Integrative factorial methods to explore the relationships between genotypes, phenotypes and climate in Holstein cows

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A first step: Synthesizing lactation curves

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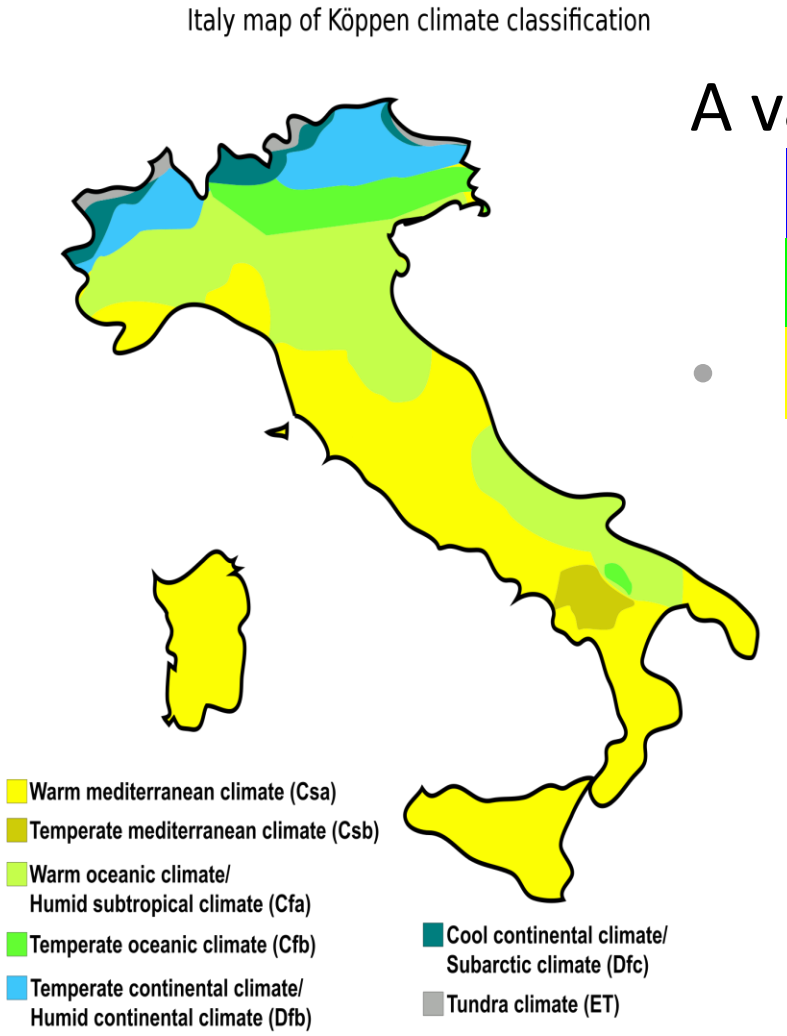
Introduction
The map of italian climates



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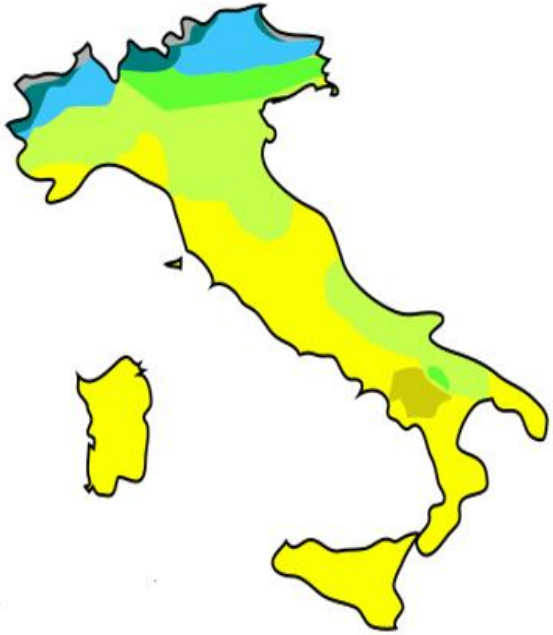
A variety of climates

- Continental
- Oceanic / Temperate
- Mediterranean

Introduction
The map of italian climates

A variety of climates
(compared to other european countries)



