12th World Congress on Genetics Applied to Livestock Production
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Session 09. Challenges
Resource allocation and genetics of feed intake and efficiency (1)

# Feed efficiency and resource allocation trade-offs: theory, evidence and prospects

**Frédéric DOUHARD, Rachel RUPP, and Hélène GILBERT**

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Genetics, Physiology and Livestock Systems

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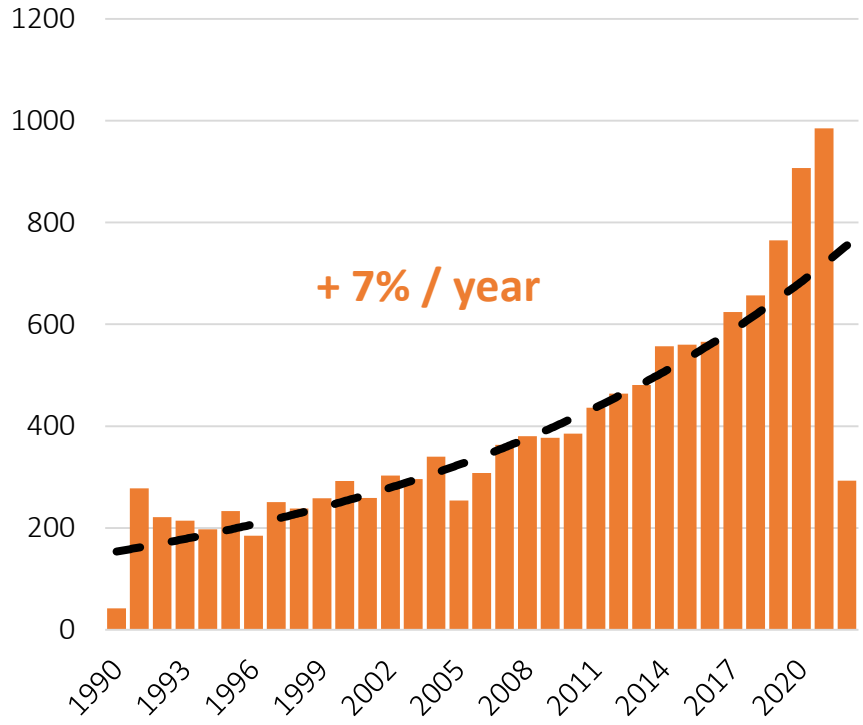
*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement n°772787*

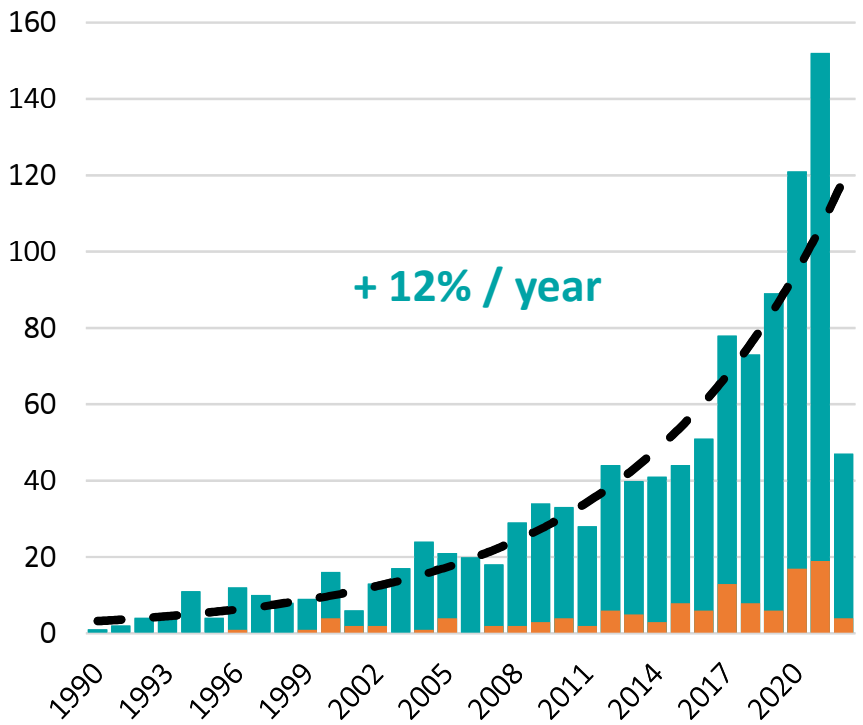
# Introduction

## Feed efficiency and robustness: two research areas that tend to develop separately

Results of number articles on Web of Science in Category  Agriculture Dairy Animal Science




TOPIC = Feed efficiency  OR Residual feed intake




~ 1/10 mentioning efficiency

TOPIC = Robustness OR Resilience OR Trade-off* OR Resource allocation

# Introduction

## Feed efficiency and robustness: two perspectives on livestock?

| | Feed efficiency | Robustness |
|---|---|---|
| Production strategy | Less feed per amount of product under controlled conditions | Produce when feed quantity or quality can drop unexpectedly |
| Exemple of related traits | RFI;<br>Feed conversion ratio | Survival; Longevity<br>Disease resistance |
| Range of constraints | Narrow, focus on feed | Large, including feed, disease, biophysical conditions … |
| Production intensity | Moderate to high | Low to moderate |
| Environmental impacts | Minimise negative impacts on the environment | Minimize overall reliance on inputs<br>Provide ecosystem services |
| Global scenario | Sustainable intensification | Agroecology |

A framework needed to predict the consequences of breeding for feed efficiency or robustness in contrasting environments

# Introduction

## The resource allocation theory as a general framework to adress robustness & efficiency

J. Anim. Breed. Genet. 110/3 (1993) 161–170
© 1993 Verlag Paul Parey, Hamburg und Berlin
ISSN 0931–2668

*Ms. received: 15. 1. 1993*

*Agriculture and Forestry, The University of Melbourne, Parkville, Vic., 3052, Australia*

**Quantitative genetics and evolution:
Is our understanding of genetics sufficient to explain evolution?**

By R. G. Beilharz, B. G. Luxford and J. L. Wilkinson

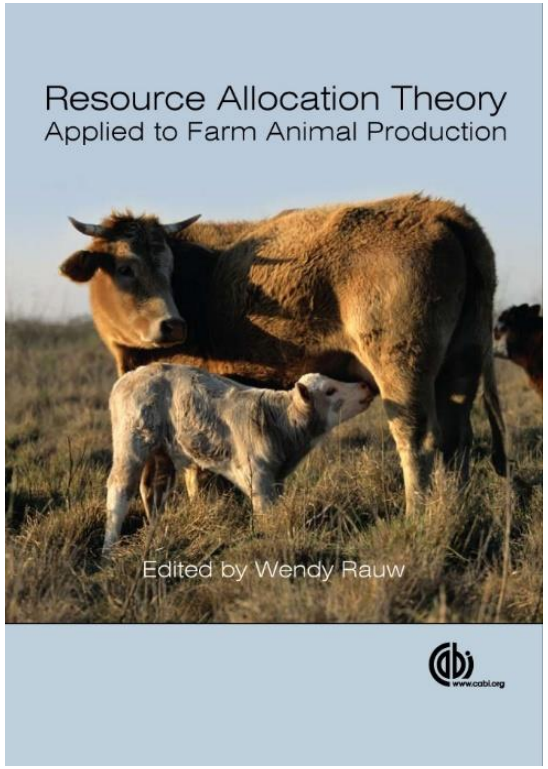
ELSEVIER

Livestock Production Science 56 (1998) 15–33

LIVESTOCK PRODUCTION SCIENCE

Undesirable side effects of selection for high production efficiency in farm animals: a review

W.M. Rauw[a,*], E. Kanis[b], E.N. Noordhuizen-Stassen[c], F.J. Grommers[c]



# Introduction

## The resource allocation theory as a general framework to adress robustness & efficiency

### An evolutionary framework

Cody 1966; Williams 1966




### applied to animal breeding

Beilharz et al. 1993; Rauw et al. 1998

# Introduction

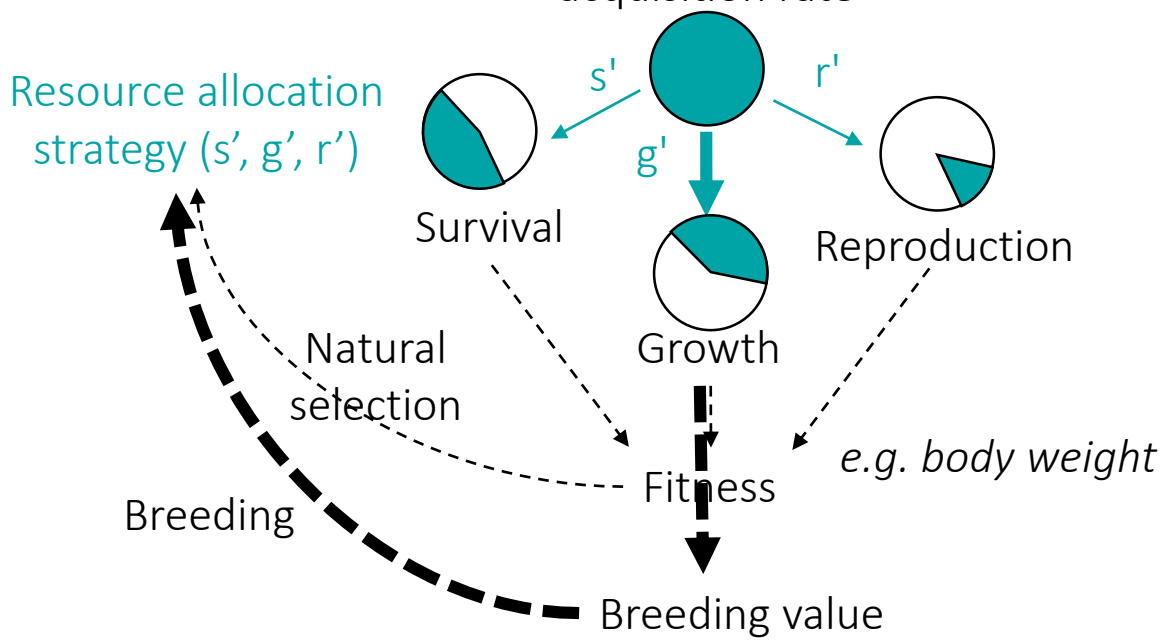
## The resource allocation theory as a general framework to adress robustness & efficiency

- Consequences when feed resources drop?
  → **Robustness**
- To what extent increased production is supported by increased intake vs. increased allocation?
  → **Efficiency**

Current evidence for energy allocation trade-offs in livestock?

applied to animal breeding

Beilharz et al. 1993; Rauw et al. 1998



# Outline

- What is the evidence for energy allocation trade-offs?

