10\))

\(^1\)Treatment: HI were high exposure cows with THI ≥ 72 for 30-45\% of the total DP; MOD were moderate exposure cows with THI ≥ 72 for 15-29.9\% of the total DP; LOW were low exposure cows with THI ≥ 72 for 0-14.9\% of total DP

\(^2\)Gestation Length: HI (n = 26); MOD (n = 85); LOW (n = 59)

\(^3\)Colostrum yield: HI (n = 21); MOD (n = 61); LOW (n = 49)

\(^4\)Colostrum quality: HI (n = 24); MOD (n = 74); LOW (n = 50)

\(^5\)Total milk yield for 21 DIM: HI (n = 13); MOD (n = 53); LOW (n = 20)

\(^6\)Δ LS: Change in locomotion score from dry-off to calving; HI (n = 26); MOD (n = 80); LOW (n = 52)

\(^7\)Δ BCS: Change in body condition score from dry-off to calving; HI (n = 25); MOD (n = 80); LOW (n = 52)

\(^8\)Δ BW: Change in body weight from dry-off to calving; HI (n = 25); MOD (n = 84); LOW (n = 50)
Table 2.4. Least squares means of gestation length, colostrum yield, colostrum quality, 21 d milk yield, change in LS, BCS, and BW from dry-off to calving in Holstein cows exposed to varying degrees of heat stress throughout early (22-42 d pre-calving) and late (21 d pre-calving) DP.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>SEM</th>
<th>Early DP (EDP)</th>
<th>Late DP (LDP)</th>
<th>EDP x LDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestation length, d</td>
<td>LL</td>
<td>276.7</td>
<td>276.1</td>
<td>276.6</td>
<td>274.7</td>
</tr>
<tr>
<td>Colostrum yield, kg</td>
<td>LH</td>
<td>6.3</td>
<td>5.5</td>
<td>5.7</td>
<td>5.6</td>
</tr>
<tr>
<td>Colostrum quality, % solids</td>
<td>HL</td>
<td>24.3</td>
<td>24.2</td>
<td>25.2</td>
<td>24.2</td>
</tr>
<tr>
<td>Total milk yield for 21 DIM, kg</td>
<td>HH</td>
<td>919</td>
<td>901</td>
<td>936</td>
<td>785</td>
</tr>
<tr>
<td>Δ LS</td>
<td>LL</td>
<td>0.29</td>
<td>0.60</td>
<td>0.36</td>
<td>0.50</td>
</tr>
<tr>
<td>Δ BCS</td>
<td>LH</td>
<td>0.04</td>
<td>0.03</td>
<td>0.07</td>
<td>-0.02</td>
</tr>
<tr>
<td>Δ BW, kg</td>
<td>HL</td>
<td>0.6</td>
<td>6.6</td>
<td>4.5</td>
<td>-6.9</td>
</tr>
</tbody>
</table>

a-bMeans within a row with different superscripts are significantly different (P ≤ 0.05)

x-yMeans within a row with different superscripts have a tendency to be different (0.05 > P ≤ 0.10)

1Treatment: Low exposure – THI ≥ 72 for 0-27.5% of early or late DP; High exposure – THI ≥ 72 for 27.6-55% of early or late DP. LL – low exposure during early DP/low exposure during late DP; LH – low exposure during early DP/high exposure during late DP; HL – high exposure during early DP/low exposure during late DP; HH – high exposure during early DP/high exposure during late DP.

2Gestation Length: LL (n = 100); LH (n = 27); HL (n = 36); HH (n = 7)

3Colostrum yield: LL (n = 79); LH (n = 23); HL (n = 26); HH (n = 3)

4Colostrum quality: LL (n = 29); LH (n = 27); HL (n = 26); HH (n = 6)

5Total milk yield for 21 DIM: LL (n = 49); LH (n = 15); HL (n = 20); HH (n = 2)

6Δ LS: Change in locomotion score from dry-off to calving; LL (n = 92); LH (n = 31); HL (n = 29); HH (n = 6)

7Δ BCS: Change in body condition score from dry-off to calving; LL (n = 91); LH (n = 31); HL (n = 29); HH (n = 6)

8Δ BW: Change in body weight from dry-off to calving; LL (n = 90); LH (n = 31); HL (n = 31); HH (n = 7)

---

Table 2.5. Least squares means of birth weights of calves born to Holstein dams exposed to varying degrees of heat stress throughout the DP.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>SEM</th>
<th>Treatment (T)</th>
<th>Sex (S)</th>
<th>T x S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight, kg</td>
<td>CH (n=17)</td>
<td>43.1</td>
<td>0.62</td>
<td>&lt; 0.01</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>CM (n=78)</td>
<td>43.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CL (n=49)</td>
<td>43.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Treatment: CH were calves born to high exposure cows with THI ≥ 72 for 30-45% of the total DP; CM were calves born to moderate exposure cows with THI ≥ 72 for 15-29.9% of total DP; CL were calves born to low exposure cows with THI ≥ 72 for 0-14.9% of total DP.
Table 2.6. Least squares means of average daily gain and serum total protein in calves born to Holstein dams exposed to varying degrees of heat stress throughout the DP.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment$^1$</th>
<th>SEM</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CH</td>
<td>CM</td>
<td>CL</td>
</tr>
<tr>
<td>ADG$^2$, kg/d</td>
<td>1.00</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Serum total protein$^3$, g/100 ml</td>
<td>6.3</td>
<td>6.2</td>
<td>6.5</td>
</tr>
</tbody>
</table>

$^1$Treatment: CH were calves born to high exposure cows with THI ≥ 72 for 30-45% of the total DP; CM were calves born to moderate exposure cows with THI ≥ 72 for 15-29.9% of total DP; CL were calves born to low exposure cows with THI ≥ 72 for 0-14.9% of total DP

$^2$ADG: Average daily gain from birth until weaning; CH (n = 8); CM (n = 31); CL (n = 22)

$^3$Serum total protein; CH (n = 13); CM (n = 31); CL (n = 24)
Figure 2.1. Average daily THI between July 6\textsuperscript{th} and October 23\textsuperscript{rd}, 2020 (date of first dry-off enrollment until the last calving). Straight lines represent THI thresholds of 68 and 72.

Figure 2.2. Average daily THI between May 4\textsuperscript{th} and October 27\textsuperscript{th}, 2021 (date of first dry-off enrollment until the last calving). Straight lines represent THI thresholds of 68 and 72.
Figure 2.3. Daily median reticular temperatures (°C) in dry Holstein cows exposed to episodic heat stress before calving.
CHAPTER 3: EFFECTS OF LATE GESTATION EPISODIC HEAT STRESS IN NORTHERN VERMONT ON HOLSTEIN DAMS IN HYBRID OUTDOOR-CONFINEMENT HOUSING AND THEIR CALVES

E. M. Fread*, C. S. Ballard†, A. E. Pape†, and R. J. Grant†.

*University of Vermont, Department of Animal Science
†William H. Miner Agricultural Research Institute
3.1. Abstract

Heat stress negatively impacts dry dairy cows in subtropical climates, but impacts in moderate climates are unknown. This study aimed to determine if dry cows and their calves in Northern VT are impacted by episodic heat stress when housed in minimal heat abatement. During the summer of 2020 and 2021, 66 dry Holstein cows were enrolled 42 d pre-calving. Cows were housed on pasture for their early dry period (DP; 22-42 d pre-calving) and on a bedded pack with access to an outdoor sandlot for their late DP (21 d pre-calving). Fans were installed over the bedded pack in 2021. Temperature (°C), relative humidity (%), wind speed (WSPD; m/s), and solar radiation (RAD; W/m²) were recorded to calculate temperature-humidity index (THI) and THI adjusted for WSPD and RAD (THI_adj) every 10 min. Reticular temperature (RT) and rumination were measured every 2 and 10 min, respectively. Change in body weight (BW), body condition score (BCS), and locomotion score (LS) during DP was calculated. Colostrum weight and quality (BRIX) were assessed. Calf birth weights and stature measurements were collected at birth and weaning. Calves were blood sampled to assess passive transfer of immunity. To evaluate the impact of heat events on cows, average median RT and rumination were compared between d when average THI was > 72 (HOT) and ≤ 68 (COOL) and when THI_adj was > 72 (HOT_adj) and ≤ 68 (COOL_adj). To assess cumulative heat exposure, three categories were created retrospectively: low exposure (LOW; THI ≥ 72 for 0-14.9% of DP; n = 24), moderate exposure (MOD; THI ≥ 72 for 15-29.9% of DP; n = 29), and high exposure (HI; THI ≥ 72 for 30-45% of DP; n = 15). To assess cumulative heat exposure during the early and late DP, four more categories were created: LL (n = 34), LH (n = 15), HL (n = 15), and HH (n = 4), where low (L) exposure cows experienced THI ≥ 72 for 0-27.5% of early
or late DP and high (H) exposure cows had THI ≥ 72 for 27.6-55% of early or late DP. Calves were assigned to categories depending on the heat exposure of their dams: low exposure (CL; THI ≥ 72 for 0-14.9% of dam’s DP; n = 6), moderate exposure (CM; THI ≥ 72 for 15-29.9% of dam’s DP; n = 11), and high exposure (CH; THI ≥ 72 for 30-45% of dam’s DP; n = 9). Data were summarized 42 d pre-calving and analyzed using PROC MIXED (SAS v 9.4) with the fixed effects of treatment and year and a random effect of the cow. Cows had 0.1 °C higher RT on HOT adj d on pasture than COOL adj d and ruminated for 58 more min on HOT d than on COOL d. Cows exposed to high levels of heat stress during the late DP had lower second milking BRIX and greater BW loss than those exposed to low levels of heat stress during the late DP. Dry cows may have been impacted by episodic heat stress on pasture, as this was when higher RT was observed. Calves were not affected by in-utero episodic heat stress in this study.
3.2. Introduction

The negative impacts of heat stress on lactating cattle have been well documented throughout the published literature (Collier et al., 1982; West et al., 2003; Cook et al., 2007). More recently, the negative impacts of heat stress on dry cows have been explored (Fabris et al., 2019; Laporta et al., 2020). Cows that are heat-stressed during late gestation will have impaired mammary development during the dry period (DP), leading to lowered milk production during the following lactation (Tao et al., 2011). When considering the dry cow, you must also consider the calf she is carrying, as the last 60 d of gestation are most important for in-utero development (Bauman et al., 1980). Florida researchers have observed decreased birth weights and growth rates, reduced passive transfer of immunity (Tao et al., 2012), and lowered milk production in the first three lactations in animals born to heat-stressed dams (Laporta et al., 2020).

