Genetic parameters for calf resilience and milk feeding traits recorded by automated milk feeding machines and their relationship with bovine respiratory disease in North American Holstein calves

Jason Graham, Masoomeh Taghipoor, and Luiz Brito

Introduction

- ✓ Dairy calves are especially vulnerable to major **environmental and disease perturbations**, such as thermal stress, social stress, bovine respiratory disease (BRD), and enteric diseases

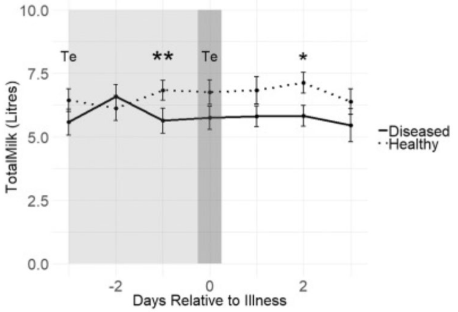
- ✓ In addition to **welfare issues**, these stressors have large **economic impacts**:

  - Heat stress can lead to increased disease susceptibility (Alhussien et al., 2024; Thornton et al., 2021)
  - $42.15 to treat each BRD case and $444.32 in total costs for a mortality incidence due to BRD (USDA, 2014; Dubrovsky, 2020)
  - BRD (24%) and enteric diseases (56.4%) are the main causes of all mortalities in young calves (USDA, 2018; Kaura et al., 2024 ; Cho & Yoon, 2014)

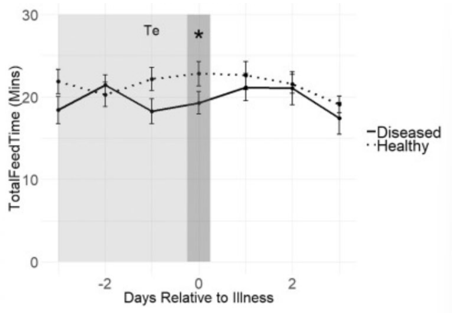
Milk Consumption and Feeding Behavior

✓ Milk consumption and feeding behaviors are **predictors of diseases** in pre-weaning dairy calves (Conboy et al., 2022; Duthie et al., 2021; Swartz et al., 2017)

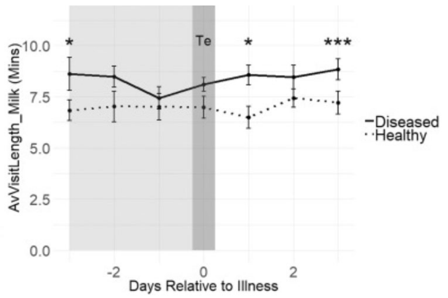
Total milk consumption



Total feeding time



Average visit length



✓ **Precision technologies** (e.g., automated milk feeders) generate longitudinally recorded datasets on individual calves ➔ **opportunity to derive novel traits**

Longitudinal Data: Resilience Indicators

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Between-herd variation in resilience and relations to herd performance

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Validation of resilience indicators by estimating genetic correlations among daughter groups and with yield responses to a heat wave and disturbances at herd level

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Genomic-based genetic parameters for resilience across lactations in North American Holstein cattle based on variability in daily milk yield records

Shi-Yi Chen,[1,2] Jacquelyn P. Boerman,[1] Leonardo S. Gloria,[1] Victor B. Pedrosa,[1] Jarrod Doucette,[3] and Luiz F. Brito[1*]

Genetic parameters for novel climatic resilience indicators derived from automatically-recorded vaginal temperature in lactating sows under heat stress conditions

Hui Wen[1], Jay S. Johnson[2], Leonardo S. Gloria[1], Andre C. Araujo[1], Jacob M. Maskal[1], Sharlene Olivette Hartman[1], Felipe E. de Carvalho[1], Artur Oliveira Rocha[1], Yijian Huang[3], Francesco Tiezzi[4,5], Christian Maltecca[4], Allan P. Schinckel[1] and Luiz F. Brito[1*]

Exploring milk loss and variability during environmental perturbations across lactation stages as resilience indicators in Holstein cattle

