Residual feed intake (RFI): An indirect approach for reducing GHG emissions.

Basarab, Beauchemin, Baron, Ominski, Guan, Miller and Crowley

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Genetic Selection for Feed Efficiency – Why?

- Safe, affordable, nutritious and **environmentally sustainable beef products** (12-17% of global GHG emissions from ruminant production)

Increasing global population (**FAO**)

- 8 billion by 2030; 9 billion by 2050
- **Global demand for meat is expected to increase by 55%**
  
  (3 billion people trying to move into the middle class in emerging economies will increase demand for meat)
Past Success

Production Efficiency 1977-2007

Same amount of beef now required

- 70% of the animals
- 81% of the feed
- 88% of the water
- 67% of the land

resulting in a 16% decrease in the carbon footprint of beef

(Capper 2011, Animal Frontiers)
<table>
<thead>
<tr>
<th>Species</th>
<th>CH₄</th>
<th>NH₃</th>
<th>N₂O</th>
<th>GWP₁₀₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chickens – layers</td>
<td>-30</td>
<td>-36</td>
<td>-29</td>
<td>-25</td>
</tr>
<tr>
<td>Chickens – broilers</td>
<td>-20</td>
<td>10</td>
<td>-23</td>
<td>-23</td>
</tr>
<tr>
<td>Pigs</td>
<td>-17</td>
<td>-18</td>
<td>-14</td>
<td>-15</td>
</tr>
<tr>
<td>Cattle – dairy</td>
<td>-25</td>
<td>-17</td>
<td>-30</td>
<td>-16</td>
</tr>
<tr>
<td>Cattle – beef</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sheep</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

CARBON FOOTPRINT (CO₂e/kg product): Pork 2.8-4.5 kg; Chicken 1.9-2.9; Dairy 1.3 kg; **Beef 18-36 kg**

Trait criteria for Genetic Selection

- Measurable with at least moderate repeatability
- Heritable
- Few if any adverse genetic correlations
- Economically (socially?) important
Measurable: Individual Animal Feed Intake Facilities

- body weight
- production
- gender
- age
- season
- temperature
- physiological status
- previous nutrition

Global GrowSafe capacity: ~68,000 animals; facilities in Canada (8%), US (76%), UK, Brazil, Aus (16%); Sunstrum 2012.
Repeatability (r) of Feed Intake

Feed intake for 99 young bulls fed a growing diet for 77 days (72.1% barley silage, 24.6% barley grain & 3.3% protein sup., DM basis)

- **Feeder cattle**
  \[ r = 0.325-0.407 \]

- **Repl. heifers**
  \[ r = 0.286-0.380 \]

- **Young bulls**
  \[ r = 0.374-0.449 \]

- **Beef cows**
  \[ r = 0.361-0.491 \]

r = within animal var., across + within
Effect of days of feed intake data on phenotypic residual variance (adapted from Wang et al. 2006, JAS, 84:2289)

Suggests at least 35 days of feed intake data
Residual Feed Intake (RFI) $h^2 = 0.29-0.46$
reflects energy requirement for maintenance.

RFI: Feed intake adjusted for body size and production.
Repeatability of RFI across diets

Grower diet vs. finisher diet, steers and heifers, \( r_g = 0.45-0.62 \)

example, 75% barley-silage vs. 75% barley grain, as fed basis

Crews et al. 2003; Kelly et al. 2010; Duranna et al. 2011.

Heifers to 1\(^{st}\), 2\(^{nd}\) and 3\(^{rd}\) parity cows; \( r_p = 0.2-0.4 \)

(Lawrence 2012)

Conclusion:
High & positive genetic association between RFI-g and RFI-f when cattle are consuming roughage vs. grain, but traits are not biologically equivalent

More importantly, no convincing evidence that bull and heifer RFI would be antagonistic to progeny RFI or feed intake as a cow.
### Repeatability of RFI in heifers to cows

Preliminary data, Basarab et al. 2012

<table>
<thead>
<tr>
<th>Traits</th>
<th>RFI measured as a heifer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>RFI, kg DM/day</td>
<td></td>
</tr>
<tr>
<td>Number of females</td>
<td>12</td>
</tr>
<tr>
<td>8-12 mo old heifers</td>
<td>0.365</td>
</tr>
<tr>
<td>4-7 year old cows</td>
<td>0.459</td>
</tr>
</tbody>
</table>

Heifers fed 90:10 barley silage:barley grain, free choice  
Cows fed 70:30% grass hay:barley straw cube, restricted to gain at 0.25-0.50 kg/day

