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Derivation and genome-wide association study of a principal component-based measure of heat tolerance in dairy cattle

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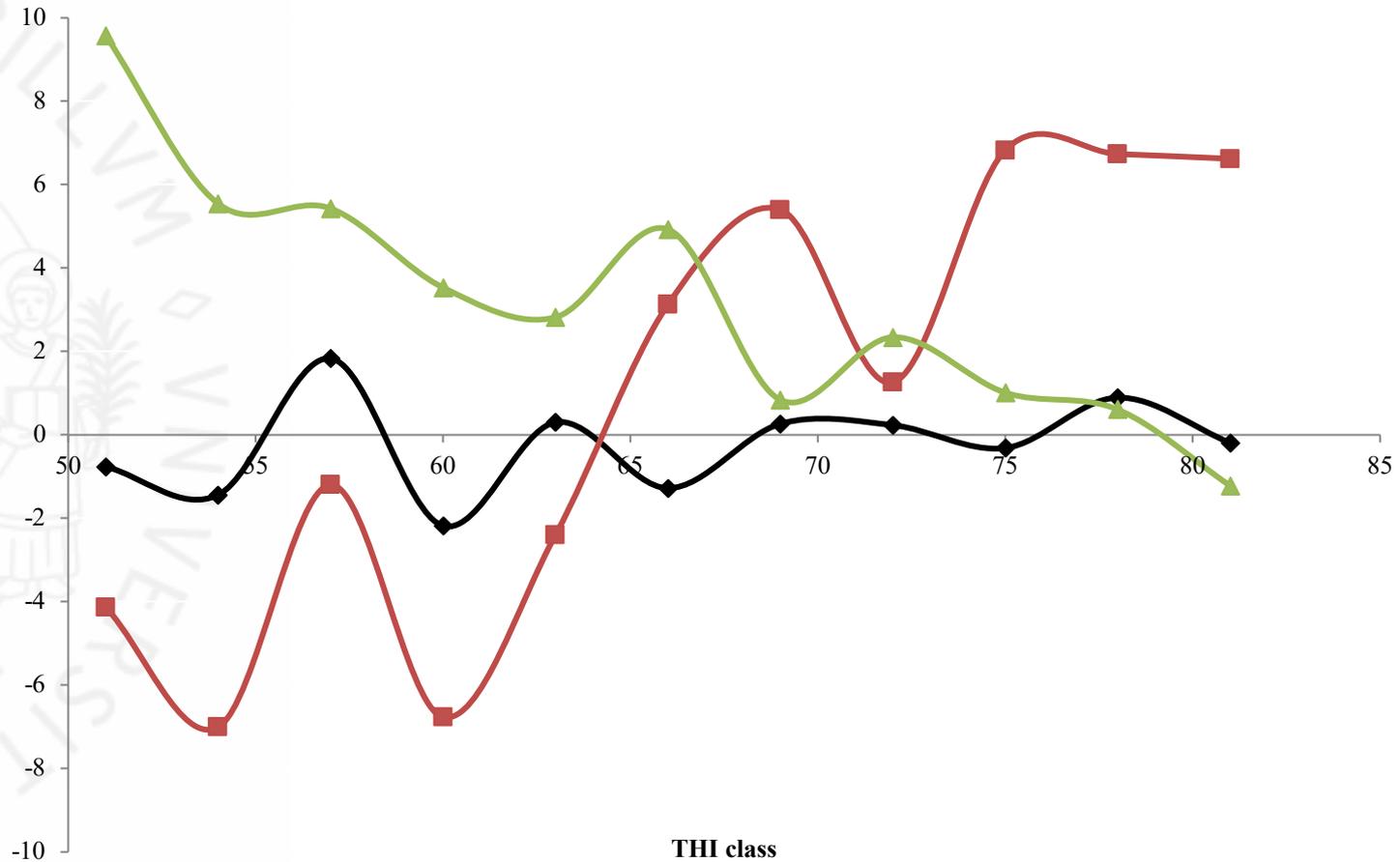
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Heat stress in cattle