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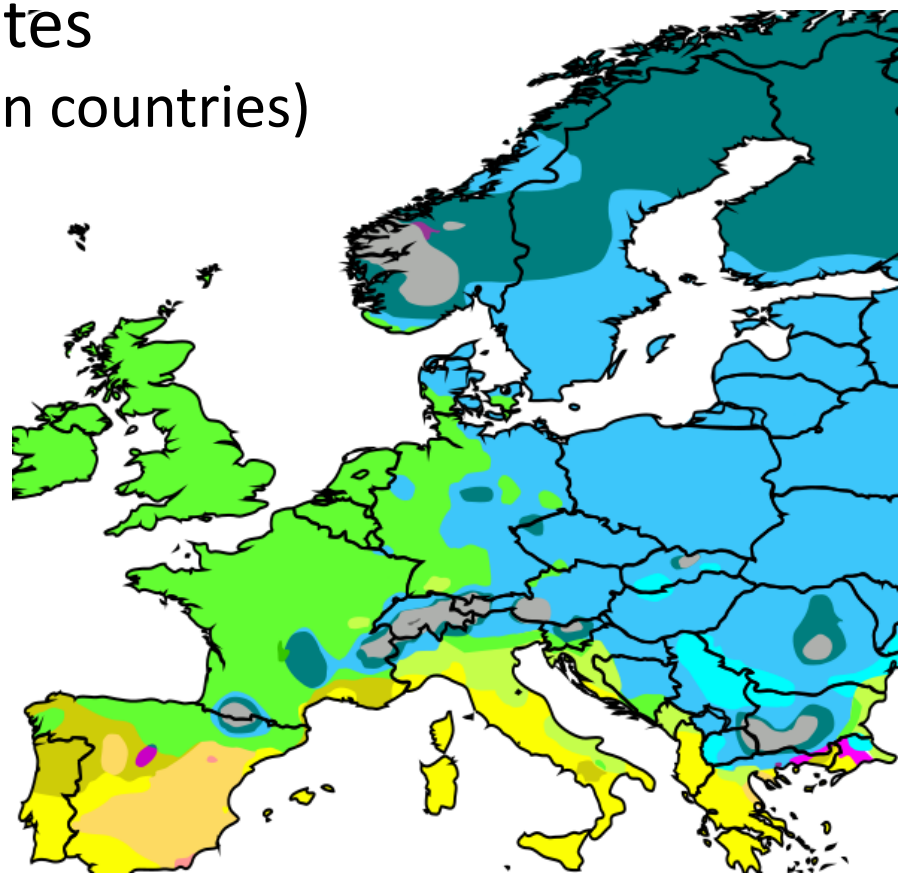

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Introduction
Accounting for environment

The fine-scale (day) classical approach:
Reaction norms model on test-day records : test-day phenotypes linked to day-recorded meteo variables

Bernabucci, U., Biffani, S., Buggiotti, L., Vitali, A., Lacetera, N., & Nardone, A. (2014). The effects of heat stress in Italian Holstein dairy cattle. Journal of dairy science, 97(1), 471-486.

Landi, V., Maggiolino, A., Cecchinato, A., Mota, L. F. M., Bernabucci, U., Rossoni, A., & De Palo, P. (2023). Genotype by environment interaction due to heat stress in Brown Swiss cattle. Journal of Dairy Science, 106(3), 1889-1909.

Vinet, A., Mattalia, S., Vallée, R., Bertrand, C., Cuyabano, B. C., & Boichard, D. (2023). Estimation of genotype by temperature-humidity index interactions on milk production and udder health traits in Montbeliarde cows. Genetics Selection Evolution, 55(1), 1-17.

An other larger-scale approach:
Effect of general environment (through geography)

1. Functional PCA (fpca) on lactation curves (milk yield, fat, protein) -> a few synthetic variables
2. Links of fPCA results with geography / climate

Methods: Functional Principal Components Analysis

Data recorded at different discrete times-> Curve

Functional pca:

- **Irregular measurement times, irregular number of measurements**
- **Extract the common temporal characteristics of a set of curves**
- **Essential modes of temporal variation: Principal Functions**
  - **% of variance**
  - **interpretation**

An extension of classical PCA (Macciotta et al (1015)

	PCA	FPCA
Dimension	$P< \infty$	∞
Mean	E(X) : scalar	E(X(t)) : function
Covariance	$Cov(x_p, x_q) = \Sigma$	Cov (X(s),X(t) : surface
Eigenvectors / Eigenfunctions	v_1 , v_2 ,…	$f_1(t)$, $f_2(t)$,…

*Macciotta et al(2015). Genome-wide association analysis in Italian Simmental cows for lactation curve traits using a low-density (7K) SNP panel. *Journal of Dairy Science*, *98*(11), 8175-8185.

