Is there a relationship between residual feed intake and weather resilience?

G. M. Silva and M. Londono-Mendez

Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada.

Corresponding author: gleise.silva@ualberta.ca

Abstract

Extreme temperature fluctuations might have a profound impact on livestock welfare and productivity. Heat stress (**HS**) occurs when external temperatures rise beyond an animal's ability to dissipate body heat effectively. Under HS conditions, cattle typically reduce feed intake to lower metabolic heat production, seek shade, and increase rest periods. Conversely, cold stress (**CS**) arises when ambient temperatures drop below the animal's thermoneutral zone, causing a decline in body temperature. In response, cattle increase feed intake, seek shelter, and activate mechanisms to generate heat and maintain homeostasis. With projections forecasting more extreme temperature fluctuations, the challenges to animal welfare and productivity are expected to escalate, underscoring the critical need to prioritize the selection of weather-resilient livestock.

Residual feed intake (**RFI**) is a widely recognized metric for evaluating feed efficiency across various livestock species. Animals with a negative RFI are considered more feed-efficient, as they consume less feed to achieve the same level of production compared to their counterparts with a positive RFI value, that require more feed to reach equivalent performance. Residual feed intake is calculated by subtracting the expected feed intake from the actual feed intake, using data such as daily feed intake, average daily weight gain, mean body weight, and metabolic weight. Based on the results, animals can be classified as either high-RFI or low-RFI. Five major physiological processes are likely to contribute to variation in RFI, which include feed intake and digestion, metabolism (anabolism and catabolism), physical activity, and thermoregulation. It is estimated that heat production from metabolic processes and physical activity explains 73% of the variation in RFI in cattle, which could directly impact how animals respond to weather conditions. In this proceeding, we will explore how RFI influences cattle responses to both hot and cold environments and how genetic selection based on RFI could be a strategy to improve weather resilience in livestock.

Introduction

In recent years, there has been a significant intensification of extreme temperatures, with projections indicating a global temperature increase of 2.4 to 6.4°C by the end of this century (Nardone et al., 2010). In Canada, such changes have already resulted in extreme weather events. For instance, during the summer of 2021, temperatures soared to 49.6°C in British Columbia, exacerbating drought conditions in the region (WMO, 2021). Simultaneously, due to global warming, the Arctic region has experienced significant melting processes (Zhang et al., 2020), resulting in increased occurrences of cold spells and heavy snowfalls in regions geographically close to the Arctic, such as Canada. This melting contributes to the loss of grounded ice sheet mass in Greenland, which is projected to raise sea levels significantly over the next several decades to centuries (Smith et al., 2020). Additionally, this reduction in ice mass may accelerate airflow velocities, resulting in substantial shifts in global weather patterns (Morard et al., 2010). During the winter months, higher wind speeds can amplify windchill effects, leading to further decreases in surface temperatures in exposed areas (Shitzer and Tikuisis, 2012). These shifting dynamics underscore the critical need for strategies to mitigate the impacts of extreme weather on ecosystems, including livestock welfare and productivity.

The Government of Canada operates numerous meteorological stations to monitor weather conditions across the country, providing public access to this information at no cost (Alberta Climate Information Service [https://acis.alberta.ca/acis/]). From this source, data from 2007 to 2023 at Kinsella in the province of Alberta in Western Canada was analyzed. During the summer, the highest recorded temperatures were 31.3°C, 32.3°C, and 32.7°C, while the lowest winter temperatures were -37.7°C, -36.9°C, and -41.6°C, corresponding to the periods 2007–2012, 2013–2018, and 2019–2023, respectively. Notably, summer temperatures have increased by 1.4°C over the past eighteen years, while winter temperatures have dropped by 4.6°C in the last twelve years, suggesting a trend toward both extremes. This information could serve as an important alert for cattle producers in backgrounding, feedlots, and cow-calf operations across Canada.

Extreme variations in weather have the potential to impact cattle physiology and overall well-being, ultimately affecting animal productivity. Heat stress (**HS**) is characterized by elevated external temperatures that impose a greater heat load on cattle while simultaneously reducing their capability to dissipate body heat (Lees et al., 2019). The physiological changes associated with HS include a decrease in feed intake to mitigate metabolic heat generated during digestion (Collier et al., 2012), increased reliance on shade, and an increase in the duration of lying time in areas with reduced solar radiation exposure (Silva et al., 2021). Additionally, heat stress (HS) can weaken the immune response, as demonstrated by reduced lymphocyte counts after three hours of continuous in vitro exposure to 45°C, along with impaired growth performance in cattle (Nonaka et al., 2007). On the contrary, cold stress (**CS**) occurs when external environmental conditions are extremely cold, and an animal's body is unable to generate sufficient heat to maintain normal body temperature (Roland et al., 2016), leading to hypothermia. This response involves a combination of metabolic and physical adaptations, including increased food intake to meet elevated energy demands (Young, 1983) and a heightened need for shelter to mitigate the effects of wind chill and precipitation (Fogsgaard et al., 2018). Furthermore, cold exposure activates the sympathetic nervous system (Kozyreva et al., 2015), triggering the release of catecholamines, which may suppress immune function (Madden et al., 2003).