Ao Wang[1], Luiz F. Brito[2], Hailiang Zhang[1], Rui Shi[1], Lei Zhu[1], Dengke Liu[3], Gang Guo[4] and Yachun Wang[1*]

Opportunities to Improve Resilience in Animal Breeding Programs

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Investigating the relationship between fluctuations in daily milk yield as resilience indicators and health traits in Holstein cattle

Ao Wang,[1] Guosheng Su,[2] Luiz F. Brito,[3] Hailiang Zhang,[1] Rui Shi,[1] Dengke Liu,[4] Gang Guo,[5] and Yachun Wang[1*]

Genetic analysis of resilience indicators based on milk yield records in different lactations and at different lactation stages

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Exploring Phenotypes for Disease Resilience in Pigs Using Complete Blood Count Data From a Natural Disease Challenge Model

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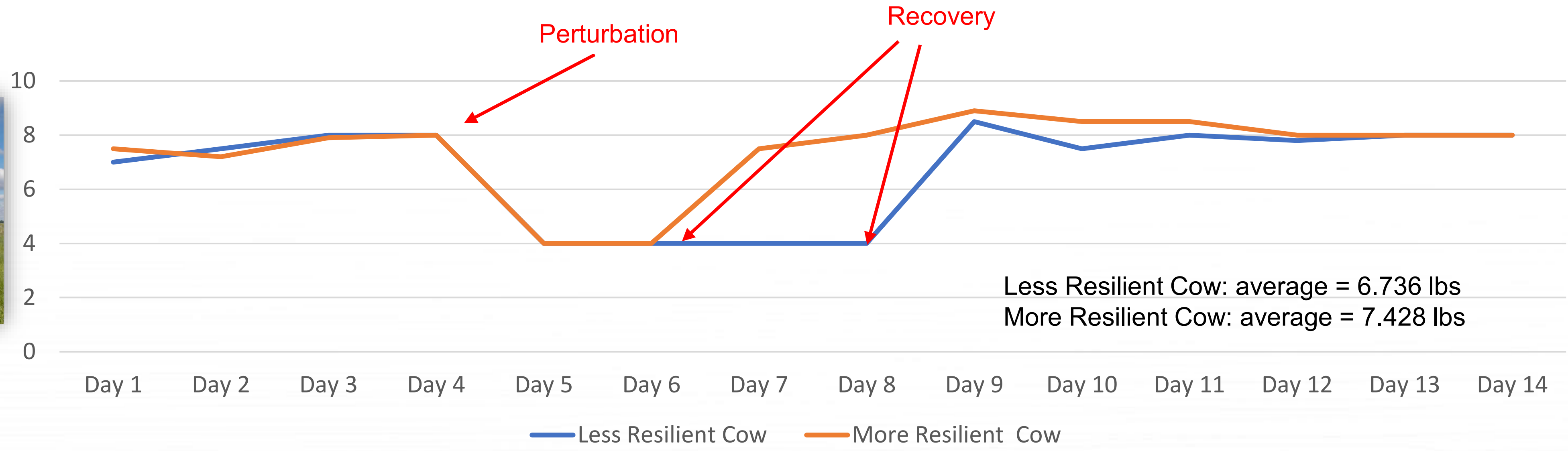
Defining Resilience

✓ Definition: "The individual's capacity to be minimally affected by environmental disturbances or to rapidly bounce back to the previously undisturbed states" (Colditz and Hine, 2016)



Objectives

- ✓ Derive novel traits related to calf **feeding behavior and health** based on data from AMF and BRD treatments in North American Holstein calves
- ✓ Detect perturbations in the individual milk consumption data and derive metrics to characterize perception of perturbations by calves
- ✓ Estimate variance components and genetic parameters for the derived calf feeding behavior, calf resilience traits, pre-weaning survival, and BRD susceptibility

Datasets

✓ 14,749 female Holstein calves with phenotypic records (AMF data)

✓ > 566,156 daily observations (>5 million per-visit records)

