Variations in milk lactose content and mechanisms underlying in dairy cows

Guinard-Flament J., Hamon A., Decoopman N., Boutinaud M., Gaillard C., Hurtaud C., Gelé M., Mériaux L., Dufour S., Larroque H., Lemosquet S.

French dairy sector is facing two major challenges:

- Decline in the number of dairy farms and in workforce due an insufficient renewal of generations

- Climate changes -> forage production

Number of new dairy farms: 2 times lower than the number of retirements
By 2026, 49% of dairy farmers will be over the age of 60.
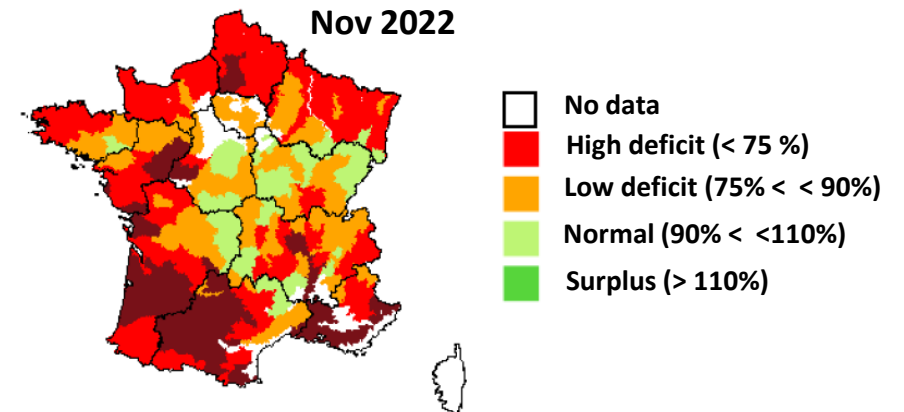-> Larger herds / higher labor productivity

More or less severe drought-induced feed shortages

Nov 2022

Solutions:

Milking frequency
Automated milking systems

Monitoring

No data
High deficit (< 75 %)
Low deficit (75% < < 90%)
Normal (90% < <110%)
Surplus (> 110%)

Cumulated permament grassland production

Agreste – Isop – Météo-France – INRAE

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p. 2

Lactose: a major component of milk

Easy to measure at low cost and on a large scale with MIR analysis

Little studied in the past, mainly because :
- not a criterion for the milk payment system
- assumed to be nearly constant

# Lactose content varies in milk of commercial dairy farms

Organic commercial farms
204 farms - 184 597 controls
Years: 2019-2020-2021

Breeds	Data number
Prim'Holstein	134 591
Normande	28 983
Montbéliarde	15 623
Jersiaise	5 400

- Lower lactose content for jersiaise cows
- Higher content in spring / lower in autumn
- jersiaise cows: highest amplitude of fluctuations during the year
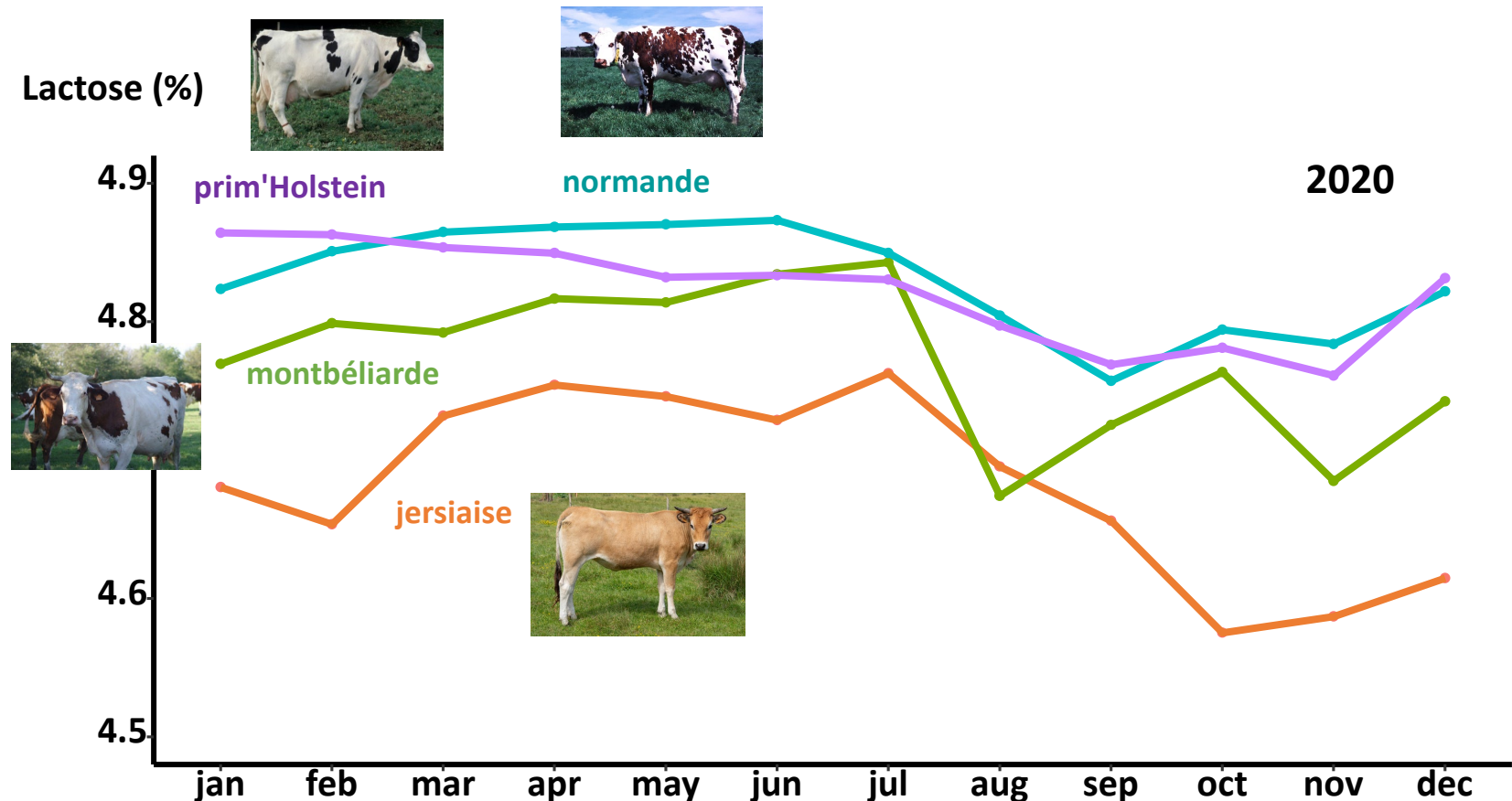
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(Igier & Machefaux, 2023)