  i. A global approach based on lines/breeds comparisons in livestock and related laboratory model species fed *ad libitum*

  ii. A case study in meat sheep focusing on trade-off between parasite resistance and feed efficiency

- Future directions


PERSPECTIVE | Open Access

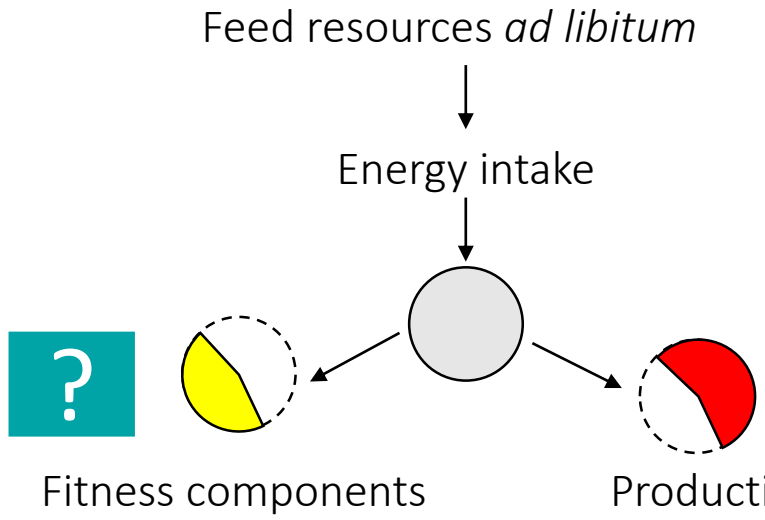
**How much energetic trade-offs limit selection? Insights from livestock and related laboratory model species**

Frédéric Douhard, Mathieu Douhard, Hélène Gilbert, Philippe Monget, Jean-Michel Gaillard, Jean-François Lemaître

First published: 11 November 2021 | https://doi.org/10.1111/eva.13320

# Global approach based on breed or lines comparisons

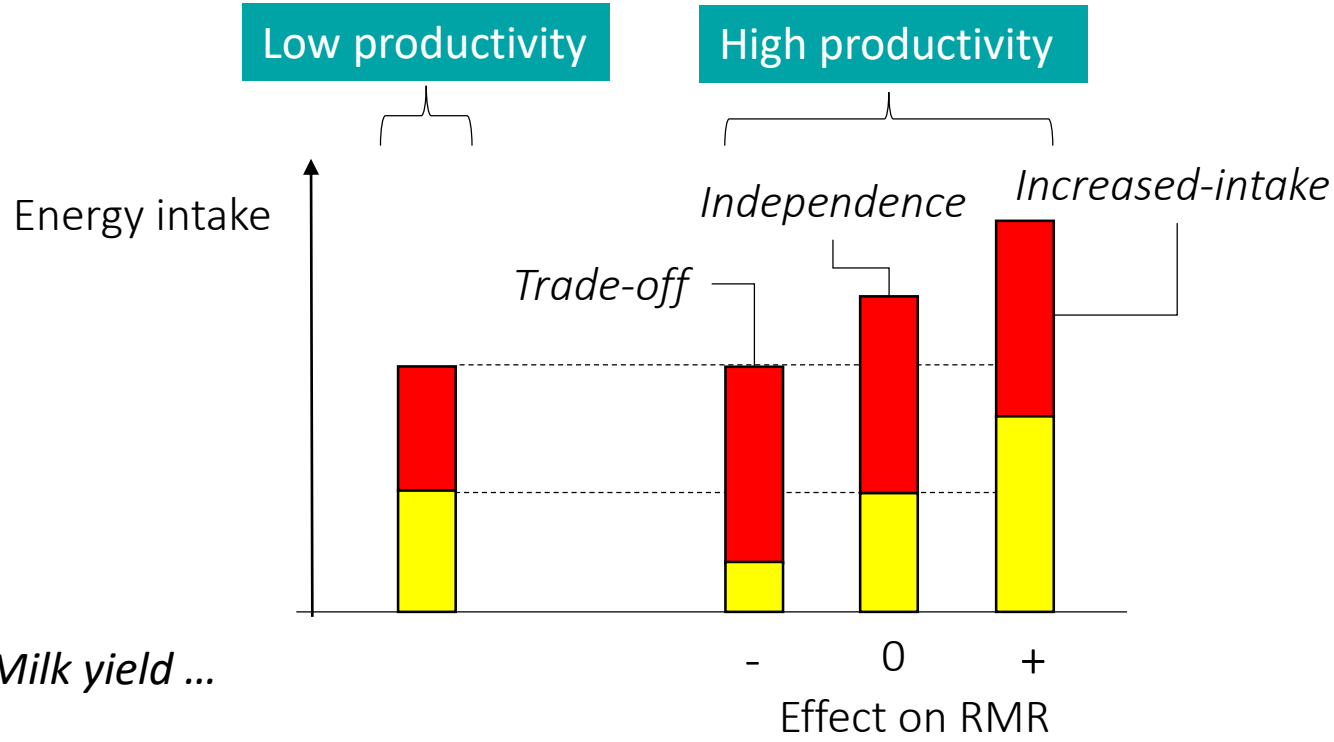
## (1) energy allocation constraints when selecting for productivity?




**Maintenance**
*Resting metabolic rate (RMR)*

**Biosynthesis**
*Body weight, Egg yield, Milk yield …*

Selection on productivity

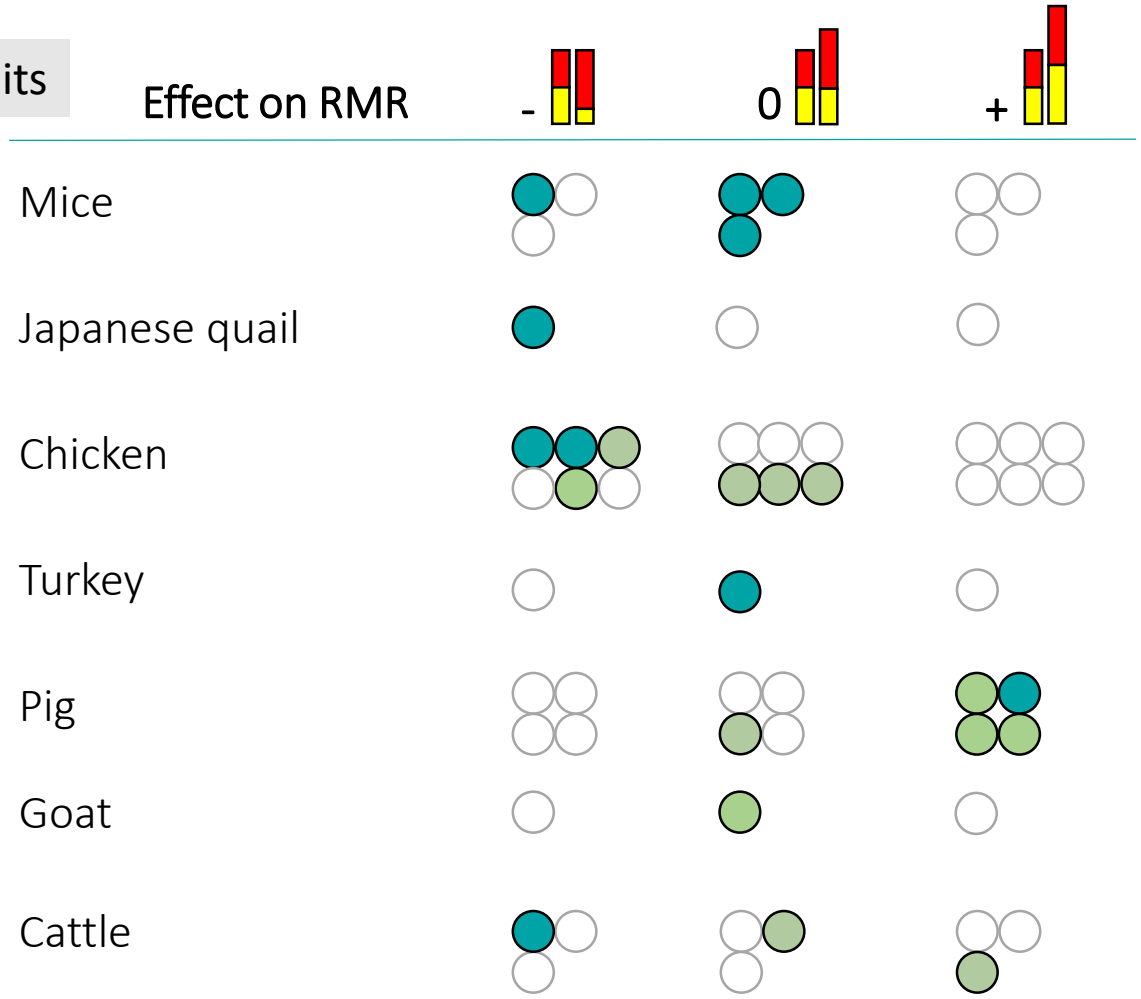



Survey of RMR comparisons between breeds/lines
- N = 19 with contrasting growth
- N = 6 with contrasting reproduction

# Global approach based on breed or lines comparisons

## (1) energy allocation constraints when selecting for productivity?

Growth traits




- RMR adjusted for allometry effect (dividing by $BW^{0.75}$ or using BW as covariate)
- Different methods to measure RMR (indirect calorimetry, comparative slaugther technique)
- Most RMR estimates at single age/stage and mostly in young animals