Dry dairy cattle experience elevated rectal temperatures during heat stress (Fabris et al., 2019). Although rectal temperature is a typical measurement to indicate heat stress, reticular temperature (RT) provides a more continuous look at body temperature. RT correlates with rectal temperature (Bewley et al., 2008) and has less human error. Another physiological parameter typically affected by heat stress is rumination. Rumination is indicative of the health and DMI of dairy cattle and is reduced with heat stress (Moretti et al., 2017).

A temperature-humidity index (THI) value of 68 has become widely accepted as the heat stress threshold for high–producing lactating dairy cattle (Zimbelman et al., 2009). Recently, it has been observed that dry cows do not experience typical signs of heat stress (i.e., increased rectal temperatures and respiration rates) until a THI of 77 (Ouellet et al., 2020).
Most published studies regarding heat stress have been conducted in tropical and sub-tropical environments that experience daily THI values above 68 for the entire study duration (Monteiro et al., 2016; Fabris et al., 2019). Although heat stress is a critical issue in these regions that experience chronic high temperatures, it must also be addressed in moderate climates. Most dairy cows in the United States are located in areas with fewer than 80 heat stress days (average daily THI ≥ 68) per year (Laporta et al., 2020). Cows in these regions experience episodic heat stress, meaning hot days are often interspersed with cool days, and cooler nighttime temperatures often occur. It takes weeks for dairy cattle to acclimatize to heat stress (Collier et al., 2006). Acclimatization occurs through homeorhetic mechanisms responding to multiple stressors, including high temperatures and humidity (Collier et al., 2006). These animals experiencing episodic heat stress can never acclimatize, as there are no prolonged heat events. Several years of research indicated that high-producing lactating dairy cows are negatively affected by episodic heat stress in Northern NY, regardless of the heat abatement system (Ballard et al., 2020). Northern NY and VT have very similar climates.

Cows on pasture are more susceptible to harsh solar radiation (RAD) than cows housed in the shade of a barn. Without access to shade, dairy cattle decrease time spent ruminating (Vizzotto et al., 2015) and have increased body temperatures on hot days (Kendall et al., 2006). The impacts of RAD and wind speed (WSPD) on pastured animals must be accounted for when evaluating heat stress, as these factors can impact their thermoregulation abilities. This can be accomplished by adjusting THI for RAD and WSPD (Mader et al., 2006). This adjusted THI (THI_{adj}) was initially developed for feedlot beef
cattle (Mader et al., 2006) but has recently been validated in multiple studies involving dairy cattle (Hammami et al., 2013; Almuhanna et al., 2021).

This study aimed to assess the occurrence of heat stress in dry cows in VT under minimal heat abatement through RT and rumination monitoring. The second objective was to determine the physiological and behavioral impacts of cumulative episodic heat stress events on dry cows in VT housed in minimal heat abatement. The final goal was to determine the implications of cumulative in-utero episodic heat stress events on calf development with dams in VT under minimal heat abatement. It was hypothesized that episodic heat stress would negatively impact dry cows and their calves in VT.

3.3. Material and Methods

A retrospective cohort study was conducted at a commercial farm in Georgia, VT, during the summers of 2020 and 2021, in compliance with the William H. Miner Agricultural Research Institute's Animal Care and Use Committee (ACUC). Between July 3rd and August 28th, 2020, 26 primiparous and multiparous Holstein cattle were enrolled weekly at dry-off; 41 were enrolled between May 7th and August 27th, 2021, for 67 cows between the two summers.

During their early DP, cows were housed on pasture (22 to 42 d pre-calving). Pastured animals were fed a TMR in addition to available grass and had access to hedgerow trees for shade. Cows were moved into a barn with a bedded pack with access to an outdoor sandlot for their late DP (21 d pre-calving). The bedded pack had no heat abatement in the summer of 2020, but NCF 152-cm three-blade panel fans (Norbco, Watkins, MN) were added over the lying area in 2021. Big Ass Fans (5.5 m; Big Ass Fans, Lexington, KY)
were present in the barn in 2020 and 2021, providing only enough air movement for acceptable air quality, but not enough to cool cows (St. Pierre et al., 2003).

3.3.1. Environmental measurements

Air temperature (T) and relative humidity (RH) were measured every 10-min using Kestrel DROP D2AG data loggers (Nielsen-Kellerman Company, Boothwyn, PA) mounted in ventilated PVC pipes. These loggers were used only on the pasture in 2020 but in the barn and outdoor sandlot during both years. A weather station (Onset Computer Corporation, Bourne, MA) was mounted just outside the pasture in 2021 to allow more environmental parameters to be measured. The weather station measured T, RH (Onset 12-bit Temperature/Relative Humidity Smart Sensor), WSPD, gust speed (Onset Wind Speed Smart Sensor), wind direction (Onset Wind Direction Smart Sensor), and RAD (Onset Solar Radiation (Silicon Pyranometer) Smart Sensor) every 15-min. Temperature Humidity Index (THI) was calculated according to Dikmen et al. (2008), where \( THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)] \). THI was calculated every 10-min using data from the Kestrel loggers and every 15-min using data from the weather station. THI adjusted (THI_{adj}) for WSPD (m/s) and RAD (W/m^2) was calculated every 15-min in 2021 using weather station data, where \( THI_{adj} = [4.51 + THI - (1.992 \times WSPD) + (0.0068 \times RAD)] \) (Mader et al., 2006). THI and THI_{adj} were summarized as both hourly and daily average values.

Water temperature was measured every 15-min using HOBO Water Temperature Pro V2 data loggers (Onset Computer Corporation, Bourne, MA). Water temperature was measured in the water tank on the pasture in 2020 and 2021 and measured in the barn and on the outdoor sandlot in 2020. WSPD was measured at standing (140 cm) and lying (82
cm) heights on pasture once weekly using a Kestrel 5200 Anemometer (Nielsen-Kellerman Company, Boothwyn, PA) mounted on a tripod in the summer of 2020. WSPD was measured at standing and lying heights on the outdoor sandlot and in feed alleys and lying areas of the bedded pack in 2020 and 2021. WSPD was only measured in the outdoor sandlot when cows were utilizing it during each weekly visit; i.e., if it was raining or muddy, cows may not have been using it or had been denied access.

3.3.2. Cow measurements

At dry-off, cows were bolused with smaXtec Classic boluses (smaXtec Animal Care GmbH, Graz, Austria). Cows enrolled in 2020 received SX1 boluses capable of measuring RT (°C) and activity every 1-min. Cows enrolled in 2021 who were not previously enrolled in 2020 received SX2 boluses capable of measuring RT, activity, and rumination (s/d) every 1-min. Although the boluses captured measurements every 1-min, smaXtec reported RT and activity averages every 10-min. smaXtec reported rumination as a 24-hour rolling average every 10-min. The last rumination measurement for the day (at 23:50) was used to represent the total rumination time for that day. RT data was further summarized as average hourly and daily values.

Cow coat color (i.e., mainly black, mainly white, or half white/half black) was recorded at dry-off. Cows were body condition scored (BCS), locomotion scored (LS), and weighed at dry-off and calving. BCS was assigned on a 5-point scale, in 0.25 increments, with one being the lowest score and five being the highest (Ferguson et al., 1994) by two trained scorers. LS was assigned on a 5-point scale, where 1 = normal, 2 = mildly lame, 3 = moderately lame, 4 = lame, and 5 = severely lame (Sprecher et al., 1997) by two trained scorers.
scorers as cows walked on a flat concrete surface. BW were obtained using a Coburn Holstein Dairy weigh tape (Coburn, Whitewater, WI).

Gestation length was calculated by subtracting the most recent insemination date from the calving date. Colostrum weights from the first and second milking were collected using a Rubbermaid Digital Scale (Rubbermaid, Atlanta, GA). Colostrum quality was assessed using a Milwaukee Digital BRIX Refractometer (Milwaukee, Brookfield, WI).

3.3.3. Calf measurements

Calves were weighed on a Raytec Waypig 15 scale (Raytec LLC, Ephrata, PA) with a Digi-Star I2210 scale indicator (Digi-Star LLC, Fort Atkinson, WI) upon birth. Calves were bled from the jugular vein 48 ± 12 h after birth to assess serum total protein (TP) levels using a Leica Temperature Compensated Hand-Held Refractometer (Leica Inc., Buffalo, NY). Serum was obtained one hour after blood collection by centrifugation at 1,300 x g for 20 min. Based on serum TP, calves fit into one of four categories that reflect passive transfer of immunity status: excellent (≥ 6.2 g/100 ml), good (5.6 to 6.1 g/100 ml), fair (5.1 to 5.7 g/100 ml), and poor (< 5.1 g/100 ml) (Lombard et al., 2020). Stature measurements, including body length, heart girth, hip width, hip height, and wither height, were collected at birth (3 ± 3 d) and at weaning (55 ± 8 d) to assess growth rates. Weaning weights were collected using the same scale on which birth weights were collected. ADG was calculated by dividing the difference between birth and weaning weights by the number of days between collections.

3.3.4. Statistical analyses
Data were analyzed using SAS (Statistical Analysis System, version 9.4; SAS Institute Inc., Cary, NC). Significance was declared at $P \leq 0.05$, and a tendency was reported at $0.05 < P \leq 0.10$. Shapiro-Wilk and Levene's tests were used to assess all data, except for environmental parameters, for normality and homogeneity of variance, respectively, using the GLM procedure of SAS (v 9.4). Environmental parameters (THI, THI$_{adj}$, WSPD, gust speed, solar radiation, and water temperature) were reported as descriptive statistics (mean ± SD).

Cows were excluded if their DP lasted less than 42 d. RT and rumination data were excluded 3 d before calving to account for changes due to parturition. Rumination data were excluded if values were below 200 min/d or were outside of 3 SD for that cow. Cows were excluded from the RT analysis if they had twins, and specific days of RT data were excluded if there were missing data points.