Yao F., Müller H.G., and Wang J.-L. (2005). Journal of the American Statistical Association 100 (470): 577–90. https://doi.org/10.1198/016214504000001745

Zhou Y et al (2022). _fdapace: Functional Data Analysis and Empirical Dynamics, R package

Arnal, M., Robert-Granié, C., & Larroque, H. (2018). Diversity of dairy goat lactation curves in France. *Journal of dairy science*, *101*(12), 11040-11051.

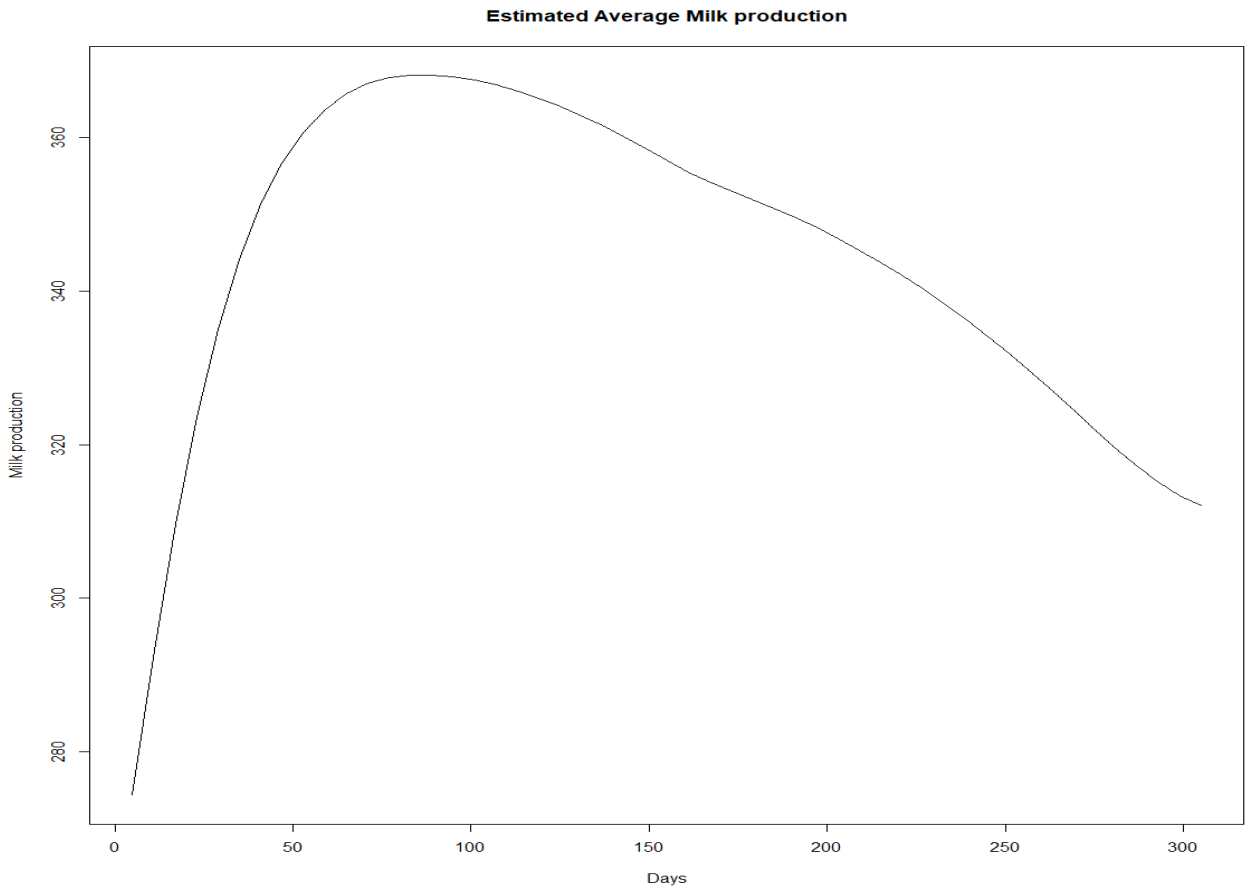
Data (ANAFI): Milk records

- Editing : First lactations, in the same herd , with > 4 records.