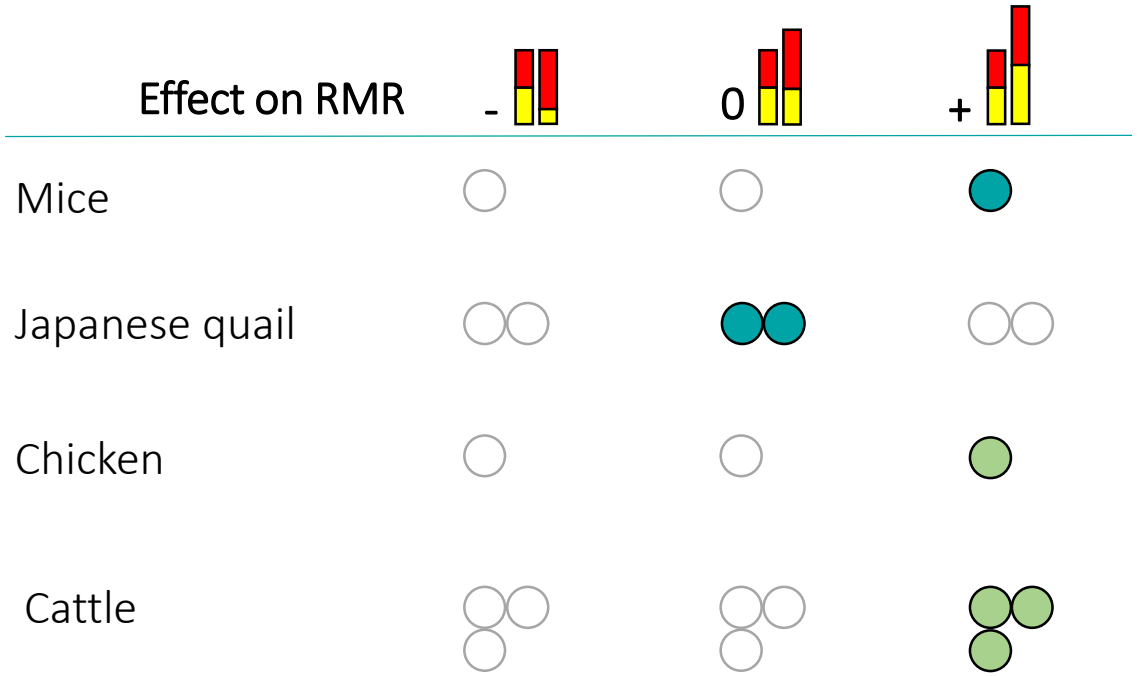
Selection experiments

Comparisons of independent lines or breeds

# Global approach based on breed or lines comparisons

## (1) energy allocation constraints when selecting for productivity?

### Maternal reproductive outputs traits

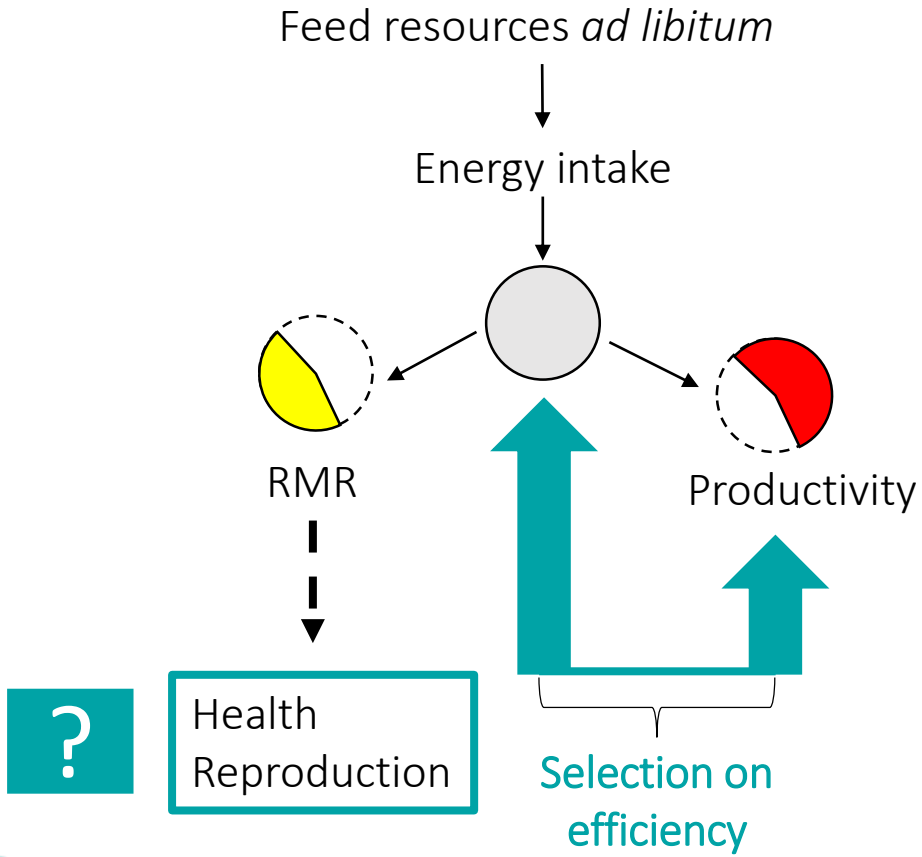


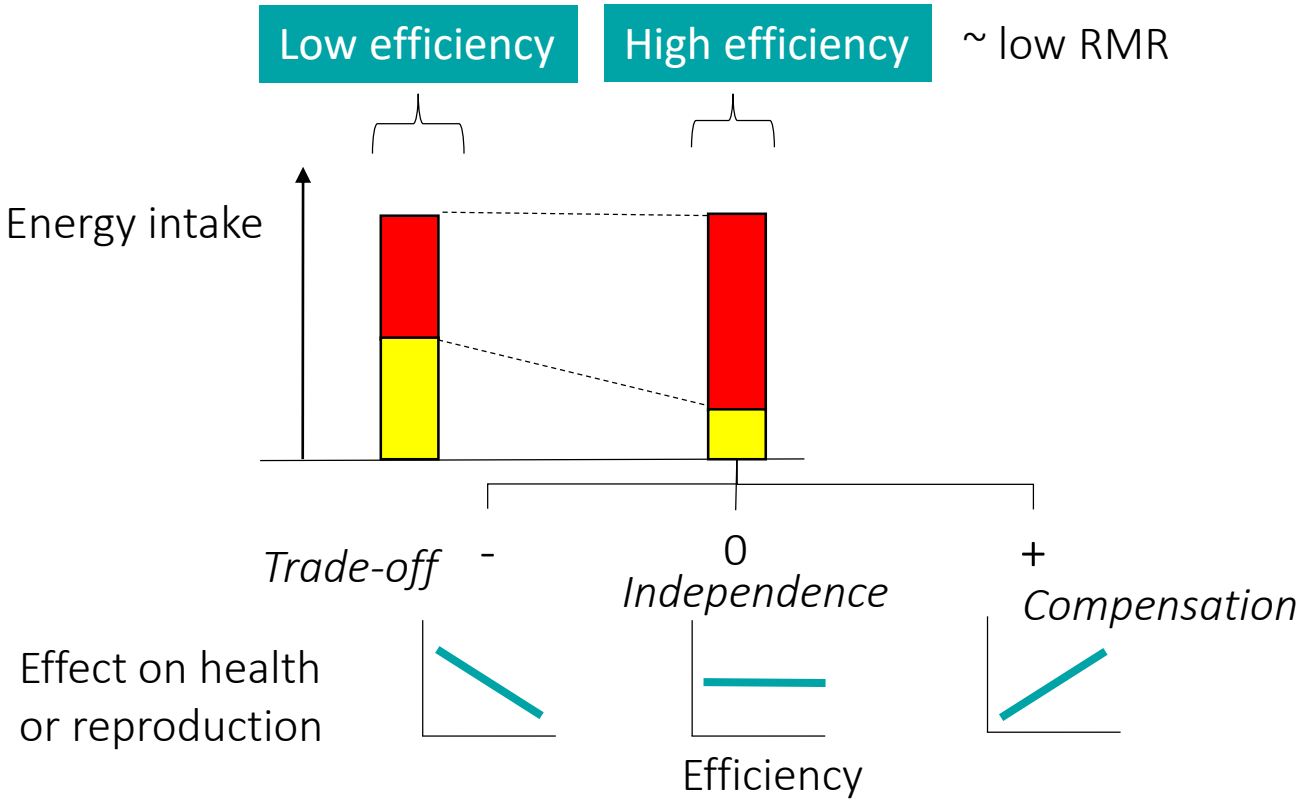

- Selection experiments
- Comparisons of independent lines or breeds

"Increased-intake" hypothesis
→ consistent with increase in intake and metabolic machinery during female reproduction

# Global approach based on breed or lines comparisons

## (2) consequences of energy allocation on health and/or reproduction?

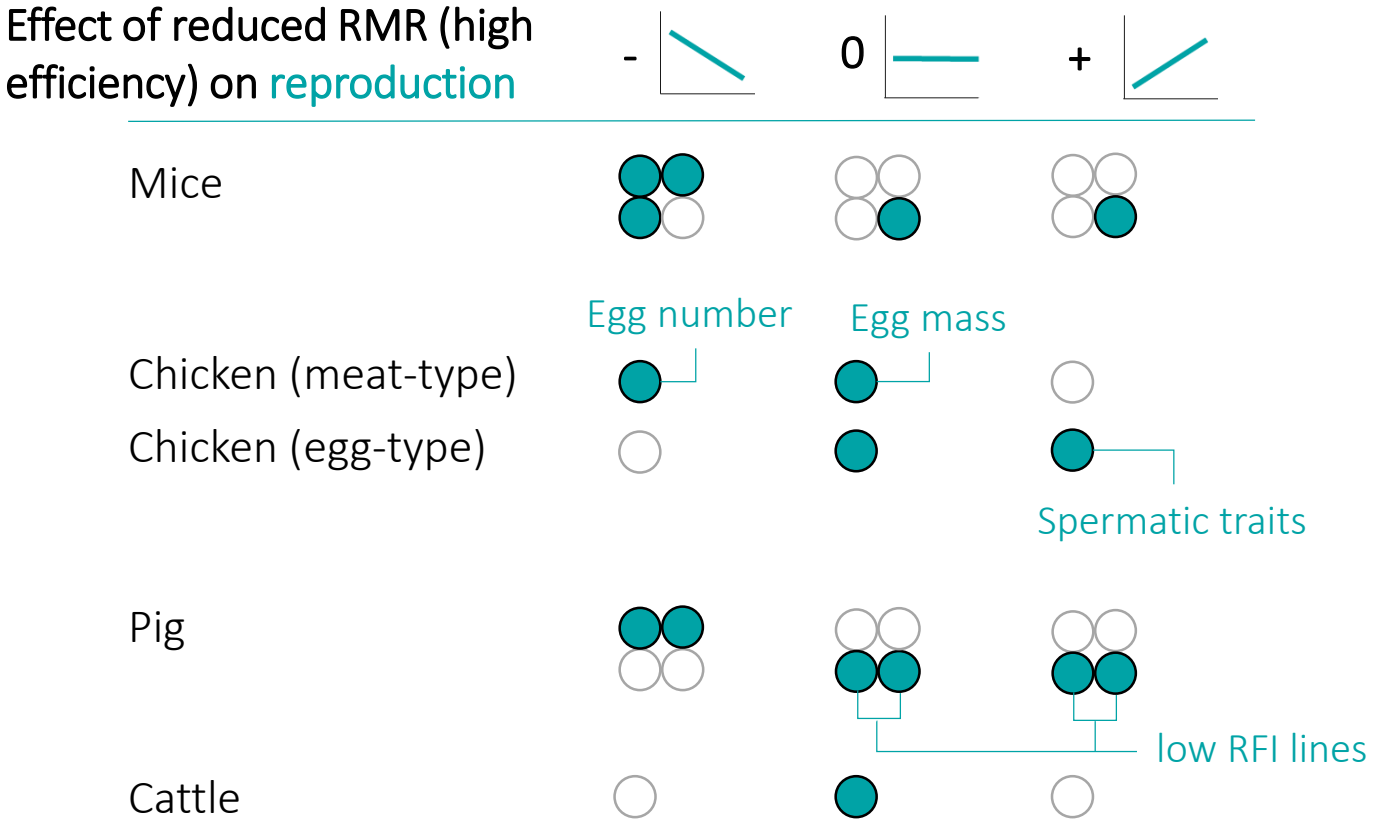



Survey of comparisons of health or reproduction traits between lines selected for high vs. low feed efficiency (N = 13)