To assess the impact of heat events on cows retrospectively, the average daily median RT was compared between HOT (daily average THI > 72) and COOL (daily average THI ≤ 68) d, using the MIXED procedure of SAS (v 9.4) with the following model:

$$Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk}$$

where $Y_{ij}$ was the dependent variable (RT), $\mu$ was the overall mean, $S_i$ was the fixed effect of treatment (HOT vs. COOL), $P_j$ was the fixed effect of yr (2020, 2021), $SP_{ij}$ was the fixed effect of the interaction between treatment and yr, $C_k$ was the random effect of cow (n = 36), and $E_{ijk}$ was the residual error. Cows were excluded from this analysis if they experienced < 5 HOT or COOL d during their DP.
Average median RT was also looked at specifically during the time cows were on pasture to determine the impacts of coat color on RT on HOT and COOL d using the MIXED procedure of SAS (v 9.4) with the following model:

\[ Y_{ijk} = \mu + S_i + W_j + SW_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (RT), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HOT or COOL), \( W_j \) was the fixed effect of coat color, \( SW_{ij} \) was the fixed effect of the interaction between treatment and coat color (black, white or half black/half white), \( C_k \) was the random effect of cow (\( n = 22 \)), and \( E_{ijk} \) was the residual error. Cows were excluded from this analysis if they experienced < 3 HOT or COOL d while on pasture.

Average median RT was compared between HOT\textsubscript{adj} (average daily THI\textsubscript{adj} > 72) and COOL\textsubscript{adj} (average daily THI\textsubscript{adj} ≤ 68) days during the entire DP, when cows were on pasture, and when cows were housed in the outdoor sandlot/barn area, using the following model:

\[ Y_{ijk} = \mu + S_i + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (RT), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HOT\textsubscript{adj} or COOL\textsubscript{adj} d during entire DP, on pasture, and in outdoor sandlot/barn), \( C_k \) was the random effect of cow (\( n = 39 \)), and \( E_{ijk} \) was the residual error. Cows were excluded from this analysis if they experienced < 3 HOT\textsubscript{adj} or COOL\textsubscript{adj} during the period that was being analyzed.
Average median RT was also looked at specifically during the time cows were on pasture to determine the impacts of coat color on RT on \( \text{HOT}_{\text{adj}} \) and \( \text{COOL}_{\text{adj}} \) days using the MIXED procedure of SAS (v 9.4) with the following model:

\[
Y_{ijk} = \mu + S_i + W_j + SW_{ij} + C_k + E_{ijk}
\]

where \( Y_{ij} \) was the dependent variable (RT), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (\( \text{HOT}_{\text{adj}} \) or \( \text{COOL}_{\text{adj}} \)), \( W_j \) was the fixed effect of coat color (black, white, or half black/half white), \( SW_{ij} \) was the fixed effect of the interaction between treatment and coat color, \( C_k \) was the random effect of cow \( (n = 29) \), and \( E_{ijk} \) was the residual error. Cows were excluded from this analysis if they experienced < 3 \( \text{HOT}_{\text{adj}} \) and \( \text{COOL}_{\text{adj}} \) days while on pasture.

Rumination was compared between \( \text{HOT} \) and \( \text{COOL} \) days using the MIXED procedure of SAS (v 9.4) with the following model:

\[
Y_{ijk} = \mu + S_i + C_k + E_{ijk}
\]

where \( Y_{ij} \) was the dependent variable (RT), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (\( \text{HOT} \) or \( \text{COOL} \)), \( C_k \) was the random effect of cow \( (n = 15) \), and \( E_{ijk} \) was the residual error. Cows were excluded from this analysis if they experienced < 5 \( \text{HOT} \) or \( \text{COOL} \) days during their DP.

Rumination was compared between \( \text{HOT}_{\text{adj}} \) (average daily THI\(_{\text{adj}} > 72 \)) and \( \text{COOL}_{\text{adj}} \) (average daily THI\(_{\text{adj}} \leq 68 \)) days during the entire DP, when cows were on pasture, and when cows were housed in the outdoor sandlot/barn area, using the following model:
\[ Y_{ijk} = \mu + S_i + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (RT), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (\( \text{HOT}_{\text{adj}} \) or \( \text{COOL}_{\text{adj}} \)), \( C_k \) was the random effect of cow (\( n = 24 \)), and \( E_{ijk} \) was the residual error. Cows were excluded from this analysis if they experienced < 3 \( \text{HOT}_{\text{adj}} \) or \( \text{COOL}_{\text{adj}} \) d during the period that was being analyzed.

Pearson correlation coefficients were calculated using the CORR procedure of SAS (v. 9.4) between average median RT and THI and RT and THI\text{adj}. Pearson correlation coefficients were also calculated between rumination and THI and rumination and THI\text{adj}. These relationships were analyzed both on pasture and during the whole DP.

To assess cumulative heat exposure, three categories were created retrospectively: low exposure (\( \text{LOW} \); THI \( \geq 72 \) for 0 – 14.9% of DP; \( n = 21 \)), moderate exposure (\( \text{MOD} \); THI \( \geq 72 \) for 15-29.9% of DP \( \geq 72 \); \( n = 30 \)), and high exposure (\( \text{HI} \); THI \( \geq 72 \) for 30-45% of DP \( \geq 72 \); \( n = 15 \)). Although these cumulative heat exposure categories focused on the last 42 d of the DP, cows were dry for different lengths of time, so the change in BW, BCS, and LS from dry-off to calving was across varying days. Average days (mean ± SD) dry were as follows: \( \text{HI} \) (52.5 ± 8.2 d), \( \text{MOD} \) (54.9 ± 9.0), and \( \text{LOW} \) (56.8 ± 11.8 d). Some samples were missed, so the variables had different sample sizes.

BW, BCS, and LS change data were excluded if they were more than three SD from the mean. The relationship between the three heat exposure categories and gestation length, colostrum weight and quality, changes in LS, BCS, and BW from dry-off to calving, and exposure categories were analyzed using the MIXED procedure of SAS (v 9.4) with the following model:
\[ Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (gestation length, colostrum quantity and quality, change in LS, BCS, and BW from dry-off to calving), \( \mu \) was the overall mean, \( S_i \) was the fixed effect of treatment (HI, MOD, or LOW), \( P_j \) was the fixed effect of yr (2020, 2021), \( SP_{ij} \) was the fixed effect of the interaction between treatment and yr, \( C_k \) was the random effect of cow (n = 66, 61, 60, 34, 57, and 57), and \( E_{ijk} \) was the residual error.

To assess heat exposure during the early and late DP, four more categories were created: low exposure for early DP/low exposure for late DP (LL; n=31); low exposure for early DP/high exposure for late DP (LH; n=15 cows); high exposure for early DP/high exposure for late DP (HH; n=4); high exposure for early DP/low exposure for late DP (HL; n=16). Low exposure cows experienced THI ≥ 72 for 0-27.5% of either early or late DP, and high exposure cows experienced THI ≥ 72 for 27.6-55% of either early or late DP. Average days dry (mean ± SD) were as follows: LL (56.9 ± 11.7), LH (53.5 ± 9.3), HL (53.5 ± 6.4), HH (50.8 ± 4.3).

The relationship between gestation length, colostrum quantity and quality, change in LS, BCS, and BW from dry-off to calving, and the four early/late exposure categories were analyzed using the MIXED procedure of SAS (v 9.4) with the following model:

\[ Y_{ijk} = \mu + F_i + L_j + FL_{ij} + C_k + E_{ijk} \]

where \( Y_{ij} \) was the dependent variable (gestation length, colostrum quantity, and quality, change in LS, BCS, and BW from dry-off to calving), \( \mu \) was the overall mean, \( F_i \) was the fixed effect of early DP exposure (low or high), \( L_j \) was the fixed effect of late DP exposure (low or high), \( FL_{ij} \) was the fixed effect of the interaction between early and late DP.
exposure, $C_k$ was the random effect of cow ($n = 66, 61, 60, 56, 57, \text{ and } 57$), and $E_{ijk}$ was the residual error.

Calves were assigned categories corresponding to their dam's exposure level: low in-utero exposure ($\text{CL; n=6}$), moderate in-utero exposure ($\text{CM; n=11}$), and high in-utero exposure ($\text{CH; n=9}$). The relationship between the calf exposure categories and birth weight was assessed using the MIXED procedure of SAS (v 9.4) with the following model:

$$Y_{ijk} = \mu + S_i + G_j + SG_{ij} + C_k + E_{ijk}$$

where $Y_{ij}$ was the dependent variable (birth weight), $\mu$ was the overall mean, $S_i$ was the fixed effect of treatment ($\text{CL, CM, or CH}$), $G_j$ was the fixed effect of sex (male or female), $SG_{ij}$ was the fixed effect of the interaction between treatment and sex, $C_k$ was the random effect of cow ($n = 58$), and $E_{ijk}$ was the residual error.

The relationship between heifer calf exposure categories and ADG and serum TP were assessed using the MIXED procedure of SAS with the following model:

$$Y_{ijk} = \mu + S_i + P_j + SP_{ij} + C_k + E_{ijk}$$

where $Y_{ij}$ was the dependent variable (ADG or serum TP), $\mu$ was the overall mean, $S_i$ was the fixed effect of treatment ($\text{CL, CM, or CH}$), $P_j$ was the fixed effect of yr (2020, 2021), $SP_{ij}$ was the fixed effect of the interaction between treatment and yr, $C_k$ was the random effect of calf ($n = 25 \text{ and } 26$), and $E_{ijk}$ was the residual error.

### 3.4. Results and Discussion

#### 3.4.1. Environmental conditions
Between the first day of enrollment at dry off until the last calving date (July 7th - October 21st, 2020; May 8th - October 16th, 2021), there were 13 HOT d in 2020 and 25 in 2021. (Figure 3.1). There were fewer HOT d in 2020 than in 2021 due to a shorter enrollment period. These HOT d were often interspersed with COOL d and nighttime cooling, creating a different environment than studies dealing with chronic heat stress, where dry cows experienced a THI > 72 for their entire DP (Fabris et al., 2019).

