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VETERINARY
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Seville
Spain
6th-10th March
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10th International SHEEP VETERINARY Congress 2023

6th - 10th March Seville Spain
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Breeding for sheep resilience and robustness

I De Barbieri, E Navajas, F Douhard,
J Conington, Z Ramos, G Ciappesoni

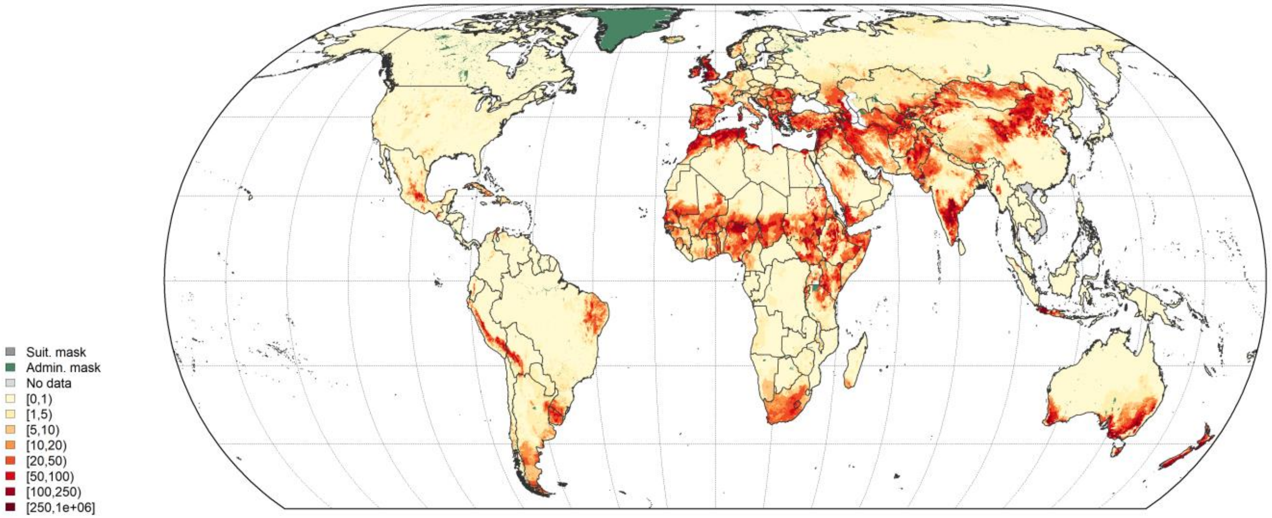
RUMIAR · GrassToGas · Smarter – SMAll RuminanTs breeding for Efficiency and Resilience · INIA URUGUAY · INRAE · SRUC · MASSEY UNIVERSITY TE KUNENGA KI PŪREHUROA UNIVERSITY OF NEW ZEALAND

Outline:

- Sheep production context
- Definitions and concepts behind words
- Potential traits (breeding)
- Final remarks

Sheep production context

Gilbert et al. 2022. Global sheep distribution in 2015,Harvard Dataverse, V1
WWF. 2018. Living Planet Report - 2018: Aiming Higher. 75 p
Mottet et al. 2017. Global Food Security 14, 1–8.
Joy et al. 2020. Animals 10, 867



From wet to arid regions

From grazing outdoors on marginal soils to high controlled intensive indoors production systems

Variable access to food (quantity and quality) and *water*

Being:

- **A source of fibre and food**
- **Socio-economic relevance** (income, food security, human well-being)
- **Potential to play a role in Biogenic C cycle**
- **Ecosystem services (recycling, biodiversity,…)**

Global challenges:

- **Feed/food competition**
- **Use of arable lands**
- **Contribution to GHG emissions**
- **Coexistence with wildlife**
- **Labour**

Sheep production context

Higher temperatures
Changes in precipitation (amount, seasonality, variability)
More extreme weather events
Tropical and sub-tropical areas
Henry et al. 2018. *Animal*, *12*, S445–S456.

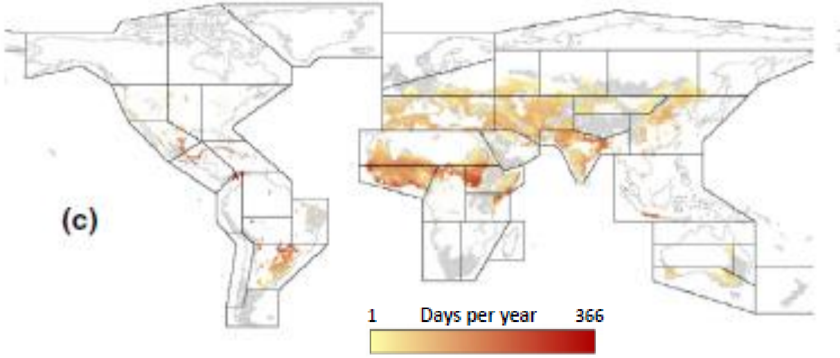
Animal physiology, welfare, behaviour, production (Bwgain, milk, wool, reproduction)