# Global approach based on breed or lines comparisons

## (2) consequences of energy allocation on health and/or reproduction?

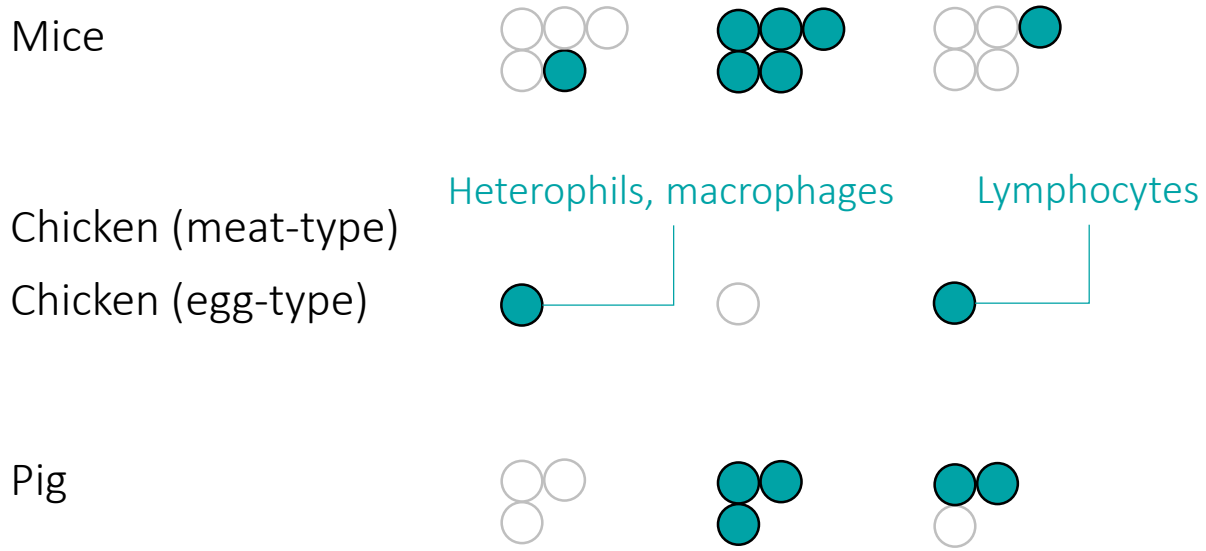



- Mostly female traits (litter size, egg number, calf mass at weaning …); few male traits
- Some components of reproduction traits differently affected
- Higher feed efficiency → Lower feed intake but not always lead to lower reproductive outputs (e.g. in pig low RFI lines with higher body reserves mobilization during lactation)

# Global approach based on breed or lines comparisons

## (2) consequences of energy allocation on health and/or reproduction?

Effect of reduced RMR (high efficiency) on health


- Survival, immune responses, oxidative stress
- Some components of health traits differently affected
- Some traits particularily challenging to assess (e.g. oxidative stress → multiple markers, tissue-dependence, age/stage dependence …)

# Main results

Consequences of breeding for feed efficiency or robustness look much more difficult to predict than one could anticipate from the energy allocation framework alone

- Few evidence that trade-offs between production traits and other fitness-related traits can be underpinned by changes in energy allocation

- Negative consequences of a reduced energy allocation to maintenance on health or reproduction are unclear

→ Focus on a particular aspect of energy allocation to maintenance that can be recruited under challenging conditions

- What is the evidence for energy allocation trade-offs?

  i. A global approach based on lines/breeds comparisons in livestock and related laboratory model species fed *ad libitum*


PERSPECTIVE Open Access

How much energetic trade-offs limit selection? Insights from livestock and related laboratory model species

Frédéric Douhard | Mathieu Douhard | Hélène Gilbert | Philippe Monget | Jean-Michel Gaillard | Jean-François Lemaître

11 November 2021 | https://doi.org/10.1111/eva.13320

ii. A case study in meat sheep focusing on trade-off between parasite resistance and feed efficiency


- Limitations and future directions

# Case study in meat sheep

## (1) A trade-off between feed efficiency and resistance to parasites?

### Experimental design

Romane meat sheep flock, INRAE experimental unit (Bourges, France)

Lines divergently selected on feed efficiency based on concentrates (efficient = RFI- vs. inefficient = RFI+)

Tortereau et al. 2020. Animal

Lines divergently selected on resistance to artificial infection with *Haemonchus contortus* (Resistant = R vs. Susceptible = S)

Sallé et al. 2021. Evol. App.

*Hæmonchus contortus*

3,500 larvae / animal

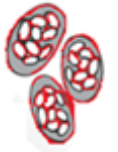
treatment

10,000 larvae / animal

treatment

Naïve female lambs (4-5 months of age)

Infection 4 weeks | 2 weeks | Infection 5 weeks

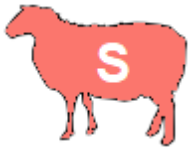


Parasites fecal egg count (**FEC**)

RFI during 2nd infection



| | RFI+ | RFI- |
|---|---|---|
| INFECTED | 30 | 29 |
| CONTROL | 16 | 15 |

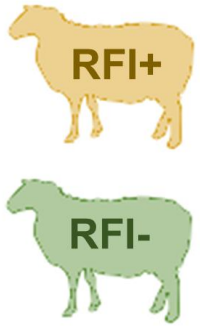



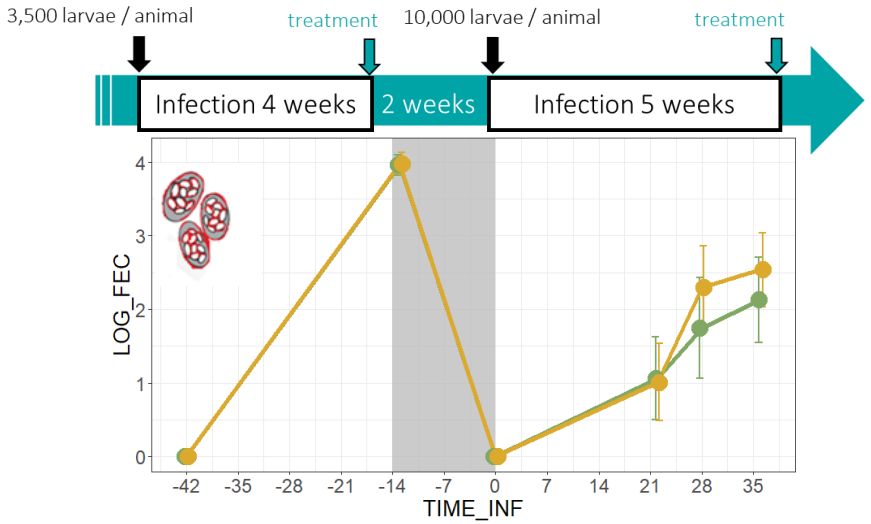

| | R | S |
|---|---|---|
| INFECTED | 31 | 30 |
| CONTROL | 15 | 15 |

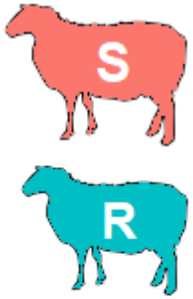
# Case study in meat sheep

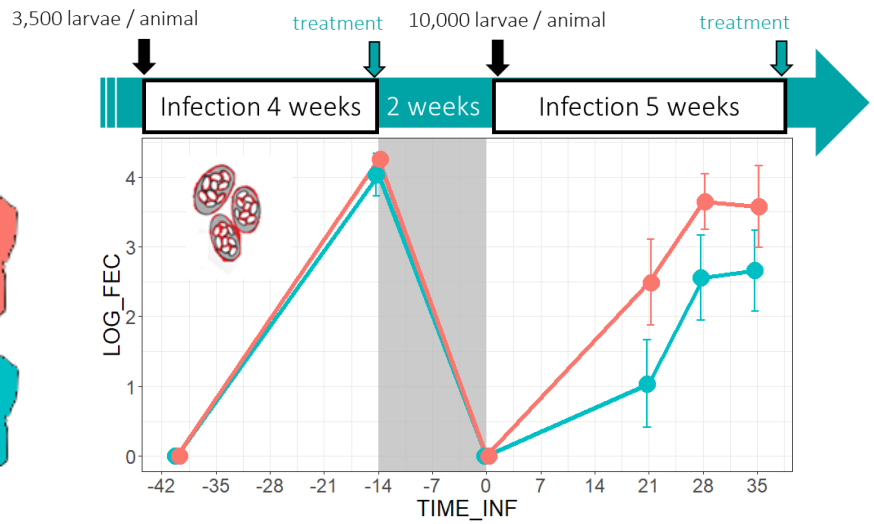
## (1) A trade-off between feed efficiency and resistance to parasites?

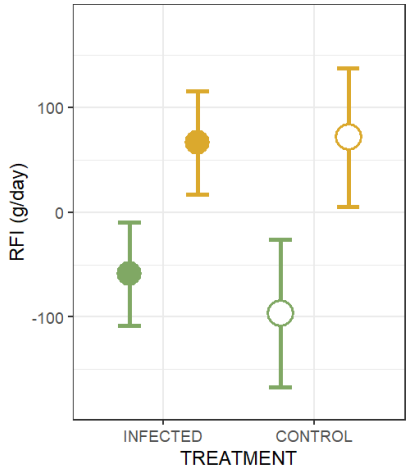
Results




Similar results in Urugayan sheep lines ←

Ferreira et al. 2021 Anim. Prod. Sci.