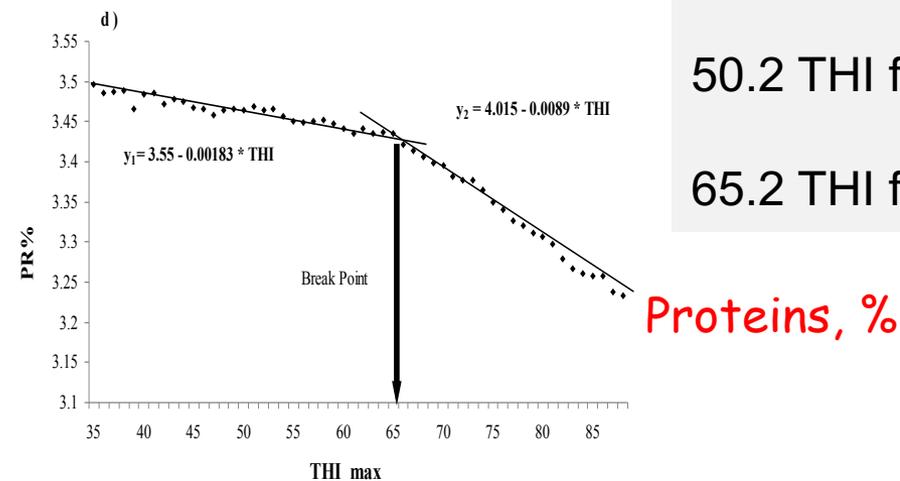
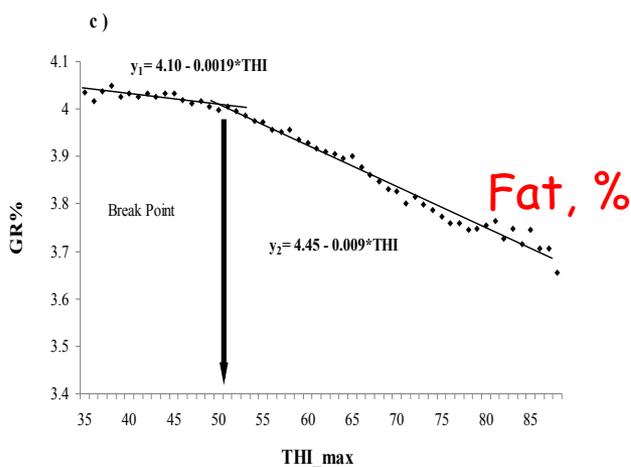
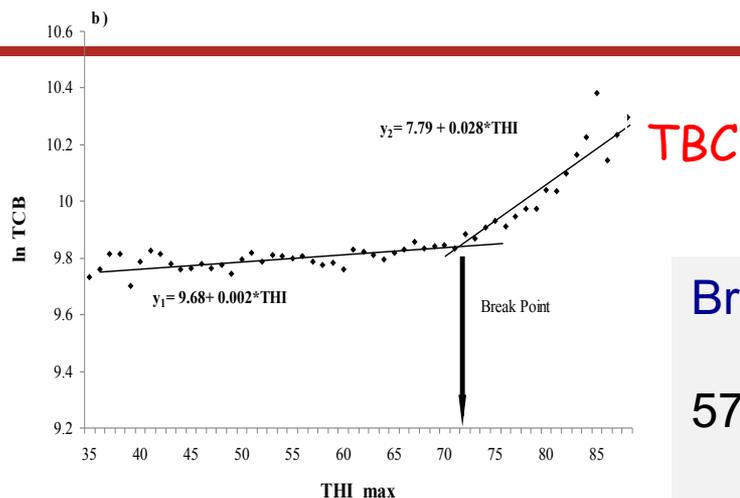
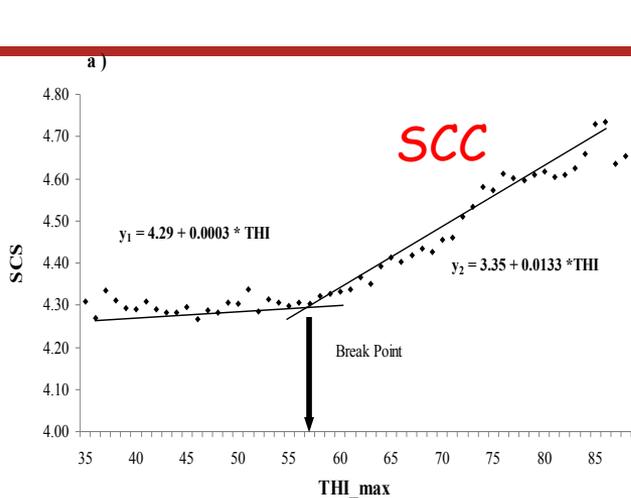
- ❑ The animal is not able to adequately dissipate the excess of heat to maintain body thermal balance
- ❑ negative effect on reproductive and productive performances
- ❑ Related to selection for improving milk yield and to climate changes

