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Heat stress is detrimental to gut health in ruminants, swine

Research sheds light on nutritional strategies to decrease "leaky gut" in livestock.

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MOST livestock producers in the U.S. are all too familiar with the visible economic ramifications that accompany heat stress.

It is estimated that the annual cost of heat stress to the dairy industry is approximately $900 million, while cost estimates for the swine and beef industries are each greater than $300 million (St. Pierre et al., 2003; Pollman, 2010). Based on these estimates, it should come as no surprise that investments in on-farm cooling systems are highly prevalent.

Event cascade

Upon the onset of heat stress, animals experience a marked reduction in dry matter intake, which has been hypothesized as a mechanism to help reduce metabolic heat (Baumgard and Rhoads, 2012). This reduction in feed intake may only partially explain why animals under heat stress have poorer performance (Wheelock et al., 2010).

Other reasons include changes in blood flow, as well as oxygen and energy availability. For example, when animals are under heat stress, blood flow is diverted from visceral tissue to the skin, which allows for heat dissipation. Less blood flow to visceral tissue causes a reduction in the amount of oxygen (hypoxia) and energy available to the enterocytes lining the intestinal tract.

In addition, a higher respiration rate from the animals trying to cool themselves results in the production of oxygen and nitrogenous free radicals, which can weaken or destroy the intestine's tight junctions (protein strands called claudins and occludins).

Severe heat stress may lead to morphological changes in the intestine, such as decreased gut villi height, greater gut villi width and potentially a breakdown of the tight junctions of the enterocytes. The intestine may become vulnerable to paracellular transfer of lipopolysaccharides (LPS), or endotoxins, across the intestinal wall (Hall et al., 2001). This is what is commonly referred to as "leaky gut" (Figure 1).

Evidence for leaky gut may be explained by the animal's characteristic increase in insulin secretion during heat stress, despite reduced feed consumption (Rhoads et al., 2009). Researchers have hypothesized that this rise in insulin is an adaptation to conserve glucose for use in the activated immune system to overcome the paracellular transfer of endotoxins.

Zinc requirement

Several research studies have established that zinc plays a key role in maintaining intestinal integrity; however, this mechanism is not fully understood. Researchers do know that zinc is required to regenerate and localize stem cells in the gut (Noah et al., 2011). Researchers have also shown that zinc upregulates tight junction proteins (Sturniolo et al., 2002) and heat shock proteins (Odashima et al., 2012).

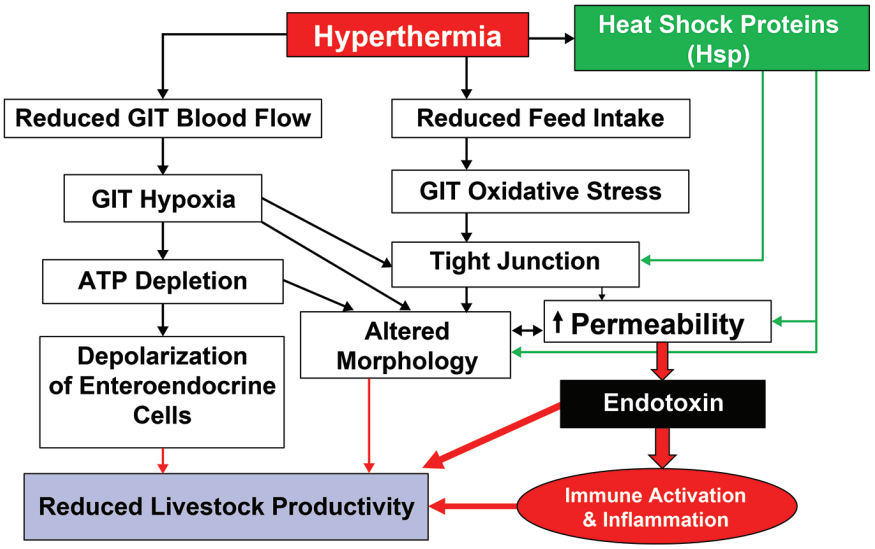
Furthermore, zinc is an antioxidant (Waeytenz et al., 2009), and oxidative stress may play a key role in initiating leaky gut. Additionally, research has shown that the form of zinc fed can influence its effectiveness at reducing leaky gut (Abuajamieh, 2015; Pearce et al., 2015).

