Improvement of feed efficiency: lessons from residual feed intake studies in pigs - part 1

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OUTLINE

- From feed efficiency to residual feed intake (RFI)
  - Properties and measures of RFI
  - Selection experiments for RFI
  - Genetic parameters and correlated responses to selection
  - Biological bases of RFI

Part 1

- Measuring (residual) feed intake / bio-markers for RFI
- Management rules and RFI
- What selection strategies?
From feed efficiency to RFI

**Costs of production / Gains**

- Feed (€/T) >60% production costs
- Feed intake
- Growth duration
- Disease/mortality
- Market body weight
- Carcass composition
- Meat quality
- Reproduction
- Mortality
- Number of piglets
- Labor
- Growing-finishing

Feed efficiency to RFI

Growing-finishing

Costs of production / Gains

0 50 100 150 200 250 300 350
Feed (€/T)

1999 ... 2010 2011 2012 2013...
Feed efficiency = \frac{\text{weight gain}}{\text{feed intake}} = \frac{\text{average daily gain}}{\text{daily feed intake}}

Not included: payment for carcass composition
pig level: mortality

Feed Conversion Ratio = \frac{\text{DFI}}{\text{ADG}}
Correlations with production traits

From Clutter et al, 2011

**FCR**
- $h^2 = 0.30$

**DFI**
- $h^2 = 0.29$
  - $r_A = 0.40$

**ADG**
- $h^2 = 0.29$
  - $r_A = -0.37$

**BFT**
- $h^2 = 0.49$
  - $r_A = 0.31$
From feed efficiency to RFI  
Indirect selection vs DFI records

From Clutter et al, 2011
From feed efficiency to RFI

Components of Feed Intake

\[ FCR = \frac{DFI}{ADG} \]
From feed efficiency to RFI

**Components of Feed Intake**

Body gain
Gain composition
Time

production requirements

metabolic body weight

maintenance requirements

residual

FCR = \( \frac{DFI}{ADG} \)
Components of Feed Intake

From feed efficiency to RFI

Body gain
Gain composition
Time

production requirements

metabolic body weight

maintenance requirements

residual

Net feed efficiency

Gross feed efficiency

FCR = \frac{DFI}{ADG}
Components of Feed Intake

From feed efficiency to RFI

Components of Feed Intake

Recorded DFI

<table>
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DFI

pen

sex

19%
From feed efficiency to RFI

Components of Feed Intake

- Recorded DFI: 69%
- Corrected DFI: 55%
  - Residual: 26%
  - Production: 19%
  - Maintenance: 19%
Components of Feed Intake

From feed efficiency to RFI

- Recorded DFI: 69%
  - DFI
  - Pen sex

- Corrected DFI: 55%
  - Residual: 19%
    - Genetic
  - Production: 26%
    - Res
  - Maintenance: 19%
    - Pen sex

RFI = 20 to 35% of DFI variability
From feed efficiency to RFI

Residual Feed Intake / phenotypic regression

RFI = DFI

- a. maintenance
- b. production
- pen...

Include measurement errors

Koch et al. (1963)
From feed efficiency to RFI 

**What traits to include?**

\[ \text{RFI} = \text{DFI} \]

- a. *maintenance* – b. *production* – ...

**Metabolic Body Weight**

**Growth rate** ADG

**Composition tissue deposition**

Ultrasonic BFT

Lean meat content

Loin Eye Area ...

*Kennedy et al.* (1993)
Properties and measures of RFI \( h^2 \)

When body composition included

0.22 (22 estimates in the litterature)

When body composition is not included

0.36 (8 estimates in the litterature)

Saintilan et al (2012)
Correlations with components?

Properties and measures of RFI

Kennedy et al. (1993)

Phenotypically

Genetically

Expected to be null

depends on $h^2$, $r_A$, and $r_e$

between DFI

and component traits

Kennedy et al. (1993)
Properties and measures of RFI

Correlations with components?

Kennedy et al. (1993)

Phenotypically Genetically

Expected to be null depends on h², rA, and re

between DFI and component traits

- 0.5
- 0.4
- 0.3
- 0.2
- 0.1
0
0.1
0.2
0.3
0.4
0.5

sd(yi)

response to selection production traits

rgfp=0.1  rgfp=0.5  rgfp=0.9

Kennedy et al. (1993)
Properties and measures of RFI  Genetic correlations with prod.