Between May 8th and October 4th, 2021 (day of first enrollment until the last day cows were on pasture), there were 63 HOT_dep d (Figure 3.1). The greater number of HOT_dep d compared to HOT d illustrates solar radiation's enormous impact on heat load. Although there were many more HOT_dep d than HOT d, it was still not hot 100% of the time, as observed in chronic heat stress studies (Fabris et al., 2019), demonstrating that THI Dep is also an effective way to quantify episodic heat stress.

Water tank temperature was higher on HOT d regardless of the location of the water tank but was still well below the recommended maximum drinking water temperature of 30°C (Table 3.1; Beede, 1993). Water tank temperature was higher on HOT_dep d than COOL_dep d (Table 3.2) on pasture, and the difference was slightly lower than between HOT and COOL d. Water temperature was about 9°C lower in the barn than on the pasture or outdoor sandlot on HOT d, indicating that shade is essential for keeping water tank temperatures low. It would be interesting to compare the difference in RT drop with these variable water temperatures, as Bewley et al. (2007) observed that even though warm water can lower RT, it is not as prolonged of an impact as cold water. The current study did not investigate the effects of water temperature on RT. Still, it may have provided
information about the effects of varying water temperature on the thermoregulation of cows experiencing episodic heat stress.

WSPD was higher on both HOT and HOT$_{adj}$ d on the pasture, which was interesting as there was no artificial air movement created by fans (Tables 3.1 and 3.2). This may be explained by higher gust speeds measured on HOT$_{adj}$ d, increasing overall WSPD for those days. Unlike on pasture, WSPD was lower on HOT d but higher on HOT$_{adj}$ d on the outdoor sandlot.

Unfortunately, WSPD was never measured on a HOT d in 2020 on the outdoor sandlot or barn. It would have been interesting to compare the WSPD on HOT d in the barn between years, as fans were installed in 2021. Fans created higher WSPD in the barn on HOT d than on COOL d, but values fell below the recommended 8 kph needed to cool cows (Tyson, 2017). Fans may need to be added or existing fans repositioned or re-angled to create adequate airflow in dead spots throughout the pen.

### 3.4.2. Reticular body temperature

Different sample sizes were used to analyze variables as some samples were missed or some cows did not meet the analysis criteria, which can be found in the statistical analysis and table foot notes. Cows were universally dropped from all analyses if their dry period was less than 42 days, most commonly due to an incorrect breed date record or the birth of twins. Average median RT (mean ± SD; 39.5 ± 0.02°C) was similar between HOT and COOL d (Table 3.3). These unexpected results differed from RT observed in a previous study where lactating animals exposed to episodic heat stress experienced higher body temperatures on hot days (Ballard et al., 2020). Dry cows naturally have a lower
metabolic heat load than lactating animals (Purwanto et al., 1990), which may partly explain the differing results. Blood flows away from the gastrointestinal tract and toward the periphery during heat stress to better dissipate heat (Bernabucci et al., 2010), which may further explain why no difference was measured in RT between HOT and COOL d. A recent meta-analysis dealing with chronic heat stress in dry cows showed that rectal temperatures and respiration rates are not increased until a THI threshold of 77. This may further explain why there was no difference in RT measured between HOT and COOL d. The current study may not have spent enough time above this THI threshold to increase RT on HOT d.

Cows had similar RT between HOT_{adj} and COOL_{adj} d during the DP as a whole and when housed in the outdoor sandlot/barn but had 0.1 °C higher RT (P < 0.05; Table 3.4) on HOT_{adj} d compared to COOL_{adj} when housed on pasture. This indicates that cows may have been able to thermoregulate better when provided the option of shade from the barn. Although this significant difference on pasture was observed, RT was not significantly correlated with THI or THI_{adj} (Table 3.7).

Coat color (mainly black, mainly white, or half black/half white) had no impact on RT in either analysis comparing HOT and COOL d or comparing HOT_{adj} and COOL_{adj} d. The lack of difference between coat colors differed from Hansen (1990), who found that primarily black Holsteins have greater body temperatures in the direct sun than mostly white Holsteins. It may be that the solar radiation in VT is lesser than that in FL, where Hansen (1990) conducted their study. Hansen (1990) also used lactating animals, who may be more susceptible to solar radiation than dry cows because of their naturally higher metabolic heat load.
An interesting pattern in RT was observed (Figure 3.2), where body temperature began to increase about 30 days before calving, peaking roughly 29 days later before quickly plummeting. The literature suggests a decrease in vaginal and rectal temperature 24 hours before calving (Burfeind et al., 2011), which was observed in the current study but did not mention a pattern similar to that observed starting at 30 days pre-calving.

3.4.3. Rumination behavior

Cows ruminated for 58 more minutes \((P < 0.05; \text{Table } 3.3)\) on HOT d than COOL d, but rumination did not differ between HOT_{adj} and COOL_{adj} d \((550 \pm 5 \text{ min/d}; \text{Table 3.4})\). Rumination results differ from previous studies regarding heat stress in dry cows (Maia et al., 2020) and lactating cows (Tapki et al., 2006; Abeni et al., 2017; Moretti et al., 2017), which observed a decrease in rumination due to heat stress. Unlike the moderate climate here, these studies were conducted in environments with high THI and may not reflect the impact of episodic heat stress on rumination.

A significant correlation was observed between daily rumination and THI_{adj} > 72 during the DP as a whole \((P < 0.05; \text{Table 3.7})\). Although this was a significant positive correlation, the Pearson correlation coefficient was relatively close to zero, indicating that these variables were weakly correlated.

3.4.4. Body weight, body condition score, and locomotion score

No statistically significant difference was observed in the change in BW \((11.9 \pm 7.0 \text{ kg}), \text{LS } (-0.15 \pm 0.11), \text{or BCS } (-0.05 \pm 0.03)\) from dry-off to calving between HI, MOD, and LOW groups (Table 3.8). Although there was no statistical difference, HI cows had the greatest loss numerically in BW from dry-off to calving compared to MOD and
LOW groups. Cows in the HI group may have numerically lost the most BW from dry-off to calving due to lowered DMI or greater energy demands of thermoregulation. This numeric difference could indicate a Type II error, where the null hypothesis was not rejected when it should have been, indicating no difference between HI and LOW groups. A power analysis was conducted to determine whether this was indeed a Type II error, and it was determined not to be, as there was sufficient power.

There was no difference in LS or BCS change from dry-off to calving between HH, HL, LH, and LL groups (Table 3.9). Cows who experienced high amounts of heat stress during their late DP tended to have greater BW loss from dry-off to calving than low amounts of heat stress during the late DP ($P = 0.09$). This is different from Fabris et al. (2019), who measured reduced BW in cows heat stressed during their early DP, but no difference in BW in the late DP. Fabris et al. (2019) exposed cows to chronic heat stress in the shade of the barn, much different than cows in the current study that experienced episodic heat stress under the influence of solar radiation.

3.4.5. Lactation performance, colostrum quality, and quantity

No difference was observed in first (5.6 ± 0.5 kg) or second (6.2 ± 0.4 kg) milk weights or BRIX readings from first (23.4 ± 0.6), or second (15.9 ± 0.5) milkings between HI, MOD, and LOW groups (Table 3.8). No difference was measured in the first or second milk weight or BRIX from the first milking between LL, LH, HL, and HH groups (Table 3.9). Cows who experienced high heat stress during the late DP had lower second milking BRIX ($P < 0.01$) than those who experienced low heat stress during the late DP. Late gestation chronic heat stress literature illustrates similar results, with no change in colostrum quantity due to heat stress (Tao et al., 2012; Dado-Senn et al., 2021). There is
conflicting literature regarding the impacts of chronic heat stress on the IgG content of colostrum. Some report lowered IgG content (Nardone et al., 1997), while others report no difference despite chronic heat stress exposure (Lacetera et al., 2002).

3.4.6. Gestation length, calf immunity, and growth

No statistically significant difference was measured in gestation length (279.1 ± 0.5 d) between HI, MOD, or LOW (Table 3.8) groups or LL, LH, HL, and HH groups (Table 3.9). These results contradict studies that demonstrated that dry cows exposed to chronic heat stress had reduced gestation lengths (Tao et al., 2012; Fabris et al., 2019). Although there was no statistically significant difference in gestation length between groups, HI cows numerically had the shortest gestation length compared to MOD and LOW cows, and LL cows numerically had the longest gestation length compared to LH, HL, and HH groups. This may indicate another Type II error, where the null hypothesis was not rejected as it should have been. It may warrant another round of enrollment in this study to increase cow numbers. The cost of a Type II error to the farmer must be considered when deciding to continue this study; an incorrect recommendation could reduce profits. This Type II error would indicate no difference in gestation length between groups when there was. This may lead farmers to believe heat abatement is unneeded for dry cows when it is, therefore cutting into profits in the subsequent lactation. A power analysis was conducted, indicating that this study was underpowered for this variable, with a power value of 0.59; 39 more cows would need to be enrolled to provide sufficient power.

No statistically significant difference was observed in birth weights (41.1 ± 0.7 kg), ADG (0.79 ± 0.02 kg/d), or serum TP (6.1 ± 0.1) between CH, CM, or CL groups (Tables 3.10 and 3.11). This contradicts literature that observed decreased birth weights, ADG,
and passive transfer of immunity due to chronic in-utero heat stress (Laporta et al., 2017). Numerically, CH calves had the lowest birth weights and serum TP, while CL calves had the highest ADG. A power analysis indicated sufficient power regarding birth weights. Calves may have been statistically unaffected by episodic in-utero heat stress because their in-utero body temperature remained relatively stable when cows had access to the shade of the barn and was only affected when cows were on pasture.

3.5. Conclusions

Although few differences were measured between treatments in this study, dry cows were negatively impacted by episodic heat stress when exposed to solar radiation on pasture, reflected by increased reticular temperatures. Cows exposed to high amounts of episodic heat stress, specifically during the late DP, also tended to have greater BW loss from dry-off to calving than cows exposed to low amounts of episodic heat stress. This demonstrates the need to provide shade to dry cows as a minimal form of heat mitigation in the Northeast. For the measured variables, calves were not impacted by episodic in-utero heat stress. It would be interesting to continue this study through another enrollment period to increase cow numbers to understand if the observed numeric differences were insignificant because of a lack of power.
3.6. References


physiological attributes of dairy cows during the hot season in the subtropics. Animal. 9:1559-1566.