Feed availability, composition, quality
Water availability

Pest/Disease changes due to environmental modifications

Expected modifications/challenges regionally linked
Positive and negative

Extreme heat stress (THI).
Potential modification to the actual situation under worst case scenario
Thornton et al. 2021. Global Change Biology 27, 5762–5772



Sheep population (%) with at least 1 day of HS

	2090	
2000	**Best-case scenario**	**Worst-case scenario**
10.7	19.9	63.2

Future

- Less human-edible foodstuffs to sheep
- Less access to land suitable to cereals
  - Poorer quality feed
  - More variable feeds
  - Marginal areas
- Environmental perturbations
- Heterogeneous environmental conditions
- Harsh weather conditions
- Pathogens, pests

Robustness
Resilience

↑

Already selected for high production

Friggens et al. 2017. Animal, 11(12), 2237–2251.

Definitions (animal level)

- **Robustness**
  - **The ability, in the face of environmental constraints, to carry on doing the various things that the animal needs to do to favour its future ability to reproduce** (Friggens el al., 2017)
    - **Combination of multiple and interacting mechanisms**
    - **Survival (death, culling), growth, reproduction**
    - **Productive longevity, consequence of lifetime animal's ability to overcome challenges (similar environments + end time measure, general)**

Friggens et al. 2017. Animal, 11(12), 2237–2251.

Definitions (animal level)

- **Robustness**
  - The ability, in the face of **environmental constraints**, to carry on doing the various things that the animal needs to do to favour its future ability to reproduce

Harshness
Stable factors:
Nutrition, farming system, environment

Adaptation mechanisms

Perturbations

Resilience mechanisms

Robust animal:
quantity and quality of product
use of nutritional resources (acquisition, utilisation, allocation)
matches with environment
reproduce well/regularly
health status (disease resistance/resilience)
behavioural environment

Friggens et al. 2017. Animal, 11(12), 2237–2251.

Definitions (animal level)

- **Resilience** (Friggens et al. 2022. Peer Community Journal 2, e38)
  - **Underpins Robustness**
  - **“Capacity of an animal to respond to environmental disturbances”** (Sheffer et al., 2018)
  - **“The ability of an animal to be minimally affected in its functioning by an external disturbance, or to quickly return to the state that it had before the challenge”** (Colditz and Hine, 2016)

Environment	Good	Poor
Stable		Robustness
Variable	Resilience	Robustness Resilience

General Resilience

Hine et al. 2014. Breeding Focus 2014, 49-64

Disease Resilience
(pathogen/health challenges)

Dynamic Resilience

Indirect trait

Knap and Doeschl-Wilson. 2020. Genetics Selection Evolution, 52, 1–18

Environmental perturbations

Resource allocation

(limiting resources among different activities)

Resource acquisition

(grazing, feed intake)

Can be altered in the long term

Short term, unpredictable changes

Long term, predictable changes

Dynamic (life stages)

Environment dependent

e.g. body reserves

Friggens et al. 2017. Animal, 11(12), 2237–2251.

