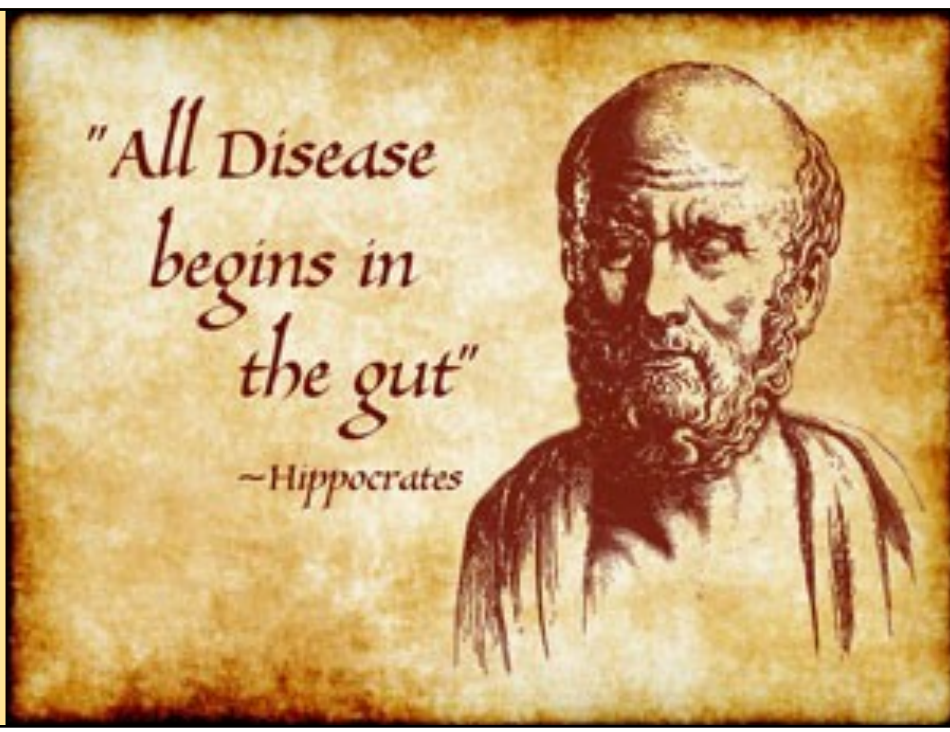
Benefits of Mitigating Heat Stress in Dairy Cows

Lance Baumgard PhD
Jacobson Professor
Iowa State University
Baumgard@iastate.edu

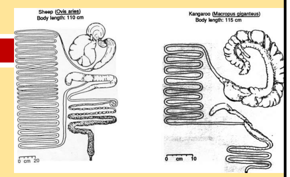
Department of Animal Science

1



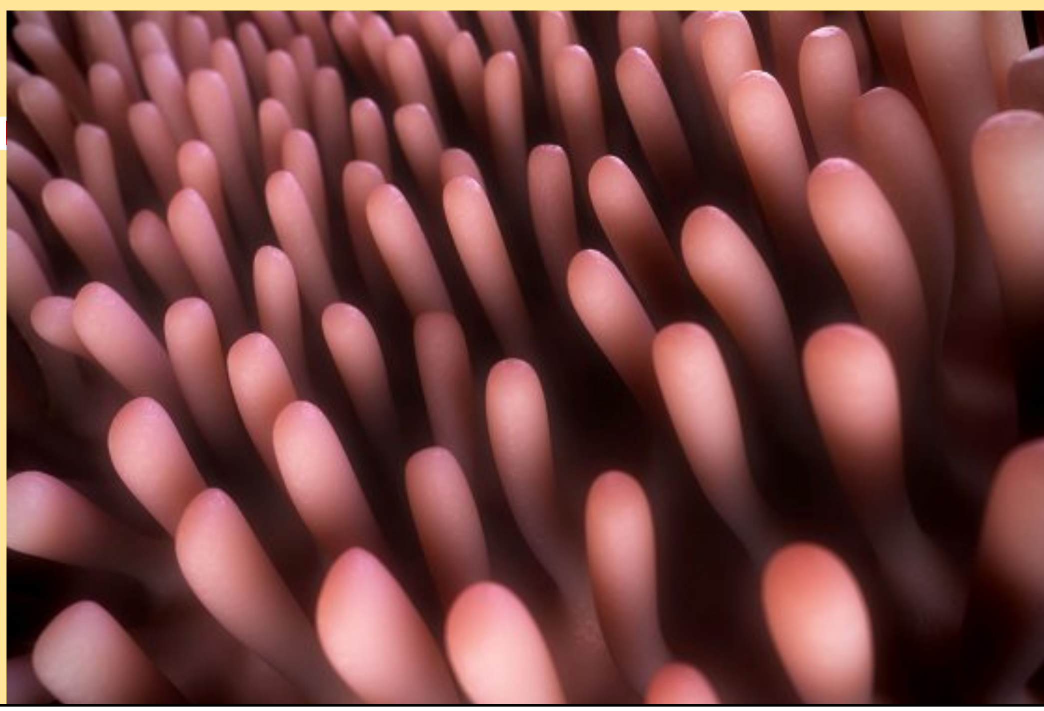
2

Reminder: Intestinal Functions



- GIT is a tube running from the mouth to the anus
  - Everything inside of the tube is technically "outside" of the body
- Digest and absorb nutrients
  - GIT lumen is a inhospitable environment
- Prevent parasites, pathogens, antigens, enzymes, acids, toxins etc.. From infiltrating "self"
  - Barrier function

3



4

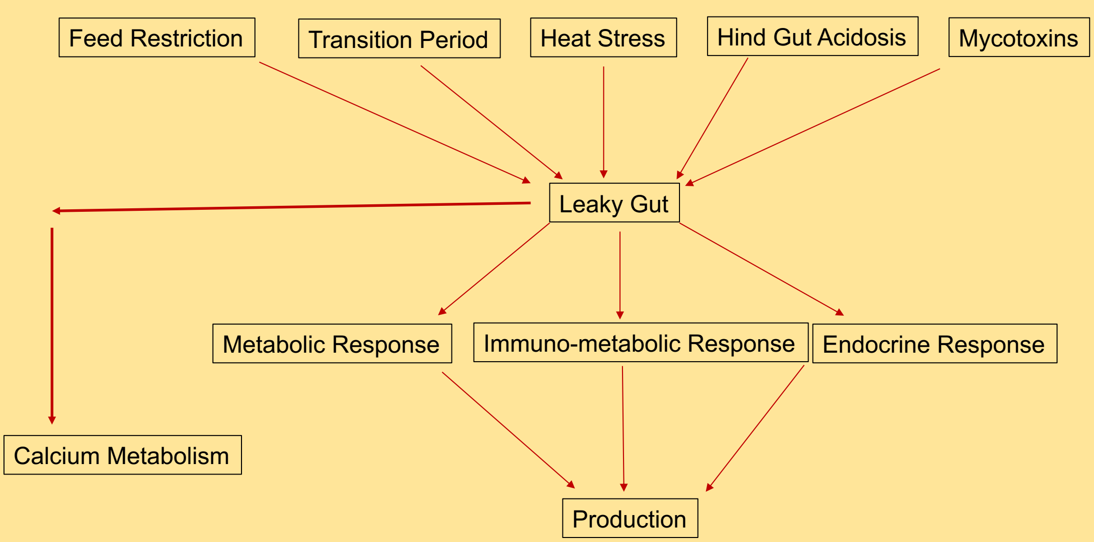
Human GIT Surface Area:

That's an enormous amount of area to "defend"!