Changes originate from 3 udder mechanisms

Osmotic pressure in cells and milk
-> balance between osmotic agents in milk

Metabolic activity of mammary epithelial cells

Udder

(mammary epithelial cells and acini)

Glucose

Lactose

Lactose
Na⁺ K⁺ Cl⁻
Proteins …

Integrity of mammary epithelium

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p. 5
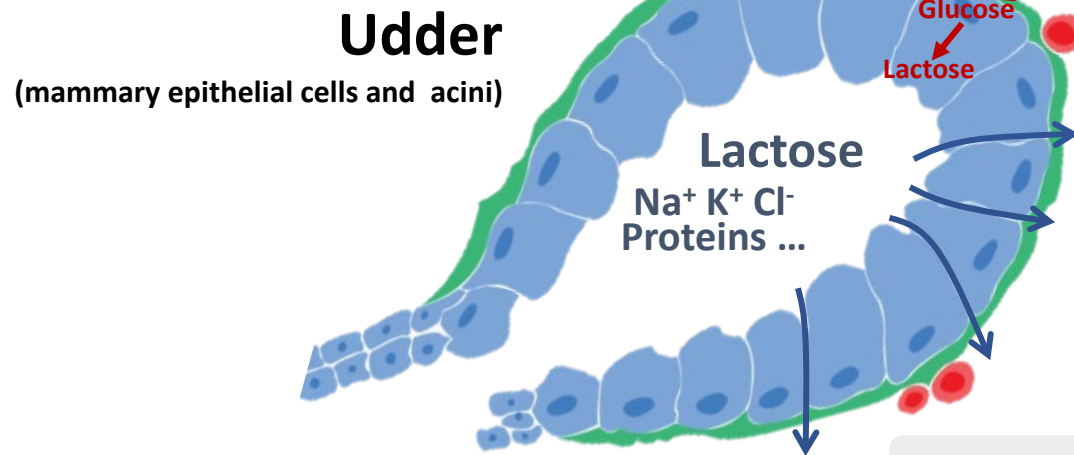
Many factors responsible for changes in milk lactose content
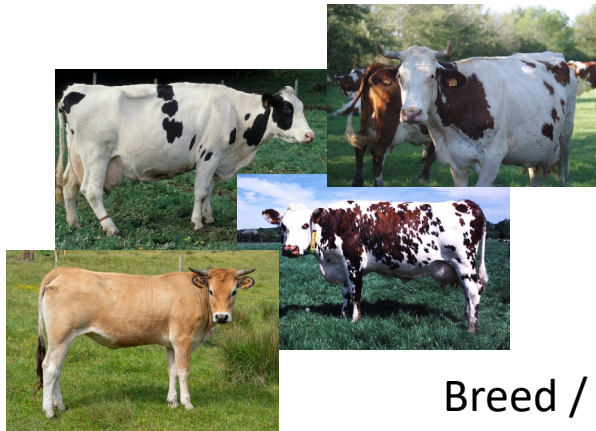
Quarter health	Lactose (%)
Healthy quarter	5,02 ± 0,19[a]
Unhealthy quarter (SCC > 100,000 cells/mL)	4,71 ± 0,27[b]

(Bansal et al, 2015)

Season

Mastitis

Breed / genetic

Osmotic pressure in cells and milk

Metabolic activity of mammary epithelial cells

Udder (mammary epithelial cells and acini)

Lactos?

Integrity of mammary epithelium

Feeding

Lactose (%)

4.86
4.82
4.78
4.74
4.70

-60   -40   -20   0   20   40

NE_{L100} supply (MJ/d)

(Daniel et al, 2016)

Parity
Stage of lactation

Lactose (%)

5

4.5

0   50   100   150   200   250   300

Days in milk

1st lactation
2nd
3rd

(Haile-Mariam & Price, 2017)

Milking

5.0
4.6
4.2
3.8
3.4

Lactose, %

-20 -10 0 10 20 30 40 50 60 70 80 90 100

% of milking

(Nielsen et al, 2005)

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p. 6

› Milk yield & dilution-concentration effects

r = 0.98

Milk yield (kg/d) vs Lactose yield (g/d)