✓ Records from birth to weaning (~60 days) → ~50 calves/pen

✓ Genomic data: 57,019 SNPs after QC

✓ Climatic variables and other systematic effects

Automated Milk Feeders: Valuable Data Source

Recorded variables included:

- Daily milk consumption (DMC)
- Per-visit milk consumption (PVMC)
- Daily sum of drinking duration (DSDD)
- Drinking duration per visit (DDPV)
- Daily number of rewarded visits (DNRV)
- Total number of visits per day (TNV)

Additional traits created from these variables:

- Total consumption variance (TCV)
- Duration variance (TDV)
- Feeding interval (FI)
- Drinking speed (DS)
- Pre-weaning stayability (ST)

BRD-related trait:

- Number of times a calf was treated for BRD (NTT)
- NTT was determined by counting the number of BRD incidences prior to 60 days of age

AMF-derived Traits Are Heritable

Trait[2]	σ_u^2 (± SE)	σ_{pe}^2 (± SE)	σ_e^2 (± SE)	h^2 (± SE)
PVMC (L/visit)	0.016 ± 0.0013	0.023 ± 0.0009	0.58 ± 0.0008	0.025 ± 0.002
DMC (L/d)	0.56 ± 0.04	1.63 ± 0.03	5.89 ± 0.01	0.069 ± 0.005
TCV (L^2)	0.0076 ± 0.0009		0.029 ± 0.00082	0.21 ± 0.023
DDPV (min)	0.04 ± 0.004	0.09 ± 0.003	1.49 ± 0.002	0.024 ± 0.002
DSDD (min)	3.27 ± 0.18	4.67 ± 0.11	40.92 ± 0.078	0.067 ± 0.004
TDV (min^2)	0.14 ± 0.016		0.47 ± 0.014	0.23 ± 0.024
DS (L/min)	0.002 ± 0.00010	0.0027 ± 0.00006	0.017 ± 0.000032	0.08 ± 0.004
DNRV	0.25 ± 0.02	0.55 ± 0.013	7.22 ± 0.014	0.032 ± 0.0021
TNV	1.70 ± 0.15	2.78 ± 0.13	29.12 ± 0.06	0.051 ± 0.004
FI (min)	81.73 ± 11.85	253.95 ± 12.35	9845.2 ± 28.07	0.008 ± 0.0012
NTT	0.04 ± 0.005		0.38 ± 0.06	0.09 ± 0.01
ST (d)	0.16 ± 0.03		2.79 ± 0.05	0.054 ± 0.011

Repeatability model

Records from 0 to 60 days

Trait[2]	σ_u^2 (± SE)	σ_{pe}^2 (± SE)	σ_e^2 (± SE)	h^2 (± SE)
PVMC (L/visit)	0.025 ± 0.002	0.032 ± 0.001	0.58 ± 0.0009	0.04 ± 0.003
DMC (L/d)	0.48 ± 0.03	0.88 ± 0.02	4.02 ± 0.01	0.09 ± 0.009
DDPV (min)	0.025 ± 0.0019	0.03 ± 0.0012	0.57 ± 0.001	0.04 ± 0.003
DSDD (min)	6.05 ± 0.34	8.64 ± 0.20	43.15 ± 0.11	0.10 ± 0.005
DS (L/min)	0.003 ± 0.002	0.004 ± 0.00008	0.013 ± 0.00004	0.15 ± 0.007
DNRV (count)	0.046 ± 0.004	0.11 ± 0.003	2.44 ± 0.006	0.02 ± 0.0015
TNV (count)	0.88 ± 0.055	1.45 ± 0.038	16.60 ± 0.043	0.05 ± 0.003
FI (min)	169.5 ± 19.71	355.22 ± 17.54	7000 ± 27.43	0.023 ± 0.0026