No wonder 70% of the immune system resides in GIT

5

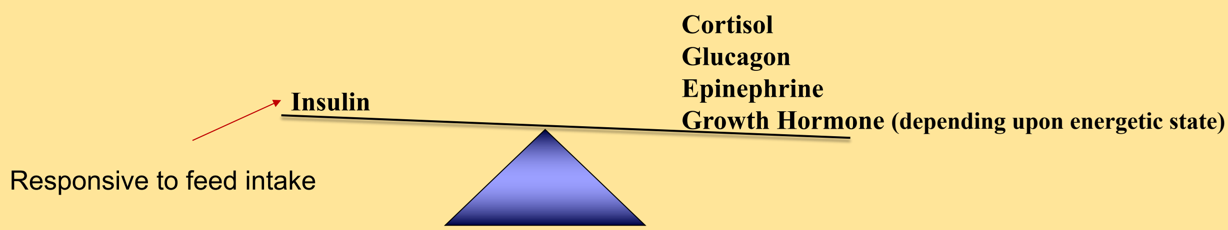
Baumgard Research Group Priorities: Ruminants and Pigs



6

"Normal" Metabolism Review

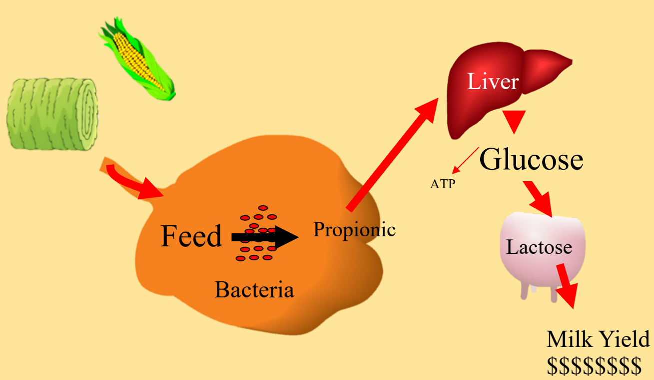
- <u>Ad Libitum Intake</u>
  - ↑ Insulin
  - ↓ NEFA
  - ↓ catabolic hormones
- <u>Suboptimal Intake</u>
  - ↓ Insulin
  - ↑ NEFA
  - ↑ catabolic hormones



7

Friendly Reminder of Glucose's Importance

Glucose is primarily made from propionate
Lactose is made from glucose
72 g of glucose/ 1 kg of milk (Kronfield, 1982)
<u>Milk yield</u> is primarily determined by the amount of synthesized lactose



8

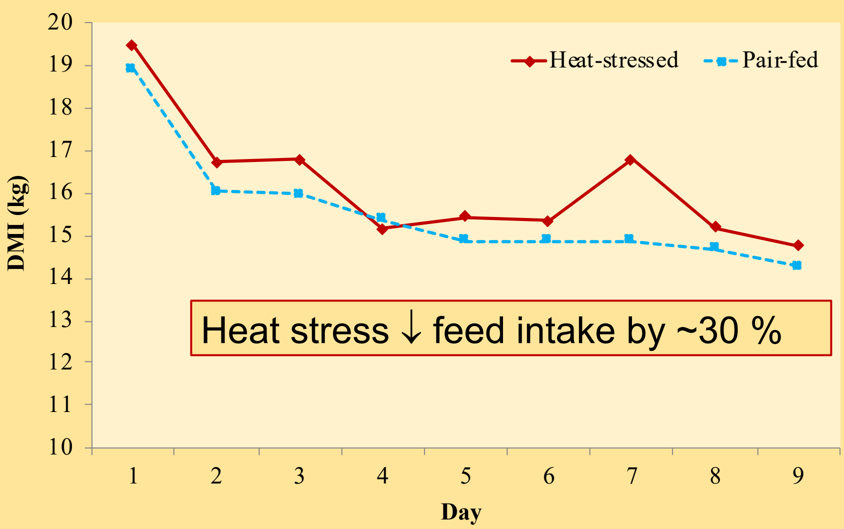
Heat Stress: Economics and Food Security

- Cost: (lost productivity, mortality, product quality, health care etc.)
  - American Agriculture: > $4 billion/year
    - $1.7 billion in dairy industry
  - Global Agriculture: > $350 billion/year
- It will get worse in the future if:
  - Climate change continues as predicted
  - Genetic selection continues to emphasize milk synthesis, lean tissue accretion, piglets/sow etc..
    - Heat producing processes

