The Metabolism and Productive Responses to Heat Stress: Potential Nutritional Strategies

Lance Baumgard and Rob Rhoads
baumgard@iastate.edu
Iowa State University
Virginia Tech University

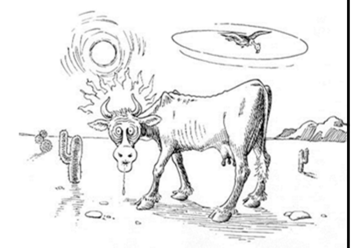
Department of Animal Science

Heat Stress is not Fever

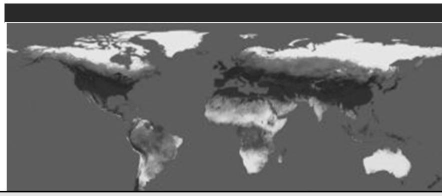
When environmental temperature nears the animal's body temperature, the animal's cooling mechanisms are impaired.

Fever vs. Hyperthermia

Very different biology



Heat Stress is a Global Problem



January 2003, NASA

40% of W. Canadian summer days THI > 72
Ominski et al., 2002

July 2003, NASA

Heat Stress: Economics and Food Security

- Cost: (lost productivity, mortality, product quality, health care etc.)
  - American Agriculture: > $4 billion/year
  - Global Agriculture: > $100 billion/year
- Heat abatement is the primary strategy to mitigate heat stress
  - But most developing countries and small stake-holders lack the resources to afford cooling technology
- Heat stress is the largest impediment to efficient animal agriculture (even in developed countries)
- Threatens global food security
- Regionalizes animal agriculture

St. Pierre et al., 2003; Baumgard and Rhoads, 2013

Heat Stress will Become More an Issue in the Future if:

- Climate change continues as predicted
- Genetic selection continues to emphasis lean tissue accretion, milk synthesis, etc..
  - Heat producing processes
- Developing countries become more affluent
- Human population continues to migrate towards the equator
  - Animal agriculture will migrate with the consumer

Baumgard & Rhoads, 2013

Temperature Humidity Index (THI)

- Easy way to measure and evaluate heat stress
- Based on cows only under shade..solar radiation is incredibly potent
- 72 thought to be when cows become susceptible
- Based on 60 year old data when cows were producing 10-15 kg/d

SYMPOSIUM: NUTRITION AND HEAT STRESS

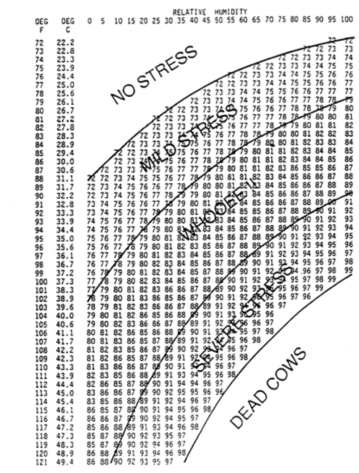


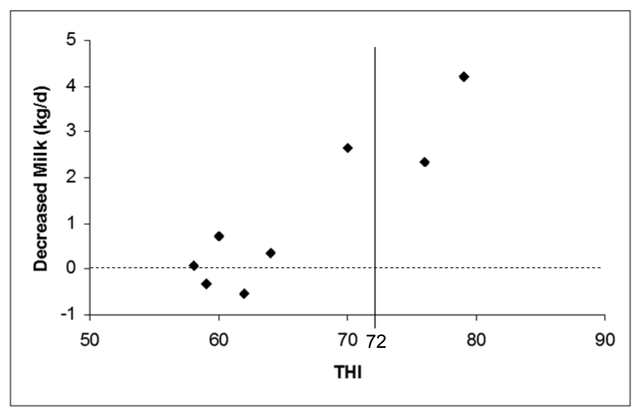
Figure 1. Temperature-humidity index table for dairy producer to estimate heat stress for dairy cows. Deg = Degrees. Relative humidity expressed as percentage. (From Frank Wiersma, 1990, Department of Agricultural Engineering, The University of Arizona, Tucson.)

Journal of Dairy Science Vol. 77, No. 7, 1994

Time to Re-Evaluate THI?

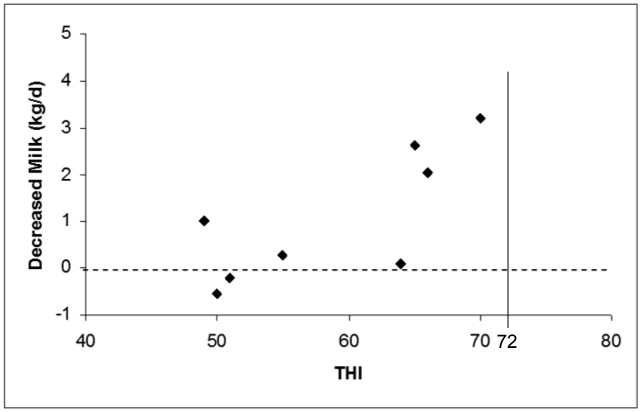
- When do modern dairy cows begin to experience heat stress?
- When should dairymen initiate cooling systems?
- Is it peak daily heat, average daily THI or minimum daily THI that is most indicative of heat stress?