From Clutter et al (2011)
Properties and measures of RFI

Genetic correlations with prod.

From Clutter et al (2011)
Properties and measures of RFI

What’s in RFI?

- DFI
- Residual
- Production (ADG + BFT)
- Maintenance
- Pen
- Sex

(Cattle) Richardson and Herd 2004
Develop divergent lines for RFI to study the responses to selection for RFI

the biological basis of ingestion and feed efficiency
Selection experiments for RFI Measure of feed intake

ACEMA 64

FIRE©

+ electronic identification
Selection experiments for RFI

Selection procedure

Large White
Divergent selection

6 M × 40 F
random

96 M tested for RFI between 35-95 kg

Index\textsubscript{RFI} = DFI − 1.6 AGD − 37 BFT
between fixed body weights

DFI = b_1 BW\textsubscript{ontest} + b_2 age\textsubscript{ontest} + b_3 BW\textsubscript{offtest} + b_4 ADG\textsubscript{gen} + b_5 BF\textsubscript{gen} + BV\textsubscript{RFI} + e

Yorkshire
LRFI from generation 0
HRFI from generation 4

8 M × 50 F

EBV\textsubscript{RFI}

96 M tested for RFI between 35-110 kg

EBV\textsubscript{RFI}
**Responses to selection**

- **RFI**: -149 g/d
- **ADFI**: -172 g/d
- **FCR**: -0.27 kg feed/kg BW

**Correlated responses to selection**

INDEX = selection index; RFI = residual feed intake; FCR = feed conversion ratio; DFI = daily feed intake; ADG = average daily gain; BFT = backfat thickness.
(Correlated) responses to selection

Responses to selection

INDEX= selection index; RFI=residual feed intake; FCR=feed conversion ratio; DFI=daily feed intake; ADG= average daily gain; BFT= backfat thickness
Responses to selection

(Correlated) responses to selection

INDEX = selection index; RFI = residual feed intake; FCR = feed conversion ratio; DFI = daily feed intake; ADG = average daily gain; BFT = backfat thickness

- RFI: -149 g/d
- ADFI: -172 g/d
- FCR: -0.27 kg feed/kg BW
- LMC: +2.83%
- MQI: -3.64%
Body composition = up to 87% of line difference for net energy feed intake
Some indicators of unfavorable impact of selection for RFI on meat quality

- Low in ISU lines
- Very large early correlated response in INRA lines

Smith et al, 2010
Gilbert et al, 2007
Faure et al, 2012
Some indicators of unfavorable impact of selection for RFI on meat quality

- Smith et al, 2010
- Gilbert et al, 2007
- Faure et al, 2012

- Low in ISU lines
- In INRA lines

(Correlated) responses to selection: Meat quality

- (Correlated) responses to selection

Red colour homogeneity***

Red colour intensity***

Marbling homogeneity***

Marbling intensity**

Global flavour

Juiciness

Tenderness

Equivalent to genetic antagonism between meat quality and FCR

Meat quality accounts for about 3% of variability of DFI
(Correlated) responses to selection

Reproduction

No deleterious responses to selection on reproductive sows

See Renaudeau et al EAAP 2013

- Hot climate is a problem for pig production
  - Tropical & Temperate regions
  - Concerns about the thermal susceptibility of “moderns” pigs

- Reduction in pig performance under thermal stress is directly/indirectly related to thermoregulation responses (for e.g. in lactating sows)

- Selection for a low residual feed intake in growing pigs reduces feed intake in lactating sows (Gilbert et al 2007).

➡ Evaluate the consequences of selection for RFI in growing pigs on sows performance in tropical climate
Biological basis of RFI

Maintenance requirements

Figure 2. Body weight of select and control line pigs under adlib or weight-stasis feeding (n=10 per treatment combination)

- **LRFI**: lowered maintenance requirements

Boddicker et al, 2011
Barea et al, 2010
Energy metabolism turned to fast glycolytic in LRFI pigs
Affected proteic turn over

see Gondret et al EAAP 2013

To clarify the relationships between adipose tissue and feed efficiency in growing pigs