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

9

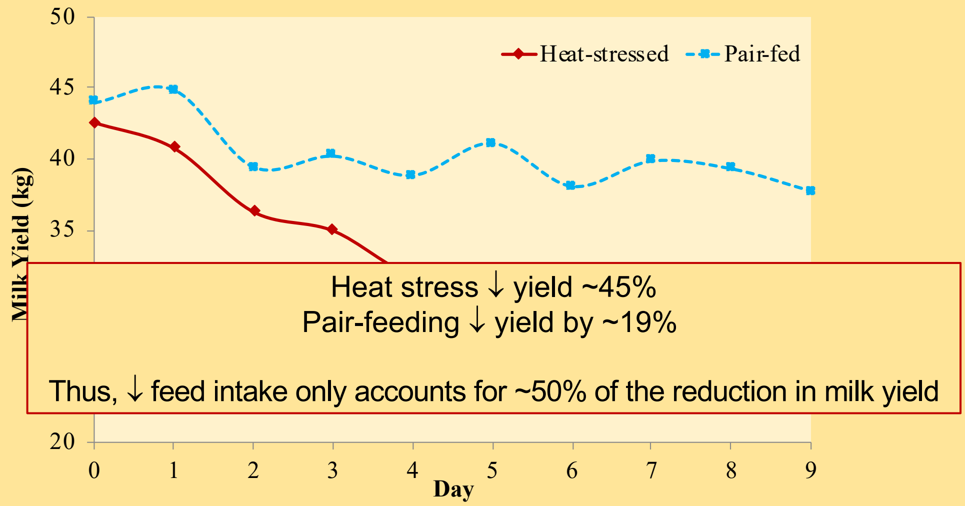
Effects of HS on Feed Intake



Rhoads et al., 2009

10

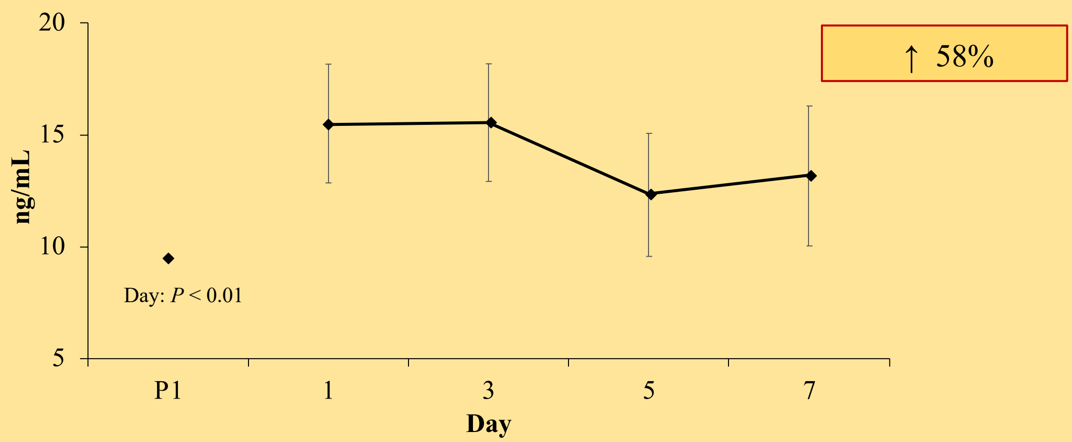
Effects of HS on Milk Yield



Rhoads et al., 2009

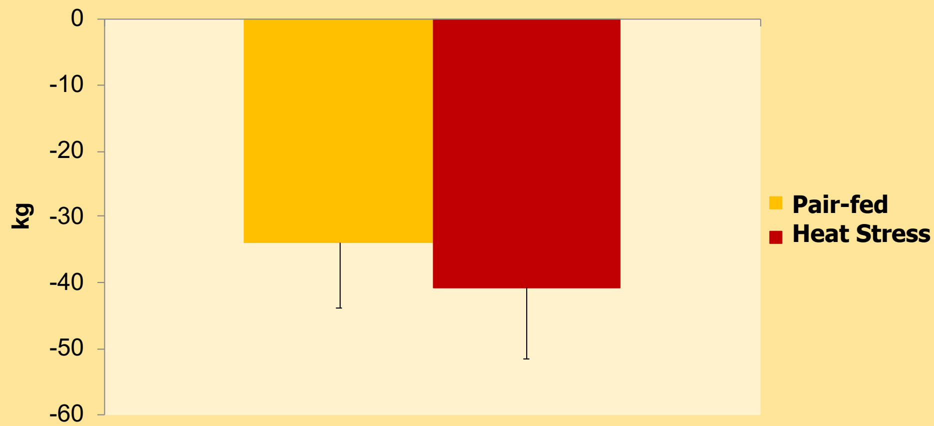
11

Heat Stress Increases Cortisol



12

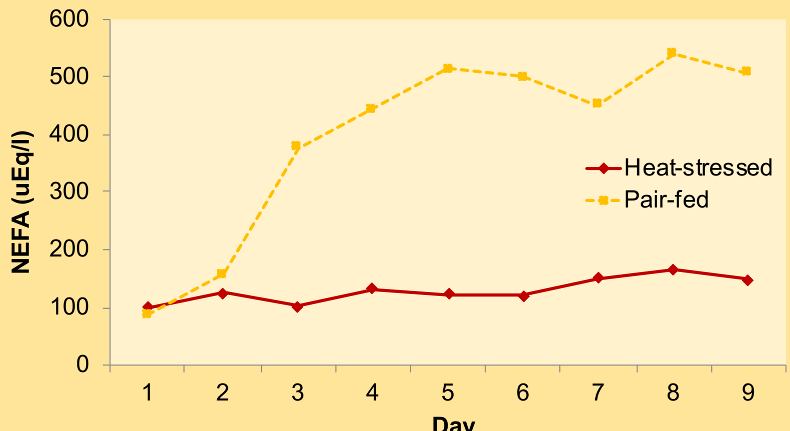
Body Weight Loss During 9 days



Rhoads et al., 2009

13

Heat Stress Reduces Basal and Stimulated Adipocyte Lipolysis



Rhoads et al., 2009
Wheelock et al., 2010
Baumgard and Rhoads, 2013

14

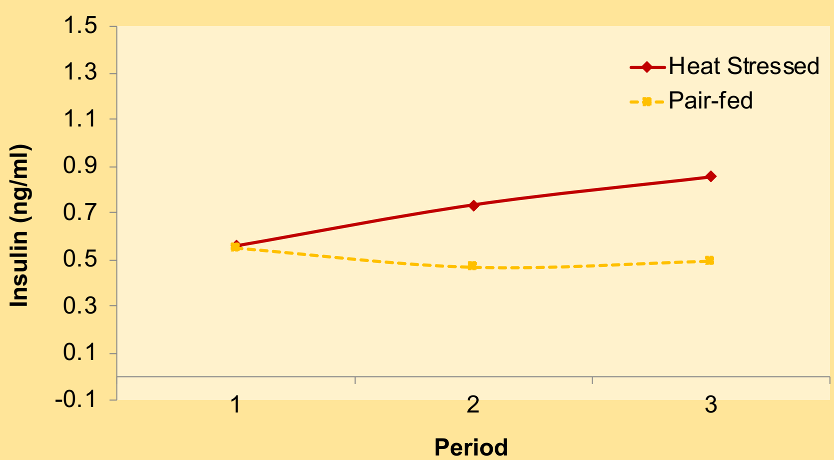
Lipid Metabolism

- Basal and stimulated (epinephrine) lipolysis is blunted during heat stress in multiple species
  - Ruminants
  - Pigs
  - Chickens
  - Rodents

- What is preventing lipid mobilization?
- What's the purpose of preventing lipid metabolism during a hyper-catabolic state?

15

Circulating Insulin in Cattle



Wheelock et al., 2010

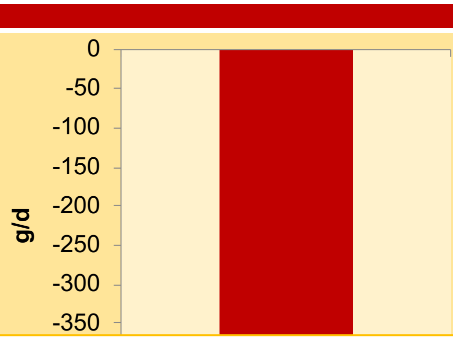
16

HS and Hyperinsulinemia

- Basal and stimulated (GTT) increases conserved across species
- Especially when compared to pair-fed thermal neutral controls
  - Dairy
  - Beef
  - Pigs
  - Rodents
  - Rabbits
  - Snakes
  - Human

17

Milk Sugar Output



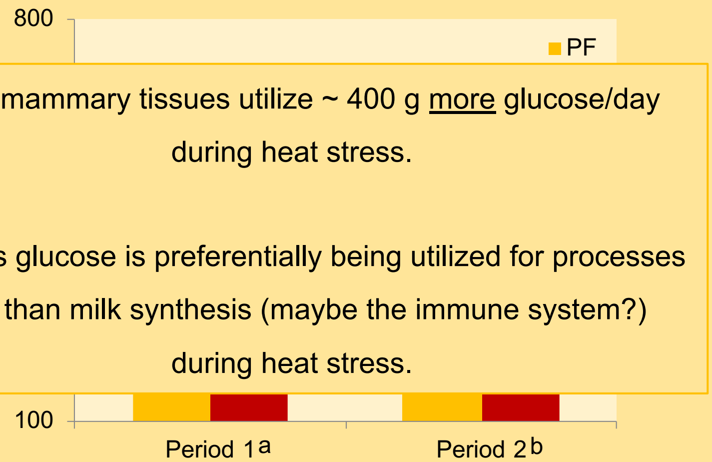
Heat Stress Cows Secrete ~400 g <u>less</u> lactose/day than Pair-Fed Thermal Neutral Controls

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

18

Whole Body Glucose Production



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

Indicates glucose is preferentially being utilized for processes other than milk synthesis (maybe the immune system?) during heat stress.

Period: $P < 0.05$

Baumgard et al., 2011

19

Biology of Heat Stress Symptoms

20

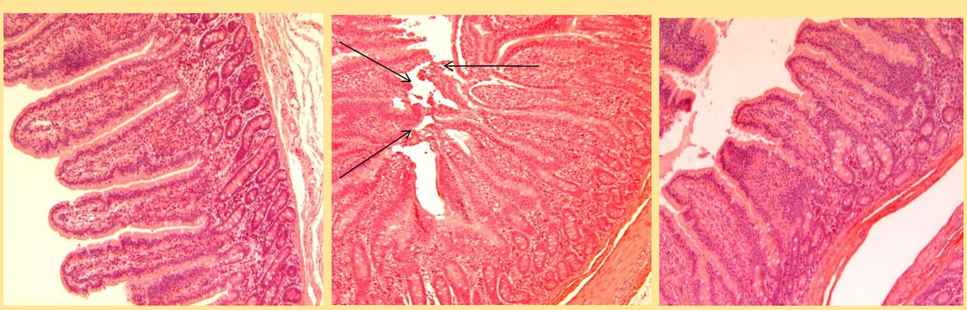
Heat Stress and Gut Health

- Diversion of blood flow to skin and extremities
  - Attempting to maximize radiant heat dissipation
- 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 and Rhoads, 2013