Temperature Humidity Index Daily Average



Zimbelman et al., 2009

Temperature Humidity Index Daily Minimum



Zimbelman et al., 2009

THI Summary

- Modern high producing cows begin to experience heat stress at a THI of 65-68
  - Much lower than the traditional 72
- As milk production continues to increase, the THI at which cows become “stressed” will continue to decrease
- Pasture based cows will become heat-stressed sooner than those under shades…….solar radiation

Heat Stressed Cow

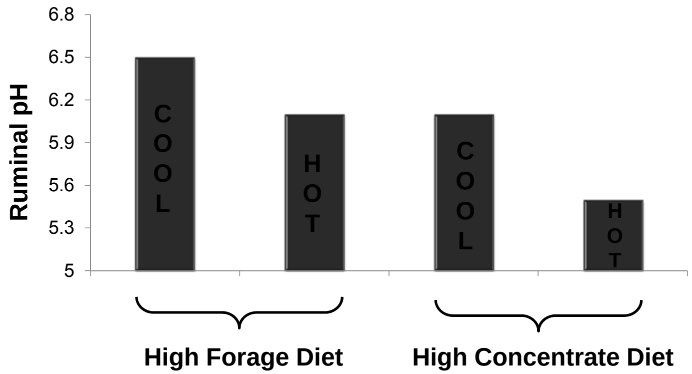
Results of Heat Stress

- Decrease in production (milk and growth)
- Reduced body condition
- Acute health problems
- **Rumen acidosis**
- Significant drop in pregnancy rate
  - See Albert DeVries webinar
- High incidence of abortions
- High death loss

Added all up … costly!

Effect of Heat Stress on Ruminal pH of Holstein Cows

(Mishra et al., JAS 30:1023)



Heat Stress Induced Rumen Acidosis

- Originates via:
  1) Altered respiration
     - Loss of systemic buffering capacity
  2) Changes in feed and feeding behavior
     - Reduced feed intake
     - Increased concentrates
     - “sorting”
     - “bout/slug” feeding
     - Drooling
     - Less saliva production

Increased Respiration Rate

- Body requires 20:1 ratio of HCO_3:CO_2 in blood
- Increased expired CO_2
- To compensate, the kidney dumps HCO_3
- Therefore less HCO_3 to buffer the rumen

Summary

- ↑ Respiration = ↓ blood HCO_3 = ↓ saliva HCO_3
- ↓ Feeding = ↓ rumination = ↓ saliva production
- ↑ Drooling = wasted saliva
- Altered feeding habits and “hotter” rations

- Accumulated effects = rumen acidosis

Heat Stress and Rumen Acidosis, Avoid It!

Metabolism Review

- Ad Libitum Intake
  - ↑ Insulin
  - ↓ NEFA
  - ↓ catabolic hormones
- Restricted Intake
  - ↓ Insulin
  - ↑ NEFA
  - ↑ catabolic hormones

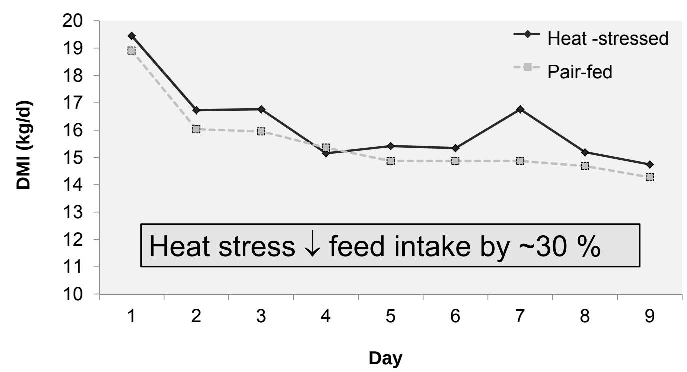
Heat Stress Questions??

- Does the decrease in feed intake explain the reduced milk yield during heat stress?

  Indirect vs. direct effects of heat

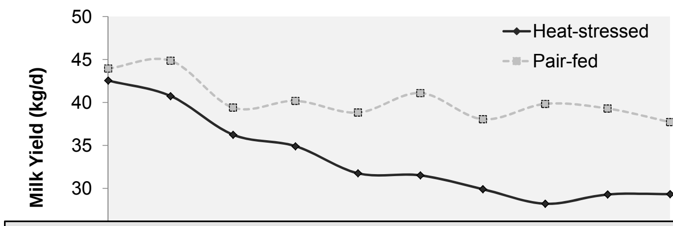
- If we have a better understanding of the biological reasons WHY heat stress reduces production, we'll have a better idea of how to alleviate it.