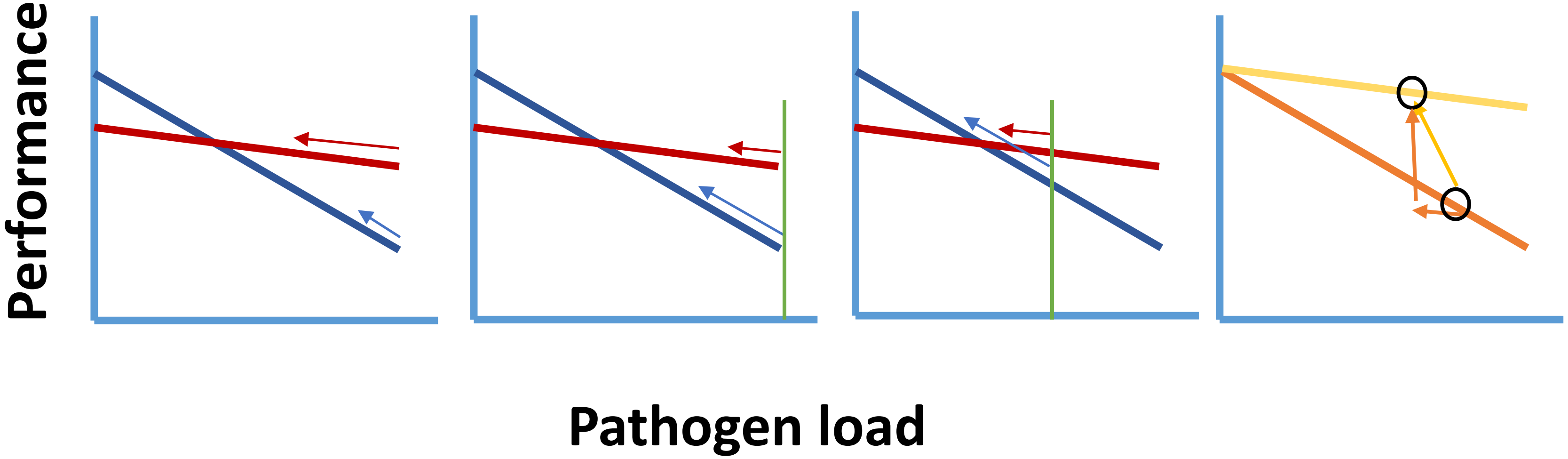
Disease Resilience

Knap and Doeschl-Wilson. 2020. Genetics Selection Evolution, 52, 1–18

- **Ability of an animal to maintain a reasonable level of productivity when challenged by infection**
- **The reaction norm of performance on different environmental pathogen load**

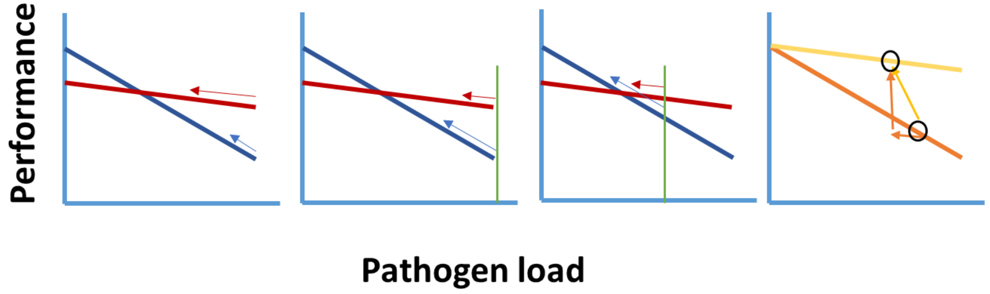
Disease Resilience

Resistance **Tolerance**



Disease Resilience

Knap and Doeschl-Wilson. 2020. Genetics Selection Evolution, 52, 1–18
Berghof et al. 2019. Frontiers in Genetics 10, 1–15



Difficult ($, tech) to measure the different parameters (PLw, PLe, PL0)

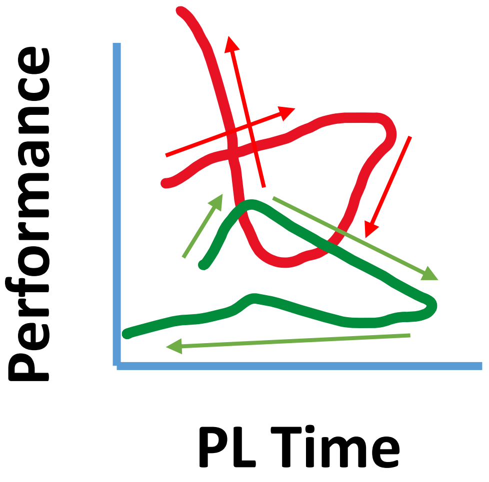
Correlation between R and T

QTLs,Genomics
Major genes
or

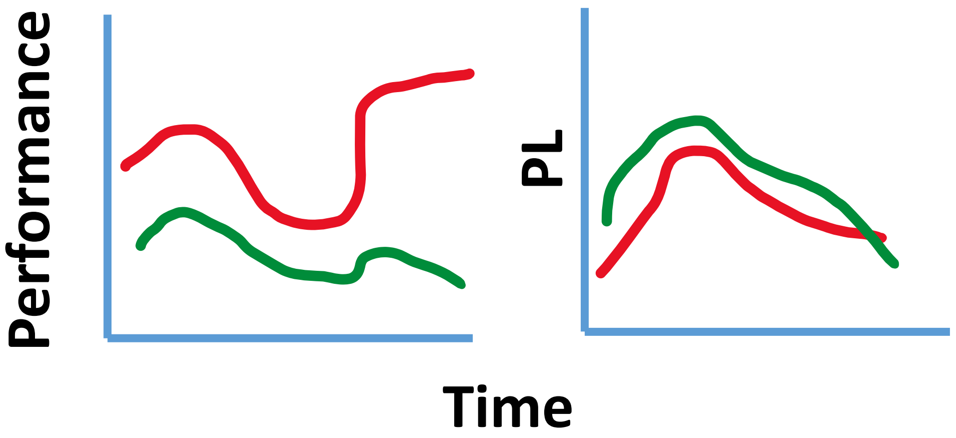
Dynamic Resilience

challenge events are often unrecorded or from unknown source (Friggens et al., 2017)