Lactose secretion depends on both mammary and systemic regulations

1 Nutrient flows

triglycerid
acetate   amino acids
NEFA   glucose
BHB

Nutrient extraction

2

3 Nutrient metabolism

Lactose   Protein   Fat

755 data – Prim'Holstein – IE PL Méjusseaume
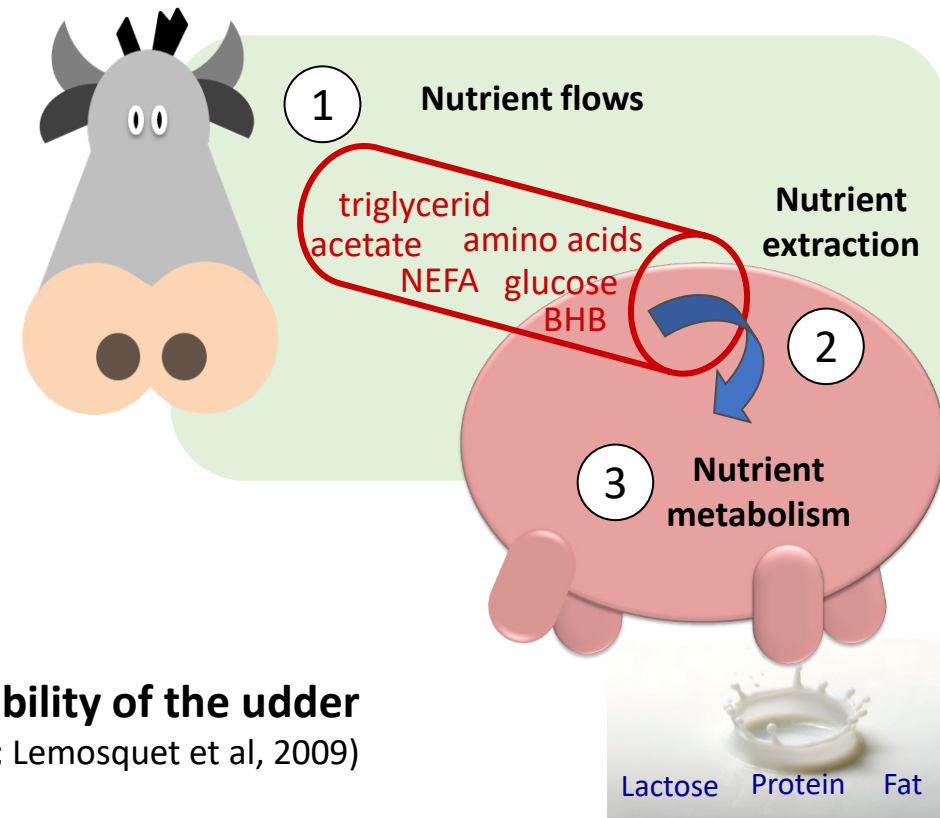
-> High metabolic flexibility of the udder
(Guinard-Flament et al, 2007 ; Lemosquet et al, 2009)

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p. 7

Why to investigate lactose?

Milk yield & dilution-concentration effects

Effect of cessation of milking
(after 18h of milk accumulation into the udder)
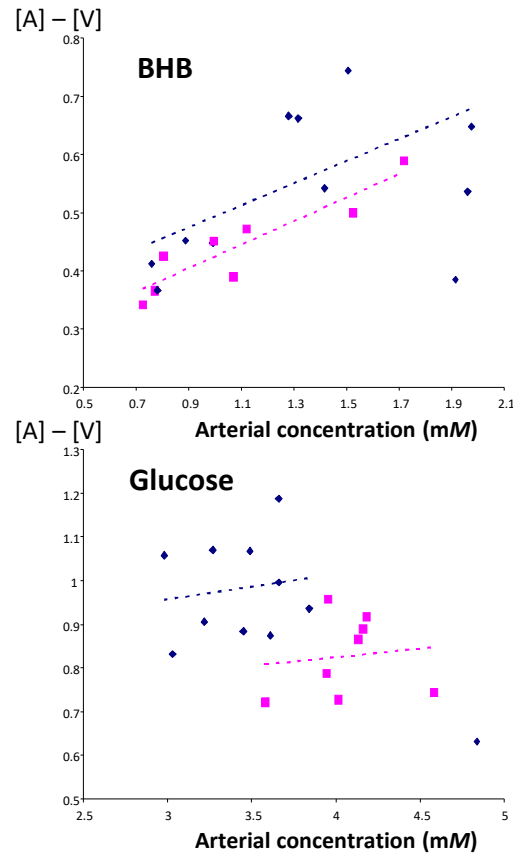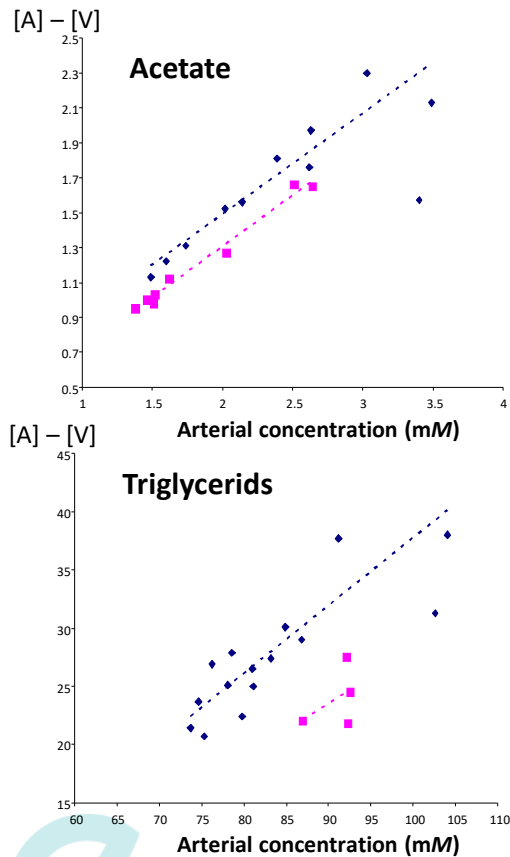
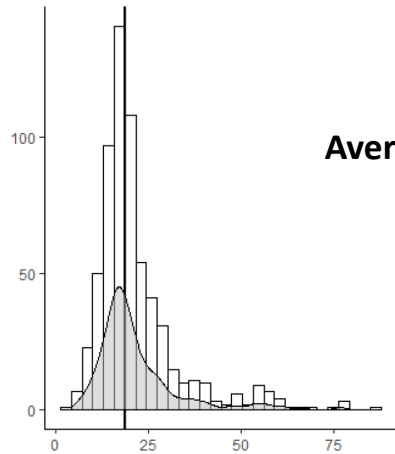
(Guinard-Flament et al, 2011)
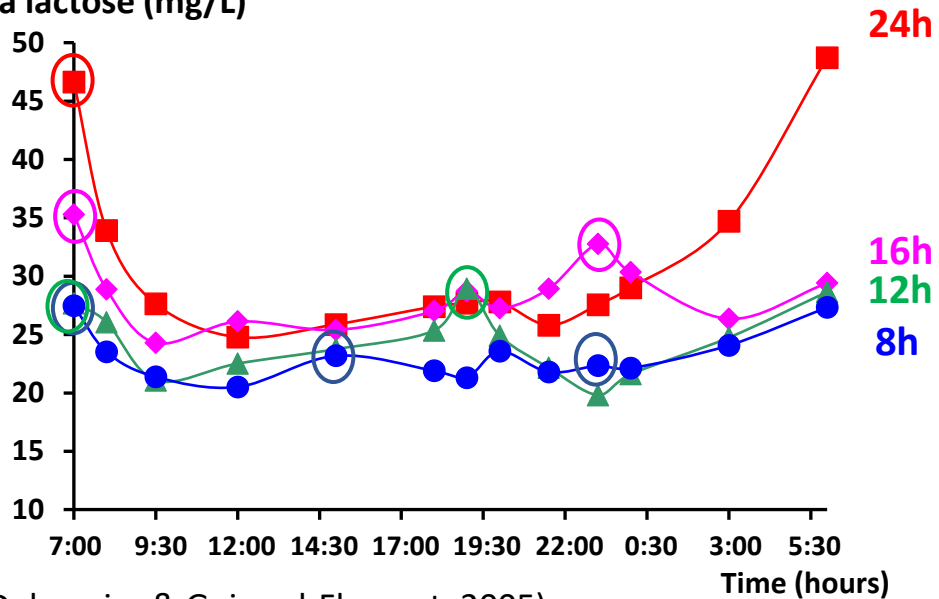
30% feed restriction
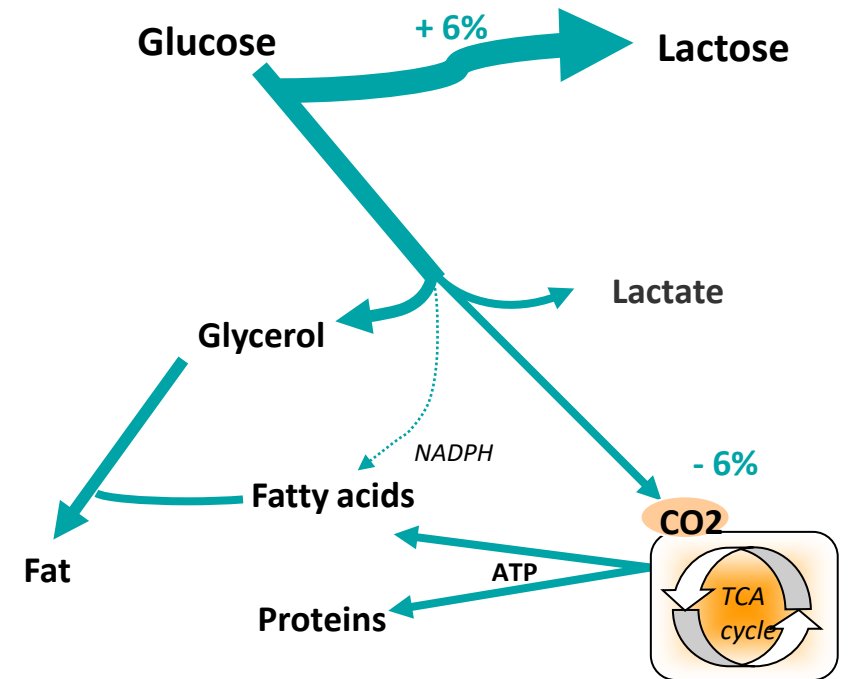
(Guinard-Flament et al, 2007)