	Number
Records	120245
Lactations / Cows	15545
Herds	881

Number of records / lactation	Number
5	898
6	1788
7	4162
8	4140
9	2845
10	1664
11	48

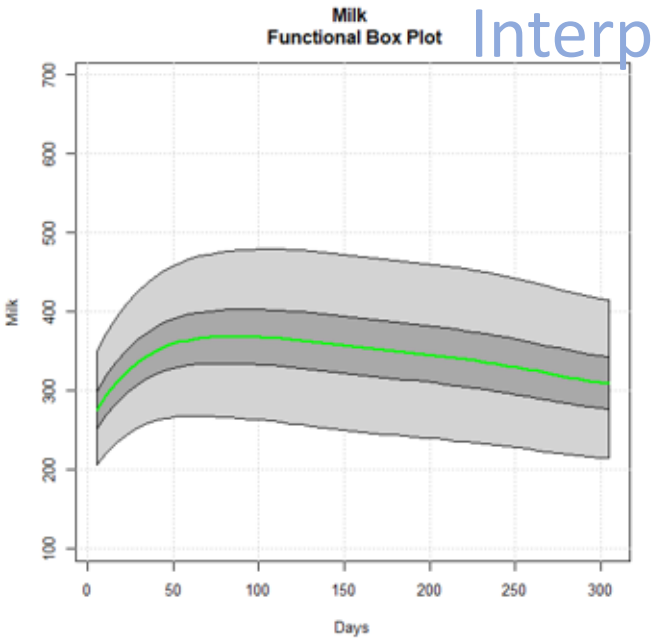
Functional PCA Milk yield
Average curve

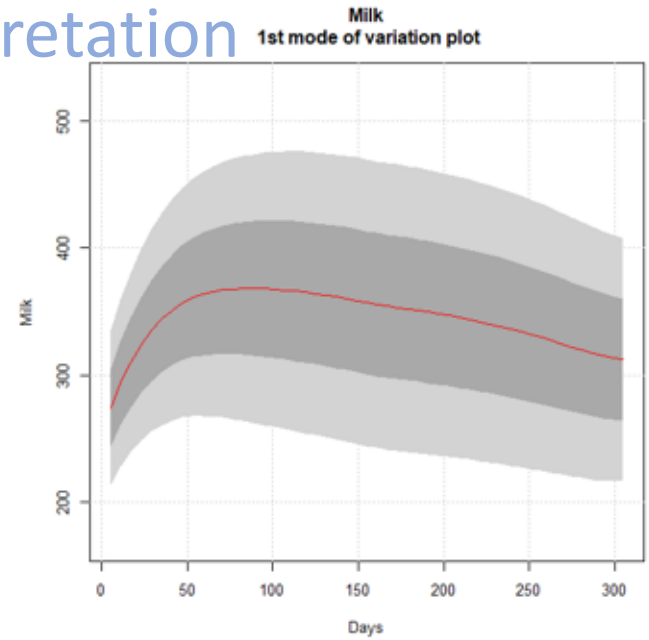


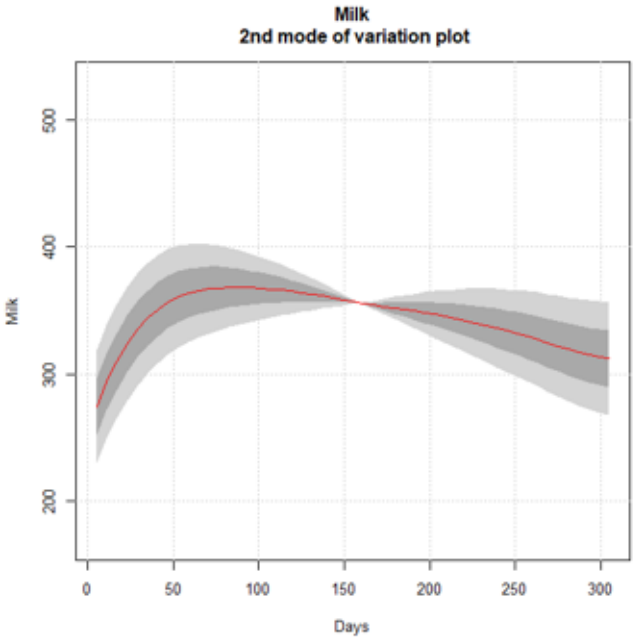
Functional PCA Milk yield Interpretation