21

Intestinal Morphology



Thermal Neutral Heat Stress Pair-fed

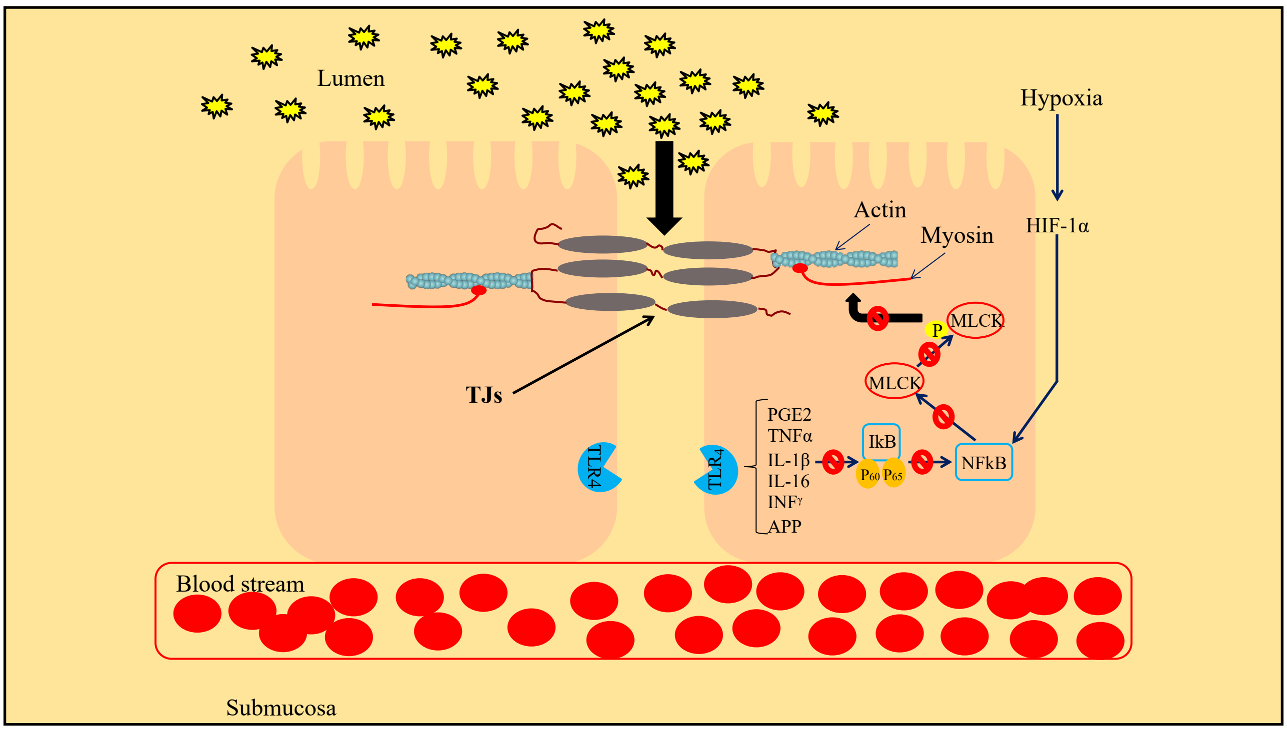
Pearce et al., 2011

22

Heat Stress and Gut Health

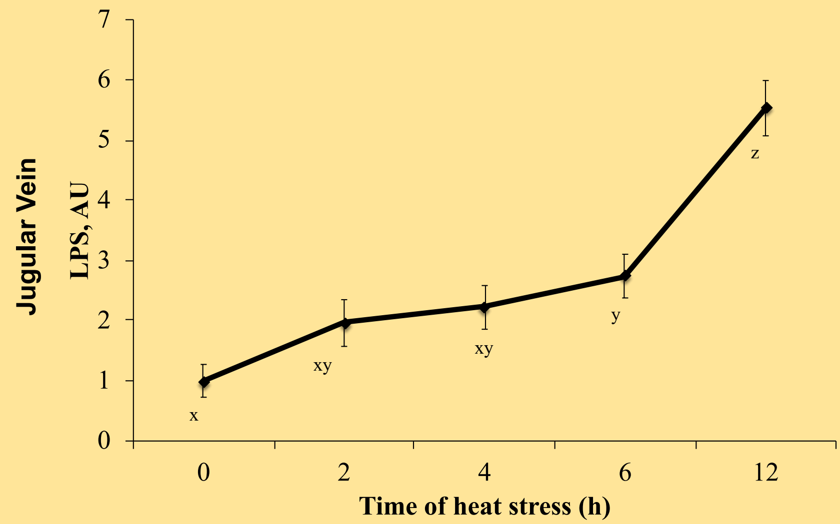
- Lipopolysaccharide (LPS) stimulates the immune system
- LPS promotes inflammation production….catabolic condition
  - TNFα, IL-1 etc..
    - Reduced appetite
    - Stimulates fever
    - Causes muscle breakdown
    - Induces lethargy
    - ....reduces productivity

23



24

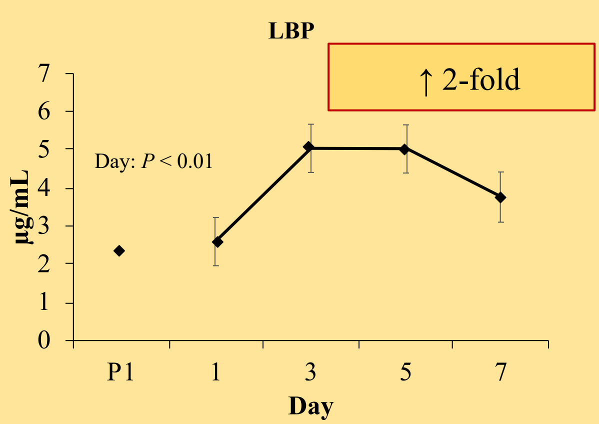
The Effects of Heat Stress are Rapid!

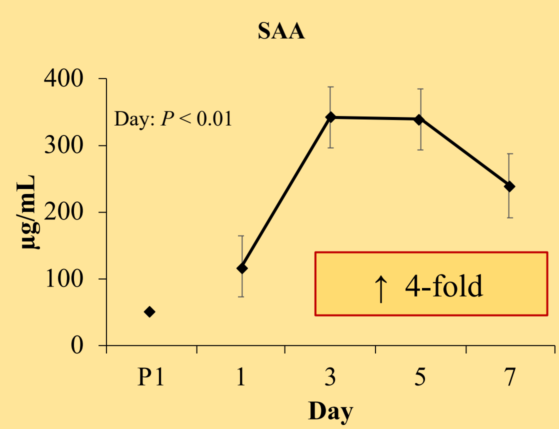


Pearce et al., 2015

25

Acute Phase Proteins Increase During Heat Stress





26

Heat Stress Summary

- Direct and indirect effects
  - ↓DMI only accounts for 50% of reduced milk yield
- Hyperinsulinemia
  - Blunted adipose mobilization
  - Explains why heat-stressed pigs & chickens prioritize adipose tissue
- Liver remains sensitive to catabolic signals
- Leaky gut
  - Inflammation and acute phase protein response
- Heat stress is <u>essentially immune activation</u>
- Unknown whereabouts of 400 g of glucose

27

So the Gut Becomes Leaky….the Immune System is Activated…….who Cares?

28

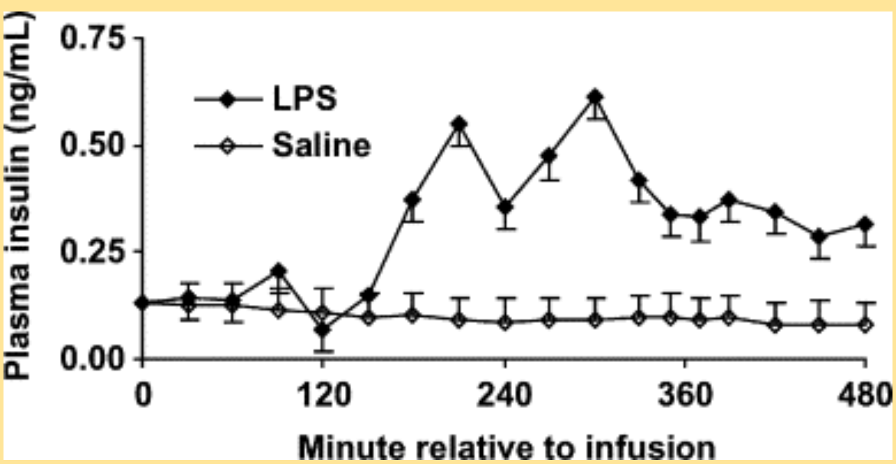
Insulin??

- Increased during heat stress
- Increased or not changed in ketotic cows
  - Metabolically, a ketotic cow should be hypoinsulinemic

- What's insulin's role during immuneactivation and inflammation?