Why to investigate lactose?
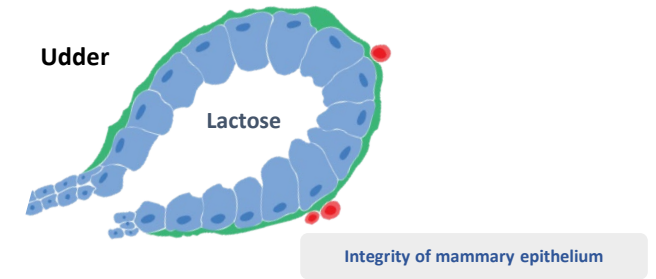
Plasma lactose 1 h before evening milking (mg/L)

Average = 21.9 mg/L

> **Integrity of mammary epithelium**

Udder
Lactose
Integrity of mammary epithelium

Measurements both in milk and blood plasma

Plasma lactose (mg/L)

Milking intervals

24h
16h
12h
8h

Time (hours)

(Delamaire & Guinard-Flament, 2005)

Plasma lactose (mg/L)

36-h milking interval

Time after morning milking (h)
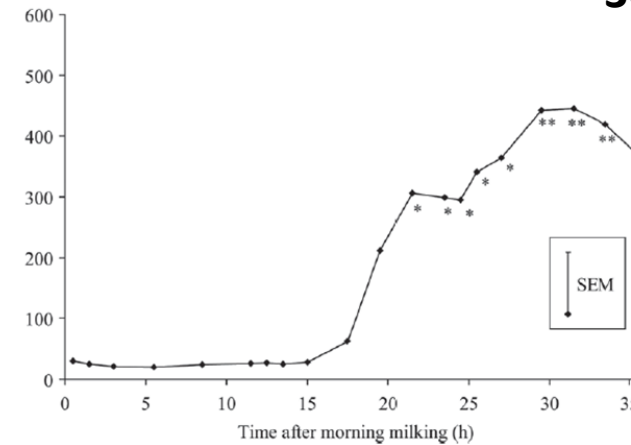
(Guinard-Flament et al., 2011)

Milk accumulation in the udder: alveoli distension and alteration of epithelium integrity
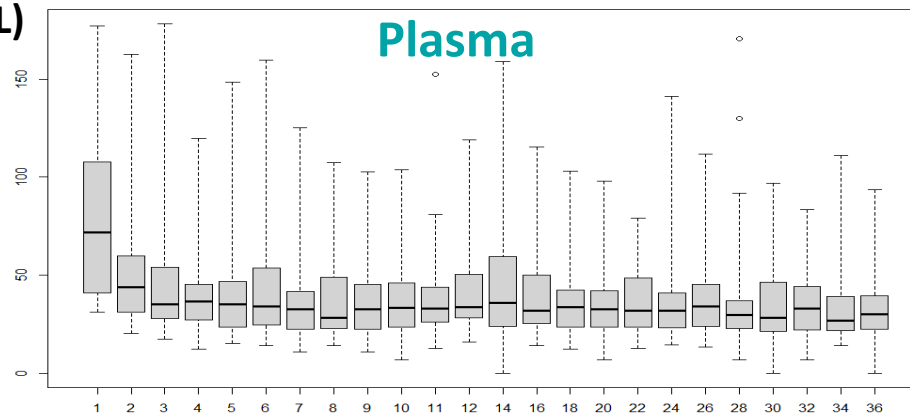
Why to investigate lactose?

