The Physiology Behind Improved Feed Efficiency in Swine

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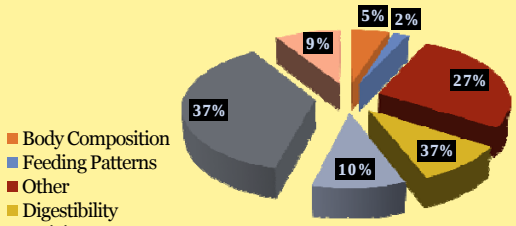
Contributions of Biological Mechanisms to Variations in RFI (cattle)



(Richardson and Herd, 2004)

Factors Influencing Feed Efficiency

- Energy is first used for maintenance, then for protein deposition and fat deposition
- The more a pig eats after its maintenance needs, the more lean gain it will deposit
- Temperature can affect feed intake
  - Heat stress will vary with geography, barn site and type and season
- Chronic and acute disease conditions decrease feed consumption

Psuedo

Temperature

Strep

Dust

Salmonella

Crowding

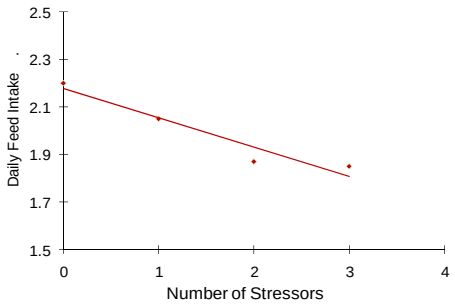
E. coli

Group Size

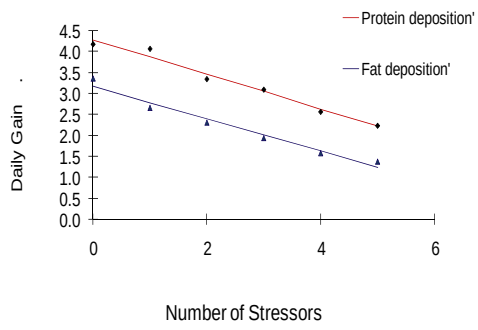
Lawsonia

PRRS

Social Factors



Hyun et al., 1998



Variation in Efficiency

Five major processors may account for the variation in efficiency

1. Feed Intake
2. Digestion (and the associated energy costs)
3. Metabolism (homeostatic, catabolic and anabolic processors) and Body Composition
4. Activity
5. Thermoregulation

Feed Intake

- As feed intake increases, the amount of energy expended to digest the feed increases
  - Known as the Heat Increment (thermic effect) of Feeding
- High fiber diets > high protein diets > high fat diets
  - Sugars are in the middle in heat increment
  - Digestion is harder and creates more heat in the process
- Net Energy (NE) system may explain why high fiber, and high protein diets have resulted in poorer performance

Feed Intake

- Feeding behavior
  - Low RFI pigs eat faster and less often than control pigs (Young et al., 2009)
  - Postprandial satiety signals?
    - Leptin
    - Ghrelin
    - Insulin
    - PYY_{3-36}
    - Neuropeptide Y (NPY)
    - Pro-opiomelanocortin (POMC)
    - α-Melanocyte Stimulating Hormone (α-MSH)
    - Cocaine and Amphetamine Regulated Transcript (CART)

Digestion

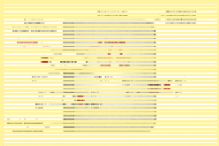
- As the level of feed relative to maintenance increases, the digestion of feed tends to decrease
- Low RFI efficiency correlates with higher digestibility in cattle (Richardson and Herd, 2004)
  - This correlation is not seen pigs (de Haer et al., 1993)
- Absorption of nutrients in pigs in relation to feed efficiency has not been fully characterized
  - Nutrient transporter number and kinetic efficiency?

Metabolism

- Feed efficiency is heavily influenced by basal metabolic rate
- Two possible physiological variation in metabolism
  - Ion pumps (i.e., Na^+/K^+ ATPase)
  - Mitochondria

Ion Channels

- H^+, Ca^+, Na^+/K^+ ATPase etc…
- Of the 80% of oxygen consumption coupled to ATP synthesis
  - H^+ , Na^+/K^+ ATPase: 19-28%
  - Ca^+ ATPase: 4-8%
  - Actinomyosin ATPase: 2-8%
  - Ca^+ ATPase: 4-8%



Mitochondria

- Free energy comes from the oxidation of food compounds (i.e., carbohydrates, lipids and protein)
- Mitochondrial inefficiencies
  - Electron transport chain coupling is better in more efficient animals
  - Proton uncoupling from ATP synthesis and its leakage
  - Reactive oxygen species production