Repeatability model

Records from 0 to 32 days

AMF-derived Traits Are Heritable

Trait[2]	Type[3]	Additive genetic variance Mean	Additive genetic variance Minimum to maximun	Heritability Mean	Heritability Minimum to maximum
PVMC (L/visit)	QFull	0.03	0.013–0.05	0.05	0.02–0.07
	LFull	0.04	0.01 –0.12	0.06	0.02–0.16
	Q32	0.034	0.015–0.072	0.05	0.025–0.10
	L32	0.032	0.018–0.069	0.05	0.03–0.10
	QHR (4)	**0.04**	**0.009–0.07**	**0.07**	**0.02–0.11**
DMC (L/d)	QFull	1.98	0.12–3.81	0.27	0.031–0.44
	LFull	2.27	0.64–6.99	0.19	0.08–0.40
	Q32	1.95	0.32–5.39	0.25	0.07–0.48
	L32	2.08	0.39–6.80	0.24	0.07–0.54
	QHR (4)	**5.15**	**0.12–11.03**	**0.46**	**0.05–0.68**

Random regression models

Linear and quadratic Legendre orthogonal polynomials

Homogeneous and heterogeneous residual variances

Records from 0-32 days and 0-60 days (Full)

Genetic correlations with NTT and ST with feeding behavior traits

	NTT	ST
PVMC	0.11 ± 0.03	0.20 ± 0.10
DMC	-0.59 ± 0.02	0.47± 0.07
TCV	-0.11 ± 0.084	0.14 ± 0.13
DDPV	0.46 ± 0.08	-0.60 ± 0.12
DSDD	0.05 ± 0.06	0.22 ± 0.07
TDV	0.24 ± 0.080	0.23 ± 0.055
DS	-0.44 ± 0.05	0.31± 0.08
DNRV	-0.34 ± 0.05	0.29 ± 0.08
TNV	-0.36 ± 0.05	-0.014 ± 0.08
FI	0.27 ± 0.11	0.18 ± 0.11
NTT	-	-0.16 ± 0.16

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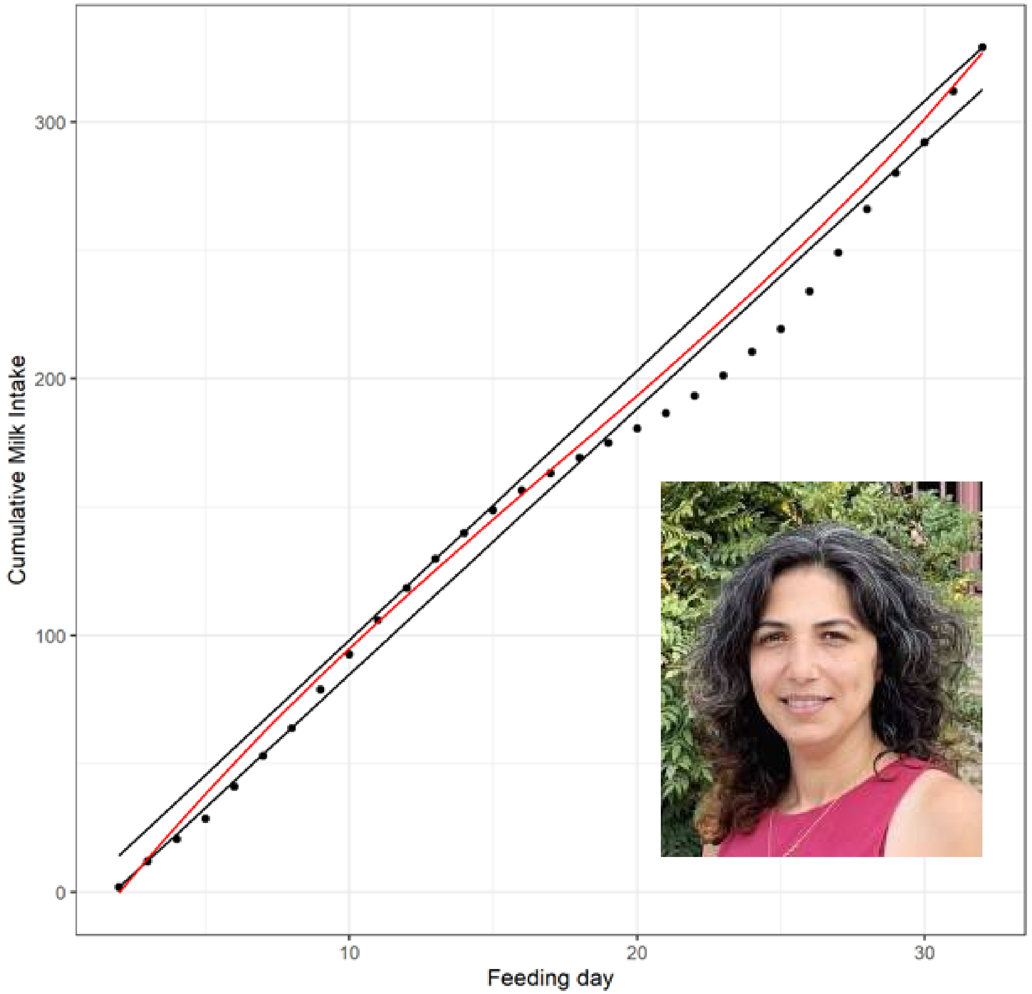
Deriving Calf Resilience