Mammary epithelium integrity varies mainly during early lactation
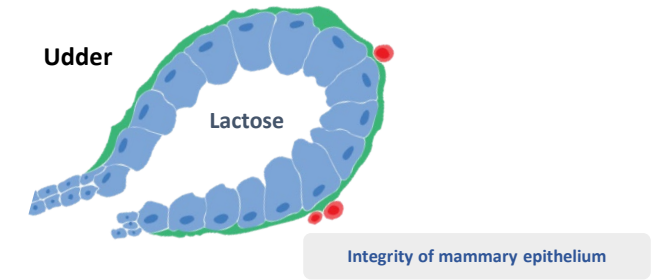

Milk lactose (%)
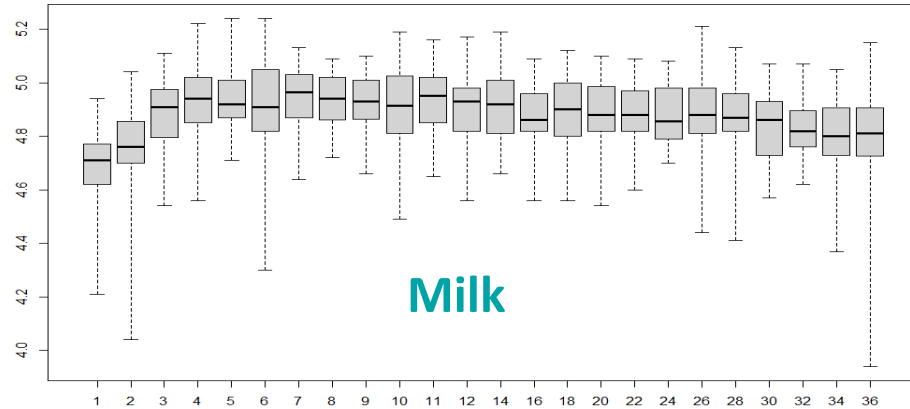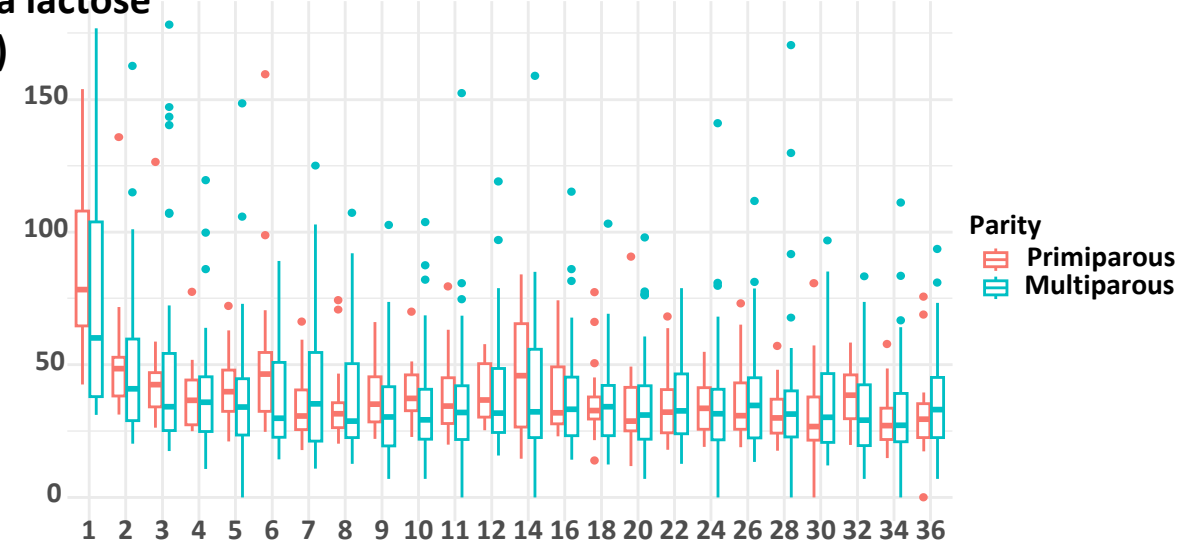
Milk

Plasma lactose (mg/L)

Plasma

Week of lactation (n=53)

Integrity of mammary epithelium

Udder
Lactose
Integrity of mammary epithelium

Primiparous cows -> lower variability
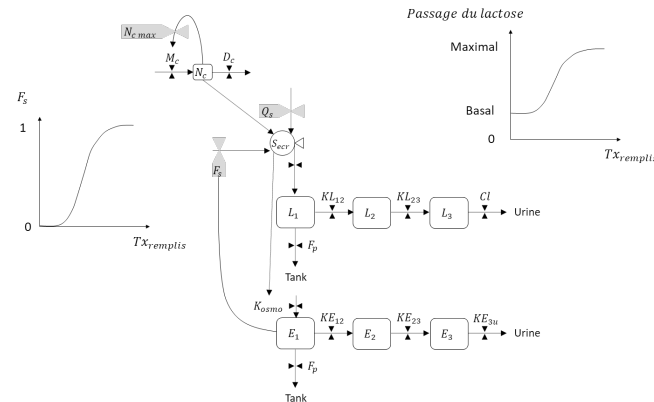
Less diruption of mammary epithelium integrity

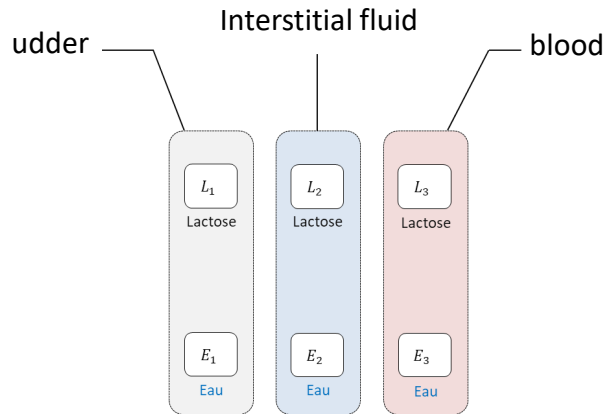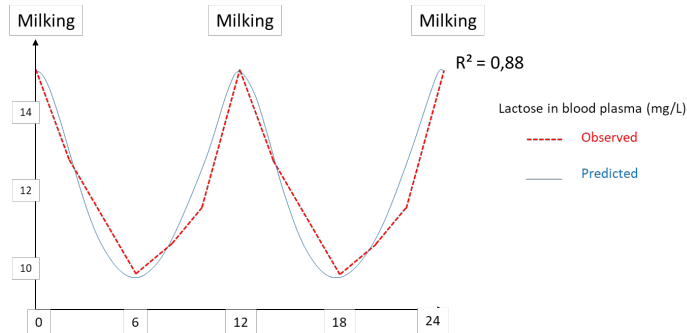Plasma lactose (mg/L)