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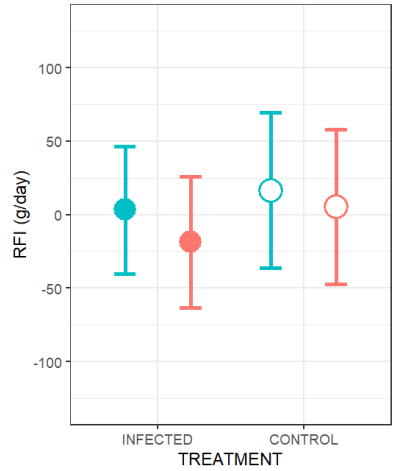
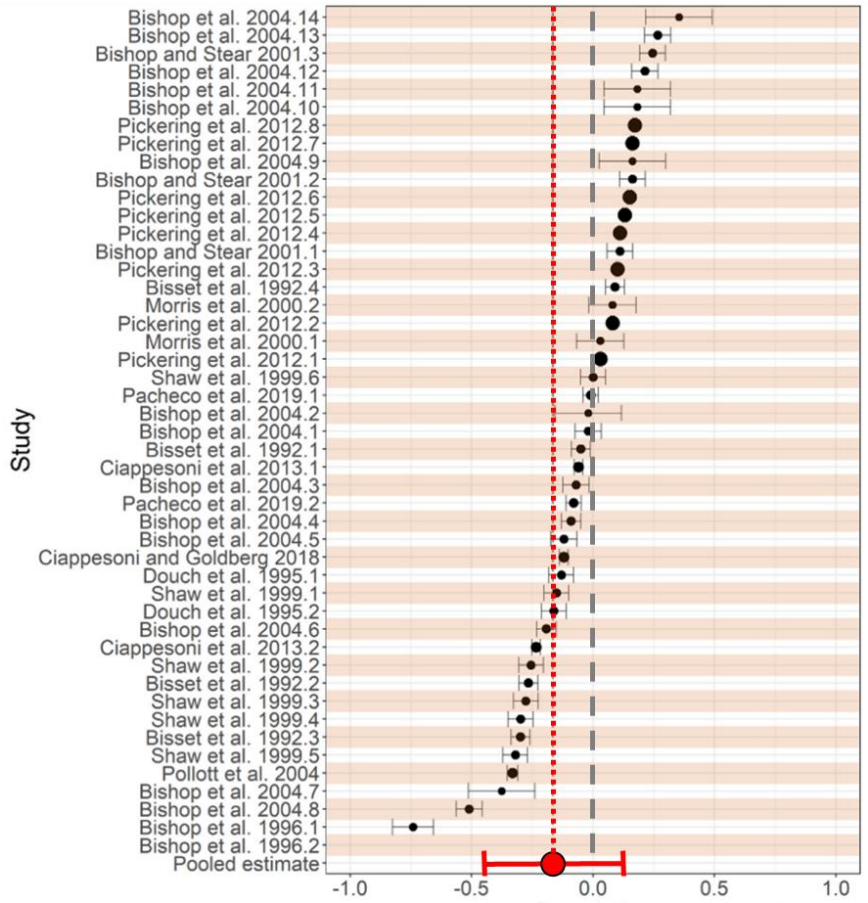


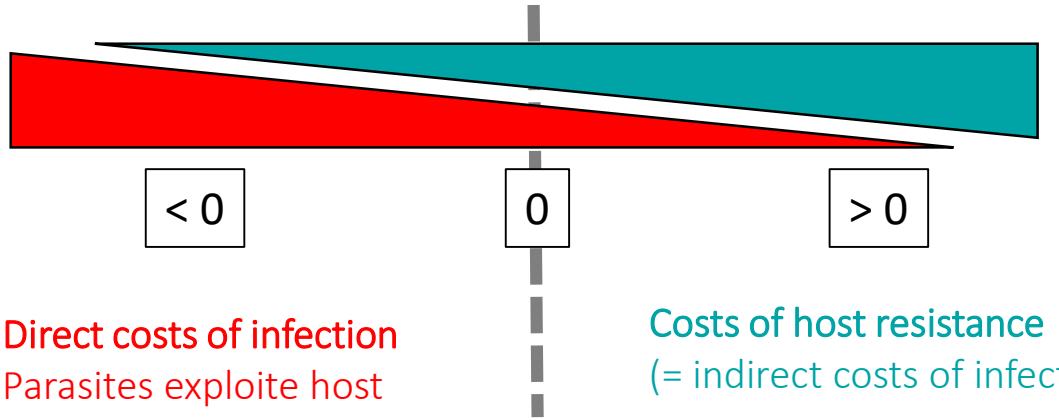
# Case study in meat sheep

## (2) Is there a cost of resistance after all?

$r_G$ FEC | BW

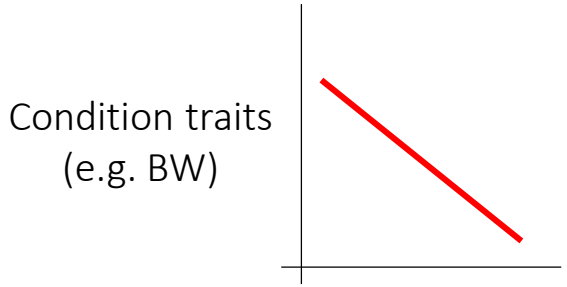



Mucha et al. 2022. Animal




**Direct costs of infection**
Parasites exploite host resources

**Costs of host resistance**
(= indirect costs of infection)




→ Importance of repeated-measures to account for direct infection costs (residual correlation $r_e$)

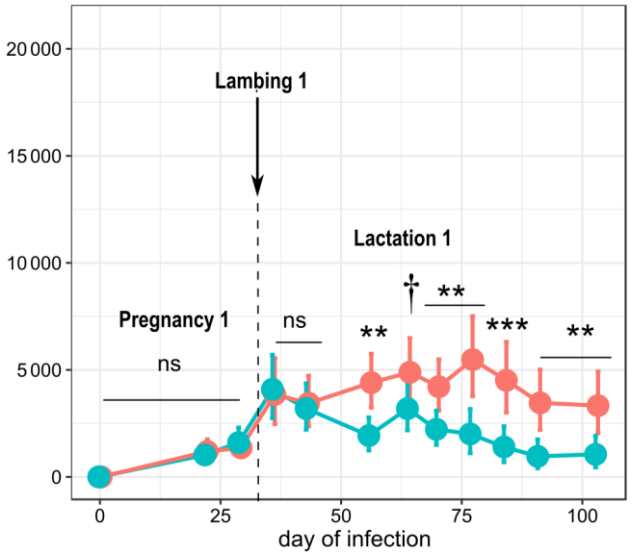
# Case study in meat sheep

## (2) Is there a cost of resistance after all?

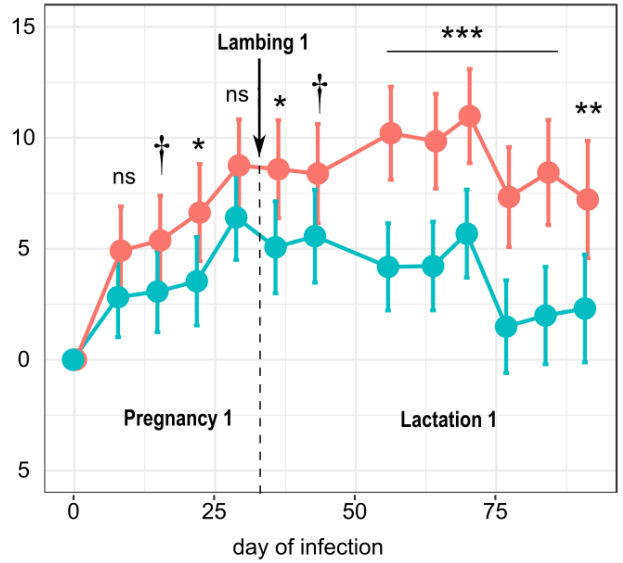
→ Infection of R and S ewes during the periparturient period when allocation to immunity may be constrained


2 infection traits

**FEC** (eggs/g)

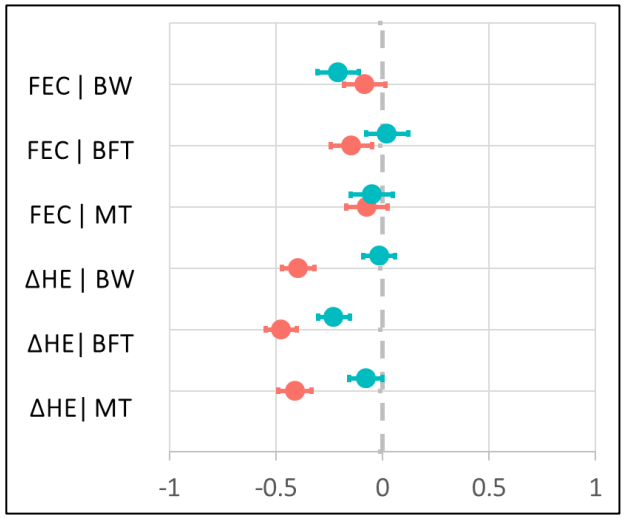



Δ blood haematocrit (**ΔHE**, %)

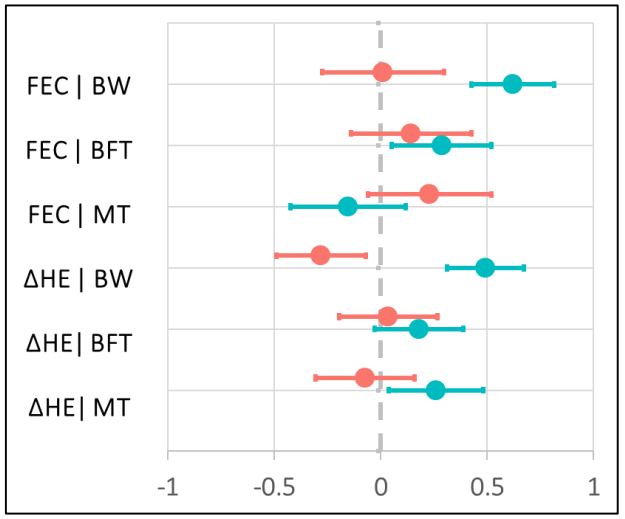



Correlations infection | condition

$r_e$




$r_{ind}$




Direct infection costs ($r_e < 0$) tend to prevail within-individual

Some evidence for resistance costs ($r_{ind} > 0$) among-individual

+ 3 condition traits: **BW**, Muscle Thickness (**MT**), Backfat thickness (**BFT**) → without apparent differences between lines

Douhard et al. *in press*. Evol. App.