Body fat = genetics + environment

Divergent selection on RFI*

Feed restriction

6th to 8th generations

Source of feed energy

*The difference between observed feed intake and expected feed intake (based on growth potential and body composition)  Gilbert et al., 2007

see Louveau et al EAAP 2013

Objectives

- To determine the influence of RFI selection on the proteome and transcriptome of skeletal muscle of 115 kg pigs
- To differentiate variations due to genetic orientation from those related to spontaneous feed intake level

Aim of the study
Biological basis of RFI

Feeding behavior

LRFI:
- Smaller quantity
- Less time for feeding
- Fewer visits
- Eat faster

→ Reduced energy used for feeding behavior

Generation 5
Difference HRFI-LRFI

<table>
<thead>
<tr>
<th>RFI</th>
<th>ADFI</th>
<th>Time FI</th>
<th>Rate FI</th>
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-1     -0.5     0     0.5     1     1.5     2     2.5

RFI
ADFI
Time FI

2.9 g/min

Young et al, 2011
Gilbert et al, 2009
% time standing during a 24h-scan

Less standing
Less interactions (others and substrates) (but no leg issues)

$\Rightarrow$ 14% line difference for DFI = activity (INRA)

Saddler et al, 2012
Meunier-Salaün et al, in prep.
**Biological basis of RFI**

**Digestive tract /digestive efficiency**

**INRA:** no associated increase of digestive efficiency (total or for intestine segments)

**ISU:** increase of digestive efficiency in LRFI

**LRFI:** smaller viscera → lower maintenance → more energy available (relatively to ADFI) to support growth

**ISU:** No difference

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**Barea et al, 2011**

**Harris et al, 2012**

**Montagne et al, submitted**
see Montagne et al EAAP 2013

Introduction.

Question of research and aim of the study

- Studies exploring the genetic and physiological basis of RFI mainly considered pigs receiving a non-limiting concentrated diet with a low level of dietary fibre

  10-15% NDF and 9.5-10 MJ Net energy / kg

  Gilbert et al. (2013)

- The impact of RFI selection on the ability of the pigs to valorise a fibre-rich diet remains unknown

Does the selection to lower RFI impacted on the lines’ ability to cope with a high fibre diet ?

To measure the performances and feeding behaviour of 2 lines of Large white pigs divergently selected for RFI
Properties and measures of RFI

What’s in RFI?

- DFI
- Residual
- Production
- ADG + BFT
- Pen
- Sex
- Maintenance

Cattle, Herd and Arthur, 2009
INRA (30 to 60 pigs/line, urine)

No significant line difference

ISU (6 gilts/line, plasma):

LRFI tended to be less responsive to the challenge. Both lines recovered within 90 min

P Mormède, N Gabbler
Biological basis of RFI

Inflammatory challenges

**LRFI**
better use of nutrients,
faster decrease of inflammation,
lower impact on growth

**LRFI**
no poorer performance
under PRRS challenge

**Rectal temperature (°C)**

- **LRFI**
- **HRFI**

**Body Weight (kg)**

- **LRFI**
- **HRFI**

injection of Complete Freund’s Adjuvant

Le Floc’h, Merlot, Rowland et al
Environment and RFI  

**Heat stress**

Poitou-Charentes, France  
West Indies, France

- **FE x RFI+**  
- **FE x RFI-**  
- **FWI x RFI+**  
- **FWI x RFI-**

**FCR difference reduced → different metabolic responses?**

No significant differences in endocrine and metabolite responses during stress

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**FCR 15-23wk**

```
1.5 2 2.5 3 3.5
```

- a
- b

**ADG 11-15wk**

```
0.2 0.4 0.6 0.8 1
```

- a
- b
- c

**ADG 15-23wk**

```
0.2 0.4 0.6 0.8 1
```

- a

**BFT 23wk**

```
10 12 14 16 18 20
```

- a
- b

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Renaudeau et al

de los Campos, submitted

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EAAP – Nantes – 29/08/2013
Summary

- RFI: heritable, responds to selection
- Selection for reduced RFI has resulted in
  - Pigs that eat less but that are slightly leaner (and grow slower)
  - Limited changes in body composition – decreased fatness
  - Limited impact on meat quality
  - Changes in behavior – faster eaters – less active
  - Reduced maintenance requirements, tissue turnover rates
  - Low impact on digestive efficiency (but not challenged?)
- No detrimental impacts on litter size and litter performance
- No detrimental impacts on response to stress ...

⇒ Selection rules – Biomarkers
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