### 3.7. Tables and figures

**Table 3.1.** Average wind speed (kph), gust speed, solar radiation, and water temperature on pasture, in the barn, and the outside sandlot housing areas on HOT and COOL d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Housing location</th>
<th>Pasture</th>
<th>Barn</th>
<th>Outdoor sandlot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HOT¹</td>
<td>COOL²</td>
<td>HOT¹</td>
<td>COOL²</td>
</tr>
<tr>
<td>Windspeed, kph</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing height</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>6.1 ± 2.1³</td>
<td>4.7 ± 3.4</td>
<td>-</td>
<td>1.2 ± 1.9</td>
</tr>
<tr>
<td>2021</td>
<td>-</td>
<td>-</td>
<td>3.7 ± 5.6</td>
<td>2.1 ± 3.4</td>
</tr>
<tr>
<td>Lying height</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>5.8 ± 1.9</td>
<td>4.0 ± 3.2</td>
<td>-</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>2021</td>
<td>-</td>
<td>-</td>
<td>3.9 ± 7.9</td>
<td>2.1 ± 3.7</td>
</tr>
<tr>
<td>Weather station parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windspeed, kph</td>
<td>7.6 ± 3.2</td>
<td>6.6 ± 3.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gust speed, kph</td>
<td>14.3 ± 5.6</td>
<td>12.3 ± 5.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solar radiation, W/ m²</td>
<td>226 ± 93</td>
<td>190 ± 54</td>
<td>217 ± 71</td>
<td>181 ± 92</td>
</tr>
<tr>
<td>Water temperature, °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>23.0 ± 1.1</td>
<td>17.1 ± 2.9</td>
<td>13.6 ± 3.1</td>
<td>11.8 ± 1.6</td>
</tr>
<tr>
<td>2021</td>
<td>23.7 ± 1.0</td>
<td>17.7 ± 2.7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

¹HOT – d where the average daily THI > 72
²COOL – d where the average daily THI ≤ 68
³Mean ± SD
Table 3.2. Average wind speed (kph), gust speed, solar radiation, and water temperature on pasture and the outside sandlot housing areas on HOT$_{adj}$ and COOL$_{adj}$ d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pasture</th>
<th>Outdoor Sandlot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windspeed, kph</td>
<td>HOT$_{adj}$</td>
<td>COOL$_{adj}$</td>
</tr>
<tr>
<td>Standing height</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lying height</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Weather station data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windspeed, kph</td>
<td>7.7 ± 3.1</td>
<td>6.8 ± 2.9</td>
</tr>
<tr>
<td>Gust speed, kph</td>
<td>14.6 ± 5.6</td>
<td>13.0 ± 5.3</td>
</tr>
<tr>
<td>Solar radiation, W/m$^2$</td>
<td>220 ± 68</td>
<td>197 ± 92</td>
</tr>
<tr>
<td>Water temperature, °C</td>
<td>22.0 ± 1.8</td>
<td>16.5 ± 2.6</td>
</tr>
</tbody>
</table>

$^1$HOT$_{adj}$ – d where the average daily THI$_{adj}$ > 72
$^2$COOL$_{adj}$ – d where the average daily THI$_{adj}$ ≤ 68
$^3$Mean ± SD

Table 3.3. Least squares means of reticular temperature and rumination time of dry Holstein cows on HOT and COOL d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment$^1$</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>COOL</td>
<td>HOT</td>
</tr>
<tr>
<td>2020</td>
<td>36</td>
<td>39.5</td>
</tr>
<tr>
<td>2021</td>
<td>7</td>
<td>39.5</td>
</tr>
<tr>
<td>2021</td>
<td>29</td>
<td>39.5</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>15</td>
<td>542</td>
</tr>
</tbody>
</table>

$^1$Treatment: COOL – average daily THI ≤ 68; HOT – average daily THI > 72
Table 3.4. Least squares means of reticular temperature and rumination of dry Holstein cows on HOT_{adj} and COOL_{adj} d in different locations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Treatment(^1)</th>
<th>(P)-values</th>
<th>SEM</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>39</td>
<td>39.5</td>
<td>39.5</td>
<td>&lt; 0.1</td>
<td>0.26</td>
</tr>
<tr>
<td>Pasture</td>
<td>30</td>
<td>39.3</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Outdoor sandlot/barn</td>
<td>28</td>
<td>39.6</td>
<td>39.6</td>
<td>&lt; 0.1</td>
<td>0.74</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>24</td>
<td>549</td>
<td>550</td>
<td>7</td>
<td>0.83</td>
</tr>
<tr>
<td>Pasture</td>
<td>16</td>
<td>555</td>
<td>561</td>
<td>9</td>
<td>0.33</td>
</tr>
<tr>
<td>Outdoor sandlot/barn</td>
<td>17</td>
<td>550</td>
<td>541</td>
<td>11</td>
<td>0.28</td>
</tr>
</tbody>
</table>

\(^1\)Treatment: COOL_{adj} – average daily THI_{adj} ≤ 68; HOT_{adj} – average daily THI_{adj} > 72

Table 3.5. Least squares means of reticular temperature on pasture of dry Holstein cows with varying coat colors on COOL and HOT d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Treatment(^1)</th>
<th>(P)-values</th>
<th>SEM</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>22</td>
<td>39.3</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>0.36</td>
</tr>
<tr>
<td>Black</td>
<td>9</td>
<td>39.4</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>0.80</td>
</tr>
<tr>
<td>White</td>
<td>7</td>
<td>39.3</td>
<td>39.4</td>
<td>0.1</td>
<td>0.97</td>
</tr>
<tr>
<td>Half black/ half white</td>
<td>6</td>
<td>39.4</td>
<td>39.4</td>
<td>0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\)Treatment: COOL – average daily THI ≤ 68; HOT – average daily THI > 72

Table 3.6. Least squares means of reticular temperature on pasture of dry Holstein cows with varying coat colors on COOL\(_{adj}\) and HOT\(_{adj}\) d.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Treatment(^1)</th>
<th>(P)-values</th>
<th>SEM</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>29</td>
<td>39.3</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Black</td>
<td>15</td>
<td>39.3</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>0.51</td>
</tr>
<tr>
<td>White</td>
<td>8</td>
<td>39.2</td>
<td>39.3</td>
<td>&lt; 0.1</td>
<td>0.93</td>
</tr>
<tr>
<td>Half black/ half white</td>
<td>6</td>
<td>39.4</td>
<td>39.4</td>
<td>&lt; 0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\)Treatment: COOL\(_{adj}\) – average daily THI\(_{adj}\) ≤ 68; HOT\(_{adj}\) – average daily THI\(_{adj}\) > 72
Table 3.7. Pearson correlation coefficients of rumination, reticular temperature from 2021, and THI adjusted for wind speed and solar radiation on pasture and during the entire dry period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Environmental Parameter</th>
<th>Pearson correlation</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reticular temperature, °C</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; on pasture</td>
<td>0.04</td>
<td>0.25</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; &gt; 72 on pasture</td>
<td>0.04</td>
<td>0.44</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; during entire DP</td>
<td>-0.02</td>
<td>0.48</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; &gt; 72 during entire DP</td>
<td>0.02</td>
<td>0.57</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI on pasture</td>
<td>0.05</td>
<td>0.21</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI &gt; 72 on pasture</td>
<td>0.05</td>
<td>0.58</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI during entire DP</td>
<td>-0.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Reticular temperature, °C</td>
<td>THI &gt; 72 during entire DP</td>
<td>0.05</td>
<td>0.58</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; on pasture</td>
<td>0.02</td>
<td>0.71</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; &gt; 72 on pasture</td>
<td>-0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; during entire DP</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI&lt;sub&gt;adj&lt;/sub&gt; &gt; 72 during entire DP</td>
<td>0.13</td>
<td>0.01</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI on pasture</td>
<td>0.02</td>
<td>0.76</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI &gt; 72 on pasture</td>
<td>-0.02</td>
<td>0.88</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI during entire DP</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td>Rumination, min/d</td>
<td>THI &gt; 72 during entire DP</td>
<td>0.09</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Table 3.8. Least squares means of gestation length, colostrum yield, colostrum quality, change in LS, BCS, and BW from dry-off to calving in Holstein cows exposed to varying degrees of heat stress throughout the dry period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>MOD</td>
</tr>
<tr>
<td>Gestation length(^2), d</td>
<td>277</td>
<td>279</td>
</tr>
<tr>
<td>1(^{st}) milk weight(^3), kg</td>
<td>3.8</td>
<td>5.5</td>
</tr>
<tr>
<td>2(^{nd}) milk weight(^4), kg</td>
<td>5.3</td>
<td>6.9</td>
</tr>
<tr>
<td>1(^{st}) milking BRIX(^5), % solids</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>2(^{nd}) milking BRIX(^6), % solids</td>
<td>15.2</td>
<td>16.1</td>
</tr>
<tr>
<td>Δ LS(^7)</td>
<td>-0.06</td>
<td>-0.08</td>
</tr>
<tr>
<td>Δ BCS(^8)</td>
<td>-0.09</td>
<td>-0.06</td>
</tr>
<tr>
<td>Δ BW(^9), kg</td>
<td>-35.7</td>
<td>18.6</td>
</tr>
</tbody>
</table>

\(^1\)Treatment: HI were high exposure cows with THI ≥ 72 for 30-45% of the total DP; MOD were moderate exposure cows with THI ≥ 72 for 15-29.9% of the total DP; LOW were low exposure cows with THI ≥ 72 for 0-14.9% of total DP

\(^2\)Gestation length: HI (n = 15); MOD (n = 29); LOW (n = 22)

\(^3\)1\(^{st}\) milk weight: HI (n = 14); MOD (n = 27); LOW (n = 20)

\(^4\)2\(^{nd}\) milk weight: HI (n = 10); MOD (n = 26); LOW (n = 20)

\(^5\)1\(^{st}\) milking BRIX: HI (n = 13); MOD (n = 25); LOW (n = 22)