Parity
Primiparous
Multiparous

Week of lactation

(Gaillard et al., 2022)

Mechanistic model to predict the quantity of lactose flowing from the milk into the blood

udder — Interstitial fluid — blood

L_1 Lactose | L_2 Lactose | L_3 Lactose

E_1 Eau | E_2 Eau | E_3 Eau

$N_{c\,max}$ · M_c · N_c · D_c

F_s · Q_s · S_{ecr} · F_p

L_1 · KL_{12} · L_2 · KL_{23} · L_3 · Cl → Urine · F_p · Tank

K_{osmo} · E_1 · KE_{12} · E_2 · KE_{23} · E_3 · KE_{3u} → Urine · F_p · Tank

$Tx_{remplis}$

Passage du lactose — Maximal — Basal — 0 — $Tx_{remplis}$

Model:
- **Law of mass action**
- **Half-life of lactose in plasma**

Unleaky epithelium   *Leaky epithelium*

Plasma lactose: +62.4 mg/L

Milk lactose content: -0.25 ± 0.06 %
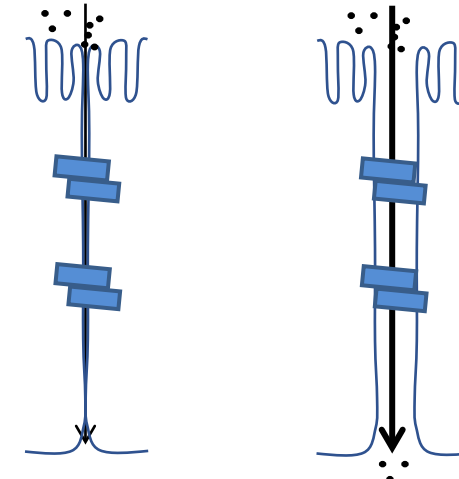
0 g / 12h   **2.1 g / 12h**
cow producing 30 kg of milk per day
(lactose content: 4.8%)

Milking | Milking | Milking

R² = 0,88

Lactose in blood plasma (mg/L)
----- Observed
——— Predicted

14 · 12 · 10 · 0 · 6 · 12 · 18 · 24

Incremental variation in milk lactose content:
- 0.04 ± 0.01% for +10 mg/L of lactose in blood plasma

(Decoopman, 2019)

4 reasons to further investigate lactose

1) Lactose -> to predict heat stability of milk?
to manage increased variability of raw milk due to climate changes

Severe feed restriction increases permeability of mammary gland cell tight junctions and reduces ethanol stability of milk

M. T. Stumpf[1†], V. Fischer[1], C. M. McManus[1], G. J. Kolling[1], M. B. Zanela[2], C. S. Santos[3], A. S. Abreu[1] and P. Montagner[4]

SHORT COMMUNICATION

Check for updates

Mammary gland cell's tight junction permeability from dairy cows producing stable or unstable milk in the ethanol test

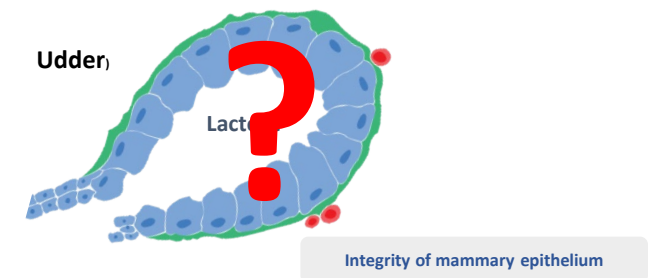Marcelo T. Stumpf[1] · Vivian Fischer[2] · Darlene S. Daltro[2] · Evelyn P. M. Alfonzo[2] · Giovani J. Kolling[3] · Marcos Vinicius G. B. da Silva[4] · Luiz Gustavo R. Pereira[4] · Concepta M. McManus[5]

18 organic commercial dairy farms South of France - 2022-2023

Distribution pour lactose en fonction de l'alcool 76

Negative (n=58)   Positive (n=7)

Alcohol test (76 °GL)
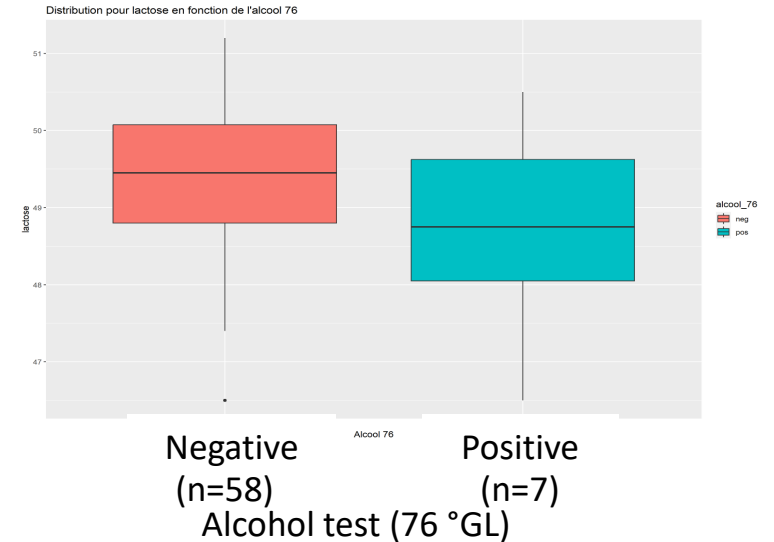
(Fanny Albert et al, Idele, personal communication)

Research group -> understand the biological determinants of the loss of heat stability of milk + the role of the integrity of the mammary epithelium (C. Hurtaud)