Lactation: Effects of Heat Stress on Feed Intake



Rhoads et al., 2009

Effects of Environment on Milk Yield

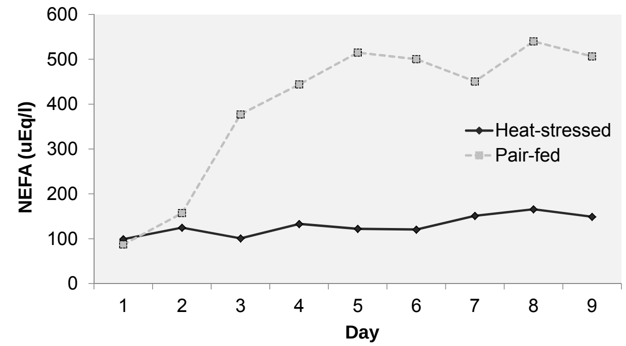


Heat stress ↓ yield ~45%
Pair-feeding ↓ yield by ~19%

Thus, ↓ feed intake only accounts for ~50% of the reductions in milk yield

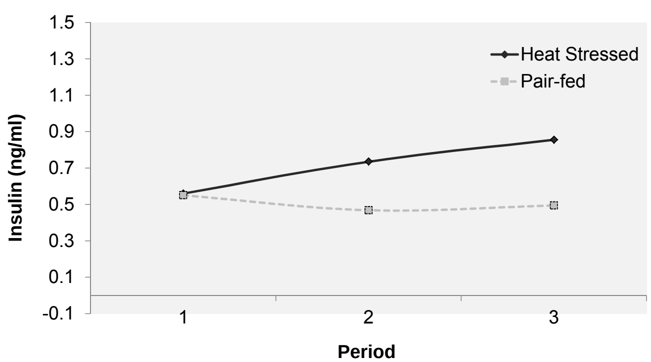
Rhoads et al., 2009
Wheelock et al., 2010

Effects of Heat Stress on Adipose Tissue Mobilization: Cattle



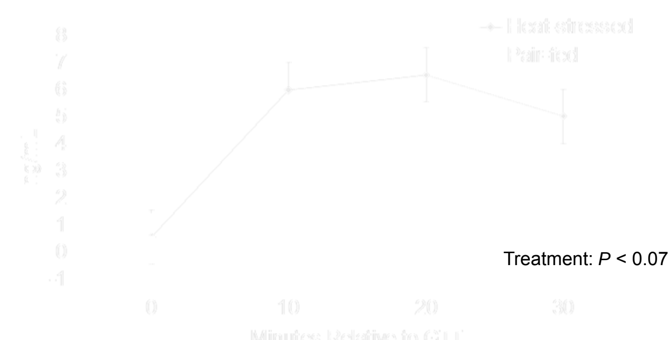
Rhoads et al., 2009

Circulating Insulin in Cattle



Wheelock et al., 2010

Insulin Response to the GTT

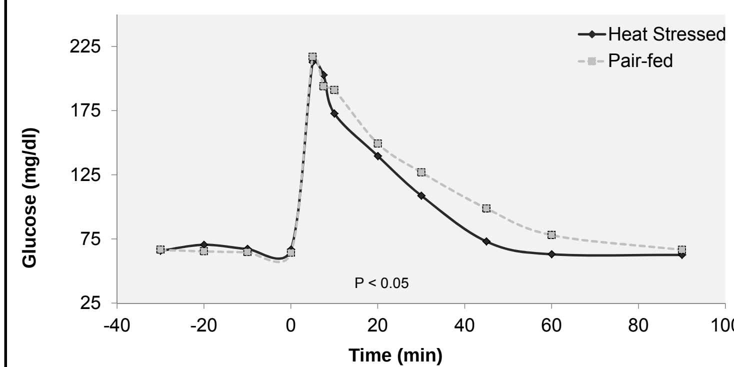


O'Brien et al., 2010

Potential Fuels for Ruminants

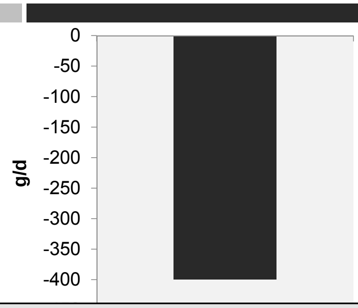
- VFA (acetate)
  - Contribution is presumably decreased b/c DMI is reduced
- NEFA
  - Do not increase during heat stress
- Amino Acids
  - Efficiency of capturing ATP is low
- <u>Glucose</u>
  - <u>By process of elimination, glucose contribution to whole animal energetics may be increased?</u>