Develop cumulative milk intake:

- AMF devices programmed for specific milk entitlement
- Step-down program improved rumen development
- Data reduction to 32-d due to entitlement program
- Missing information estimated using B-spline function
- Cumulative milk intake was calculated

Non-linear Model Testing:

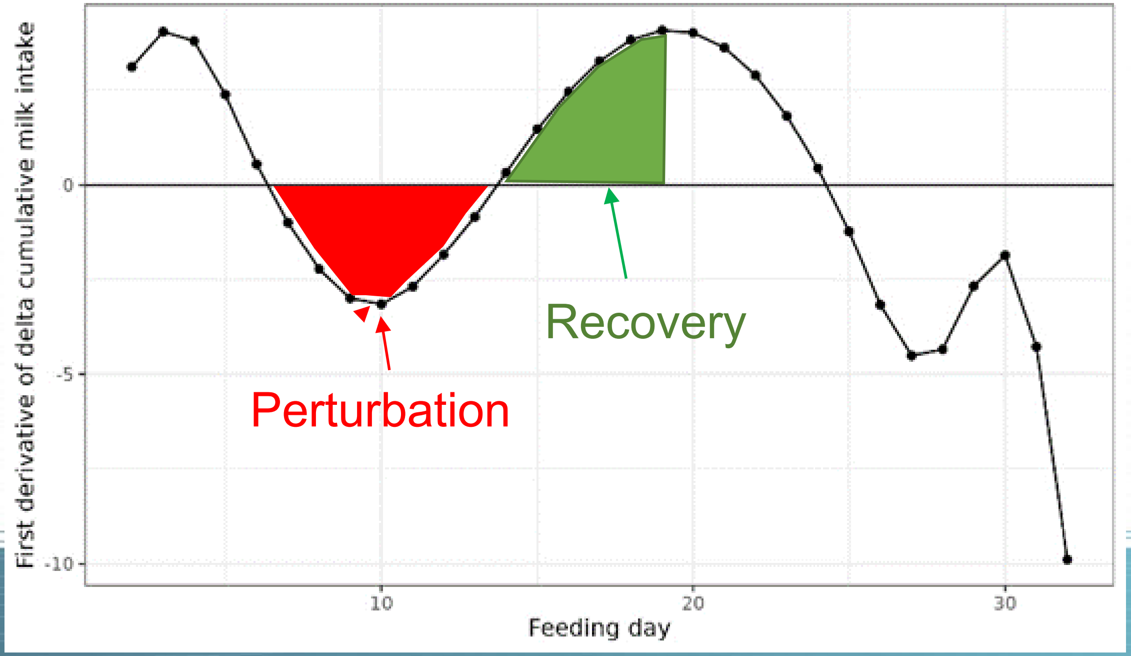
- Quantile Regression envelope calculated
- Smoothing function applied to extracted data
- Observed - Target = ΔCMI