\(^6\)2\(^{nd}\) milking BRIX: HI (n = 11); MOD (n = 24); LOW (n = 23)

\(^7\)Δ LS: Change in locomotion score from dry-off to calving; HI (n = 14); MOD (n = 24); LOW (n = 18)

\(^8\)Δ BCS: Change in body condition score from dry-off to calving; HI (n = 14); MOD (n = 24); LOW (n = 19)

\(^9\)Δ BW: Change in body weight from dry-off to calving; HI (n = 11); MOD (n = 27); LOW (n = 19)
Table 3.9. Least squares means of gestation length, colostrum yield, colostrum quality, change in LS, BCS, and BW from dry off to calving in Holstein cows exposed to varying degrees of heat stress throughout early (22-42 d pre-calving) and late (21 d pre-calving) dry period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment$^1$</th>
<th>SEM</th>
<th>Early DP (EDP)</th>
<th>Late DP (LDP)</th>
<th>EDP x LDP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LL</td>
<td>LH</td>
<td>HL</td>
<td>HH</td>
<td></td>
</tr>
<tr>
<td>Gestation length$^2$, d</td>
<td>280</td>
<td>277</td>
<td>279</td>
<td>279</td>
<td>1</td>
</tr>
<tr>
<td>1st milk weight$^3$, kg</td>
<td>6.6</td>
<td>5.2</td>
<td>4.2</td>
<td>3.7</td>
<td>1.2</td>
</tr>
<tr>
<td>2nd milk weight$^4$, kg</td>
<td>6.3</td>
<td>6.6</td>
<td>5.9</td>
<td>4.4</td>
<td>1.1</td>
</tr>
<tr>
<td>1st milking BRIX$^5$, % solids</td>
<td>23.3</td>
<td>24.5</td>
<td>22.3</td>
<td>22.1</td>
<td>2.1</td>
</tr>
<tr>
<td>2nd milking BRIX$^6$, % solids</td>
<td>16.0$^a$b</td>
<td>15.2$^ab$x</td>
<td>17.6$^{a}xy$</td>
<td>9.3$^b$y</td>
<td>1.4</td>
</tr>
<tr>
<td>Δ LS$^7$</td>
<td>-0.07</td>
<td>-0.38</td>
<td>-0.06</td>
<td>-0.25</td>
<td>0.27</td>
</tr>
<tr>
<td>Δ BCS$^8$</td>
<td>-0.04</td>
<td>-0.05</td>
<td>-0.10</td>
<td>-0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>Δ BW$^9$, kg</td>
<td>18.6</td>
<td>4.3</td>
<td>14.8</td>
<td>-45.4</td>
<td>18.9</td>
</tr>
</tbody>
</table>

$^a$Means within a row with different superscripts are significantly different ($P \leq 0.05$)  
$^b$Means within a row with different superscripts have a tendency to be different (0.05 > $P \leq 0.10$)  
$^1$Treatment: Low exposure – THI ≥ 72 for 0-27.5% of early or late DP; High exposure – THI ≥ 72 for 27.6-55% of early or late DP. LL – low exposure during early DP/low exposure during late DP; LH – low exposure during early DP/high exposure during late DP; HL – high exposure during early DP/low exposure during late DP; HH – high exposure during early DP/high exposure during late DP.  
$^2$Gestation length: LL (n = 32); LH (n = 15); HL (n = 15); HH (n = 4)  
$^3$1st milk weight: LL (n = 29); LH (n = 15); HL (n = 14); HH (n = 3)  
$^4$2nd milk weight: LL (n = 28); LH (n = 14); HL (n = 12); HH (n = 2)  
$^5$1st milking BRIX: LL (n = 31); LH (n = 14); HL (n = 12); HH (n = 3)  
$^6$2nd milking BRIX: LL (n = 31); LH (n = 15); HL (n = 10); HH (n = 2)  
$^7$Δ LS: Change in locomotion score from dry-off to calving; LL (n = 27); LH (n = 12); HL (n = 13); HH (n = 4)  
$^8$Δ BCS: Change in body condition score from dry-off to calving; LL (n = 28); LH (n = 12); HL (n = 13); HH (n = 4)  
$^9$Δ BW: Change in body weight from dry-off to calving; LL (n = 27); LH (n = 14); HL (n = 14); HH (n = 2)
Table 3.10. Least squares means of birth weights of calves born to Holstein dams exposed to varying degrees of heat stress throughout the DP.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>SEM</th>
<th>Treatment (T)</th>
<th>Sex (S)</th>
<th>T x S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight, kg</td>
<td>CH (n=12)</td>
<td>36.6</td>
<td>40.9</td>
<td>43.9</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>CM (n=26)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CL (n=20)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Treatment (T)</td>
<td>Sex (S)</td>
<td>T x S</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.45</td>
<td>0.13</td>
<td>0.85</td>
</tr>
</tbody>
</table>

1Treatment: CH were calves born to high exposure cows with THI ≥ 72 for 30-45% of the total DP; CM were calves born to moderate exposure cows with THI ≥ 72 for 15-29.9% of total DP; CL were calves born to low exposure cows with THI ≥ 72 for 0-14.9% of total DP

Table 3.11. Least squares means of average daily gain and serum total protein in calves born to Holstein dams exposed to varying degrees of heat stress throughout the dry period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>SEM</th>
<th>Treatment (T)</th>
<th>Year (Y)</th>
<th>T x Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG2, kg/d</td>
<td>CH</td>
<td>0.78</td>
<td>0.78</td>
<td>0.05</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>CM</td>
<td>0.78</td>
<td></td>
<td>0.53</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>CL</td>
<td>0.85</td>
<td></td>
<td>0.53</td>
<td>0.85</td>
</tr>
<tr>
<td>Serum total protein3, g/100 ml</td>
<td></td>
<td>5.8</td>
<td>6.3</td>
<td>6.1</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.32</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Treatment (T)</td>
<td>Year (Y)</td>
<td>T x Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.53</td>
<td>0.85</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.85</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.85</td>
<td>0.98</td>
</tr>
</tbody>
</table>

1Treatment: CH were calves born to high exposure cows with THI ≥ 72 for 30-45% of the total DP; CM were calves born to moderate exposure cows with THI ≥ 72 for 15-29.9% of total DP; CL were calves born to low exposure cows with THI ≥ 72 for 0-14.9% of total DP
2ADG: Average daily gain from birth until weaning; CH (n = 9); CM (n = 10); CL (n = 6)
3Serum total protein: CH (n = 9); CM (n = 11); CL (n = 6)
**Figure 3.1.** Average THI and THI adjusted for wind speed and solar radiation during enrollment periods.

![Graph showing average THI and adjusted THI](image)

**Figure 3.2.** Daily median reticular temperatures (°C) in dry Holstein cows exposed to episodic heat stress before calving.

![Graph showing reticular temperatures](image)
CHAPTER 4: FARMER PERCEPTIONS OF HEAT STRESS AND HEAT ABATEMENT IN NORTHERN NEW YORK AND VERMONT

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4.1. Abstract

Episodic heat stress is known to impact dairy cattle welfare negatively in the Northeast, and heat abatement systems can successfully mitigate some of these impacts. Farmer perceptions and experiences with episodic heat stress and heat abatement in the Northeast are unknown. The objective of this study was to learn farmers' viewpoints on this topic and assess where information gaps in research or farmer knowledge may exist. Eight semi-structured interviews were conducted with dairy farm owners or managers in Northern NY or VT. Dairies varied in size and heat stress management practices. All farmers felt their animals were impacted by heat stress during the summer but had varying opinions about how they were affected. A unique finding of this study was that farmers are hesitant to use sprinklers to cool cows. Most farmers thought more research was needed regarding heat stress and heat abatement, but specific proposed research topics varied.
4.2. Introduction

A well-cited economic analysis by St-Pierre et al. (2003) observed the effects of heat stress on multiple livestock industries, including lactating dairy cattle. They estimated that not providing heat abatement to lactating dairy cattle costs producers $897 million annually in lost milk production and other parameters. These researchers gathered data from weather stations in the 48 contiguous states and estimated the amount of heat stress experienced in those states every year. To estimate economic losses, they observed the impact of heat stress on milk production, DMI, pregnancy rate, days open, and the cull rate. It was estimated that NY experiences about 30 heat stress days annually, accounting for $23 million of the nation's total losses due to dairy cattle heat stress. High levels of heat abatement were recommended for lactating dairy cows in NY, including fans and sprinklers.

More recently, Ferreira et al. (2016) conducted an economic analysis of the impacts of heat stress on dry cows in the United States. They estimated that the total losses from heat stress are much more remarkable than St-Pierre et al. (2003) estimated and that dry cows specifically account for $810 million of those losses. Like St-Pierre et al. (2003), they also utilized weather station data but focused on the 25 states with the greatest dairy cow numbers and only used lost milk production as a variable. Ferreira et al. (2016) estimated that dry cows in NY experience more than 30 heat stress days annually suggested by St.-Pierre et al. (2003), and that they experience 77. They estimated that dry cows who are not provided heat abatement in NY cost producers $75 per cow per year in lost milk production in the subsequent lactation. Ferreira et al. (2016) suggested that providing shade, fans, and sprinklers for dry cows in NY is economically feasible.
These studies indicate heat stress's adverse economic impact on lactating and dry dairy cows in the Northeast. Milk production is an important variable to measure financial losses in the dairy industry, as this is how producers are paid. The study summarized in Chapter 2 concluded that when cows experience high amounts of episodic heat stress in their late dry period (DP), they decrease milk production by 4 kg/d in the first 21 DIM. Ferreira et al. (2016) estimated that dry cows who are not provided heat abatement in NY would lose 9.9 kg/d in milk production in the following lactation, an estimate greater than the losses found in Chapter 2. It may be because the cows in Chapter 2 were provided with moderate heat abatement during their DP rather than no heat abatement, as Ferreira et al. (2016) assumed. Ferreira et al. (2016) may have also assumed that cows experience chronic heat stress rather than episodic heat stress in the Northeast.

Southern regions of the US experience chronic heat stress, high temperature and humidity values every summer day, with little to no nighttime cooling. The Northeast experiences episodic heat stress characterized by fewer days with high temperatures and humidity, interspersed with cooler days and nighttime cooling. It takes dairy animals weeks to acclimate to heat (Collier et al., 2006); since the Northeast rarely experiences prolonged weeks of heat events, dairy cows are never able to adapt.