**Feed savings:**  
Heifers: $0.74 \text{ kg DM/day} \times $0.15/\text{kg DM} \times 365 = $40/\text{heifer/yr}$  
Cows: $0.83 \text{ kg DM/day} \times $0.15/\text{kg DM} \times 365 = $46/\text{cow/yr}$
Repeatability of $RFI_{fat}$ during summer grazing

Daily consumption of n-alkane labelled feed pellets during a summer grazing trail

Manually fed 0.5 kg pellets/hd twice daily
Day 8-12: twice a day fecal sampling

DMI calculated based on forage, supplement and fecal content of C31 and 32, intake of supplement and dose rate of C32 (modified from Boloventa et al. 1994; Moshtaghi-Nia and Wittenberg, 2002)
Feed intake of high and low RFI_{fat} heifers during summer grazing (n=20)

Growth and backfat, Day 0-46:

HIGH: gain = 32.7 kg
ADG = 0.71 kg/day
BF=0.5
RF=0.7 mm

LOW: gain = 44.9 kg
ADG = 0.98 kg/day
BF=0.9
RF=1.3 mm

P = 0.0003, 8.2%
Correlation: growth & animal size

Correlations (\( r_p \) & \( r_g \)) are near zero

\[ N = 2029 \text{ feeder heifers and steers} \]

Arthur et al. 2001; Basarab et al. 2003; Crews et al. 2003; Jensen et al. 1992

Basarab et al. 2013

\[ \text{ADG}=1.90 \text{ kg/day} -0.41 \text{ kg DM/day} +$42/\text{hd} \]

\[ \text{ADG}=1.89 \text{ kg/day} 0.42 \text{ kg DM/day} $0/\text{hd} \]

\[ \text{ADG}=1.28 \text{ kg/day} -0.42 \text{ kg DM/day} -$170/\text{hd} \]

\[ \text{ADG}=1.32 \text{ kg/day} 0.40 \text{ kg DM/day} -$208/\text{hd} \]

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\[ \text{ADG}=1.32 \text{ kg/day} 0.40 \text{ kg DM/day} -$208/\text{hd} \]

NOTE: Same feeder cost and price, transportation, vet & medicine, interest, yardage, death loss and marketing costs
## Correlations: RFI to other traits

<table>
<thead>
<tr>
<th>Traits</th>
<th>Direction in low RFI</th>
<th>phenotypic correlation</th>
<th>genetic correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI</td>
<td>lower intake</td>
<td>0.60 to 0.72</td>
<td>0.69 to 0.79</td>
</tr>
<tr>
<td>FCR</td>
<td>improved</td>
<td>0.53 to 0.70</td>
<td>0.66 to 0.88</td>
</tr>
<tr>
<td>Linear measurements</td>
<td>no affect</td>
<td>-0.08 to 0.15</td>
<td>-------</td>
</tr>
<tr>
<td>Feeding behaviours</td>
<td>lower</td>
<td>0.18 to 0.50</td>
<td>0.33 to 0.57</td>
</tr>
<tr>
<td>Docility /temperament</td>
<td>no affect</td>
<td>-0.01 to 0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>DM &amp; CP digestibility</td>
<td>2-5% improv.</td>
<td>-0.33 to -0.34</td>
<td>-------</td>
</tr>
<tr>
<td>Enteric methane</td>
<td>lower</td>
<td>0.35 to 0.44</td>
<td>-------</td>
</tr>
<tr>
<td>N &amp; P excretion</td>
<td>lower</td>
<td>0.67 to 0.80</td>
<td>0.38 to 86</td>
</tr>
</tbody>
</table>

Summary of studies from Australia, Canada, Ireland and USA
### Correlations: RFI to other traits

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<th>genetic correlation</th>
</tr>
</thead>
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<tr>
<td>Cow productivity</td>
<td>no affect</td>
<td>0.03</td>
<td>------</td>
</tr>
<tr>
<td>Age at puberty</td>
<td>3-7 days older</td>
<td>0.00 to -0.16</td>
<td>------</td>
</tr>
<tr>
<td>Bull fertility*</td>
<td>slight negative</td>
<td>-0.04 to 0.21</td>
<td>------</td>
</tr>
<tr>
<td>5 Carcass traits</td>
<td>2-4% less fat</td>
<td>-0.07 to 0.27</td>
<td>-0.07 to 0.19</td>
</tr>
<tr>
<td>34 meat quality traits</td>
<td>no affect</td>
<td>-0.09 to 0.12</td>
<td>------</td>
</tr>
<tr>
<td>WBSF**</td>
<td>little affect</td>
<td>-0.05 to -0.01</td>
<td>------</td>
</tr>
</tbody>
</table>

Summary of studies from Australia, Canada, Ireland and USA

* sperm morphology and motility;
** may affect tenderness and texture due to decreased lipid and postmortem protein degradation
Relationship between RFIfat and tenderness in striploin steaks aged for 3 days (Basarab & Aalhus, 2013)

1186 heifers & steers
striploins identified by DNA match to post-weaning blood sample

No or low relationship to 34 meat quality, sensory panel and retail quality traits

$ r_p = -0.09 \text{ to } 0.12 $
Three basic hypotheses: low RFI & low CH$_4$

- **Feed intake driven** - no effect on digestibility or CH$_4$ yield

- **Feed intake driven** – feed intake affects retention time (RT) and rumen volume (RV); longer RT and higher RV increased CH$_4$ emissions.