Glucose Tolerance Test



Wheelock et al., 2008

Lactose: Heat Stress vs. Pair-Fed Thermal Neutrals

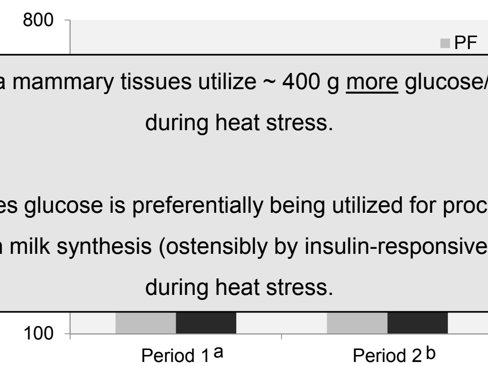


Heat Stress Cows Secrete ~400 g <u>less</u> lactose/day than Pair-Fed Thermal Neutral Controls

Is the liver producing ~ 400 g less glucose/day????
or is extra-mammary tissues utilizing ~400 g more/day

Rhoads et al., 2009
Wheelock et al., 2010

Whole Body Glucose Production



Extra mammary tissues utilize ~ 400 g <u>more</u> glucose/day during heat stress.

Indicates glucose is preferentially being utilized for processes other than milk synthesis (ostensibly by insulin-responsive tissues) during heat stress.

Period: $P < 0.05$

Wheelock et al., 2009 (ADSA abstract)

Energetic Summary

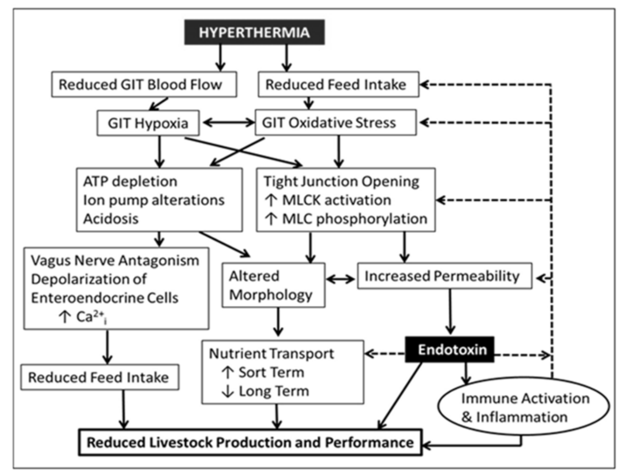
- Decreased feed intake only accounts for ~50% of the reductions in milk yield
- Tissue differences in sensitivity to catabolic and anabolic signals
- Heat-stressed cows have increased insulin action
  - Decreased NEFA
  - Increased glucose disposal
- Heat-stressed cows require extra energy
  - Especially glucose

Why Increased Insulin??

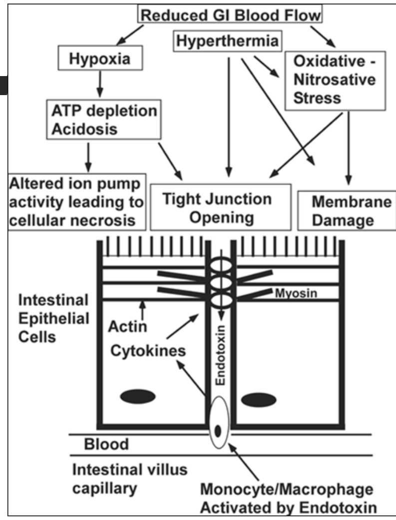
- Direct or Indirect effects of heat?
- Indirect: associated/caused by heat compromised gastrointestinal track barrier function?

Heat Stress and Gut Health

- Massive diversion of blood flow to skin and extremities
- Coordinated vasoconstriction in intestinal tissues
  - Reduced nutrient and oxygen delivery to enterocytes
  - Hypoxia increases reactive oxygen species (ROS)
- Reduced nutrient uptake increases rumen and intestinal osmolarity in the intestinal lumen
  - Multiple reasons for increased osmotic stress