Various models have been developed to assess environmental conditions impacting cattle under both hot and cold temperatures. These include the Temperature-Humidity Index (Thom, 1959; NRC, 1971), Black Globe-Humidity Index (Buffington et al., 1981), Heat Load Index (Gaughan et al., 2003, 2008), Adjusted Temperature-Humidity Index (Mader et al., 2006), Comprehensive Climate Index (Mader et al., 2010), and the Index of Thermal Stress for Cows (Da Silva et al., 2014). A more detailed version with equations was previously reported by Herbut et al. in 2018.

Residual feed intake

Beef cattle with a negative residual feed intake (**RFI**) value consume less feed than expected to meet their physiological needs, indicating greater efficiency compared to animals that require more feed to achieve the same production levels (Koch et al., 1963). These animals achieve specific production goals while consuming less feed, demonstrating improved biological or cellular efficiency (Richardson et al., 2004; Herd and Arthur, 2009). As a result, selecting for more efficient beef heifers based on RFI has become increasingly important in breeding programs over the years. Five major physiological processes contributing to variation in RFI variations are feed intake, digestion, metabolism (anabolism and catabolism), physical activity, and thermoregulation. Cattle classified as more efficient achieve the energy requirements for physiological processes more effectively, converting less feed into more body weight and obtaining more nutrients from the same quantity of feed (Castro Bulle et al., 2007). Moreover, more feed-efficient animals demonstrate a comparatively reduced environmental impact, as they produce fewer greenhouse gas emissions from enteric fermentation and manure (Haugen-Kozyra, 2021).

The RFI metric is calculated by subtracting the expected feed intake required for livestock growth and maintenance from the actual feed intake (Arthur et al., 2001; Basarab et al., 2003), which provides insights into how efficiently an animal utilizes the feed it consumes. Studies by Hoque et al. (2009) and Seabury et al. (2017) have shown that RFI's genetic potential has a heritability ranging from moderate (0.21) to high (0.60). This highlights that genetic factors play a significant role in determining an animal's feed efficiency, making RFI a valuable tool for cattle producers in breeding genetically feed-efficient offspring (Herd et al., 1997).

Estimating RFI in beef cattle involves a series of detailed steps. First, individual measurements of daily feed intake and average daily gain (ADG) are collected. Next, a linear regression model is used to predict the expected dry matter intake (DMI) for each animal. This prediction is based on factors such as body weight, average daily gain (ADG), and, in some cases, additional parameters like final ultrasound rib fat thickness (FUFAT). The RFI corrected for FUFAT (RFIf) is then calculated by determining the difference between the animal's observed daily DMI and the expected DMI predicted by the regression model using its intercept and coefficients. This correction accounts for variations in body composition, particularly differences in fat and protein, which influence energy demands. Animals are subsequently categorized as either high or low efficiency based on their RFI values. High RFI indicates less efficient animals that consume more feed than expected for maintenance and growth, whereas low RFI values signify more efficient animals that meet their physiological requirements with reduced feed intake. By incorporating RFIf into evaluations, the accuracy of feed efficiency assessments is improved, offering valuable insights into an animal's metabolic performance while accounting for body composition differences. This refined approach aids cattle producers in identifying and selecting more efficient animals for breeding and management programs.

Residual feed intake as an alternative for extreme environment

Extreme weather conditions, such as heat or cold, influence the productivity of beef cattle raised on pasture (Toghiani et al., 2020) and possibly has a greater impact in less efficient animals. Changes in feed intake, feed efficiency, and performance are associated with seasonal changes in environmental and climatic conditions with those variations being caused by differences in individual adaptation and efficiency of energy utilization (Mujibi et al., 2010). Environmental stress (cold or heat stress) occurs when air temperature deviates from the animal's thermoneutral zone, affecting production or causing discomfort (Webster, 1983). Still, cold susceptibility depends upon specific housing and pen conditions, breed type, nutrition, time after feeding, thermal adaptation, and behavior (Young, 1981). The increased energy requirements for beef cattle associated with thermoregulation during cold and heat extremes suggests that environmental conditions are worthy of consideration when evaluating RFI (Thompson et al., 2018). There is still a lack of research focused on the evaluation of the interaction between cattle feed efficiency in forage-based systems and environment, specifically during the winter season. Such information is necessary to understand the impacts of environment in animal health and production to support more sustainable beef production.