$$\bar{x}(t) \pm Q_\alpha \sqrt{d_i}\xi_i(t)$$

	Milk Yield
1	89,5
2	8,0
Total(1+2)	97.5







Variations around mean curves

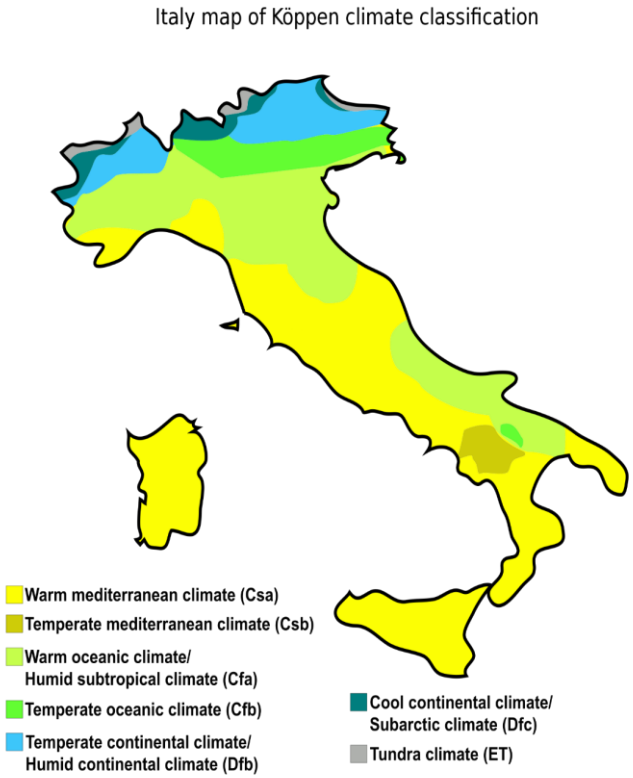
K=1 : Level of production *(Size)*
K=2: Persistency *(Shape)*

Functional PCA applied to Milk yield, Protein (%), Fat(%)

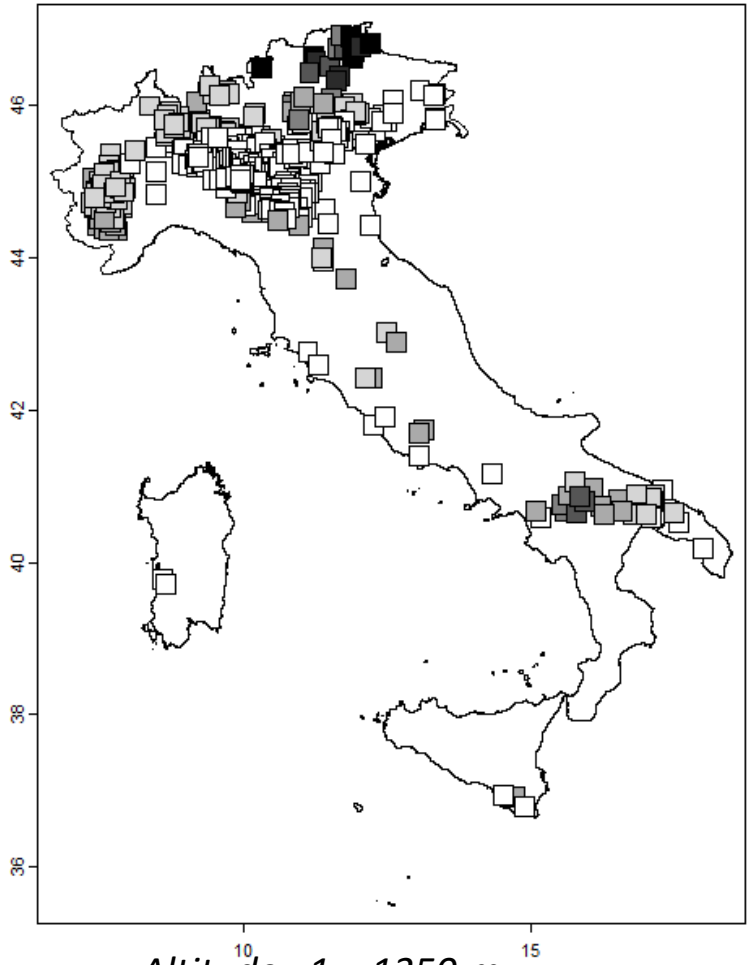
% of variance explained by the first 2 functional PCs