29

Mammary LPS Infusion Increased Circulating Insulin

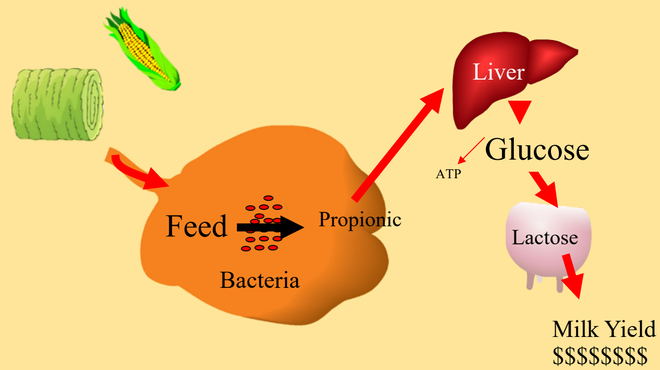


Waldron et al., 2006

30

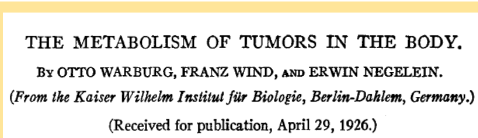
Friendly Reminder of Glucose's Importance

Glucose is primarily made from propionate
Lactose is made from glucose
72 g of glucose/ 1 kg of milk (Kronfield, 1982)
Milk yield is primarily determined by the amount of synthesized lactose

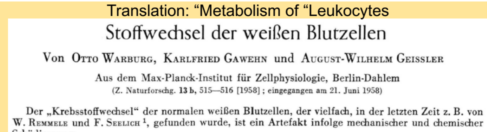


31

Professor Otto Warburg

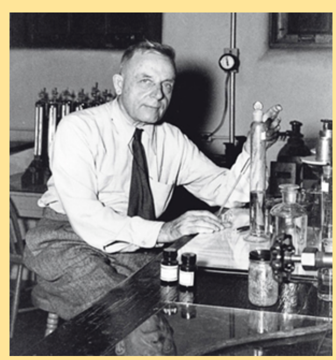

THE METABOLISM OF TUMORS IN THE BODY.
BY OTTO WARBURG, FRANZ WIND, AND ERWIN NEGELEIN.
(*From the Kaiser Wilhelm Institut für Biologie, Berlin-Dahlem, Germany.*)
(Received for publication, April 29, 1926.)

Translation: "Metabolism of "Leukocytes

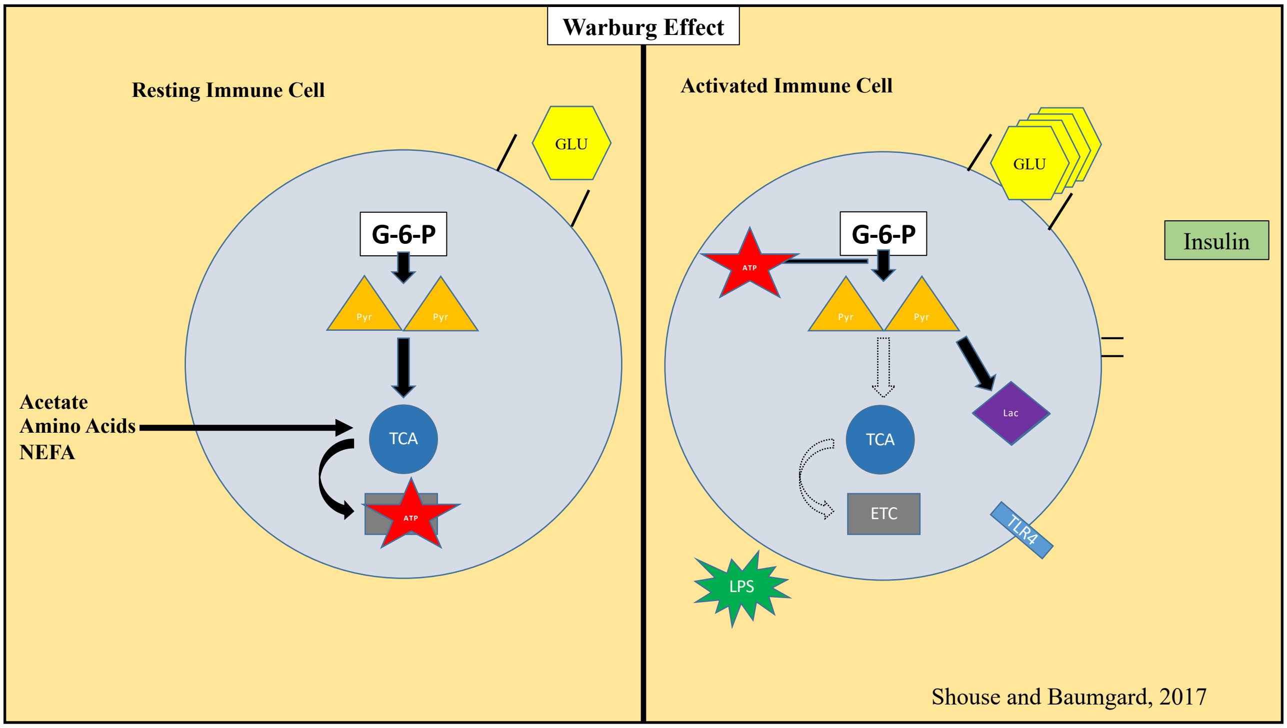

Stoffwechsel der weißen Blutzellen
Von OTTO WARBURG, KARLFRIED GAWEHN und AUGUST-WILHELM GEISSLER
Aus dem Max-Planck-Institut für Zellphysiologie, Berlin-Dahlem
(Z. Naturforschg. **13 b**, 515—516 [1958]; eingegangen am 21. Juni 1958)

Der „Krebsstoffwechsel" der normalen weißen Blutzellen, der vielfach, in der letzten Zeit z. B. von W. REMMELE und F. SEELICH [1], gefunden wurde, ist ein Artefakt infolge mechanischer und chemischer Schädigungen.

- First recognized the unique metabolism of cancer cells (1927)
  - Large glucose consumers
  - Switch from oxidative phosphorylation → aerobic glycolysis
  - 1931 Noble Prize
- Also observed activated lymphocytes become highly glycolytic (1958)
- Mentored Hans Krebs
- Drinking buddy with Albert Einstein



32



33

How much glucose is the entire body using??

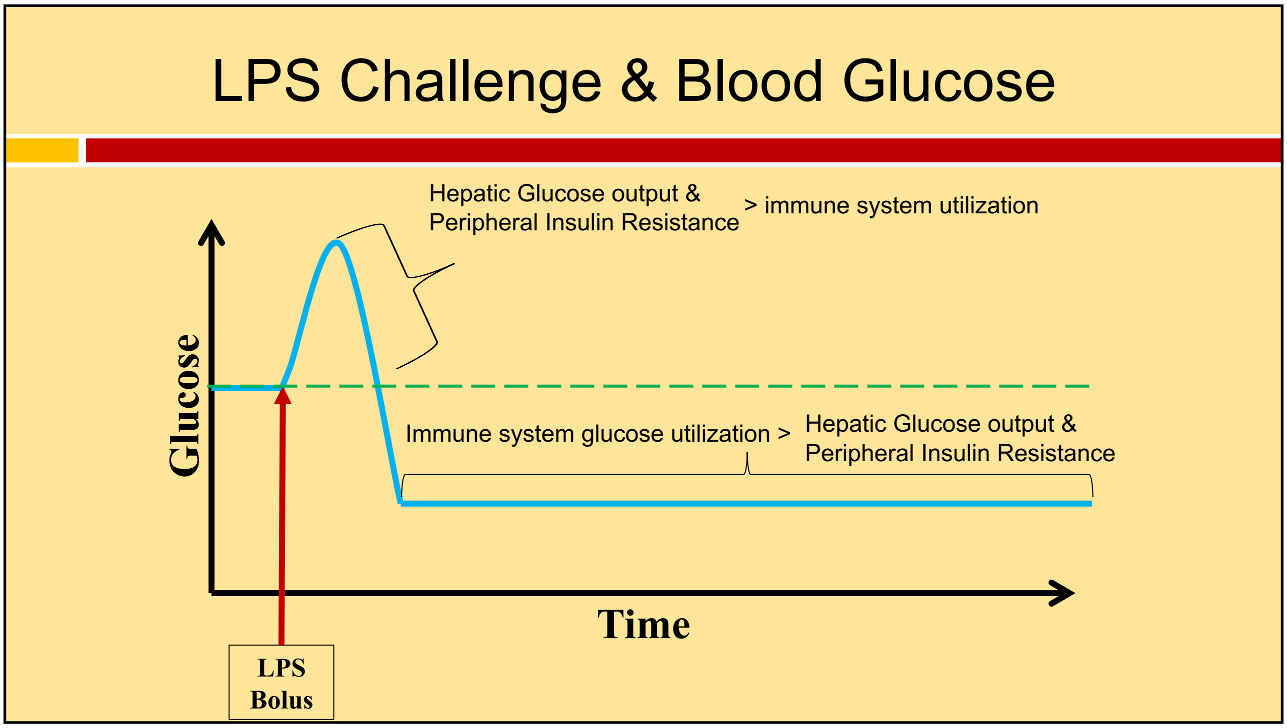
80 years later and we still not know how much glucose the immune system needs *in vivo*?