Udder
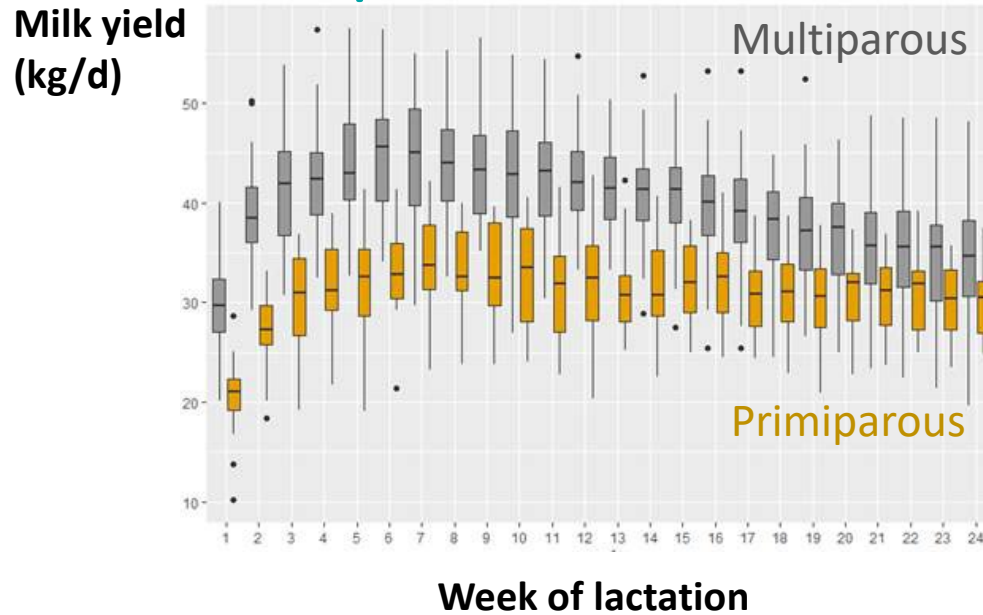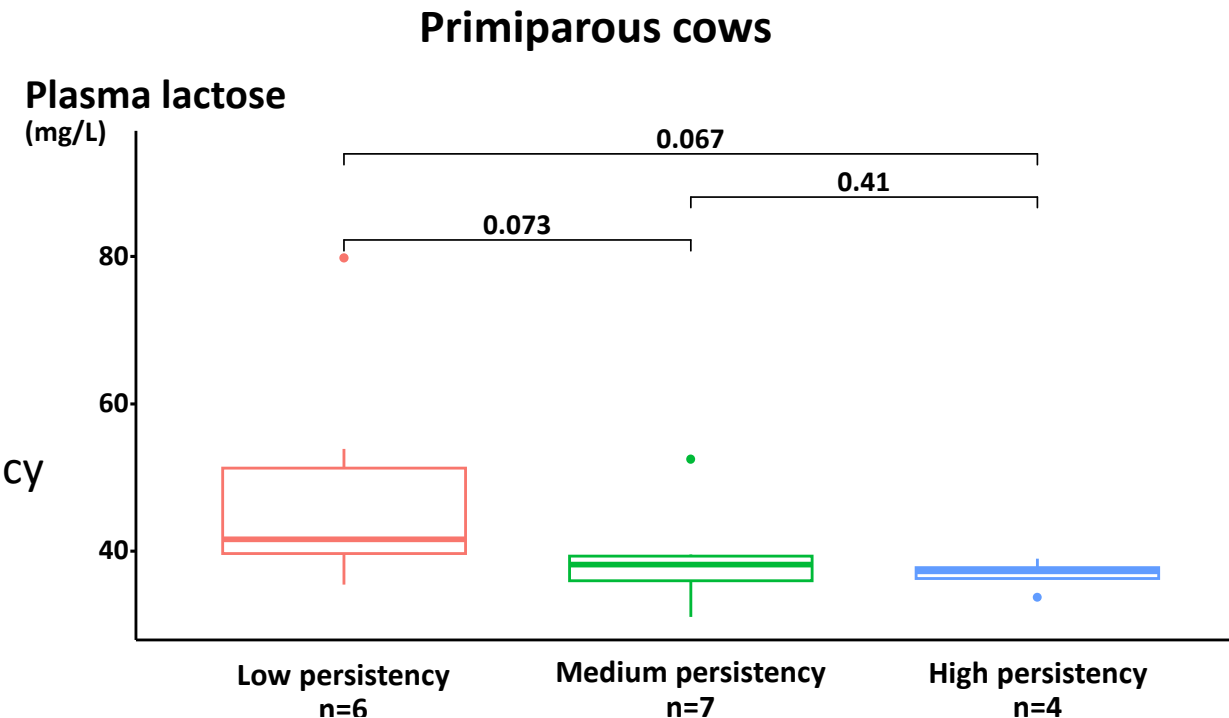
Lact

Integrity of mammary epithelium

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p. 13

2) Lactose -> to predict the persistency of lactation?
to optimize either feeding strategies or to decrease number of calving

Milk yield (kg/d)

Multiparous

Primiparous

Week of lactation

Research group -> develop methods to predict lactation persistency

Trial on **multiparous cows** (18 months of lactation – n=36):
- **milk lactose:** improved accuracy, sensitivity, and specificity of prediction models.