- **Inherent differences** in feeding behaviours, feed intake and RT result in host-mediated differences in microbial communities
Relationship between CH$_4$ emission and DMI

- determined in respiratory chambers
- Australian ($r^2 = 0.454, P < 0.0001$)
- Canadian ($r^2 = 0.677, P < 0.0001$)
- Adapted from Grainger et al. (2007), J. Dairy Sci.

IPCC 2006:
CH$_4$ production rate = ((DMI, kg DM/day * 18.45 MJ/kg DM) x (6.5%/100))/0.05565 MJ/g CH$_4$
= (10 kg DM/day * 18.45 * 0.065)/0.05565 = 215.5 g CH$_4$/day
Methane production by feed efficiency group
Yuri Montanholi et al. 2011, University of Guelph (n=24)

lower methane emission by 15-30% &
manure production by 15-20%

Okine et al. 2001; Arthur et al. 2002; Nkrumah et al. 2007; Hegarty et al. 2007
Trends in estimated breeding values for residual feed intake (RFI) for High and Low feed efficiency selection lines from 1993 to 1999
Trangie Agricultural Research Centre, NSW, Australia. Adapted from Arthur et al. 2001

Annual rate of response = -0.08 kg DM/day

25 year simulation; annual reduction of 568,100 t CO$_2$e/yr or $8.5$ million/yr in carbon credits assuming $15/t.$

Effects on manure CH$_4$ and N$_2$O, cropping N$_2$O or energy CO$_2$

Alford et al. (2006)
GHG intensity of a baseline and feed efficient herds after 25 years of selection for low RFI – life cycle assessment

Baseline herd - 120 cows

- 23.06 kg CO2e/kg carcass beef

Efficient herd - 120 cows

- 19.82 kg CO2e/kg carcass beef

14% GHG
13% land
Genetic selection for RFI or its component traits

- improve feed efficiency, with no negative affects on cow productivity
- few antagonistic effects on carcass and meat quality
- small negative affects on age at puberty, but manageable
- reduce enteric methane and GHG emissions
Repeatability of $\text{RFI}_{\text{fat}}$ during summer grazing
Total GHG emissions four beef production systems

(CO₂-equivalents, 160 cow-herd assumed.

**Calf-fed, Hormone Free**
Animal GHG emissions = 922,107 kg CO₂e

**Yearling-fed, Hormone Free**
Animal GHG emissions = 1,219,659 kg CO₂e

**Calf-fed, Growth Implanted**
Animal GHG emissions = 928,344 kg CO₂e

**Yearling-fed, Growth Implanted**
Animal GHG emissions = 1,237,082 kg CO₂e

CH₄: 12-17% of global GHG emissions from ruminant production

COWS: largest consumer of poor quality forages, low biological efficiency

Basarab et al. 2012
animals 2, 195-220
Daily feed intake pattern of the 10 highest and 10 lowest heifers for residual feed intake (RFI$_{fat}$)

90% barley silage, 10% barley grain, as fed

Feed intake, kg as fed/hr
Measuring Methane (CH4) using open path laser
Dr. T. Flesch, University of Alberta
Measuring Methane (CH4) using open path laser
Dr. T. Flesch, University of Alberta

20 animals in fresh pasture paddock

Herd Emission Rate (kg CH4 hr⁻¹)

Hour of Day
**Improve DM digestibility by 2-5%**

<table>
<thead>
<tr>
<th></th>
<th>27 beef steers, 2x maintenance; high grain diet</th>
<th>16 rumen-cannulated early lactating Holstein-Friesian heifers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-RFI</td>
<td>+RFI</td>
</tr>
<tr>
<td>DM dig., %</td>
<td>75.33</td>
<td>70.87</td>
</tr>
<tr>
<td>CP dig., %</td>
<td>74.70</td>
<td>69.76</td>
</tr>
</tbody>
</table>

Nkrunmah et al. 2006, JAS 84: 2382

Rius et al. 2012, J. Dairy Sci. 95: 2025

Feeding behaviour and feed intake contributes to animals variation in ruminal retention time and digestibility decrease metabolizability of the diet and increased heat increment of feeding at high levels of intake above maintenance.