2-dimensional RT



Black-box 1-dimensional RT



Dynamic resilience

Garcia-Baccino et al. 2021. Genetics Selection Evolution 53, 1–14

- Highly frequently recorded data more available (performance related)
- Expected production performance no needed

- Environmental challenge - Unrecorded
- Consequences of challenges on performance have been reported
- Increased variation in performance when a challenge occurs

- Work (daily feed intake in sheep):
  - Estimate the P for each day of being a stressful day (unrecorded environmental challenge)
  - Estimate genetic determinism of resilience

Dynamic resilience

Garcia-Baccino et al. 2021. Genetics Selection Evolution 53, 1–14

- **Fit a mixture model, larger variances = stressful day**
- **Include the probability (continuous) of belonging to the "stressful" component as a covariate in a reaction norm animal model (DFI and P per day)**
- **8 years, >50,000 daily records, >5,000 pedigree, 951 tested lambs . INRA RFI test.**
- **It was possible to calculate the P of any given day of being a high CV day (environmental challenge), 3.88% of the days >0.5**

- **Genetic correlation (slope and level) -0.46±0.21 (+DFI no challenge ----- -DFI under challenge)(RNAM)**
- **h^2 for DFI changes in accordance with P, and Rg DFI EBVs (G*E)(0.97-0.21)**
- **Simple and practical approach**

Outline:

- Sheep production context
- Definitions and concepts behind words
- **Traits**
  - **(direct/indirect approach)(consequences of resilience)**
- **Final remarks**

Rauw, Gomez-Raya. 2015. *Frontiers in Genetics 6*, 1–15

Resilience and efficiency - genetic parameters

Mucha et al. 2022. Animal 16, 100456

- **Disease resistance: mastitis, gastrointestinal parasitism, footrot**
- **Economic impact, zoonotic potential and animal welfare**
- **Dairy (26/12) and meat (118/50) sheep**

Dairy

Trait	Pooled h^2
Faecal egg count	**0.14** ±0.04
Somatic cell score	**0.13** ±0.02
Milk yield	0.24 ±0.02
Fat yield	0.21 ±0.06
Protein yield	0.22 ±0.04
Fat content	0.28 ±0.11
Protein content	0.33 ±0.07

Meat

Trait	Pooled h^2
Lamb survival	0.13 ±0.04
Longevity	0.08 ±0.04
Mastitis	**0.07** ±0.02
Footrot	0.15 ±0.03
Breech strike	**0.50** ±0.10
Dagginess	0.30 ±0.06
FEC	0.29 ±0.03
Haematocrit	0.32 ±0.14

Trait	Pooled h^2
Body weight	**0.32** ±0.04
Growth rate	0.20 ±0.03
Body CS	0.21 ±0.11
FAT	0.28 ±0.03
Muscle depth	0.29 ±0.02
Feed intake	0.26 ±0.04
RFI	**0.32** ±0.15
FCR	0.12 ±0.03
Methane	0.17 ±0.04
Prolificacy	**0.09** ±0.02

Resilience and efficiency - genetic parameters

Mucha et al. 2022. Animal 16, 100456

Dairy

Trait	Pooled r_g
Somatic cell score - Milk yield	-0.05 ±0.10
Somatic cell score - Fat content	0.04 ±0.05
Somatic cell score - Protein content	**0.12 ±0.03**
Somatic cell score - Fat yield	0.11 ±0.15
Somatic cell score - Protein yield	0.17 ±0.10

Close to zero
Except PC-SCS
High positive Rg between yield, but FC and PC negative with MY

Meat

Trait	Pooled r_g
Body weight - FEC	-0.16 ±0.14
Body weight - DAG	0.01 ±0.07
Growth rate - FEC	**-0.28 ±0.11**
Growth rate - DAG	**-0.33 ±0.13**

Proxies for the same disease, presented medium to high correlations (dagginess/fecal consistency) (FEC/Ig)

Rg between efficiency traits were positive (except prolificacy - BW, BW-RFI, zero)

Resilience and efficiency - genetic parameters

Mucha et al. 2022. Animal 16, 100456

Dairy

- Production, acceptable h^2 to be included in BP
- Lower in health and efficiency traits, but possible to make progress
- -Rg with SCS, implies that SCS needs to be included in the BP, otherwise udder health would be negatively affected if selection is only based on yield and content

Meat

- No clear evidence for trade offs between growth and FEC
- Different traits can be used for GIN or Fly strike resistance
- Antagonisms may exist, specific E and populations

Rg not significant to zero or moderate

Simultaneous improvement possibility if including R+E traits in the breeding goal (Index)