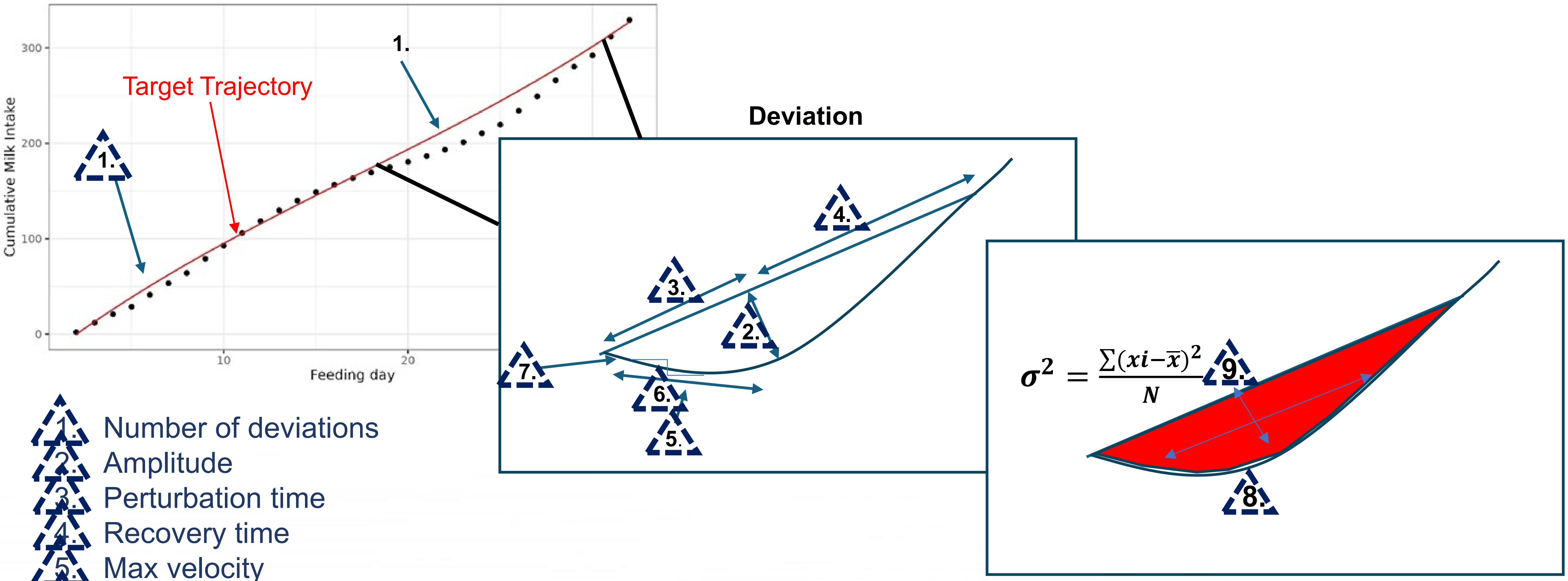


Deriving Calf Resilience

Estimation of perturbations (continued):

- 1st derivative of ∆CMI calculated to estimate transition periods
- Perturbation phase identified by negative 1st derivative
- Recovery phase marked by positive 1st derivative
- Transition periods guide assessment of original function for resilience phenotypes