	Yield	Protein %	Fat %
1	89,5	85,2	88,8
2	8,0	11,7	7,3
Total (1+2)	97.5	96.9	96.1

Data (ANAFI)
Geography



Location of herds

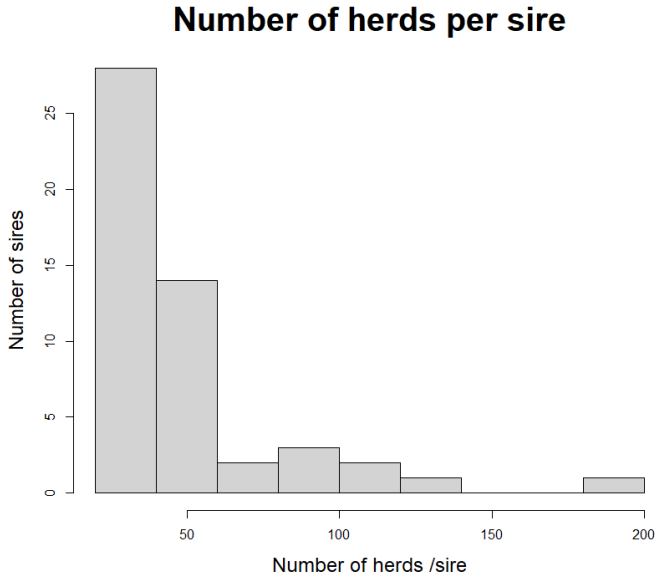


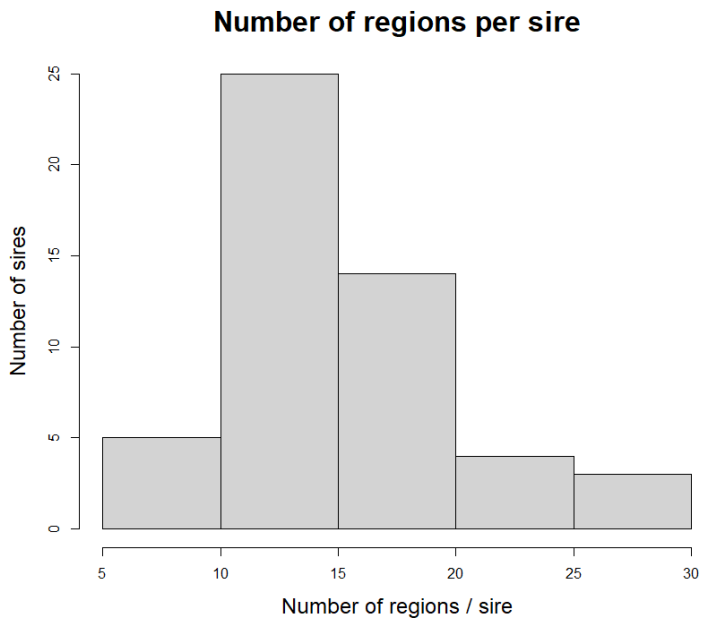
Altitude : 1 – 1350 m
The darker, the higher

Adaptation to different environments
Sire * geography interaction

2. Selection of « ubiquist » sires
   Sires that serve in > 25 herds

51 sires;
659 herds
42 provinces
6368 lactations





A first attempt for the characterization of an interaction Geography * Genotype

A mixed linear sire model (R package « nlme »)
Fixed effets : Year calving, Month calving, latitude, longitude, altitude
Random effects: Sire, interactions Sire*latitude, Sire*longitude, Sire*altitude

* ML test Presence vs Absence interactions -> Significant (except when NS indicated)
* From 6 % to 25 % of the sire variance

	Year	Month	Latit	Long	Altit	σ^2_{sire}	σ^2 sire*lat	σ^2 sire*long	σ^2 sire*alt
Milk	NS	*	NS	*	NS	0.056	0.014	0.006	0.014
Prot%	*	*	*	*	NS	0.108	0.011	0.007	*0.003 (NS)*
Fat%	NS	*	*	NS	*	0.068	0.006	0.006	*0.004 (NS)*

Pinheiro J, Bates D, R Core Team (2023). _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-162, <https://CRAN.R-project.org/package=nlme>.

Conclusion

For almost each trait*geographical coordinate, the interaction is significant, exhibiting a genotype*environment interaction

A (over?) simplified modelling
Environment (climate, breeding system, herd) synthetized by geography
Should be completed with more focused genetic studies (genetic / genomic studies)

Nevertheless,
Functional PCA allows us to synthesize a lactation curve into a few components;
- Can be seen as an extension of PCA
- Helps to relate milk yield to global climate parameters;
- could be used jointly with climate projections or scenarii (# genomic vulnerability)

A complementarity with reaction –norm approach


Thanks for Your Attention!!