Prerequisite for developing mitigation strategies

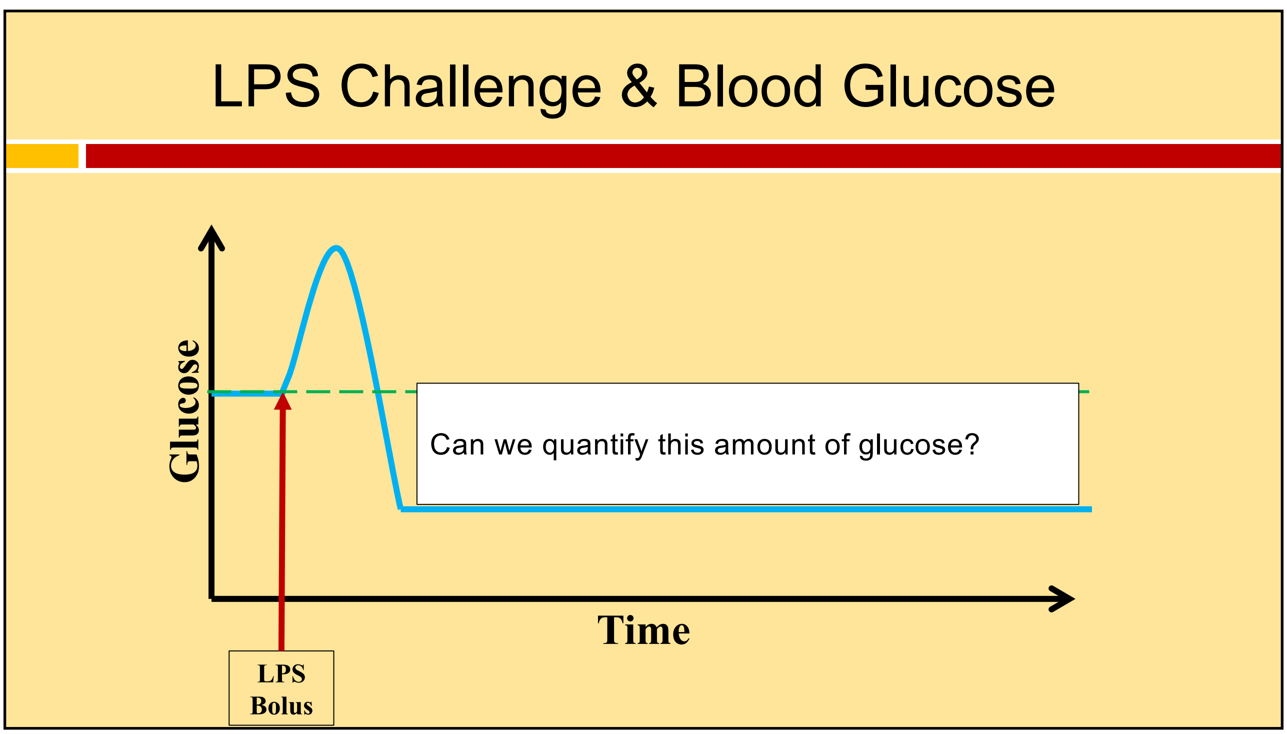
What's the Problem?:

- Dynamic and ubiquitous distribution of the immune system throughout tissues
  - Allows for quasi tissue/organ quantification but….
  - Complicates whole-body quantification

34


LPS Challenge & Blood Glucose
Hepatic Glucose output &
Peripheral Insulin Resistance
> immune system utilization
Glucose
Immune system glucose utilization >
Hepatic Glucose output &
Peripheral Insulin Resistance
Time
LPS
Bolus

35


LPS Challenge & Blood Glucose
Glucose
Can we quantify this amount of glucose?
Time
LPS
Bolus

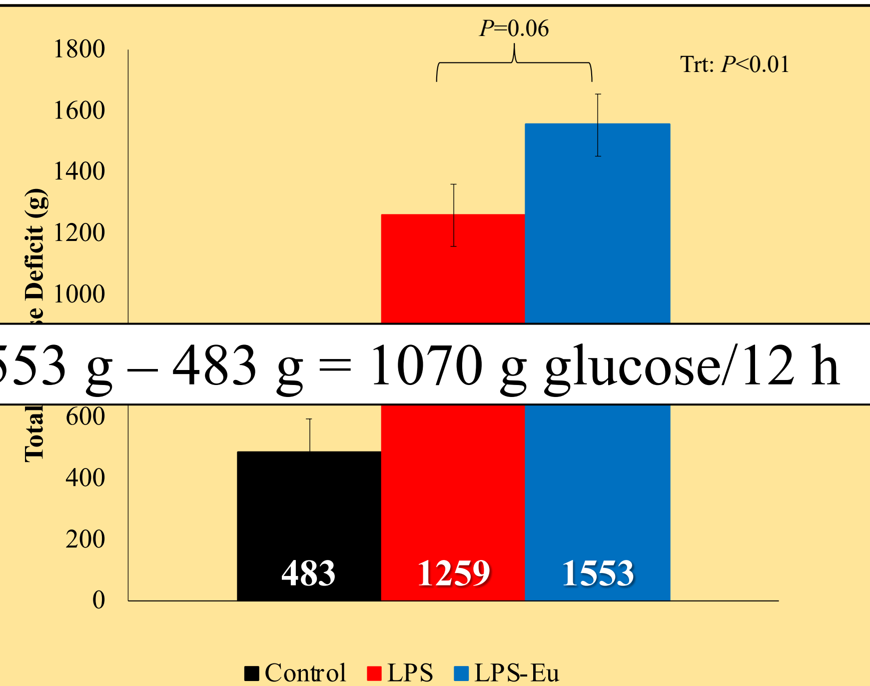
36

Cow # 8341 Target [Glu] Range: 61-67

Min	Blood Sample (✓)	[Glucose] (mg/dL)	Glucose ROI (mL/hr)	Tr (F)
60 (1 hr)	✓	96	0	101.3
70		84	0	
80		79	0	
90	✓	91	0	100.8
100		98	0	
110		116	0	
120 (2 hr)	✓	115	0	101.2
130		102	0	
140		87	0	
150	✓	68	0	100.9
160		49	50	
170		54	50	
180 (3 hr)	✓✓✓	55	75	100.7
190		56	75	

Kvidera et al., 2015

37



1553 g – 483 g = 1070 g glucose/12 h

Kvidera et al., 2015

38

8.4 Mcal of energy!

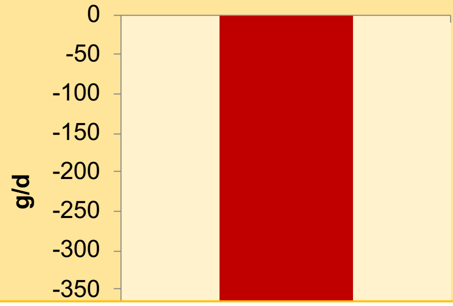
39

Conserved Response

Species:	Immune glucose utilization
Steers:	1.0 g/kg $BW^{0.75}$/h (Kvidera et al., 2016)
Pigs:	1.1 g/kg $BW^{0.75}$/h (Kvidera et al., 2015)
Cows:	0.7 g/kg $BW^{0.75}$/h (Kvidera et al., 2017)
Cows:	1.0 g/kg $BW^{0.75}$/h (Horst et al, unpublished)

40

Remember: We couldn't account for almost 1 pound of glucose during heat stress



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

41

$$ Billion Dollar Question $$

- Can the Feed or Animal Health Industry do anything about heat stress and leaky gut????
- Targets:
  - Direct action at intestine
  - Indirect via:
    - Increased feed intake

42

Heat Abatement

- By FAR the biggest impact a dairy producer can do to alleviate the negative consequences of heat stress is physically modifying the environment
  - Shade, Fans, Soakers, Misters etc…

43

Why Invest in Cooling Cows??