Large variations, environmental considerations (trade offs in challenging conditions)

Resilience: disease resistance/survival

Merino - Resilience and Resistance traits

Walkom and Brown. 2014. Breeding Focus 2014, 141–156

- Explore consequences of using Merino Indexes on resilience and resistance traits
- Body condition score and weight change - energy reserves and nutritional stress
- Worm egg count and fly stike - disease resistance
- Reproduction - animal wellbeing or fitness (reproduction occurs when maintenance is met)

BCS

- $h^2 = 0.19$
- Highly r_g across cycle
- r_g weight = 0.7
- r_g fat = 0.8
- r_g muscle = 0.68
- r_g n lambs = 0.10

Change

- BW change $h^2 = 0.02\text{-}0.11$
- BCS change $h^2 = 0.02\text{-}0.08$

Merino - Resilience and Resistance traits

Walkom and Brown. 2014. Breeding Focus 2014, 141–156

- How animals are responding to environmental stressors
- Body condition score and weight change - energy reserves and nutritional stress
- Worm egg count and fly strike - disease resistance
- Reproduction - animal wellbeing or fitness (reproduction occurs when maintenance is met)

BCS

- $h^2 = 0.19$
- Highly r_g across cycle
- r_g weight = 0.7
- r_g fat = 0.8
- r_g muscle = 0.68
- r_g n lambs = 0.10

Change

- BW change $h^2 = 0.02\text{-}0.11$
- BCS change $h^2 = 0.02\text{-}0.08$

Macé et al. 2018. Journal of Animal Science *96*, 4501–4511

Change - Meat sheep

- BW change $h^2 = 0.13\text{-}0.18$
- BCS change $h^2 = 0.04\text{-}0.16$
- High rg between mobilization and accretion BR

More BR accretion and mobilization Improved performance and stayability

Vialoux. 2020. PhD thesis. Massey University. 191

Merino - Resilience and Resistance traits

Walkom and Brown. 2014. Breeding Focus 2014, 141–156

- How animals are responding to environmental stressors
- Body condition score and weight change - energy reserves and nutritional stress
- Worm egg count and fly strike - disease resistance
- Reproduction - animal wellbeing or fitness (reproduction occurs when maintenance is met)

BCS

- $h^2 = 0.19$
- Highly r_g across cycle
- r_g weight = 0.70
- r_g fat = 0.80
- r_g muscle = 0.68
- r_g n lambs = 0.10

Change

- BW change $h^2 = 0.02\text{-}0.11$
- BCS change $h^2 = 0.02\text{-}0.08$

WEC

- $h^2 = 0.20$
- r_g low to negligible
- Fat, EM
- NLW

Breech FS

- $h^2 = 0.51$
- Low negative r_g
- BW, BCS, BWch, NLW

NLW/EJ

- $h^2 = 0.06$
- + r_g FAT, EM, BCS, BW, changes

Merino - Resilience and Resistance traits

Walkom and Brown. 2014. Breeding Focus 2014, 141–156

- Evaluated the MERINOSELECT indexes (FP, MP, DP). Relevance in FW, FD, WEC, lamb production
- Created economic values for: BCS, fly strike, BCS and BW change
- **Selection on 2014 indexes, small unfavourable consequences only in 1 R&R trait (Breech wrinkle)**
- **Include R&R traits did not significantly harm production traits**
- **From 3 to 14% increase in economic gain, depending on the index**
- **Potential underestimation of resilience and resistance trait**
- **Need of more specific data regarding different environments (G*E), extreme commercial conditions. Genomics will assist.**
- **Dairy sheep and goats:**

  Ramón et al. 2021. Breeding Strategies for Weather Resilience in Small Ruminants in Atlantic and Mediterranean Climates. Front. Genet. 12:692121

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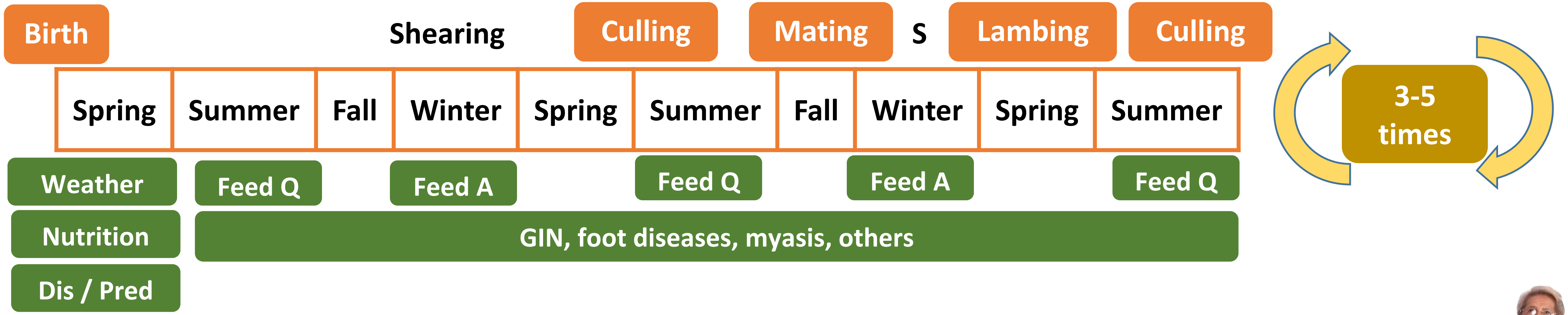
Lifetime reproduction