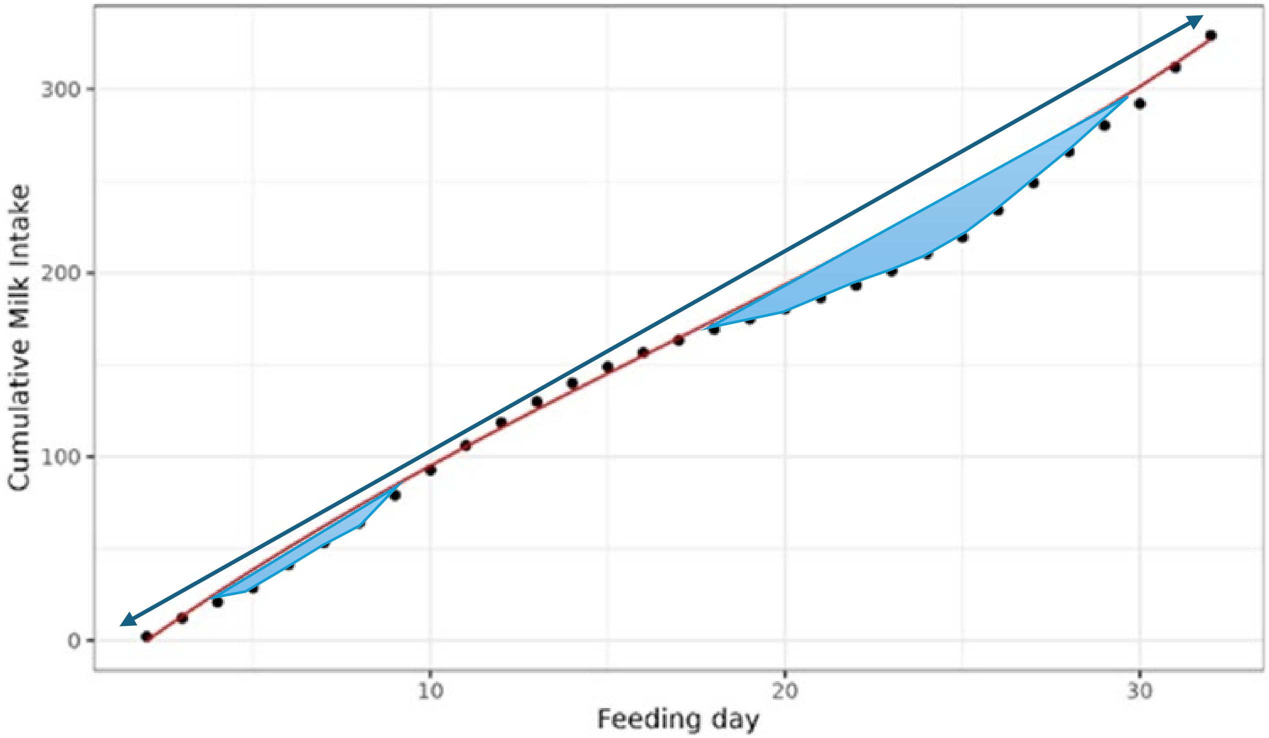




1. Number of deviations
2. Amplitude
3. Perturbation time
4. Recovery time
5. Max velocity
6. Average velocity
7. Autocorrelation
8. Area between the curve
9. Deviation variance

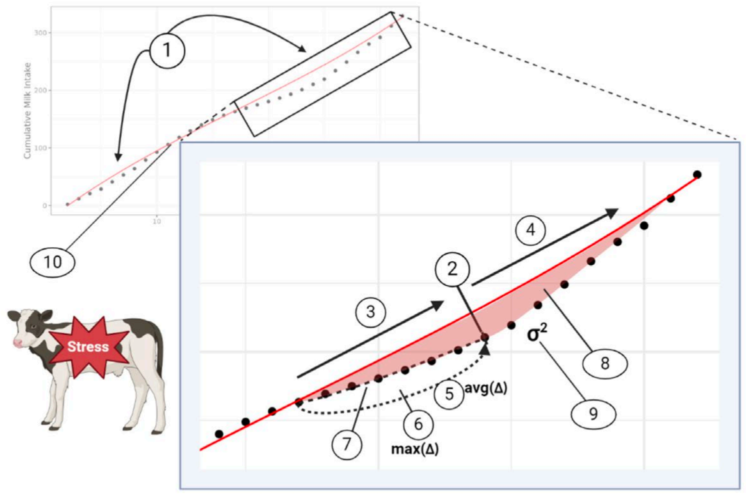
Recovery Ratio Calculation

- Recovery ratio (Rec_{ratio}) calculated as CMI/Target CMI



Descriptive Statistics of Calf Resilience Indicators

Trait (unit)	Mean	SD	Min	Max
Amplitude (L)	5.63	3.70	0	28.07
Perturbation time (d)	2.92	1.82	0	12.00
Recovery time (d)	3.23	2.26	0	15.00
Maximum velocity (L/d)	1.43	0.98	0	9.20
Average velocity (L/d)	0.98	0.67	0	6.35
ABC	28.94	33.52	0	294.11
Deviation variance (L^2)	3.32	4.68	0	75.63
Deviation log-variance ($\ln(L^2)$)	0.47	1.43	−12.54	4.33
Deviation auto-correlation	0.005	0.39	−0.85	0.87
Recovery ratio (%)	0.96	0.024	0.72	1.00
Deviation number	1.23	1.11	0.00	4.00
Number of times treated	0.70	0.71	0.00	2.00
Average milk consumption	9.44	1.55	3.81	16.67