In the ongoing effort to improve livestock efficiency and reduce the environmental footprint to enhance sustainability, studies on RFI have shown promising results not only in improving sustainability but also potential for enhanced weather resilience. We have previously demonstrated that Bos-indicus influenced replacement beef heifers previously classified as thermotolerant based on multiple vaginal temperature measurements collected throughout the summer in Florida had decreased RFI when measured in the fall, indicating the potential of more heat tolerant heifers to be more feed efficient (Silva et al., 2022). Research on Angus steers selected for divergent RFI revealed that heat production from metabolic processes and physical activity accounted for 73% of the variation in RFI (Herd and Arthur, 2009). Animals with higher body temperatures, all else being equal (e.g., feed intake), allocate a greater proportion of feed energy to metabolic heat production rather than productivity. This shift in energy utilization reduces production efficiency, as less energy is directed toward growth or other productive functions (Hill and Wall, 2017). Sprinkle et al. (2019) observed that on cooler days (maximum temperature of 23°C), inefficient cows grazed 1.5 hours longer than efficient cows. However, on hotter days (maximum temperature of 30°C), inefficient cows reduced grazing by 2 hours compared with their efficient counterparts. Authors argue that less efficient cows would be expected to have greater appetite than efficient ones to compensate for increased energy requirements and should increase daily grazing time when conditions are favorable. Yet, greater appetites are accompanied by larger gastrointestinal tracts (Sprinkle et al., 2000), increasing metabolic heat load and reducing heat tolerance. Furthermore, efficient cows exhibited compensatory behavior when compared to less efficient cows following extended periods with elevated summer temperatures. This compensatory behavior enabled these efficient cows to access more difficult terrain and distribute more evenly on rangeland during extended time periods with elevated summertime temperatures. These studies demonstrated a greater energy demand associated with activities in less efficient animals and probably lower thermotolerance capacity in less efficient animals. Richardson et al. (2001) identified a positive correlation between RFI and daily activity, showing that less efficient cattle required approximately 5% more feed energy intake due to their higher activity levels compared with more efficient cattle. Additionally, more efficient animals have lower energy requirements for maintenance (Herd et al., 2003) and produce less metabolic heat as a result of reduced energy waste during digestion (Sainz et al., 2016).

On the contrary, in non-ruminants, Schmitt et al. (2021) reported that new-born piglets classified as less feed efficient had more difficulties to maintain body temperature by displaying lower ear tip temperatures than more feed efficient cohorts. It was concluded that more efficient piglets can better adjust body temperature when required during stressful conditions. Our research demonstrated that less efficient beef heifers exhibited higher plasma leptin concentrations and lower rumen temperatures during winter compared to their more feed-efficient counterparts (Londono-Mendez et al., 2024a). These findings suggest potential thermogenic activity and an increased susceptibility to cold stress in less feed-efficient heifers. Additionally, in first-calf heifers, our group observed that RFI influenced both physiological responses (such as changes in body temperature) and behavioral activity. Less efficient animals displayed a greater number of steps, more standing time, and less lying time during the hottest hours of the day, highlighting a greater sensitivity to environmental stress. These patterns collectively favored the more feed-efficient first-calf beef heifers (Londono-Mendez et al., 2024b).

Selection of cattle based on RFI may promote thermotolerance capacities, as more efficient animals tend to have smaller visceral organs, including the liver (Zhang et al., 2017). This suggests that more feed-efficient cattle generally exhibit relatively lower liver weights compared to their less efficient counterparts (Basarab et al., 2003). Moreover, it is well established that the liver can be approximately 1°C warmer than other core tissues (Sessler, 2005), potentially contributing to an increased heat load under HS conditions in less efficient animals. A smaller liver size in more efficient animals may therefore enhance thermoregulation under extreme heat, providing them with a physiological advantage in maintaining productivity and well-being in hot environments. Furthermore, Llonch et al. (2016) assessed cortisol levels following stress-inducing events, such as transportation, and found notable differences in cortisol responses among cattle with varying RFI levels. These findings suggest that cattle with more efficient metabolism may have improved stress tolerance, which could positively impact their overall feed efficiency. However, the association between feed efficiency and thermotolerance has not been thoroughly explored (Silva et al., 2022), especially during both cold and hot conditions.

Conclusions

Residual feed intake represents a promising avenue for improving both feed efficiency and thermotolerance in beef cattle, offering potential solutions to mitigate the challenges posed by extreme environmental conditions. The intricate relationship between feed efficiency and environmental stress highlights the importance of selecting animals with superior metabolic and thermoregulatory capacities. More feed-efficient cattle demonstrate advantages such as reduced energy requirements for maintenance, better control of stress responses, and lower metabolic heat production, contributing to enhanced weather tolerance. These attributes position RFI as a valuable tool for not only enhancing cattle productivity and reducing the environmental footprint of beef production but also improving animal welfare in the face of challenging climatic conditions. However, further research is needed to fully understand the interaction between RFI, environmental stressors, and long-term cattle performance, particularly in forage-based systems during winter. Such insights will play a critical role in developing sustainable breeding programs that align with the industry's goal of producing resilient and efficient animals capable of thriving in diverse and extreme environments.

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