SMARTER – Which novel traits to improve feed efficiency?

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Why to improve feed efficiency?

Human population is increasing → higher demand in animal proteins

Livestock production has to increase BUT some limits have to be set on
- the proportion of crop dedicated to livestock (feed-food competition)
- environmental impacts of livestock production (GHG emissions, soil pollution,...)

→ Improvement of resource use efficiency
How to estimate feed efficiency?

Feed intake
- Individual trough
- Automatic feeders
- Metabolic crates

Maintenance
- Body weight

Production
- Milk, fat and protein yields
- Average daily gain
- Body composition (ultrasound, CT scan,...)

Loss estimates
- Metabolic crates (urine and faeces)
- GHG emissions
- Activity

Feed Conversion Ratio (FCR):
\[
\text{FCR} = \frac{\text{Feed intake}}{\text{Production}}
\]

Residual Feed Intake (RFI):

\[
\text{True feed intake} - \text{theoretical feed intake}
\]

Theoretical feed intake (g)

Efficient individuals

Unefficient individuals

True feed intake (g)

1400 1600 1800 2000 2200 2400 2600

1400 1600 1800 2000 2200 2400 2600
### How to improve feed efficiency?

#### Feeding strategies

**Selection**: FCR and RFI are heritable traits.

<table>
<thead>
<tr>
<th>Species</th>
<th>Breeds</th>
<th>$h^2$ RFI</th>
<th>$h^2$ FCR</th>
<th>references</th>
<th>protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meat sheep</strong></td>
<td>Targhee</td>
<td>0.26 ± 0.07</td>
<td></td>
<td>Snowder and Van Velck, 2003</td>
<td>Post-weaning period</td>
</tr>
<tr>
<td></td>
<td>Composite population</td>
<td>0.11 ± 0.05</td>
<td></td>
<td>Cammack et al., 2005</td>
<td>Post-weaning period</td>
</tr>
<tr>
<td></td>
<td>(Columbia, Hampshire, Suffolk)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Merino (from post-weaning to adult)</td>
<td>From 0.07 to 0.29</td>
<td>(± 0.08)</td>
<td>Paganoni et al., 2017</td>
<td>Post-weaning, hoggets and adults</td>
</tr>
<tr>
<td></td>
<td>New Zealand maternal breed</td>
<td>0.46 ± 0.13</td>
<td></td>
<td>Johnson et al., 2018</td>
<td>Post-weaning period under a concentrate diet</td>
</tr>
<tr>
<td></td>
<td>Romane</td>
<td>0.45 ± 0.08</td>
<td>0.30 ± 0.08</td>
<td>Tortereau et al., 2020</td>
<td>Post-weaning period</td>
</tr>
<tr>
<td><strong>Dairy sheep</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Dairy goats</strong></td>
<td>mixed-breed (Saanen, Alpine, and Toggenburg)</td>
<td></td>
<td></td>
<td>Desire et al., 2017 (feed intake : $h^2$±0.25)</td>
<td></td>
</tr>
</tbody>
</table>
How to improve feed efficiency?

Feeding strategies

Selection: FCR and RFI are heritable traits. It requires feed intake to be recorded.

Forage and concentrate automatic feeders

Individual troughs

with forage

with forage or concentrate

These devices are too expensive to be widely spread in breeding companies

→ Proxies for feed intake (and/or feed efficiency) have to be identified
Which novel traits for feed efficiency improvement?

These new traits must be relevant, easy to measure and cheap enough to be used in a large number of animals.

Non-invasive traits
- body weights
- body composition (ultrasound)
- body condition score
- body measurements (chest width, depth)
- milk yield and composition
- gas emissions (\(\text{CH}_4, \text{CO}_2\))

From milk samples:
- MIR spectra

From faecal samples:
- NIR spectra

Invasive traits
From blood samples:
- genotypes
- metabolites (targeted or untargeted)

From rumen samples:
- microbiota
- metabolites
- fatty acids

In italics are traits that can be considered for research purposes only

Breeding and feeding practices
Health status
Climatic data indoor /outdoor (\(\text{T}^\circ\), humidity,...)
First results – dairy sheep

In Greece (AUTH) – 1st records of targeted metabolites
N=30 dairy ewes from 4 breeds
Lacaune, Assaf, Chios and Frizarta

Objective = identification of body composition traits (US) as potential predictors of energy balance.