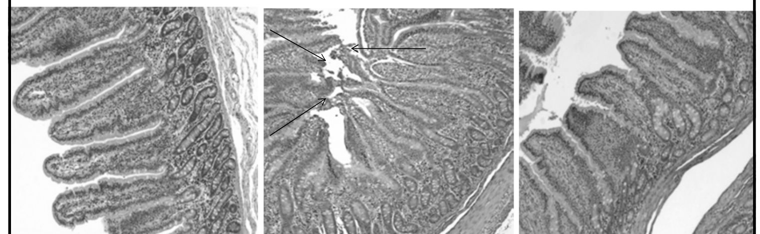


Baumgard et al., 2011



Lambert, 2009

Intestinal Morphology



Thermal Neutral | Heat Stress | Pair-fed

Pearce et al., 2011

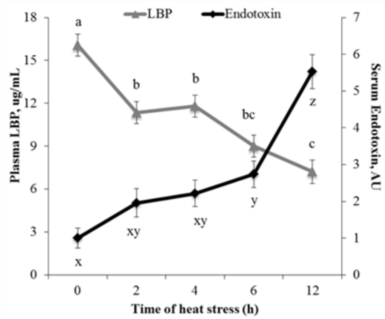
Heat Stress and Gut Integrity

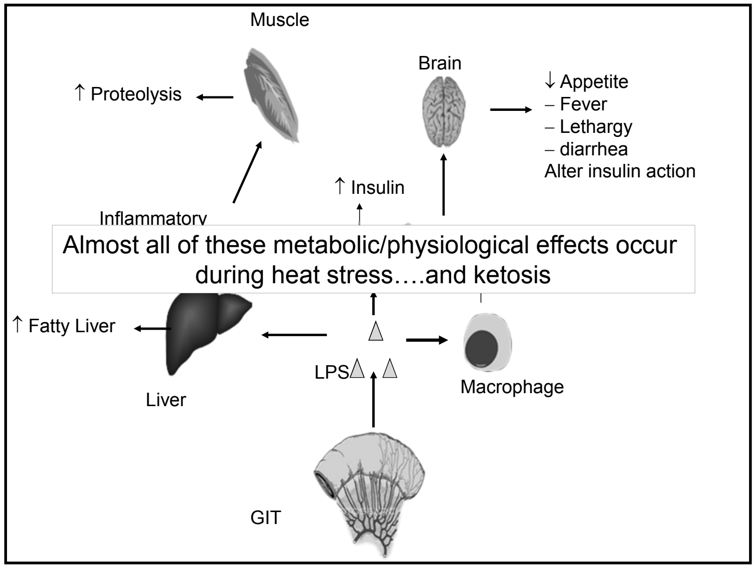
- Endotoxin (aka. Lipopolysaccharide: LPS)
- Component of bacteria cell wall
- When bacteria die, LPS is released into intestine
- Normally LPS is prevented from entering through GIT tight junctions
- During HS some LPS enters blood stream

Heat Stress and Gut Health

- LPS can cause liver damage
  - May impair gluconeogenesis capability
  - May impair ability to export VLDL (fatty liver)
  - May impair ability to secrete anabolic hormones
- LPS stimulates inflammatory cytokine production….catabolic condition
  - TNFα, IL-1 etc..
    - Reduced appetite
    - Stimulates fever
    - Causes muscle breakdown
    - Induces lethargy
    - ....reduces productivity

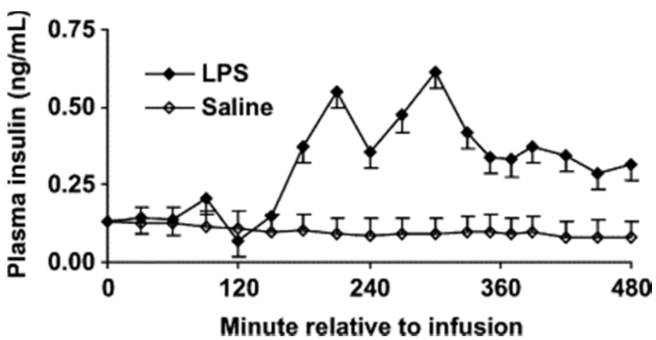
The effects are rabid!
Plasma LPS & LBP





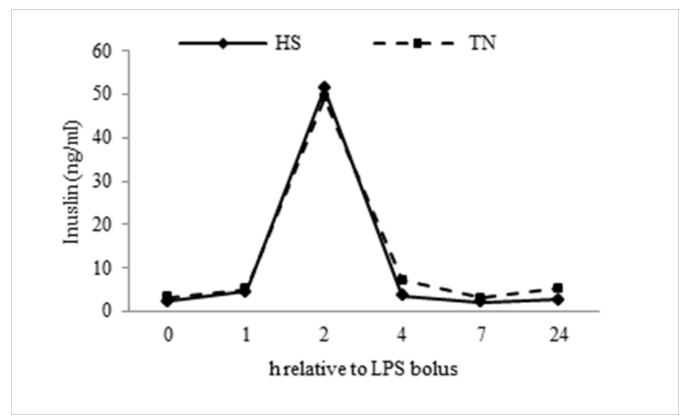
Almost all of these metabolic/physiological effects occur during heat stress….and ketosis