Body Composition

- The deposition of the same weight of lean and fat tissue has different energy costs
  - More variation in lean deposition
  - Lean has a higher turnover rate than fat → energetically expensive process
  - Decreased rates of protein degradation give rise to improved conversion of feed to gain in many species (Herd and Arthur 2009)
  - Of the 80% of oxygen consumption coupled to ATP synthesis
    - Protein synthesis: 25-30%
    - Ureagenesis: 3%

Activity

- Activity can contribute significantly to feed efficiency
- Mice with higher food intake are 3 times more active (Bunger et al., 1998)
- 80% of the genetic differences in RFI between lines of chickens divergently selected for RFI could be related to differences in physical activity (Luiting et al., 1991)
- Feeding activity

Thermoregulation

- Principal route of energy loss
  - Heat exchange
  - The rate of respiration
  - Body size or surface area

Ad Lib. RFI Old Pigs

	Control	Low RFI	P<0.05
Live BW (kg)	115.2	114.6	
ADG (kg/d)	0.83	0.81	
ADFI (kg/d)	2.9	2.6	*
Carcass (kg)	90.6	90.7	
Dressing %	78.6	79.1	
Carcass Water (kg)	46.1	49.7	*
Carcass Bone (kg)	2.5	2.6	
Carcass Fat (kg)	27.2	22.4	*
Carcass Protein (kg)	15.6	15.7	
Carcass Lean (kg)	61.7	65.4	*
Viscera (kg)	11.1	10.9	

* P<0.05

Ad Lib. RFI Pigs Serum (Fasting)

	Control	Low RFI	P<0.05
Glucose (mg/dL)	77.6	69.5	*
Insulin	4.88	4.73	
Glucose:Insulin	16.2	14.7	
IGF-1	223	201	
Free T3	2.0	2.5	
Free T4	1.32	1.36	
Triglycerides	16.9	20.8	*
NEFA	0.27	0.43	*
Lipemic	14.6	26.0	*
Blood Urea Nitrogen	13.7	11.9	*

* P<0.05

RFI Data Summary

- Low RFI pigs consumed 8% less feed
- Control vs. Low RFI, same
  - Growth rate
  - Body, carcass and viscera weights
- Higher fat deposition in control pigs
- Higher carcass water content and thus lean mass in Low RFI pigs

RFI Data Summary

- Low RFI pig have higher fasting blood lipid markers
  - Increased lipid catabolism?
  - Lower lipid deposition compared to the control pigs?
- Control pigs have higher protein catabolism?
  - Increase blood urea nitrogen

Longissimus doris 2D-DIGE

- LD muscle protein expression from the Ad Lib pigs from the control and low RFI lines is being compared

Low RFI vs Control 2D-DIGE Data

- Control pig LD protein expression
- Higher Aldolase
  - Converts Fructose 1,6 bisphosphate → Dihydroxyacetone Phosphate (DHAP) + Glyceraldehyde 3 phosphate
  - Substrates in de novo lipogenesis
  - Glyceraldehyde 3-phosphate is how glycerol (as DHAP) enters the glycolytic and gluconeogenetic pathways
- Higher Glycerol-3-phosphate dehydrogenase
  - Important enzyme in de novo lipogenesis

2D-DIGE DATA

- Control pig LD protein expression
- Higher α-B- rystalline and Heat Shock Protein B1 (HSP27)
  - Induced by oxidative stress
  - Molecular chaperones of denatured proteins
  - Found in more oxidative muscle types
- Higher Creatine kinase
  - A major enzyme of cellular energy metabolism

2D-DIGE DATA

- Control pig LD protein expression
- Higher Carbonic Anhydrase III (CAIII)
  - Catalyzes $CO_2 + H_2O \rightarrow H_2CO_3$
  - CO_2 gives rise to alkaline conditions → H^+ secretion by ATPase pumps (Requires a lot of energy)
  - Functions as an antioxidant in muscle
  - Can act as a phosphatase
  - Spares glycogen stores
  - Inhibit CAIII results in de novo lipogenesis inhibition
    - Via pyruvate carboxylase

Hypothesis and Further Research

- Low RFI pigs have decreased protein turnover and higher nitrogen retention
- Lower ATPase activity
  - 20% of maintenance energy can be contributed to these pumps
- More of a reliance on carbohydrates for ATP
- Mitochondrial protein expression differences
- Appetite/satiety regulation

- Comparison between low and high feed efficient pigs
  - Digestion and nutrient absorption
  - ATPase activity or ion pumps
  - Protein turnover
  - Energy partitioning