Ramos et al. 2023. Journal of Animal Science, skad071



- **Reproduction traits, low heritability** (Fertility: 0.14 ± 0.03, Lambing pot: 0.11 ± 0.02, Rearing ability: 0.04 ± 0.01 and NLWEJ: 0.08 ± 0.02)
- Finner wool / not negatively affect reproduction
- **Heavier fleeces / unfavourably on reproduction (CFW/LW, environment) - trade off**
- Heavier animals / positive effect on reproduction

Trait	NLWEJ	TLW	TLWW
A_FD	-0.04 ±0.10	-0.09 ±0.09	-0.03 ±0.09
A_GFW	-0.18 ±0.11	**-0.30 ±0.09**	**-0.30 ±0.08**
LWM	0.06 ±0.11	-0.03 ±0.08	0.21 ±0.09
LWPL	0.18 ±0.11	0.15 ±0.09	0.36 ±0.08

Genetic trend?

Immune competence

Hine et al. 2014. Breeding Focus 2014, 49-64
Hine et al. 2022. Animal 16, 100544

- **Protocol to evaluate it (beef cattle)**
- **Proxy for general disease resistance (part of a general resilience)**
- **To be complementary with other traits**

Disease resistance
Tolerance to stressors
Social robustness

- **Based on:**
  - Appropriate and effective immune response (adaptive)
  - Cell and Antibody-mediated immune response to vaccination
  - Clostridial vaccine at weaning (stress)
  - Skinfold thickness and anti-tetanus toxoid serum IgG1 antibody
  - Standardized residuals values for Ab-IR and Cell-IR were averaged to generate a single IC trait

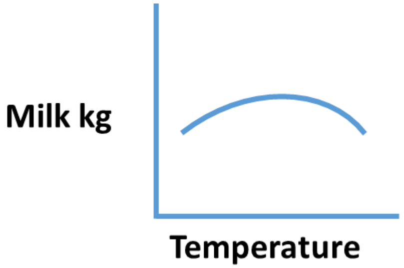
Trait	h^2
IC-Comb	0.49 ±0.14
Ab-IR	0.52 ±0.14
Cell-IR	0.36 ±0.11

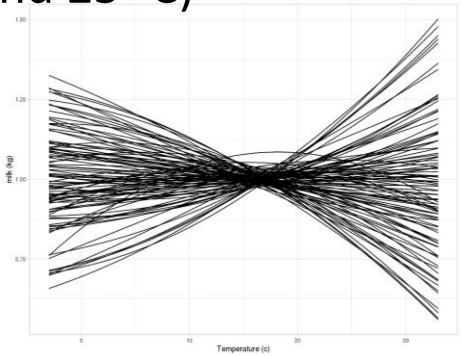
Trait	IC-Comb r_g
Breech flystrike	-0.44 ±0.39
FEC	-0.19 ±0.23
DAG	-0.26 ±0.31
Fleece rot	0.17 ±0.23
Fitness compromise	-0.35 ±0.24

Environmental temperature

Tsartsianidou et al. 2021. Genetic selection evolution, 53: 90
Joy et al. 2020. Animals 10, 867

- Chios sheep breed (15 years, >10.000 records, >500 animals)
- Milk performance resilience to temperature
- Cold and hot threshold (10° and 25° C)





Trait	AR10	AR25	LMY	PL
Animal resilience 10° C	0.03 ±0.08	**0.87 ±0.29**	-0.92 ±0.67	-0.70 ±0.95
Animal resilience 25° C		**0.20 ±0.09**	**-0.94 ±0.07**	**0.76 ±0.24**
Lifetime milk yield			**0.26 ±0.01**	-0.35 ±0.80
Productive life				0.05 ±0.07

Adaptation: morphology, behaviour, physiology, cellular and molecular, endocrine, metabolic

↓

Skin and hair type,
sweat gland capacity,
reproductive rate,
disease and drought tolerance,
metabolic heat production,
water intake,
physiological traits (RR, SR, RT),
hormones, Genes, G regions
feed conversion efficiency