# Main results

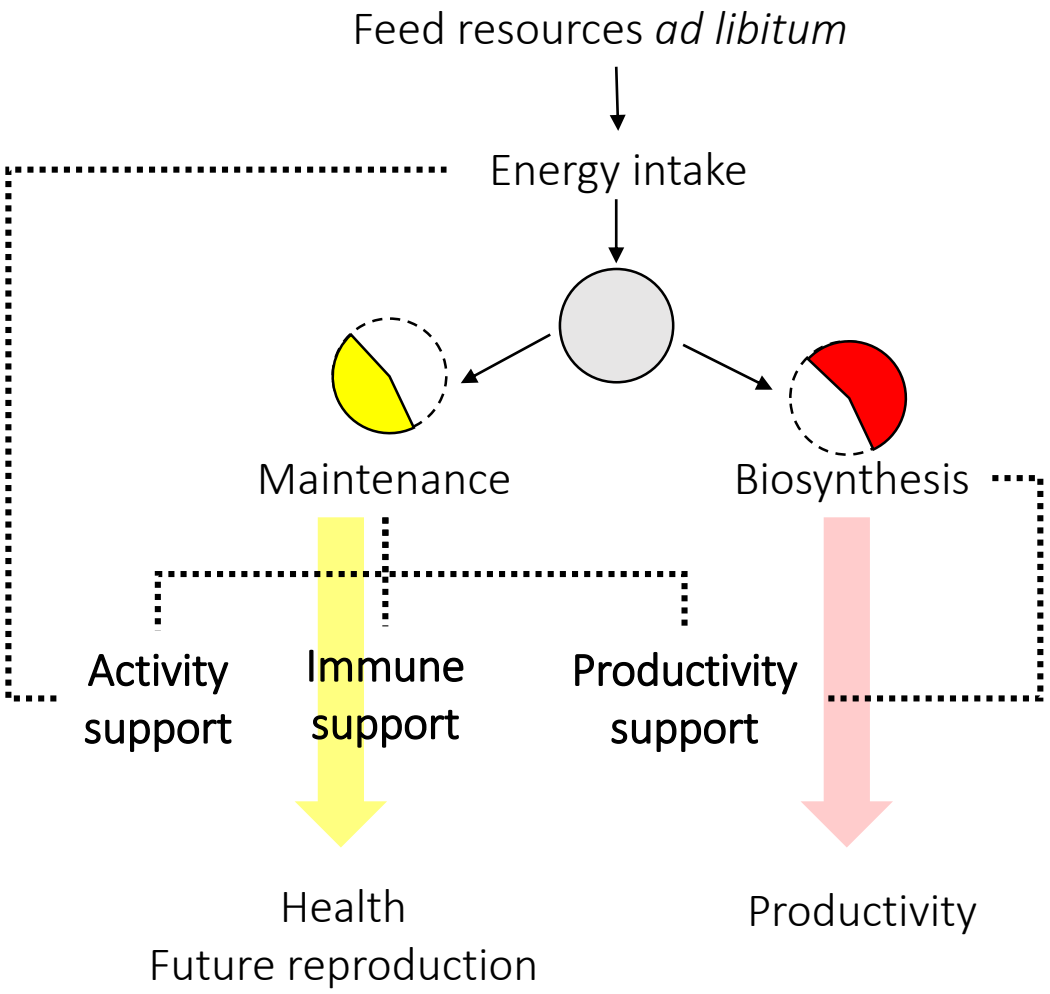
Consequences of breeding for feed efficiency or robustness look much more difficult to predict than one could anticipate from the energy allocation framework alone

- Few evidence that trade-offs between production traits and other fitness-related traits can be underpinned by changes in energy allocation
- Negative consequences of a reduced energy allocation to maintenance on health or reproduction are unclear
- Our case study neither indicates that selection for a particular health component (parasite resistance) deteriorates feed efficiency during a challenge, nor *vice-versa,* but costs may occur in particular life stage and may be challenging to detect

→ Direct or mechanistic support for the energy allocation framework applied to livestock still needs to be explored

# Future directions

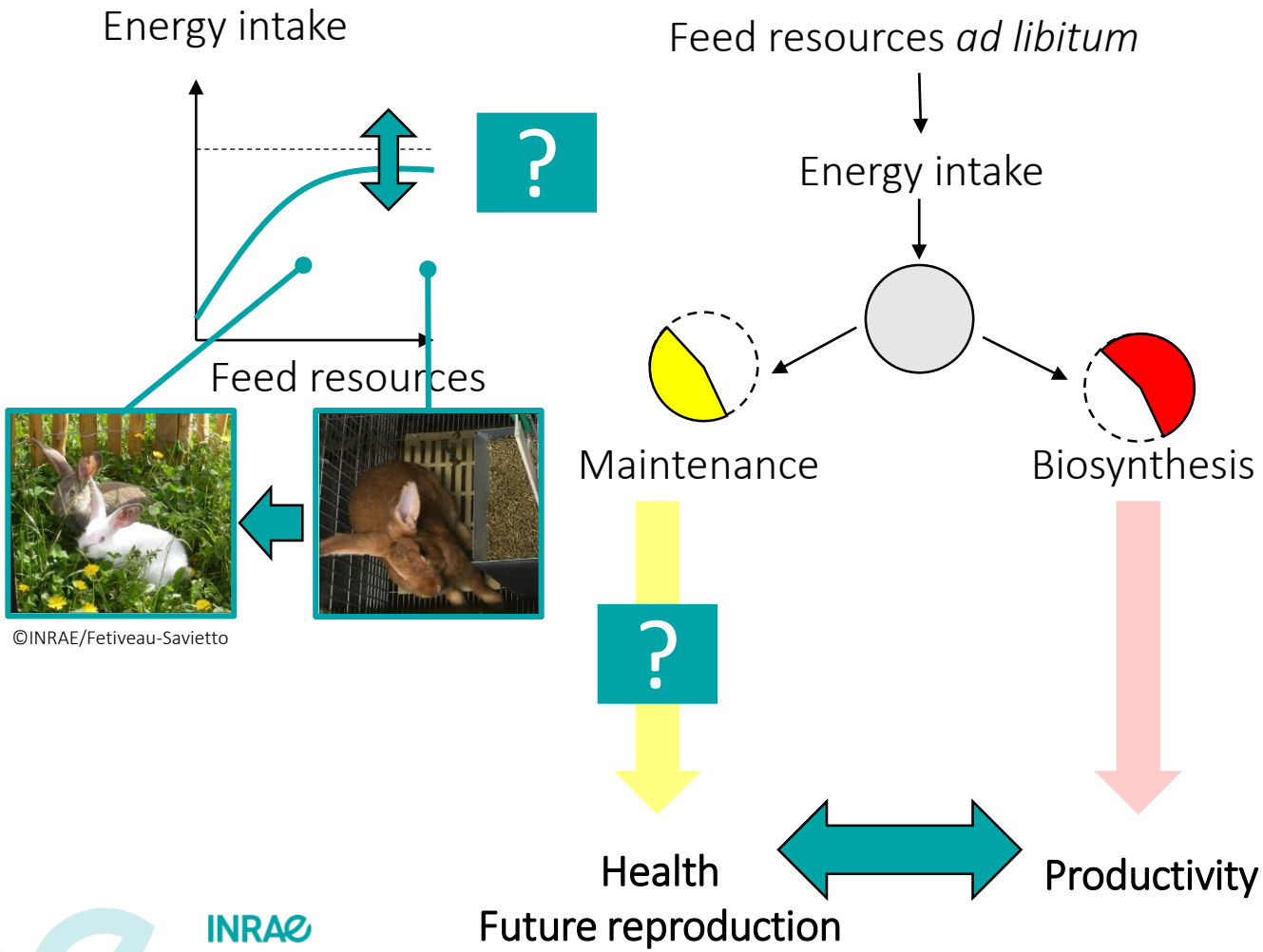
## Energy allocation to maintenance is difficult both to estimate and to interpret




- RMR or feed efficiency: two traits moderately heritable but challenging to measure accurately
- RMR or feed efficiency is more than one trait
  - Multiple processes
  - Interdependency between allocation components, between acquisition and allocation
- Can leads to context-dependent selection (e.g. selection for activity in indoor feeding systems vs. rangelands)

# Future directions

## Which aspects of energy supply and expenditure constrain selection?

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- Selective increase in productivity may not always be accounted for through higher intake
  - Physiological limits to feed intake
  - Environmental limits to feed intake

- Relation between RMR and health and reproduction traits is puzzling in general

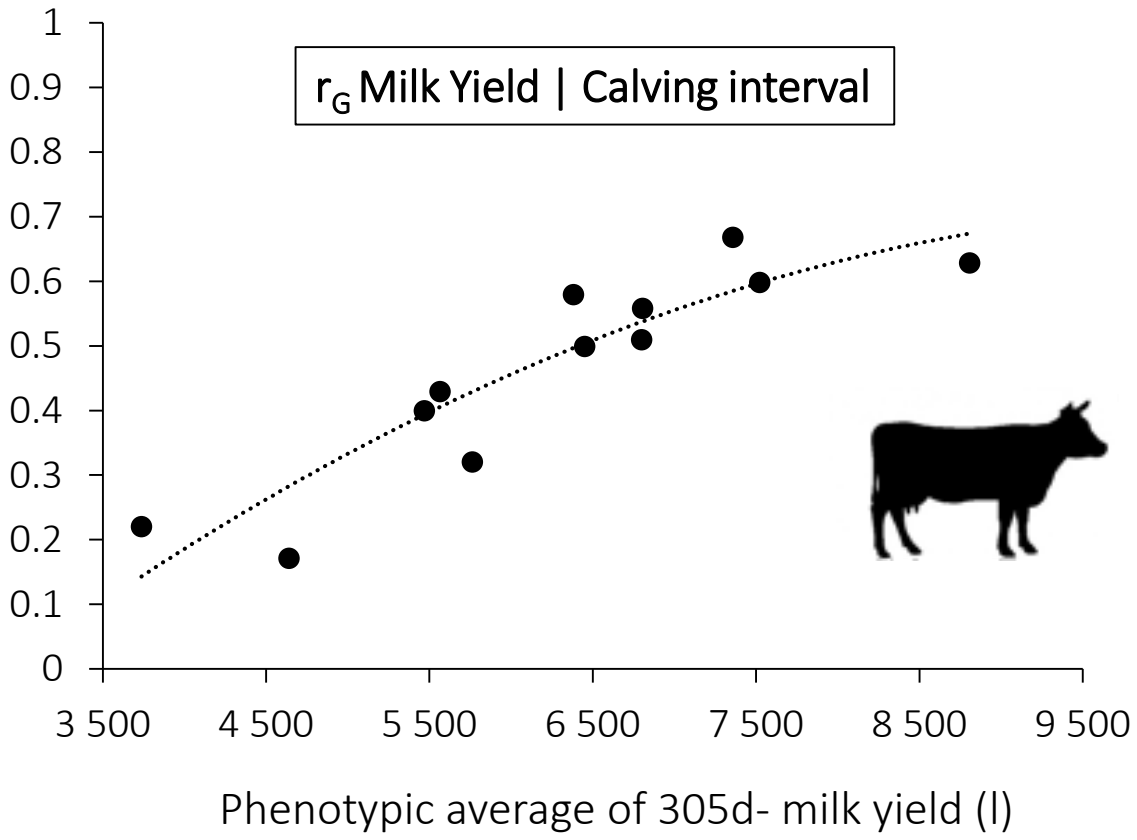
  Glazier 2015. Biol. Rev.
  Arnold et al. 2021. J. Comp. Phys. B