- **Improve production efficiency and profitability**
- **Improve summer fertility**
- **Improve animal welfare/health**
- **Improve sustainability**

44

Heat Stress Abatement Priorities

1) reduce solar radiation

2) increase evaporative heat loss in conjunction with fans

45

Effects of Shade on Surface Temperatures

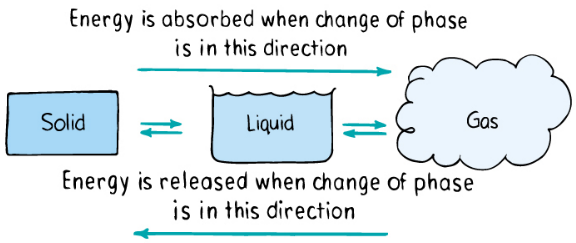
Bare ground surface temperature before and after shading at various times during the day[a]

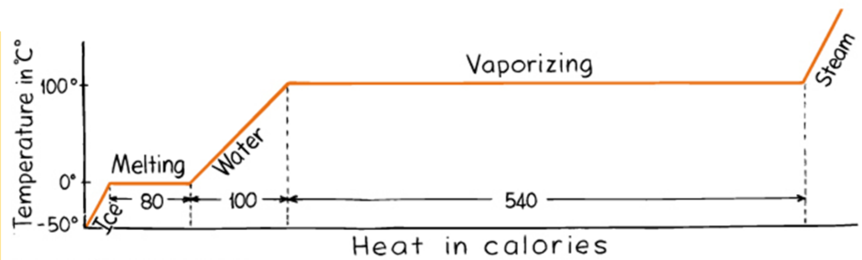
Shaded time (min)	Temperature of Ground Surface (°F) 11 a.m.	12 noon	2 p.m.	4 p.m.
In sun	124.9	144.3	151.9	153.0
5	104.0	107.6	111.6	113.7
15	98.1	103.1	109.4	109.4
30	98.1	101.3	104.0	105.8
Air temp	91.9	95.0	98.1	104.0

Kelly et al., 1950

46

Physics Review
Energy and Phase Changes





47

Evaporation

- Evaporation is a cooling process!
- The Heat of Vaporization is <u>540 calories per gram</u> of condensed water at 100 degrees.
- Why do you feel chilly when getting out of a swimming pool or out of the shower?
  - The energy (heat) required to convert water on your skin into vapor is coming from your body
- Familiar examples of using evaporation:
  - Cool coffee by blowing on it
    - Vapor escapes from the liquid, taking energy, and leaving the liquid cooler.
  - Wrap a wet cloth around a container to cool it off at a picnic.

48

Three Ways to Utilize Evaporative Cooling

- Cool the Cow
  - Evaporate water off the skin
  - Does not change air temperature
- Cool the Air
  - Change air temperature through evaporation
- Combination
  - Cool the air and the cow

49

Priorities to Reduce Heat Stress (Lactating & Dry Cows)

- 1. Water availability
- 2. Providing shade (Lactating & Dry)
- 3. Utilize evaporative cooling
- 4. Fans
- 5. Reduce walking distance to the parlor
- 5. Reduce time in the holding pen
- 6. Improve ventilation

Professor John Smith

50

Where to cool cows?

- Tie-stalls, Free stalls or dry lot pens
- Holding pen
- Maternity pen
- Parlor exit lane
- Feed lines/feed alleys
- Feed bunks
- Pre-fresh barn
- ……………………………….EVERYWHERE

51

Summary of Heat Abatement

Cool cows by providing good shade and a combination of evaporative cooling and fans

- ***More water the better if available and waste not a problem***

Don't just cool lactating cows

Prego-heifers and dry cows as well

Measure how effective cooling is

  - ***Why invest if you don't know if it's working?***
- ***Body temperatures***
- ***Summer: winter ratios***

Professor John Smith

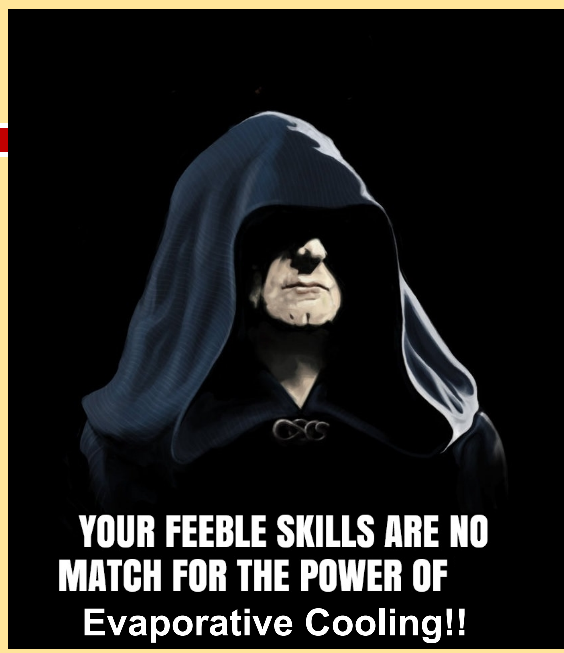
52

Pre-partum Cooling: Saudi Arabia Reproductive Effects

	Services per Conception		Pregnant after 1st or 2nd Service		Cows Culled for Reproductive Failure	
Dairy	Cooled	Control	Cooled	Control	Cooled	Control
Al Kharj	2.30	2.60	63%	55%	2%	16%
Durma	3.34	4.46	30%	27%	16%	27%
Al Zaid	3.63	3.98	40%	34%	5%	14%

Wiesma and Armstrong 1989

53



54

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" during the mid day
- Consider "short-feeding" the day before a heat wave
- Feed early in the morning and late in the night
  - Push up often
  - Remove old and "hot" feed (consider "TMR extenders")
- Avoid vaccinations during the middle of the day
- At least provide shade for dry cows

55

Dietary Strategies

- Low heat increment diets
  - Digestible Fiber
    - Consider saving best forage for the warm summer months
  - Increased fat
  - Balanced AA profile
- Supplements
  - Gut integrity (antioxidants, betaine, glutamine, Zn, etc.)
  - Feed intake stimulation
  - Immune modulation
  - Vasodilators

56

J. Dairy Sci. 93:2387–2394
doi:10.3168/jds.2009-2557

Effects of encapsulated niacin on evaporative heat loss and body temperature in moderately heat-stressed lactating Holstein cows

R. B. Zimbelman, L. H. Baumgard, and R. J. Collier[1]
Department of Animal Sciences, University of Arizona, Tucson 85721

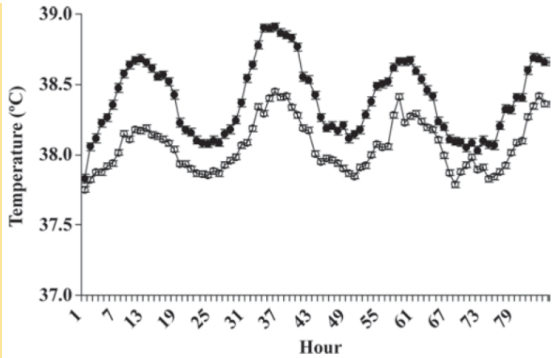


Figure 4. Pattern of vaginal temperatures at 1-h intervals of lactating Holstein cows supplemented with 0 g (●) or 12 g (○) of encapsulated niacin per day during d 4 to 7 of heat stress. The SEM derived from the pooled vaginal temperatures was 0.02. Treatments differ at $P < 0.001$.