Swine research

Recent research at Iowa State University provided evidence that heat stress contributes to leaky gut and that feeding a specific zinc form (Availa-Zn) — zinc amino acid complex (ZnAA) — helps alleviate its occurrence in pigs (Pearce et al., 2015).

Thirty-two crossbred pigs with an initial weight of 63 kg were randomly assigned to four treatments. Treatment 1 was *ad libitum* intake in thermal-neutral conditions (TN-CON). Treatment 2 was *ad libitum* intake in acute heat stress conditions (HS-CON). Treatment 3 was pair-fed to match the intake of HS-CON under thermal-neutral conditions (PFTN-CON). Those three diets contained 120 parts per million of supplemental zinc from zinc sulfate. Treatment 4 replaced 60 ppm of zinc from zinc sulfate with ZnAA, and animals were placed in heat stress conditions (HS-ZnAA).

1. Heat stress cascade of events that occur during onset of leaky gut



Baumgard et al. 2012. Impact of climate change on livestock production. Pages 413-468. Chapter 15. Environmental Stress and Amelioration in Livestock Production. Eds. V. Sejian, et al., Springer-Verlag Berlin Heidelberg.

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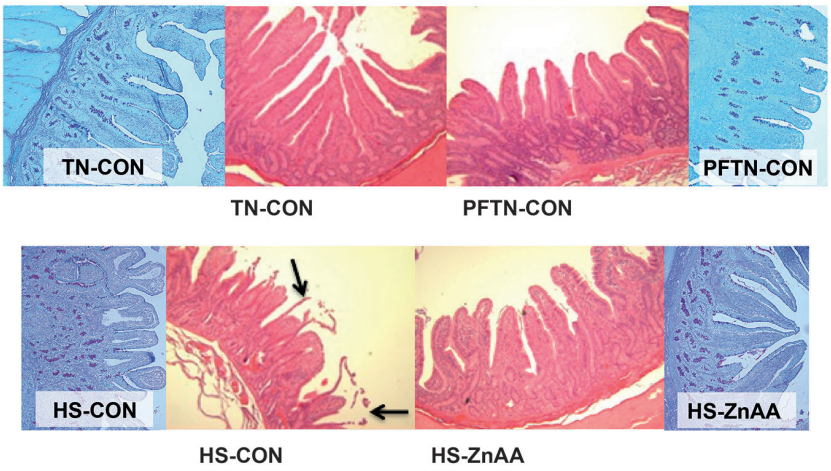
As expected, subjecting pigs to heat stress conditions increased rectal temperatures and reduced feed intake. Researchers measured ileal permeability from harvested pigs by recording FITC-dextran apparent permeability (APP) and transepithelial resistance (TER). Pigs in the HS-CON and PFTN-CON treatments showed greater gut permeability using both APP and TER coefficients compared to TN-CON. This finding indicates that a heat stress event (HS-CON), or even a period when animals are under restricted feed intake (PFTN-CON), increases the risk for intestinal permeability.

When the pigs were subjected to heat stress, feeding ZnAA maintained ileal permeability similarly to what was observed in TN-CON. Feeding ZnAA also allowed animals to mount a more effective immune response because animals in the HS-ZnAA treatment expressed greater concentrations of plasma lipopolysaccharide protein compared to HS-CON. As an acute-phase protein, lipopolysaccharide protein binds to bacterial LPS to elicit an immune response by presenting the LPS to immune cell surface receptors that destroy endotoxins.

Furthermore, HS-ZnAA pigs had numerically lower serum endotoxin levels than HS-CON pigs: 2.31 versus 5.10 arbitrary units for HS-ZnAA and HS-CON, respectively.