- Other mechanisms than resource allocation may lead to trade-offs between health/reproduction and productivity

# Future directions

## Which aspects of energy supply and expenditure constrain selection?

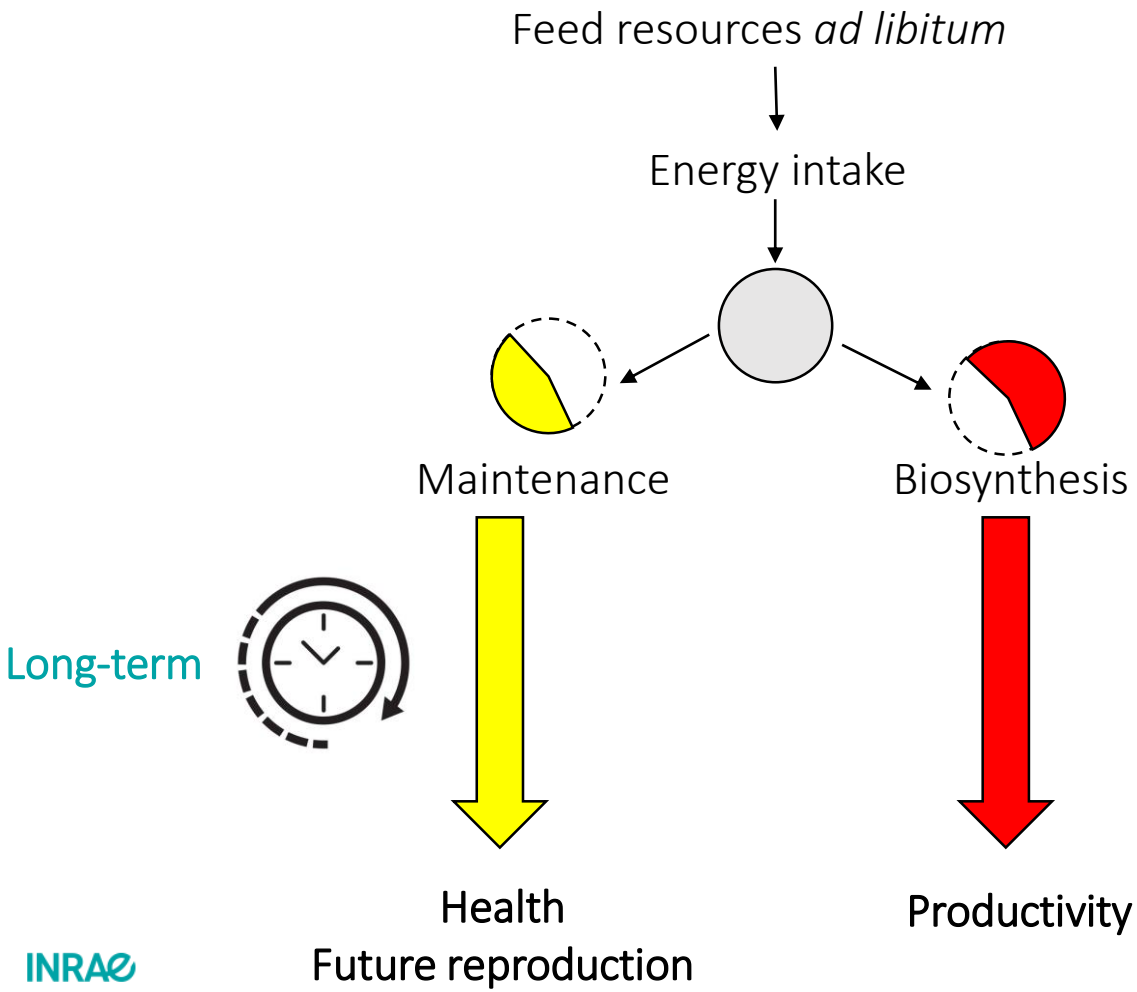
Resource limiting conditions may not always be the most favourable environment to observe trade-offs




Adapted from Pryce et al. WCGALP 2014

# Future directions

## Do we look at the right traits to assess energy allocation trade-offs?




- Most studies of feed efficiency have focused on reproduction or health traits in young adult animals
  → Consequences on the long-term?

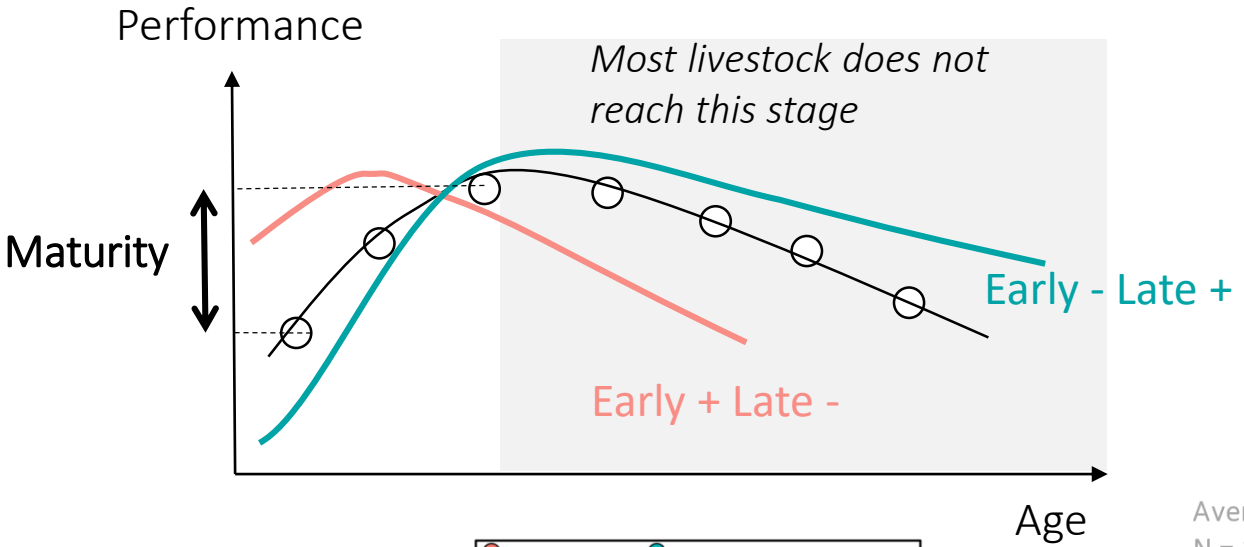
- Trade-offs early - late life performance

  Lemaitre et al. 2015. Proc. R. Soc. B

# Future directions

## Do we look at the right traits to assess energy allocation trade-offs?

### Early-late life performance trade-offs

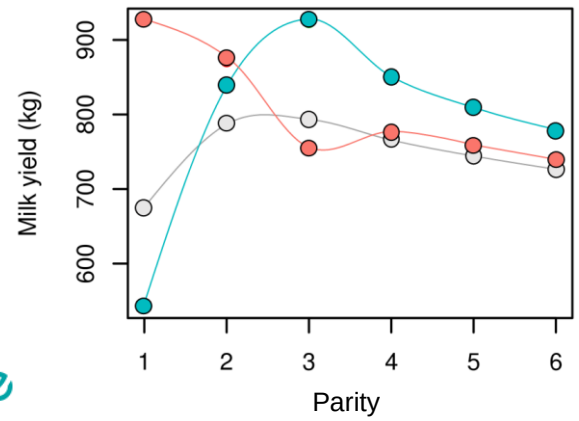


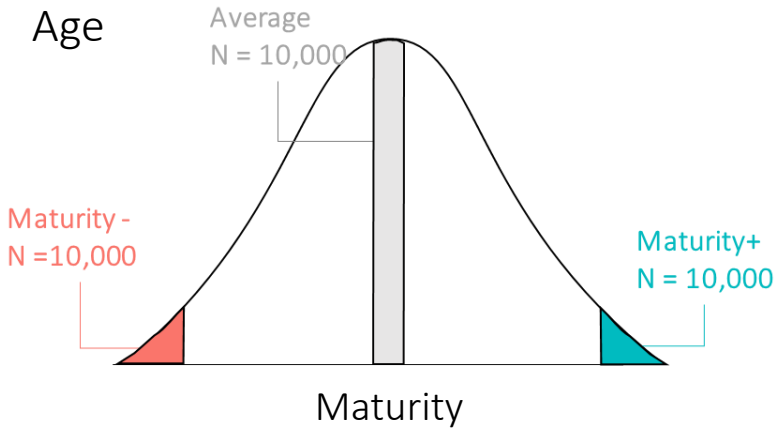

In dairy goats:

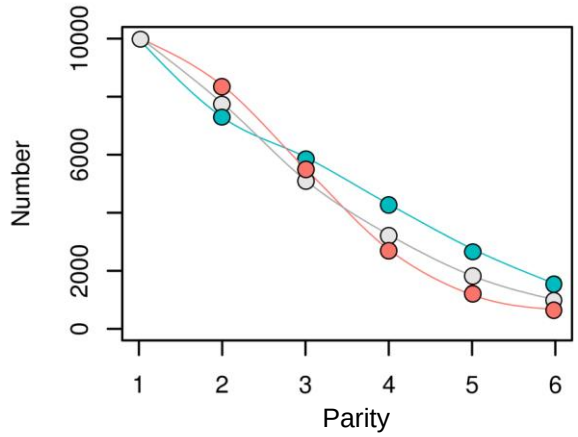
**Maturity Index** ~ difference between 305d-milk yield in 3rd lactation and 305d-milk yield in 1st lactation

$r_G$ Maturity | Longevity = 0.37 in french population

Arnal et al. WCGALP 2022 (session 34)



# Three caveats in the allocation framework assessment

→ mixed evidence for the different energy allocation hypotheses ≠ support for the independence hypothesis

→ no evidence for resource allocation trade-offs ≠ no evidence for trade-offs caused by others mechanisms

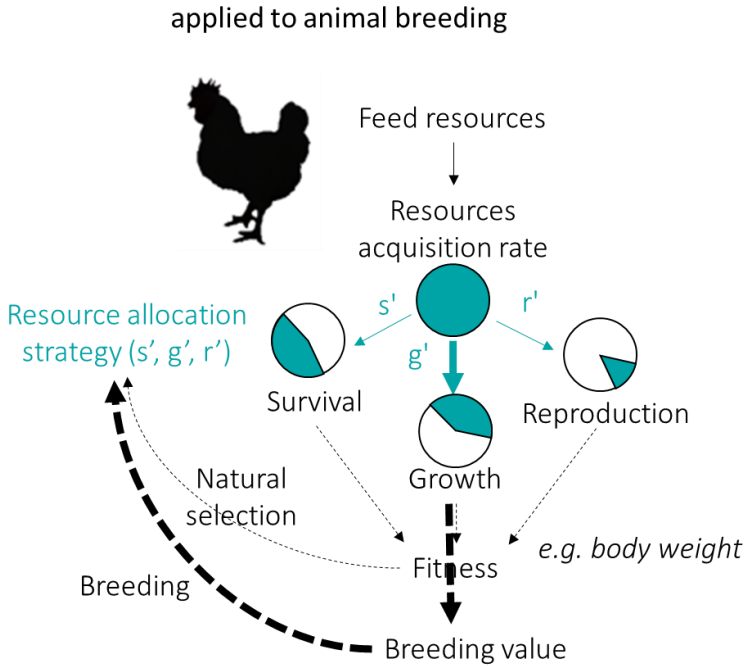
→ no trade-off detected ≠ no trade-off occurs