Mammary LPS Infusion Causes Increased Insulin Levels

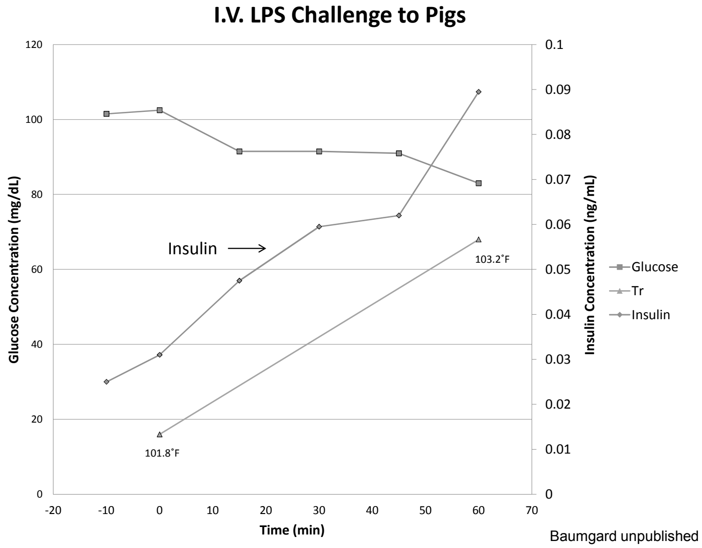


Matthew Waldron et al., 2006
University of Missouri

I.V. LPS Acutely Increases Insulin Secretion



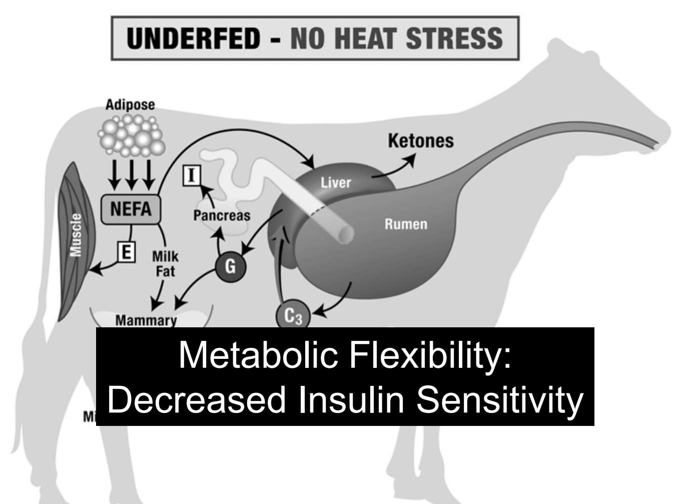
Rhoads et al., 2009 ADSA Abstract



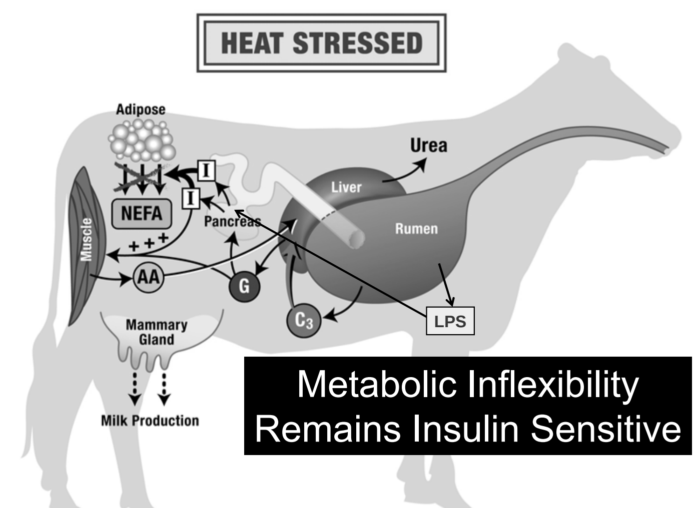
Baumgard unpublished

Lactating Dairy Cow Metabolic Adaptation to Heat Stress

Summary



Baumgard and Rhoads, 2013



Baumgard and Rhoads, 2013

Dietary and Management Options?

- Strategies recently evaluated by our group
  - Rumensin
    - Increases rumen propionate production
  - rbST
    - Partitions nutrients towards mammary gland
- BUT Heat Stress Abatement is the Key

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Reduce walking distance
- Reduce time in holding pen
  - Ventilate and cool
- Exit lane cooling
- Don’t “lock up or work” during mid day
- Feed early in the morning and late in the night
  - Push up often
  - Remove old feed
- Avoid vaccinations during the middle of the day
- At least provide shade for dry cows

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Feed more frequently
  - Especially during the cooler parts of the day
- Fiber:
  - Avoid the temptation to reduce fiber content
  - Rumen acidosis
  - Production data: see J. Santos webinar
- Protein
  - Currently unknown if protein requirements change during heat stress
  - RDP about 10% of CP: see J. Santos webinar

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Clean water tanks daily
  - Consider re-hydration therapies, especially in transition cows
    - Decreased rumen content of Na^+ and K^+ (Beede &Collier, 1982)
    - Electrolyte supplementation may be effective
  - Increased opportunity for dehydration
  - Medicate/supplement the water?
- Dietary HCO3
  - Helps prevent rumen acidosis
    - Heat stress cows are already prone to rumen acidosis
    - Can increase to 300-400 g/head/d during the summer