(Gaillard et al., 2

Primiparous cows: both high lactation persistency & milk lactose content

Primiparous cows

Plasma lactose (mg/L)

0.067

0.41

0.073

Low persistency n=6

Medium persistency n=7

High persistency n=4

Poor Lactation persistency could be associated with leakier mammary epithelium

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p. 14

3) Lactose -> to predict adaptive response to once-daily milking? to manage worforce on dairy farms

2 -> 1 milking/d

↘ **20 to 30 %**
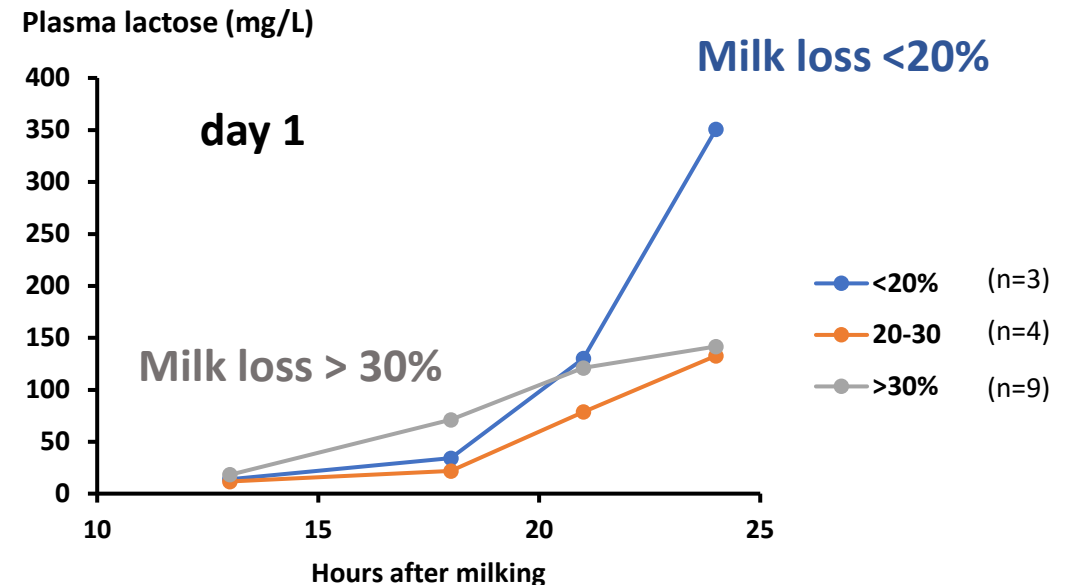**milk yield**
(from 1st day)

+   **a large between-cow variability (-15 to -50%)**

Higher milk yield losses:
Day 1 -> Less leakage of lactose from milk to blood probably due to a strong down-regulation of milk secretion and a lower alveoli distension

day 1

	Cluster 1 (n=29)	Cluster 2 (n=44)	Cluster 3 (n=20)
Initial milk yield (kg/d)	34.4[a]	32.5[ab]	29.7[b]
Milk yield loss (%)	-35.5[c]	-23.6[b]	-17.8[a]
% of cows with increase in plasma lactose > 100 mg/L	34[b]	68[a]	67[a]

(Charton et al. 2019)

Plasma lactose (mg/L) vs Hours after milking — day 1

Milk loss <20%

Milk loss > 30%

- <20% (n=3)
- 20-30 (n=4)
- >30% (n=9)

(Albaaj et al, 2018)

4) Lactose -> to predict nutritional/health status of dairy cows? to sustain animal health and welfare

204 French organic commercial dairy farms
4 breeds

Abstract 1065M

5 Canadian dairy farms – holstein

prim'holstein - 2020
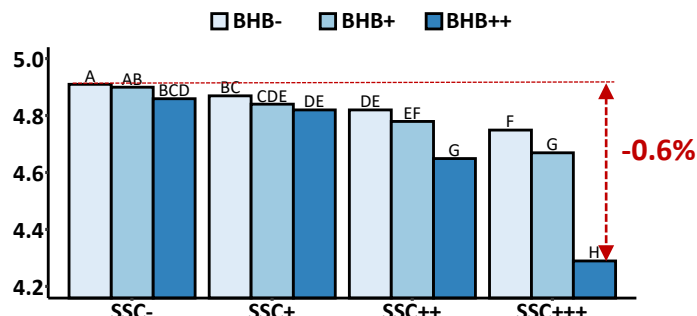
normande - 2020

monbéliarde - 2020

jersiaise - 2020

Milk lactose content
-0.6 %

SSC < 50,000   SSC > 800,000
BHB < 0.15   ----->   BHB > 0.19
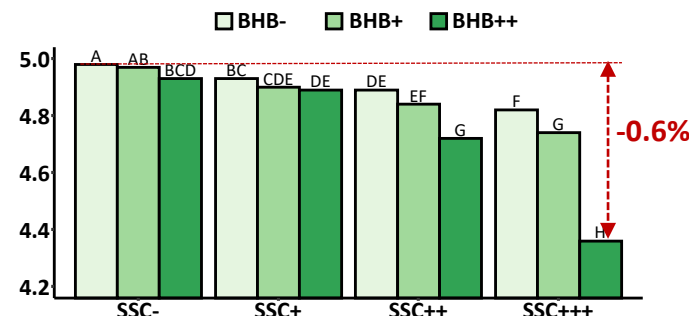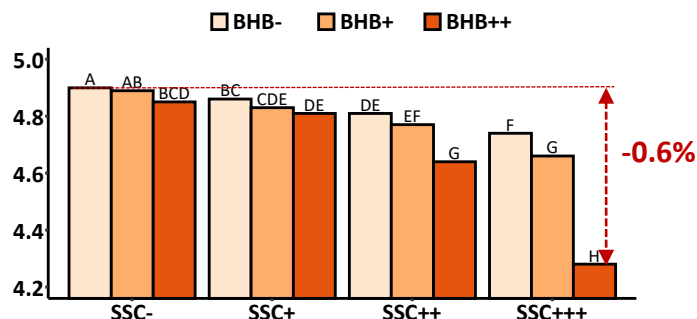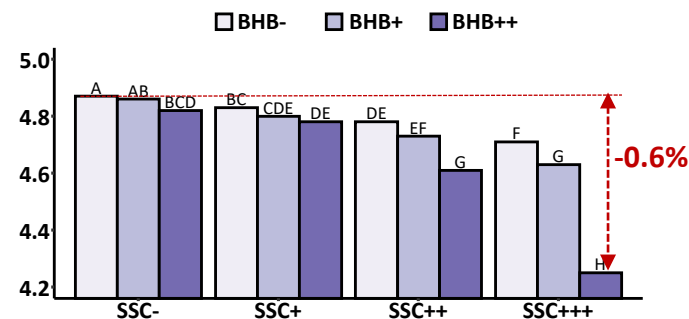
(184 597 test-day records - Igier & Machefaux, 2023)

To conclude: our futur works

-> Is it possible to use lactose as an indicator? How?

-> Which mechanisms underline its changes in milk according to factors of variation?

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