# Modelling as a way forward to bridge feed efficiency and resource allocation trade-offs

## A framework needed to predict the consequences of breeding for feed efficiency or robustness in contrasting environments

More and more opportunities to combine experimental approaches with resource allocation modelling

- Quantitify resource allocation to particular function (e.g. energy allocation to parasite resistance in sheep)
- Calibrate individual allocation strategies (*s*, *g*, *r*)
  e.g. Ramirez et al. WCGALP 2022 (session 14)
- Estimate genetic variances / covariances of resource allocation parameters
  e.g. Doeschl-Wilson et al. 2007 Animal; 2008. GSE




Scale-up consequences of energy allocation when breeding for feed efficiency

- short-term efficiency ➔ lifetime efficiency  e.g. Puillet et al. 2016. GSE
- Individual efficiency ➔ herd efficiency
- Trade-offs / synergies between feed efficiency and robustness

Explore adaptation strategies to climate change to orientate breeding objectives and promote agroecology

# To Carole Moreno

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*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement n°772787*

# Thanks for listening

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Genetics, Physiology and Livestock Systems

Smarter

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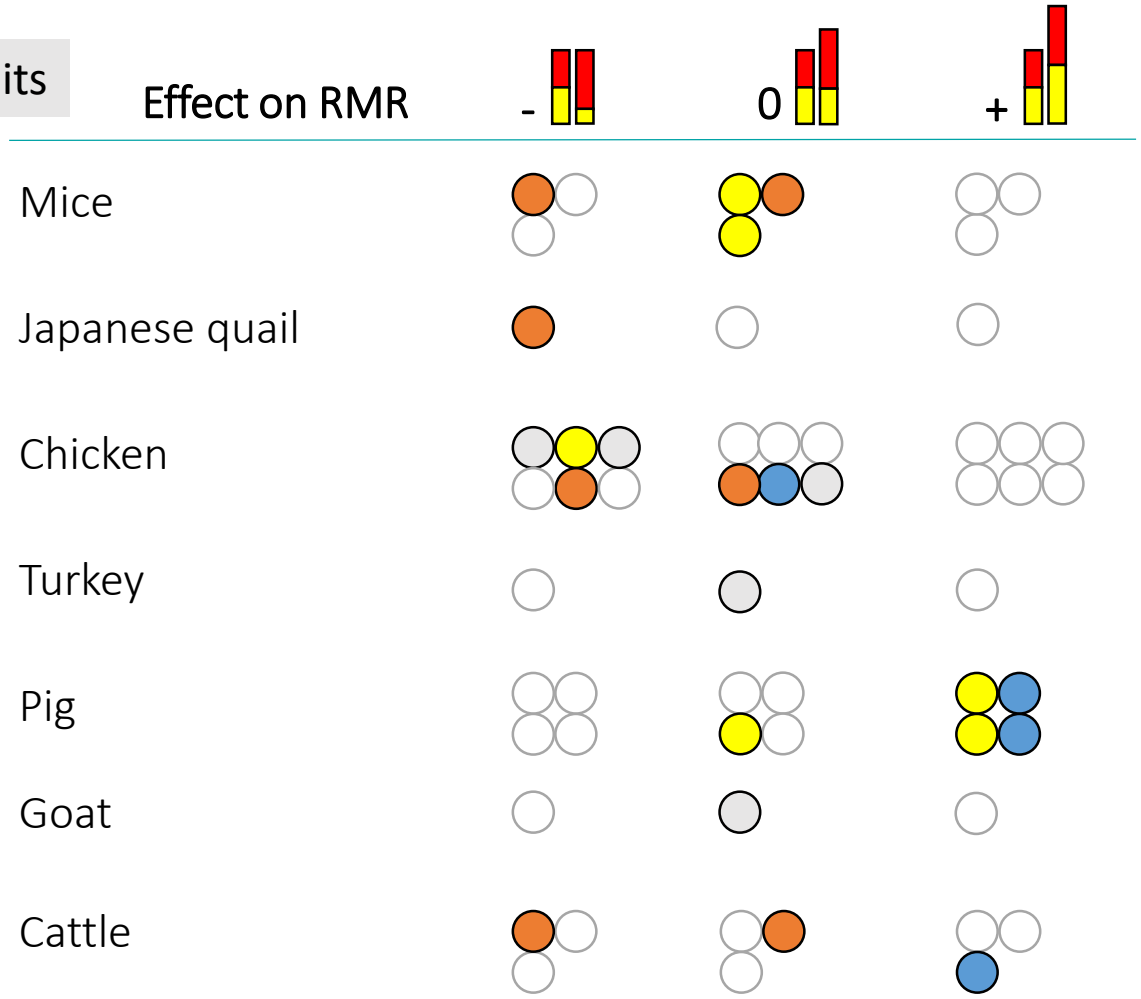
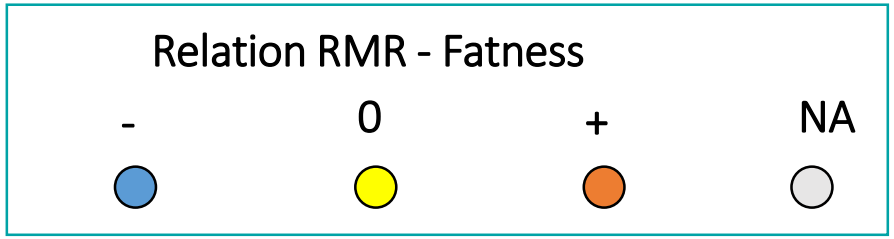
# Global approach based on breed or lines comparisons

## (1) energy allocation constraints when selecting for productivity?

Growth traits

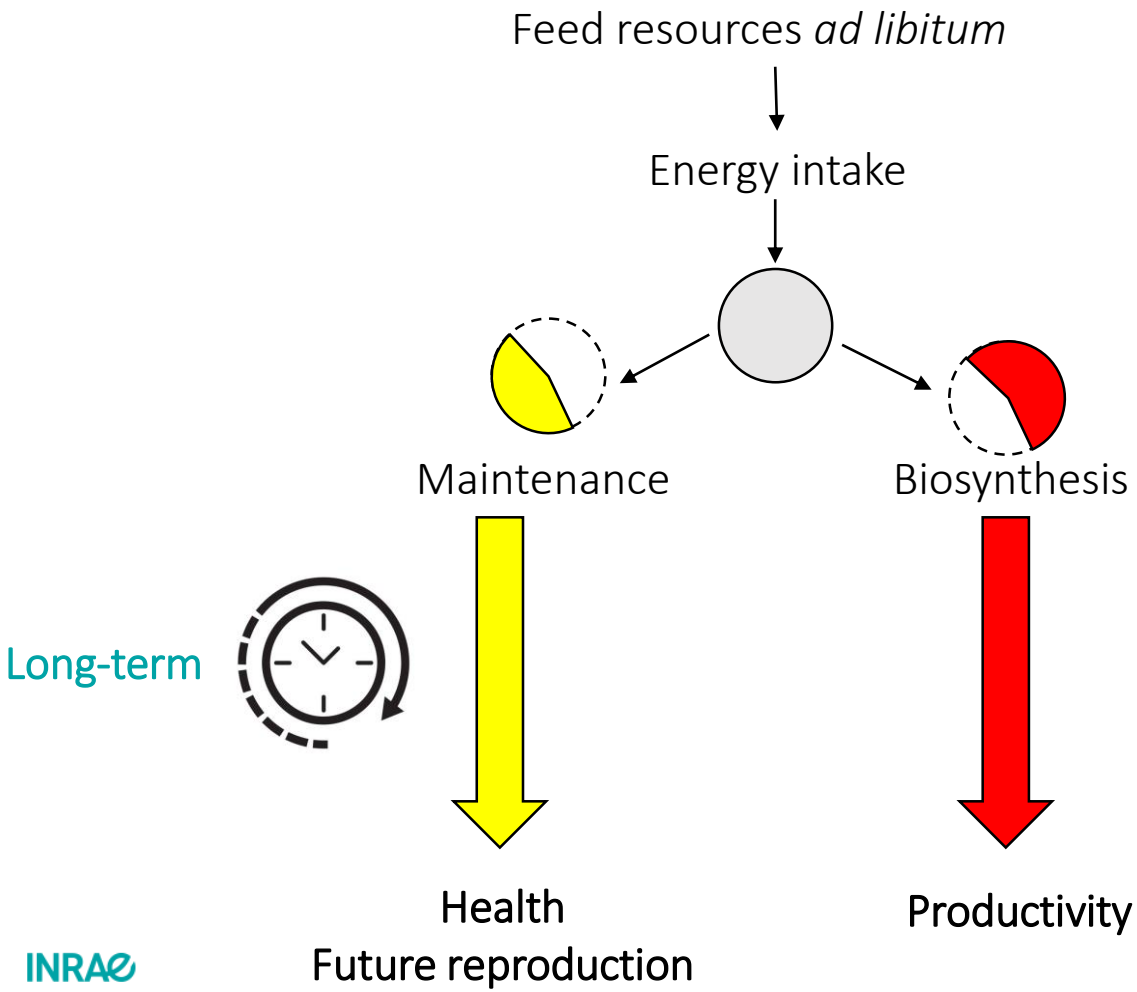



- RMR adjusted for allometry effect (dividing by $BW^{0.75}$ or using BW as covariate)
- Different methods to measure RMR (indirect calorimetry, comparative slaugther technique)
- Most RMR estimates at single age/stage and mostly in young animals
- RMR tends to be inversely related to fatness



# Future directions

## Do we look at the right traits to assess energy allocation trade-offs?




- Most studies of feed efficiency have focused on reproduction or health traits in young adult animals
  → Consequences on the long-term?

- Trade-offs early - late life performance

  Lemaitre et al. 2015. Proc. R. Soc. B

- Potential of new biomarkers (telomere dynamics, age- specific changes in the DNA methylation) to mesure late life performance

  Simpson and Chandra 2021. Aging Cells
  Ilska-Warner et al. 2019. Front. Genet.
  Caulton et al. 2021. Genes