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Dietary Fat (by-pass)
  - Additional energy without the heat increment of fermentation
    - Heat stressed cows are in negative energy balance dietary fat should help maintain milk yield and body condition
    - Can go up to 7-8% of dietary dry matter
- Potassium
  - Cows use potassium to sweat, thus there is an increased potassium need during heat stress
  - Can increase to 1.7% of ration dry matter
  - Consider K^+HC0^3……consider the costs
  - Be careful of a positive DCAD in dry cows

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Betaine:
  - Not for methyl donor reasons
  - But for GIT integrity reasons
  - Used extensively in the Asian poultry and swine industries during heat stress
- Niacin
  - Increases skin vasodilatation and decreases body temperature: Whether small decreases in rectal temperature translates into improved production remains to be determined

Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Chromium
  - Appears to improve productivity, likely due to increased DMI
- DCAD:
  - Keep in 30-40 meq/100 g of DM
  - No apparent improvements of going higher
- Direct fed microbials/yeast
  - Products that increases rumen digestion, stabilizes pH, increases propionate and increases DMI should benefit a heat stressed cow
    - The inconsistencies in the literature regarding these variables is of interest

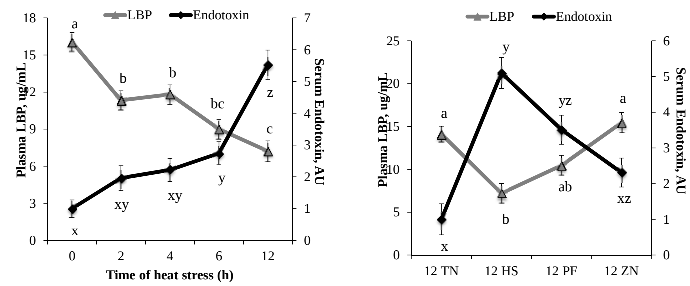
Potential nutritional strategies to ameliorate intestinal permeability

Supplement	Presumed Mechanism of Action
Bicarbonate	Acidosis prevention
Glutamine	↑ intestine integrity
Zinc	↑ intestine integrity, antioxidant
Dairy Products	↑ intestine integrity
Vitamin A	Antioxidant
Vitamin C	Antioxidant
Vitamin E	Antioxidant
Selenium	Antioxidant
Dexamethasone	↑ intestine integrity
Betaine	Osmotic regulation; CH_3 donor
Conjugated Linoleic Acid	↑ Energy balance
Chromium	↑ Feed Intake
Yeast, yeast extract/DFM	Acidosis prevention & ↑ Feed Intake
Ionophores	Acidosis prevention
β-glucan	Immune modulation
Mannanoligosaccharide	↑ intestine integrity
Rehydration therapy	↑ intestine integrity & ↑ Feed Intake
Butyrate	↑ intestine integrity
Mycotoxin binders	↑ intestine integrity

Gut Health and Zinc

- Alam et al., 1994. Enteric protein loss and intestinal permeability changes in children during acute shigellosis and after recovery: effect of zinc supplementation
- Rodriguez et al., 1996. Intestinal paracellular permeability during malnutrition in guinea pigs: effect of high dietary zinc. Gut. 39:416-422.
- Sturniolo et al., 2001. Zinc supplementation tightens “leaky gut” in Crohn’s disease. Inflamm. Bowel Dis. 7:94-98.
- Finamore et al., 2008. Zinc deficiency induces membrane barrier damage and increases neutrophil transmigration in Caco-2 cells. J. Nutr. 138:1664-1670
- Peterson et al., 2008. Moderate zinc restriction affects intestinal health and immune function in lipopolysaccharide-challenged mice. J. Nutr. Biochem. 19:193-198.
- Mahmood et al., 2009. Zinc carnosine, a health food supplement that stabilizes small bowl integrity and stimulates gut repair processes. Gut 56:168-175

Zinc: Plasma LPS & LBP



Gabler and Baumgard, unpublished

Heat Stress Abatement

BUT the primary strategy to improve production during heat stress is management!

Shade, soakers, misters, fans, etc.., even in humid Environments

Elanco Heat Abatement Management Guide

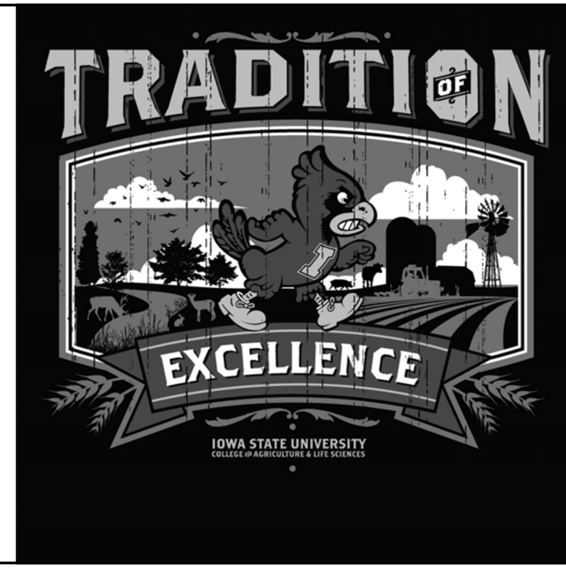
Ask your Elanco Rep for a copy or see URL