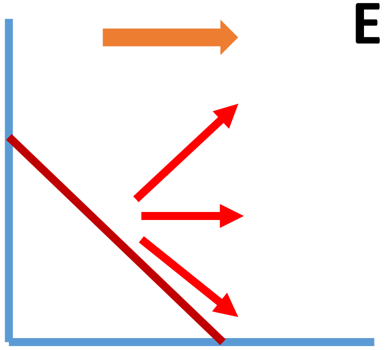
Feed efficiency

Douhard et al. 2022. Proceedings of the 12th WCGALP. 264-267
Douhard et al. 2022. Evolutionary Applications 00, 1-16
Douhard et al. 2021. Evolutionary Applications 14, 2726-2749

- **More limited feed resources**
- **Selection for feed efficiency**

→ Allocation constrains → **Trade off: production, reproduction, health**

E maintenance activity (RMR)



E intake
+
+
=

E productivity

Selection for FE leads to a decrease in RMR

↓

Little evidence on negative consequences on health/reproduction traits

↓

RFI and GIN resistance lines where tested under infectious challenge - no trade off

Trade offs

Navajas et al. 2022. Proceedings of the 12th WCGALP. 195-198
Ferreira et al. 2021. Animal Production Science, 61, 754–760

		FEC line		
		Resistent	Susceptible	p
GIN free	RFI (kgDM/d)	0,02	-0,02	0,116
	Feed intake (kgDM/d)	0,97	0,98	0,969
	Feed converstion ratio	9,0	7,6	0,161
	BW gain (g/a/d)	123	143	0,168
GIN	RFI (kgDM/d)	0,01	-0,01	0,334
	Feed intake (kgDM/d)	1,13	1,12	0,849
	Feed converstion ratio	8,0	11,1	0,074
	BW gain (g/a/d)	144	123	0,144

Health (nematodes)

GHG emissions

Feed efficiency

Wool and Growth

Pearson correlation coefficients of feed efficiency and GHG emissions with EPD of production traits and FEC

	Expected progeny difference			
	Weaning weight	Yearling weight	Gastrointestinal nematodes	Fleece weight
Residual feed intake	-0,05	-0,04	0,08	0,10
Dry matter intake adjusted	**0,19**	**0,20**	0,07	**0,23**
Methane adjusted	**0,15**	**0,16**	0,05	0,07
CO_2 adjusted	**0,24**	**0,24**	0,04	0,07

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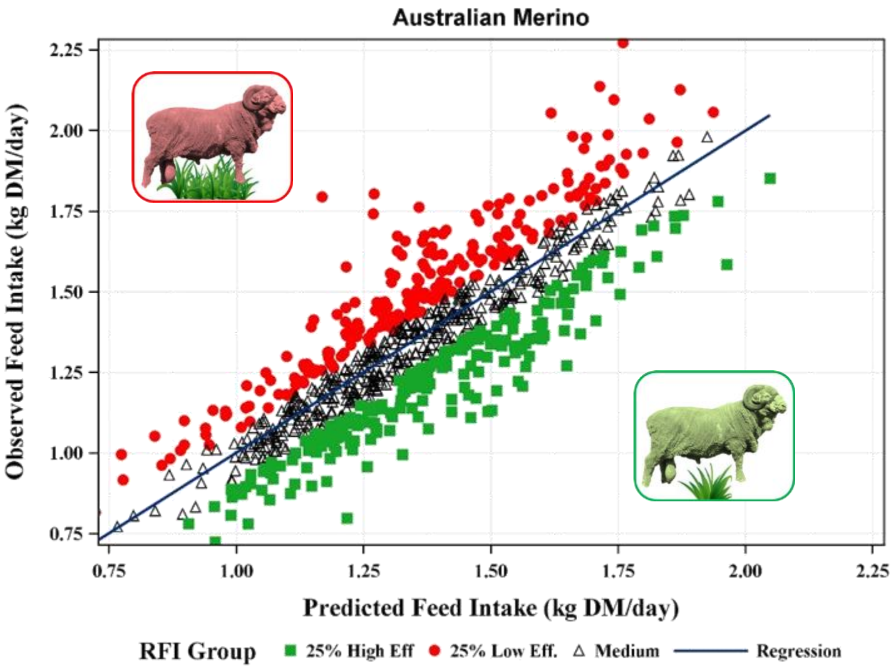
De Barbieri et al. 2022. EAAP Book of abstracts 73, 674

Trade off

261 Hoggets
Born in 2018 & 2019
first mated at 17 months of age
y = RFI group + year + pregnancy rank + e



Production:
- ✓ Body weight (cycle)
- ✓ BCS
- ✓ Wool: FD & GFW

Reproduction:
- ✓ Fertility. Prolificacy. Lambing %
- ✓ kg of weaned lambs/mated or lambed ewe