2. Changes in intestinal morphology of steers and swine fed various forms of zinc under pair-fed or heat stress conditions



Note: Thermal neutral (TN) = 70°F and 30% relative humidity. Heat stress (HS) = 81-95°F and 19% relative humidity.

Blue = steer images. TN control (TN-CON) = 75 ppm of zinc from zinc sulfate fed *ad libitum* in TN conditions. Pair-fed TN control (PFTN-CON) = 75 ppm of zinc from zinc sulfate pair-fed in TN conditions. HS control (HS-CON) = 75 ppm of zinc from zinc sulfate fed *ad libitum* in HS conditions. HS ZnAA = 35 ppm of zinc from zinc sulfate + 40 ppm of zinc from Availa-Zn fed *ad libitum* in HS conditions.

Red = swine images. TN-CON = 120 ppm of zinc from zinc sulfate fed *ad libitum*. PFTN-CON = 120 ppm of zinc from zinc sulfate pair-fed in TN conditions. HS-CON = 120 ppm of zinc from zinc sulfate fed in HS conditions. HS ZnAA = 60 ppm of zinc from zinc sulfate + 60 ppm of zinc from Availa-Zn in HS conditions.

Ruminant research

A similar study was recently conducted in Holstein steers at Iowa State University (Abuajamieh, 2015). Forty steers with a starting weight of 174 kg were randomly assigned to five treatments.

Treatment 1 was *ad libitum* intake in thermal-neutral conditions. Treatment 2 was *ad libitum* intake in cyclical heat stress conditions (HS-CON) for six days or pair-fed in treatment 3 to match the intake of HS-CON under thermal-neutral conditions (PFTN-CON). Those three diets contained 75 ppm of supplemental zinc from zinc sulfate. Treatments 4 and 5 replaced 40 ppm of zinc from zinc sulfate with ZnAA, with diet 4 being *ad libitum* intake in cyclical heat stress (HS-ZnAA) for six days and diet 5 being pair-fed to match HS-CON under thermal-neutral conditions (PFTN-ZnAA).

As anticipated, dry matter intake for heat-stressed steers was lower compared to the thermal-neutral controls. However, control animals had a greater drop in feed intake compared to those fed ZnAA in heat stress and pair-fed conditions (14.9 versus 22.8% for ZnAA and control, respectively).

Animals under the heat stress environment had greater rectal temperatures than those in thermal-neutral conditions; however, HS-ZnAA steers had lower rectal temperatures than HS-CON steers after three days of heat stress. This may indicate less inflammation occurring in the HS-ZnAA treatment after sustaining a period of heat stress. Steers fed the ZnAA diets under heat stress conditions had greater villi height and decreased villi width compared to HS-CON.

In fact, this response was observed in ZnAA diets regardless of environmental conditions. This improvement in gut morphology may be explained by the nutritional effect ZnAA had on reducing intestinal permeability.

One interesting observation about these studies is the consistent response in physical alterations in gut morphology between both studies (Figure 2). In both species, animals subjected to the TN-CON treatment had long and narrow villi. However, when animals were subjected to the PFTN-CON treatment, the shortening and widening of the villi were quite obvious.

Gut morphology was further altered when animals were subjected to the HS-CON treatment. The arrows in the swine HS-CON photo indicate areas of enterocyte destruction. When ZnAA was incorporated in the diet during heat stress, the reduction in cell damage can be observed in HS-CON, plus villi height and width have recovered to be more similar to TN-CON.

Conclusions

Heat stress is a widespread issue that most livestock producers have to manage. Therefore, it is critical to have a plan in place prior to the onset of hot weather in order to prevent the long-term effects heat stress can have on an animal. Research has proved that incorporating ZnAA as part of a nutritional strategy to elevate zinc nutrition helps maintain animal health. Healthy animals are better able to reduce the impact of leaky gut during heat stress conditions.

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