57

J. Dairy Sci. 97:5023–5034
http://dx.doi.org/10.3168/jds.2013-6970

A dose-response evaluation of rumen-protected niacin in thermoneutral or heat-stressed lactating Holstein cows

S. Rungruang,*[1] J. L. Collier,* R. P. Rhoads,† L. H. Baumgard,‡ M. J. de Veth,§[2] and R. J. Collier*[3]
*School of Animal and Comparative Biomedical Sciences, University of Arizona, Tucson 85721
†Department of Animal Sciences, Virginia Tech, Blacksburg 24061
‡Department of Animal Sciences, Iowa State University, Ames 50011
§Balchem Corporation, New Hampton, NY 10958

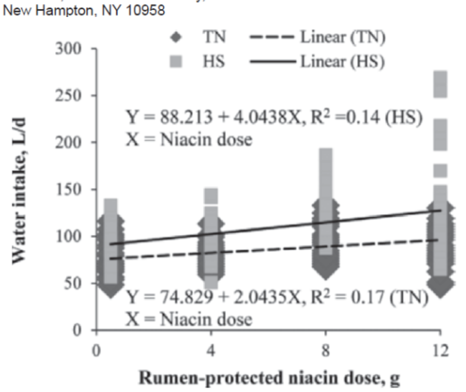


Figure 3. Effect of dose of rumen-protected niacin on water intake; environment effect ($P < 0.01$) and dose-by-environment interaction ($P < 0.02$). TN = thermoneutral environmental condition; HS = heat-stress environmental condition.

58

J. Dairy Sci. 100:4025–4037
https://doi.org/10.3168/jds.2016-11876

Effects of niacin and betaine on bovine mammary and uterine cells exposed to thermal shock in vitro

Y. Xiao,* S. Rungruang,† L. W. Hall,* J. L. Collier,* F. R. Dunshea,‡ and R. J. Collier*[1]
*School of Animal and Comparative Biomedical Sciences, University of Arizona, Tucson 85721
†Feed Technology, Charoen Pokphand Company, Bangkok, Thailand 10500
‡Faculty of Veterinary and Agricultural Sciences, University of Melbourne, Parkville, Victoria 3010, Australia

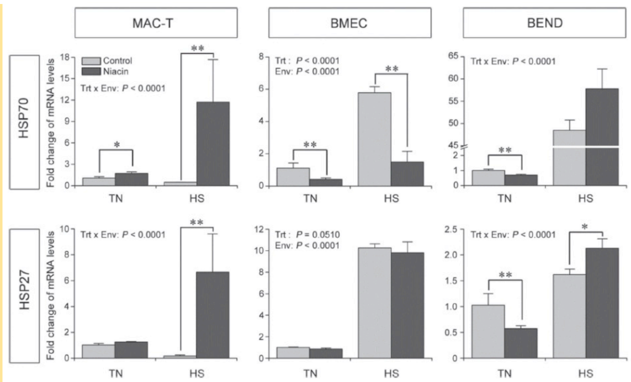


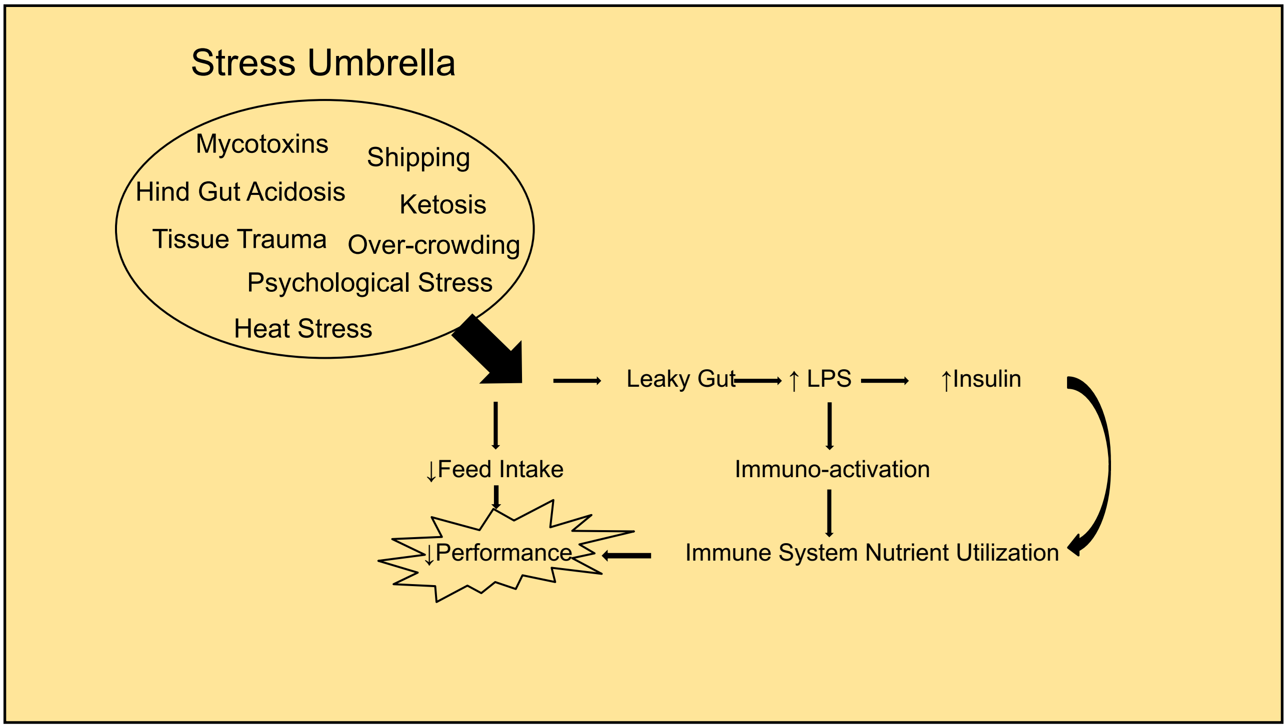
Figure 2. Effects of niacin treatment on heat shock responses of bovine cells derived from the mammary glands (mammary alveolar cells, MAC-T; bovine mammary epithelial cells, BMEC) and the uterus (bovine endometrial cells, BEND). Quantitative PCR of *HSP70* and *HSP27* was conducted on niacin-treated or control cells exposed to thermoneutral conditions (TN, 37°C) or heat stress (HS, 42°C) for 8 h. Fold change of mRNA expression levels was calculated using the $2^{-\Delta\Delta Ct}$ method, with the control cells in TN as the calibrator. Data are represented as means ± SE (n = 3). Trt = treatment; Env = environment. Differences were observed between control and niacin within the same environment; $*P < 0.05$; $**P < 0.01$.

59

Can "leaky gut" explain suboptimal production frequently observed in animal agriculture?

- Heat Stress
- Inadequate feed intake
  - "off-feed event"
    - The negative effects on growth and milk yield are bioenergetically unexplainable by reduced feed intake
  - Transition period
    - Cause of ketosis?
  - Weaning
  - Shipping
  - Overcrowding
  - Unpalatable feed
  - Drought
  - Psychological stress

60



61

Seminar Summary

- Heat Stress decreases almost every metric of productivity
- Costs everyone in the industry
- Reduced feed intake is only a portion of the problem
- Heat induced leaky gut
- Heat stress is essentially another immune activator
- Heat stress abatement should be biggest priority
- Dietary strategies

62

Acknowledgments

Funding Support

- USDA NRI/AFRI/NIFA
  - # 2005-35203-16041
  - # 2008-35206-18817
  - # 2010-65206-20644
  - # 2011-67003-30007
  - # 2014-67015-21627
  - # 2015-10843
  - # 2017- 05931
  - # 2017 -10843
  - # 2019 -07859
- Alltech
- Zinpro Inc.
- FormAFeed
- TechMix
- Elanco Animal Health
- Kemin Inc.
- ADM
- Diamond V
- ASCUS
- Novus
- Micronutrients

63

64