www.elanco.us/pdfs/usdbunon00147_heat_guide.pdf

Summary

- Concentrate on maintaining healthy rumen pH
  - It will pay dividends during late Summer and Fall
- Heat stress markedly effects metabolism independent of reduced nutrient intake
  - Can in large-part be explained by increased insulin action
  - Maximizing glucose synthesis will improve production
- There is no dietary magic pill
- Dietary and management modifications
  - Ionophores, rbST etc…
  - Fat feeding makes sense
  - Consult with your nutritionist

Questions?



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- Zinpro Inc.
- Elanco Animal Health
- Midwest Dairy Association
- National Pork Board
- Iowa Pork Producers
- TechMix
- Form A Feed
- Kemin Industries
- ViCor Corp
- Murphy Brown
- Nutriad Inc.

USDA NIFA United States Department of Agriculture National Institute of Food and Agriculture

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- Anna Gabler
- Sam Lei

Heat Increment of Feed

- Heat produced from fermentation AND post-absorptive metabolism
- Very difficult to determine
- Rumen
  - Acetate fermentation creates more heat
  - Fat has very little heat of fermentation
- Post-absorptive
  - Depends upon metabolic fate
    - Stored or oxidized
  - Acetate utilization is less efficient than propionate

Heat Increment of Common Feed Ingredients

Feed Ingredient	DM (%)	NDF % of DM	TDN % of DM	NE_L (Mcal/Kg)	HI (Mcal/ton)	HI/NE_L (Kcal/Mcal)
Haylage	35.0	53.0	59.0	1,326	277.32	658
Corn Silage	38.3	48.0	66.1	1,500	321.85	617
Grass Hay	88.0	53.0	55.0	1,228	672.10	684
Alfalfa Hay	89.9	47.5	60.0	1,350	718.59	651
Whole Cottonseed	93.0	49.0	87.0	2,453	801.15	386
Corn	87.0	10.0	88.0	2,035	886.23	550
SBM, 48%	90.0	14.0	81.0	1,866	857.54	562
Palm Oil (FA)	100.0	0.0	170.1	5,676	1,103.96	214
Prill (FA)	100.0	0.0	170.1	6,776	1,314.23	214
Tallow	99.0	0.0	191.3	6,402	1,228.81	214

Adapted from Chandler, 1994. Values for heat increment where derived from a multiple linear regression model: $y=a+bx+cx^2$. Where y= Kcal HI/Mcal NE_L and x=TDN solved constants are a= 1350.812, b= -17.1496, and c= 0.091517

Effects of Supplemental Dietary Fat on Body Temperature Indices and Production Parameters in Lactating Cows

Reference	Fat Type	RT	RR	DMI	FE	MY	MF	MP	Metabolites
1	SFA/UFA	↑	↑	↓	↑	↔	↑	↔	↑ NEFA
2	SFA	↓	↔	↔	↑	↑	↑	↑	↓ NEFA
3	SFA	NM	NM	↔	↔	↑	↓	↑	NM
4	LCFA	↔	↔	↔	↑	↑	↔	↓	↓ NEFA
5	SFA	NM	NM	↔	↔	↑	↑	↑	NM
6	SFA	↔	↔	↔	↔	↔	↔	↔	NM
7	LCFA/Tallow	↔	↔	↔	↔	↔	↔	↔	NM
8	SFA	NM	NM	↔	↔	↑	↔	↔	↔
9	SFA/UFA	↔	↔	↔	↔	↔	↔	↔	↔

NM: Not Measured
↑: Increase
↓: Decrease
↔: No Change
SFA: Saturated Fatty Acids
UFA: Unsaturated Fatty Acids
LCFA: Long-Chain Fatty Acids

RT: Rectal Temperature
RR: Respiratory Rate
DMI: Dry Matter Intake
FE: Feed Efficiency
MY: Milk Yield
MF: Milk Fat
MP: Milk Protein
NEFA: Non-Esterified Fatty Acids

1 Moallem et al., 2010
2 Wang et al., 2010
3 Warntjes et al., 2008
4 Drackely et al., 2003
5 Gallardo et al., 2001
6 Chan et al., 1997
7 Knapp and Grummer, 1991
8 Skaar et al., 1989
9 Moody et al.,1967

Feeding Dietary Fat

- Milk yield responses are variable
  - About 50% (better than most feed supplements)
- Does not appear to improve body temperature indices
  - Small decreases may be difficult to detect at specific but limited time points
  - Would be of interest to measure body temp continuously in additional fat-fed heat-stressed fat fed cows
- Dry matter intake can sometimes decrease in thermal neutral cows
  - This does not happen during heat stress