Previous research at Miner Institute illustrated the negative impacts of episodic heat stress on the health and behavior of lactating dairy cattle, regardless of the heat abatement system (Ballard et al., 2020). Current research indicates decreased milk production and detrimental impacts on animal welfare due to DP heat stress (Chapter 2), but most likely not as large of an economic impact as estimated with chronic DP heat stress (Ferreira et al., 2016). It is crucial to learn farmer perceptions of heat stress in the Northeast to better
understand heat abatement practices that are currently used and whether improvements can be made.

Although there is some published literature regarding farmer perceptions of climate change (Shattmann et al., 2016) and various environmental topics, there is no information regarding farmer perceptions of heat stress in dairy cattle. The lack of published literature and the importance of understanding producer perceptions on this topic lead to the questions: What are farmer perceptions of heat stress in the Northeast and why? Have farmers employed heat abatement systems on their farms; if they have, on what groups of animals, and what impacts have they observed? These questions will help us understand the producer's current knowledge of heat stress and the degree of heat abatement currently employed on farms.

4.3. Material and Methods

This research was part of a more extensive study investigating the impacts of episodic heat stress on dry dairy cows and their calves in Northern NY and VT (Chapters 2 and 3). The farms used in this study differed from those used in Chapters 2 and 3. These methods were approved by the University of Vermont's Institutional Review Board.

Eight dairy farm owners or managers in Northern NY or VT were selected to ensure a variety of dairy sizes and use of heat abatement. These farmers were recruited via an email from Miner Institute's Dairy Outreach Coordinator or a phone call from a Miner Institute employee with a follow-up email containing more information. Semi-structured interviews were conducted with farmers individually over Zoom in 2022, recorded with the farmer's permission. Semi-structured interviews were chosen for this study because
they allowed farmers to freely express their experiences and opinions (Strauss and Corbin, 1990; Valentine, 1997) and pose future research topics.

Interview questions can be found in Appendix 1. The first question was designed to learn about the farm’s size and general management practices. Questions 2 and 3 allowed us to understand how farmers believe heat stress affects their animals during the summer. Question 4 was asked to assess the use of heat abatement on farms and what form farmers feel is the most effective. Questions 5 and 6 inquired about the information producers use to make management decisions regarding heat stress and research they wish to be done in the future. Additional questions were asked throughout the interview based on the farmer's responses to the scripted questions.

Answers to questions were transcribed from Zoom recordings. Data were coded independently for themes and subthemes by two Miner Institute research associates, similar to accepted methods regarding semi-structured interviews (Glaser et al., 1967; Glaser, 1992; Babbie, 2010). Themes and subthemes of these interviews are summarized below.

4.4. Results

Three farmers interviewed lived in northern VT, and the rest lived in northern NY; one was a woman, and the rest were men. Farms chosen for this study ranged in size from 200 to 3200 milking cows and used varying degrees of heat abatement (Table 4.1). When recruiting farmers for these interviews, an original goal was to include farms that provided no heat abatement for their animals. Surprisingly, this wasn't easy, as most farmers have realized the need for heat abatement in the Northeast and have installed measures on their
farms. All farms interviewed milked strictly Holsteins and housed lactating cows in free stalls.

4.4.1. Farmer perceptions of heat stress in Northern NY and VT

All farmers interviewed felt their animals were negatively impacted by heat stress, but some more than others. When asked what impacts they experience on their farm, one producer said:

“Lots of them. Uh, definitely decreased milk production, decreased reproductive performance, increase of metritis, retained placentas, you name it. You expect it with heat stress, yeah, we see it.”

Six participants agreed that they experience a drop in milk production during the summer, while one disagreed and believed their production remains unchanged. Two farmers noticed that when there is a prolonged heat spell (3 to 4 days), it takes them several days to recover their milk production, and sometimes their milk production does not return to what it was.

Four farmers felt their reproductive performance was negatively impacted during the summer, while one believed their reproduction was unaffected. The farmer who felt their reproduction was steady between the summer and winter months recently installed a rumination and activity tracking system in their herd. This farmer is interested in observing if heat detections increase with this new system during the summer. One producer stated that they knew breeding was negatively affected during the summer but had no way to track it to compare it to the winter.

Several farmers observed changes in cow behavior during the summer. One has noticed their cows bunching together towards the end of a barn with better ventilation. Another farmer noticed that cows spend more time perching in stalls or standing in general.
One farmer’s unique issue that they attributed to heat stress was clogged manure pipes during the summer. This farmer doesn’t have fans over their high group of lactating animals and believes that cows splash water from the water tanks on themselves to help cool down on hot days. They believe this excess water disrupts the sand used in their freestalls, leading to clogged manure pipes. Similar problems were not mentioned among other farmers, but this significantly affected this farm as they stated that this led to an extra 10 hours of work per day for three months of the year.

4.4.2. Farmer use of heat abatement in Northern NY and VT

Almost all producers (7) provided fans for their lactating cows, while only one provided sprinklers (Table 4.1). One farmer plans to install fans for this upcoming summer, and another is installing sprinklers over lactating animals. Most farms (6) also had fans over their dry cows, and one also provided sprinklers. Most heifers were housed without heat abatement (5 farms), and one farm had fans in their heifer barn. Sprinklers were the most common in the holding area (4 farms) compared to other areas of the barn, and almost every farm (7) had fans in the holding area.

Some farmers indicated that some practices other than typical heat abatement measures (fans and sprinklers) have helped combat heat stress during the summer. These practices included insulating barns, angling fans to increase airflow, and decreasing overcrowding. Another approach mentioned was switching from a dietary cation-anion difference (DCAD) diet to a calcium-binding product in close-up cows to increase DMI through the transition period. Other farmers suggested that feed additives, incorrect barn orientation, and angling fans from middle stalls to outer stalls have not helped reduce heat stress.
Many farmers would like to try new forms of heat abatement on their farm. Six wish to install fans in a pen that is currently not equipped with them or install more fans in a pen that already has some. Two farmers stated that they had not installed more fans because they couldn’t afford to, and one said that there was an electrical issue in their barn, so they couldn’t handle more fans. Two farmers have problems with the sun in their barn and would like to install shade cloth to help mitigate some of the effects. Two other farmers would like to install sprinklers. One farmer has noticed that tunnel ventilation has worked well in one of their barns and would like to retrofit another existing barn similarly.

A prevailing theme was participants’ hesitancy to install sprinklers throughout their barns. Three farmers mentioned problems with water availability during the summer and felt that sprinklers would put more unnecessary strain on a limited water supply. Four other farmers are concerned that sprinklers would increase SCC and mastitis incidences. A farmer who does not have alley scrapers was worried that they would not have the labor to clean the barn more often to remove excess standing water that would come from sprinklers. Another farmer who installed automatic floor cleaners this year feels that sprinklers may now be a possibility for their farm but is still hesitant because they are worried about the negative health consequences that are associated with wet cows. One farmer would like more research to be done on the topic before installing sprinklers over their dry cows:

“You know, I know, there’s data that shows how much you gain by cooling them, but my question is, did you gain somatic cell count? Is there any other health issues that follow that? I mean, because, we thought about, well we do have some of the stuff to put it in, in our dry cow area, for heat abatement, with the misters, and with the bedded pack that we have for our calving area, we’re kind of like, ahh, is this the best thing?”
One farmer planning to install sprinklers for the upcoming summer was hesitant to install them but feels reassured as they have observed them to be successful on neighboring farms.

When farmers have installed sprinklers, many stated they had problems with them. One farmer who has manual sprinklers in the holding area has observed that they work differently depending on the person operating them. Another stated that sprinklers in the holding area didn’t seem to make a difference in cooling cows and observed that it was hard to keep sprinklers clean, and they often got plugged with debris. A third farmer felt that the pipe used for their sprinklers in the holding area was too small and ineffective at wetting down the cows. Before other farmers install sprinklers, it seems important to obtain information about proper installation and usage to avoid some of these issues. Only one farmer had seen benefits from sprinklers; they noticed their milk production had come back faster after a heat event since installing them.

4.4.3. Information used by farmers in Northern NY and VT to make management decisions regarding heat stress and needs for future research

Farmers obtained information regarding heat stress from varying sources. Three stated that a Miner Institute employee or student had helped them with their farm. Three have taken advice from a nutritionist or a consultant, and others have talked to fellow farmers or read well-known dairy magazines.

One dairy farm manager was unique and tracked their own data:

“It’s a known issue; I need to collect data to support why I need what I need.”
This manager wanted to provide the farm owner with specific information about how heat stress affects the animals on their farm to prove the need for fans. Overall, all of these farmers were interested in learning how to improve animal welfare and their bottom line.

Almost all farmers recognized a need for further research in this area, but they all had different questions. Some proposed topics included the impacts of misters in the holding area, the best way to set up fans to cool cows, how to angle fans to keep sawdust from blowing around, and ways to prevent bunching behavior. One farmer would like to travel to Saudi Arabia to see their heat abatement systems, as they stated that these farmers have cows in the hottest area in the world and are still the top milk producers. Another farmer wanted research to be done on backpack sprayers as a way to cool cows. This farm could not install sprinklers for multiple reasons and thought spraying cows with water from a backpack sprayer may be a good alternative as long as the labor was cost-effective. Another interview participant wanted to understand the impacts of dry period heat stress on the cows leaving in the first 30 or 60 DIM to determine if their cull rate was impacted. Another farmer wanted a comparison of heat stress in the Northeast versus the South:

“… I know the effects of heat stress on the cows in the South, but I don’t have the numbers right for the cows in the North. Like I know its still affects them, but I don’t know it, it’s probably not as big of an effect. So, ya, those numbers and stuff would be interesting to see.”

The research topics proposed by interview participants were specific to their farm but could be applied to a broader audience.

4.5. Discussion

Similar to studies conducted regarding the impacts of heat stress on lactating dairy cattle (Collier et al., 1981; West et al., 2003), several farmers experience a lag effect in
milk production, where the lowest milk production is seen a few days after a prolonged heat event. West et al. (2003) suggested that this lag effect may be due to reduced feed intake due to heat stress or changes in the endocrine system of the cow.