	High efficiency	Low efficiency
Lamb (kg weaned/mated ewe)	20.8	19.1
Body weight at mating (kg)	45.6	44.3
Greasy Fleece Weight (kg)	2.8	2.8
Fibre diameter (µm)	15.5	15.7
Fertility (%)	91	79
Prolificacy (%)	120	110
Weaning (%)	100	79

Study cases

B+LNZ Genetics Low Input Sheep, Public Report, 2021

Low input flock, New Zealand:

- **Animal welfare traits:** docking, dag control, fly strike
- **Disease resistant:** parasites, pneumonia, no drench
- **Environmentally efficient:** methane emission, feed efficiency

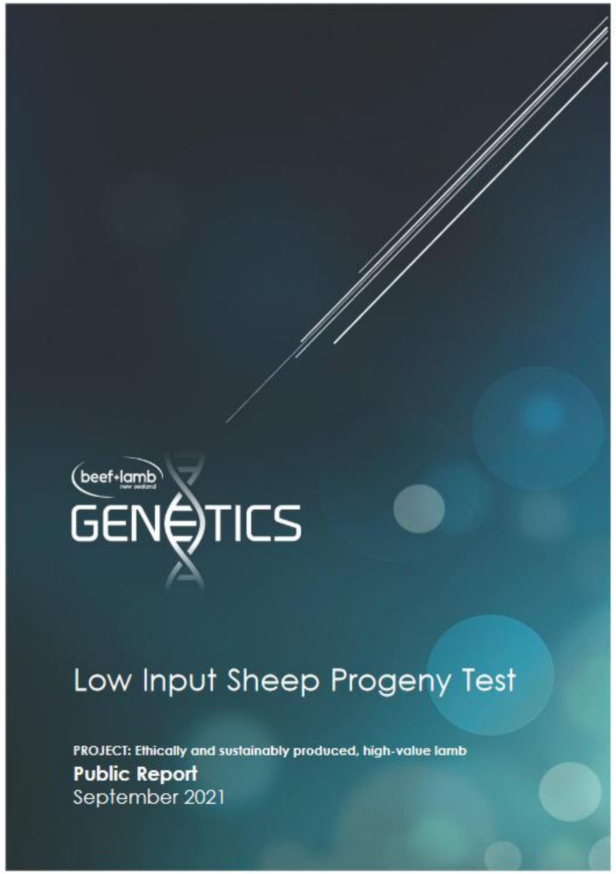
2019 first progeny

Joint work: breeders, B+LNZ, industry partners, MPI

Important traits + DNA (parentage + genomics)

SGMFD, GMFD, DPS, DPG, DPM, DPD, DPF, TL, TS, NZGE

SGMFD → Survival, Dag, FEC
GMFD → Survival
DPF → FEC
NZGE → Methane



beef+lamb new zealand
GENETICS

Low Input Sheep Progeny Test

PROJECT: Ethically and sustainably produced, high-value lamb
Public Report
September 2021

Genomics

Z. Ramos reviewed

Traits	Candidate genes / genomic regions
Reproduction	Ramos et al. 2023, Zhang et al. 2022, Wang et al. 2020
Resilience	**Tsartsianidou et al. 2021**
Faecal egg count	Benavides et al. 2016, Berton et al. 2017, Raschia et al. 2020 Carracelas et al. 2022
Dagginess	Pickering 2013, Pickering et al. 2015
BCS	Ramos et al. 2023, Macé et al. 2022
BW/BCS change	Macé et al. 2022, Waters et al. 2022
Longevity (Cattle)	*Zhang et al. 2016, Steri et al. 2018, Hamidi and Roberts 2017, Zhang et al. 2021*
Fly strike	Pickering 2013, Bolormaa et al. 2021
Footrot	Mucha et al. 2015, Niggeler et al. 2017, Raadsma et al. 2018
SCS/Mastitis	Sutera et al. 2021, Oget et al. 2019

Final remarks

- Importance of resilience and robustness
- Difficulties to measure, define (outcomes/mechanisms), analyse, breeding program
- h^2, r_g, genes, EBVs, gEBVs, phenotyping on going
- Trade offs (Y/N), G*E (local production systems/environments)
- Broader view including different levels: animal (behaviour, microbioma), herd (age, physiology), farm (all animals, resources), regional (diseases, nutrition, climate, resources)
- Combination of genetics, practices (nutrition, management, health) (Adaptherd)
- Local knowledge, international efforts
- Broad overview based published works, apologies to those not included

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Smarter
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PROJECT PARTNERS
www.smarterproject.eu

Invitation to follow the project in the social media (web, twitter, newsletters)

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