Genetic Parameters: Calf Resilience Traits

Trait	h^2
Amplitude (L)	**0.047 (0.032, 0.064)**
Perturbation time (d)	**0.011 (0.0056, 0.016)**
Recovery time (d)	0.025 (0.016, 0.035)
Maximum velocity (L/d)	0.039 (0.024, 0.053)
Average velocity (L/d)	0.038 (0.022, 0.050)
ABC	0.039 (0.027, 0.054)
Recovery ratio	**0.053 (0.036, 0.072)**
Deviation variance	0.049 (0.32, 0.068)
Deviation log-variance	0.027 (0.016, 0.044)
Deviation auto-correlation	0.010 (0.0042, 0.017)
Deviation number	0.023 (0.0094, 0.036)
Average milk consumption	**0.36 (0.33, 0.40)**
Number of times treated	**0.16 (0.13, 0.18)**

- **h^2 estimates for resilience traits:**
  - Ranged from 0.01 to 0.05
  - Similar to health traits in dairy cattle
- **Putz et al. (2019)**
  - 0.15 - 5% quantile
  - 0.21 - root mean square error
  - differences in observation duration and post-weaning stressors
- **Lenoir et al. (2022):**
  - Ranged from 0.03 to 0.09 for resilience traits

Genetic Parameters: Calf Resilience Traits

Moderate positive genetic correlations were found:

- Amplitude and perturbation time (0.55)
- Perturbation time and NTT (0.49)
- Negative correlation between perturbation time and average milk consumption (-0.53)

Genetic correlations between resilience and milk consumption and number of times treated for BRD traits.

Trait	Average milk consumption	Number of times treated for BRD
Amplitude	0.569 (0.474, 0.666)	-0.181 (-0.341, -0.025)
Perturbation time	-0.534 (-0.73, -0.342)	0.494 (0.251, 0.723)
Recovery time	-0.18 (-0.279, -0.085)	0.102 (-0.101, 0.312)
Maximum velocity	0.428 (0.346, 0.508)	-0.132 (-0.256, -0.015)
Average velocity	0.554 (0.432, 0.672)	-0.279 (-0.433, -0.106)
Area between curve	0.109 (-0.03, 0.253)	0.03 (-0.132, 0.192)
Autocorrelation	-0.339 (-0.53, -0.139)	0.348 (0.131, 0.578)
Deviation variance	0.198 (0.074, 0.314)	-0.015 (-0.174, 0.14)
Ln Deviation variance	0.28 (0.138, 0.415)	-0.068 (-0.247, 0.106)
Number of deviations	0.091 (-0.125, 0.306)	-0.294 (-0.52, -0.095)
Recovery ratio	0.204 (0.063, 0.355)	0.024 (-0.14, 0.186)

Conclusions

- ✓ Milk feeding behavior and calf resilience indicators are **heritable and genetically correlated with number of BRD treatments and pre-weaning survival**
- ✓ Random regression models captured more of the genetic variation than repeatability models
- ✓ Calf resilience traits derived based on **cumulative milk intake** are under genetic control but with low heritability estimates
- ✓ **Daily milk consumption, NTT, and perturbation time** are the **most promising indicator traits** for improved calf resilience.
- ✓ Drinking speed, total number of visits to the AMF, and recovery time are other key auxiliary traits for improved calf resilience

Additional Details:

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Trait development and genetic parameters of resilience indicators based on variability in milk consumption recorded by automated milk feeders in North American Holstein calves

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Thank You!

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