Some farmers in this study felt that their reproductive performance is negatively impacted during the summer, but few mentioned specifics about what was affected. Literature indicates that heat stress affects the length of estrus, follicular development, and conception rates (Gangwar et al., 1965; Ingraham et al., 1974; Wilson et al., 1998).

Unlike literature suggesting that bunching behavior may be related to light intensity or fly avoidance behavior (Lefcourt et al., 1989), an interview in this study indicated that bunching behavior might be related to barn ventilation. Bunching behavior can increase heat stress, as cows cannot dissipate heat as well, and it can also lead to injuries when cows try to leave the group (Mullens et al., 1987). It was interesting that only one farmer noticed increased standing in their herd during heat stress, as this is commonly observed in heat stress literature, since this is a way for cows to increase surface area to dissipate heat (Cook et al., 2007; Allen et al., 2015; and Nordlund et al., 2019).

A predominant theme through many interviews conducted in this study was the hesitancy of producers to install sprinklers in their barns because they were concerned about the health impacts. While many studies have investigated the effects of sprinklers on cooling dairy cattle (Chen et al., 2015; Chen et al., 2016; Tresoldi et al., 2018), no literature focuses on the impacts of sprinklers on SCC or mastitis. This seems to be an important area of future research, as this is holding many producers back from installing sprinklers on their farms.
Although all farmers had received some information about heat stress, some were unaware of research dealing with episodic heat stress in the Northeast (Ballard et al., 2020) that would be directly applicable to them. It is vital to ensure that when research is conducted at universities or research institutions, that is appropriately conveyed to farmers in one of the ways they commonly receive information.

4.6. Conclusions

Despite the small sample size in this study, this exploratory research allowed for unique findings regarding farmer perceptions of heat stress in the Northeast. Overall, these dairy farmers believed their animals were negatively impacted by episodic heat stress, and most have installed heat abatement systems to help mitigate these impacts. A finding unique to this study was that producers were hesitant to install sprinklers in their barns because of concerns about increased health events and water availability. More research is needed regarding the impacts of sprinklers on SCC before being implemented widely in the Northeast. This study illustrated that farmers utilize research from various institutions and that focusing on topics that will help them solve on-farm problems is essential. If research is done regarding the impacts of sprinklers on health concerns, this information should be conveyed to producers in one of the ways they mentioned receiving information above.

It would be interesting to do follow-up interviews with the farmers who added new heat abatement measures this summer to understand if further heat abatement was necessary on their farms. It would also be beneficial to conduct similar interviews with farmers who experience the chronic heat stress of the Southern United States to compare their experiences with the farmers in the Northeast. In the future, a more extensive scale
study in the Northeast would be beneficial to understand if different results are found when not limited by a small interview sample size. Overall, this exploratory study laid the framework for future farmer interviews regarding heat stress.
4.7. References


### 4.8. Tables and Figures

**Table 4.1.** Use of heat abatement on surveyed farms.

<table>
<thead>
<tr>
<th>Group of cows/area of barn</th>
<th>Heat abatement type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Fans</td>
<td>Sprinklers</td>
<td></td>
</tr>
<tr>
<td>Lactating</td>
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<td>1</td>
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</tr>
<tr>
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<td>3</td>
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<td></td>
</tr>
<tr>
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<td>0</td>
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</tr>
<tr>
<td>Holding area</td>
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</tbody>
</table>
CHAPTER 5: CONCLUSIONS AND IMPLICATIONS

The impacts of heat stress on lactating dairy cattle have been researched for many decades, and more recently, the effects of heat stress on dry dairy cattle have been explored. Published literature has quantified the impacts of chronic heat stress on dry dairy cattle in tropical and subtropical climates. Still, little is known about the effects of episodic heat stress in moderate or temperate climates. The objectives of the studies in this thesis (Chapters 2 and 3) were to investigate the impacts of episodic heat stress on dry cows and their calves in different housing systems with varying use of heat abatement. It was hypothesized that dry cows and their calves would be negatively impacted by episodic heat stress regardless of the heat abatement system they were housed in. The goal of the last study in this thesis (Chapter 4) was to understand farmer perceptions of heat stress in the Northeast, the use of heat abatement on farms, and the need for future research that would be applicable on-farm.

Chapters 2 and 3 suggested that dry dairy cattle were negatively impacted by episodic heat stress under moderate and minimal heat abatement. Cows housed in moderate heat abatement (Chapter 2) had decreased lying time on hot days, indicating they were heat stressed, even though it was not reflected in reticular temperature or rumination data. Reduced gestation length was measured in cows with high amounts of heat stress, and 21-day milk yield was reduced in cows who experienced high amounts of heat stress in the late dry period. These impacts suggest that heat abatement is necessary for dry cows in the Northeast and is specifically important during the late dry period.

Cows housed in minimal heat abatement (Chapter 3) experienced increased reticular temperatures on hot days when on pasture but not when provided with the shade...
of the barn. This suggests that dry dairy cattle cannot adequately regulate body temperature when under harsh solar radiation. Besides reticular temperature and rumination, few significant results were observed in Chapter 3. Because of farm size, fewer cows were enrolled in this study than in Chapter 2. It may be necessary to continue the study summarized in Chapter 3 for another summer to understand if the numeric differences measured were only insignificant because of a lack of power. These numeric differences could indicate a Type II error, where the null hypothesis was not rejected as it should have been. This Type II error could lead farmers to believe that heat abatement is not necessary for dry cows in the Northeast, when it is, leading to reduced profits down the road. It would be interesting to have been able to measure milk production and resting behavior on this farm, as these variables were significantly impacted on the farm in Chapter 2. Unfortunately, this farm had no system to measure individual milk weights, and there was no easy way to restrain the cows on pasture to change leg loggers weekly to measure resting behavior.

Surprisingly, rumination was greater on both farms on hot days; this contradicts chronic heat stress literature and is difficult to explain. It may be that dry cows in the Northeast can better maintain their rumination through episodic heat stress than cows experiencing chronic heat stress. It would be interesting to investigate the impacts of heat events on rumination the day after to see if there is a lag effect. Although rumination results were unexpected on the day of heat events, other parameters indicate that dry cows were affected by episodic heat stress.

A recent study conducted in Florida showed that dry cows do not experience increased rectal temperatures or respiration rates until a THI of 77 (Ouellet, 2021). Between
both years of the current study, there were only 3 days where the average daily THI was 77 or higher, which may explain the unusual reticular temperature, rumination, and calf variables results seen in Chapters 2 and 3. Although some cow parameters may be unaffected until a THI of 77, it still seems appropriate to use a lower THI threshold of 72 to describe heat stress in the Northeast, as variables such as lying time and milk production were impacted at this level.

Results may have also differed from previous work done in Florida (Dahl et al., 2016; Fabris et al., 2019; Laporta et al., 2020), as animals in those studies experienced a THI greater than 72 for their entire DP, rather than parts of their DP as in the current study. Florida researchers also defined heat stress differently than in the current study. These authors indicated that only cows housed without heat abatement experienced heat stress (Dahl et al., 2016; Fabris et al., 2019; Laporta et al., 2020), while the current study assumed that cows experienced heat stress when the THI was above 72, regardless of heat abatement. This could explain why calf growth parameters, passive transfer of immunity, and body temperatures of cows differed from the Florida work.

Overall, dry cows in both studies were negatively impacted by episodic heat stress despite the heat abatement system. Although calves were not affected by in-utero episodic heat stress in either study, it is still important to provide heat abatement for dry cows in the Northeast to improve dairy welfare and milk production. This research should be shared with farmers so they can make necessary on-farm changes. Most farmers interviewed in Chapter 4 provided fans as a form of heat abatement for their dry cows, so it is especially important to communicate these results to the few that did not. As climate change increases
ambient temperatures worldwide, it is crucial to continue to address heat abatement in the Northeast.

Semi-structured interviews summarized in Chapter 4 illustrate that farmers in the Northeast believe their animals are impacted by heat stress during the summer, and most provide some form of heat abatement. These interviews also indicated that producers are wary of installing sprinklers and that more research regarding the impacts of sprinklers and misters on SCC and mastitis is needed. It would be helpful if these interviews were also conducted with farmers in subtropical or tropical climates to compare their experiences of chronic heat stress to the experiences with episodic heat stress in the Northeast. Another interesting comparison would be between farmers who milk Jersey cows instead of just Holsteins, as Jerseys are known to be more heat tolerant and could potentially handle episodic heat stress better than Holsteins.

A follow-up study to this thesis may be researching the impacts of sprinklers on dry cows in the Northeast. This may help address some of the questions producers had in Chapter 4 and illustrate whether sprinklers are a necessary form of heat abatement for dry cows in a moderate climate or if fans are adequate. It would be interesting to measure wind speed on the farms included in these interviews that provide fans for their dry cows and feel they see positive impacts. Wind speeds measured in the current study showed that fans increased airflow on hot days, but did not meet literature recommendations; it would be interesting to see if this was similar on other farms in the region. This thesis indicates that fans should be provided as a form of heat abatement to dry cows in the Northeast as negative impacts of dry period episodic heat stress were observed, and farmers recognized this as an issue.


Lamp, O., M. Derno, W. Otten, M. Mielenz, G. Nurnberg, and Bjorn Kuhla. 2015. Metabolic Heat Stress Adaption in Transition Cows: Differences in Macronutrient
Oxidation between Late-Gestating and Early-Lactating German Holstein Dairy Cows. PLoS ONE 10: e0125264.


APPENDIX 1

Questions for semi-structured farmer interviews (Chapter 4)

1. Tell me about your operation: size, breed, milking frequency, etc.
2. To what extent and how do you think heat stress impacts your animals? What have you observed? What impacts have you noticed?
3. How do you think different groups (lactating, dry, bred heifers, calves, etc.) are impacted by heat stress? Why do you say this?
4. Do you provide heat abatement to your animals? To what extent? What have you tried? Is there anything you tried but did not continue (why did you stop it)? What impacts have you noticed? Is there any measure you would like to try but haven’t? Why haven’t you?
5. What measures or data do you use when deciding on heat stress management practices?
6. What information or research would help you make better decisions about heat stress management?