Negative energy balance status
\[ \beta\text{-HB} \geq 0.8 \text{ mmol/L}, \text{ NEFA} \geq 0.3 \text{ or } 0.7 \text{ mmol/L} \]

Blood biochemical analysis (= targeted analyses)
- Beta-hydroxy-butyrate
- Non-esterified fatty acids
- TP
- Albumin
- BUN

In Spain (UniLéon) – 1st records of feed intake, ~1 year after nutritional challenge
N=40 dairy ewes (breed = Assaf)

Objective = determine the effects of a severe protein restriction of ewe replacement lambs during their pre-puberal stage on their feed efficiency in their adult life (as dairy ewes).

High variability in voluntary feed intake among ewes
SMARTER

Which novel traits to improve feed efficiency?

2021 ICAR - Leeuwarden

First results - dairy goats

INRAE

In France (INRAE) : 1st records of feed intake (concentrate) on goats divergently selected on longevity

→ additional information on feeding behaviour

<table>
<thead>
<tr>
<th>Trait</th>
<th>N</th>
<th>Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LGV-/LGV+</td>
<td>LGV-</td>
<td>LGV+</td>
</tr>
<tr>
<td>Nb visits / day</td>
<td>18 / 29</td>
<td>15.8</td>
<td>17.4</td>
</tr>
<tr>
<td>Intake per visit (kg)</td>
<td>18 / 29</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Intake per day (kg)</td>
<td>18 / 29</td>
<td>0.64</td>
<td>0.63</td>
</tr>
<tr>
<td>Intake duration per day (s)</td>
<td>18 / 29</td>
<td>551</td>
<td>678</td>
</tr>
<tr>
<td>Intake speed per day (kg/hrs)</td>
<td>18 / 29</td>
<td>4.72</td>
<td>4.40</td>
</tr>
</tbody>
</table>

In Scotland (SRUC)

Automatic feeders developed at INRAE
First results – meat sheep

In France (INRAE): divergent selection on residual feed intake

Phenotypic results for lambs fed ad libitum with concentrate, in the 3rd generation of selection (2019 and 2020):

<table>
<thead>
<tr>
<th>Trait</th>
<th>RFI+ (n=79)</th>
<th>RFI- (n=90)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily feed intake (g/d)</td>
<td>2111 ± 240</td>
<td>1916 ± 195</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>RFI (g/d)</td>
<td>75 ± 130</td>
<td>-66 ± 117</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>End-test Backfat thickness (mm)</td>
<td>5.76 ± 0.97</td>
<td>5.76 ± 0.91</td>
<td>0.73</td>
</tr>
<tr>
<td>End-test Muscle depth (cm)</td>
<td>2.81 ± 0.24</td>
<td>2.76 ± 0.20</td>
<td>0.34</td>
</tr>
<tr>
<td>End-test Body weight (kg)</td>
<td>55.16 ± 6.23</td>
<td>53.41 ± 5.43</td>
<td>0.0003</td>
</tr>
<tr>
<td>ADG (g/d)</td>
<td>334 ± 64</td>
<td>327 ± 60</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Δ ADFI= 195 g/d
Δ RFI= 1.9σg

Due to the 2020 serie mainly

Differences observed on:
- plasmatic amino acids
- microbiota composition

In Norway (NSG): first records of GHG emissions, and estimations of genetic parameters

Single trait animal model
1,624 phenotyped animals; 16,092 animals in pedigree

Fixed class effect: flock*group, age
Fixed regressions: Live weight 1, minutes since off feed

1) Regression on weight included for traits 1, 2, 4 and 5.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Heritability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) gram CH₄ per hour</td>
<td>0.181</td>
</tr>
<tr>
<td>2) gram CO₂ per hour</td>
<td>0.455</td>
</tr>
<tr>
<td>3) gram CH₄ per hour / kg live weight</td>
<td>0.141</td>
</tr>
<tr>
<td>4) gram CH₄ per hour / gram CO₂ per hour</td>
<td>0.263</td>
</tr>
<tr>
<td>5) gram CH₄ per hour / (gram CH₄ per hour + gram CO₂ per hour)</td>
<td>0.262</td>
</tr>
<tr>
<td>6) Live weight</td>
<td>0.317</td>
</tr>
</tbody>
</table>
Conclusions

Many fine phenotypes collected in experimental farms to:
- dissect the biology underlying feed efficiency
- identify proxies of feed intake/feed efficiency

Use these proxies in larger populations (commercial populations) to:
- Estimate genetic parameters
- Estimate the feasibility of a routine collection of these new traits
- Include feed efficiency in selection programs