- ❑ Direct measurements (rectal temperature, respiration rate) difficult to measure routinely
- ❑ Indirect evaluation by measuring variation of milk production traits under warm environmental conditions
- ❑ THI most frequently used environmental variable

Daughter Trait Deviations



Cow's milk characteristics in relation to maximum temperature-humidity index (THI) recorded two days before sampling-day.



Break points:

57.3 THI for (a) SCC;

72.8 THI for (b) TBC;

50.2 THI for (c) Fat %;

65.2 THI for (d) Pr %.

Modeling tolerance to heat stress

- ❑ Reaction norm approach
- ❑ Concerns in defining a common threshold for the broken line model, problems in estimating individual thresholds
- ❑ Recently a PCA based index has been proposed
- ❑ Multivariate statistics requires no missing data



Aim of the work

- **Use of a test day mixed model to estimate (co)variance matrices between different THI classes**
- **PCA of the estimated (co)variance matrix to derive new variables related to heat stress tolerance**

Data

- ✓ 590,174 TD records (MY, FP, PP, SCS)
- ✓ 39,261 Italian Holstein cows, sired by
4,184 bulls
- ✓ 47 herds
- ✓ Climate data, 35 stations (<5 km)
- ✓ THI max

$$\text{THI} = (1.8 \times \text{AT} + 32) - (0.55 - 0.55 \times \text{RH}) \times [(1.8 \times \text{AT} + 32) - 58]$$

Statistical analysis

✓ DTD calculation

$$Y = Mo(Y) + AGE + H(Y) + DIM \times PAR + e$$

✓ Averages for 11 THI classes (50-52, 53-55, ..., >79)

✓ Correlation matrix estimation

$$DTD = \text{sire} * \text{THI class} + e$$

✓ Sire (Co)variance 11*11 UN matrix

PCA calculation

✓ PCA carried out on the estimated sire \mathbf{x}

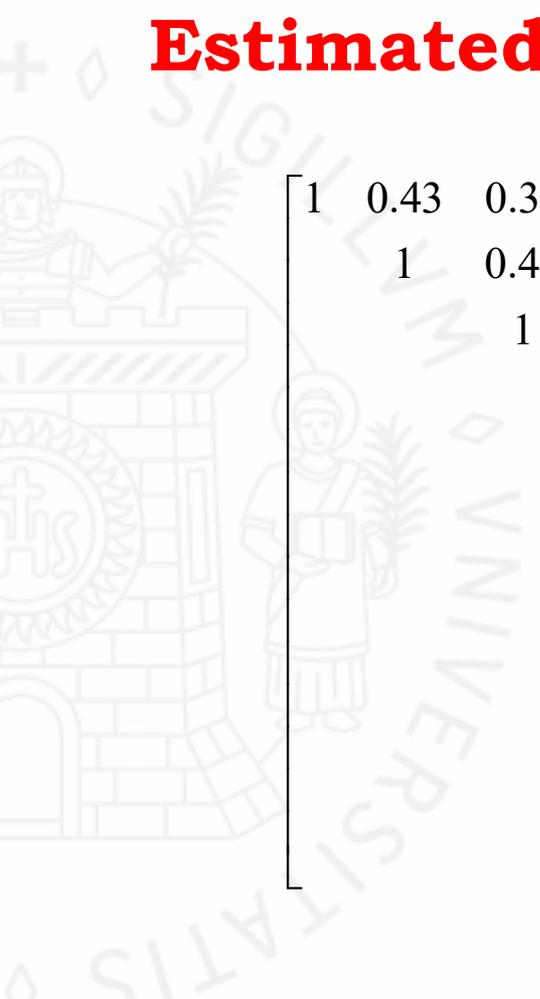
THI UN matrix

✓ PC SCORES = $\mathbf{E} \mathbf{x} \mathbf{Z}$

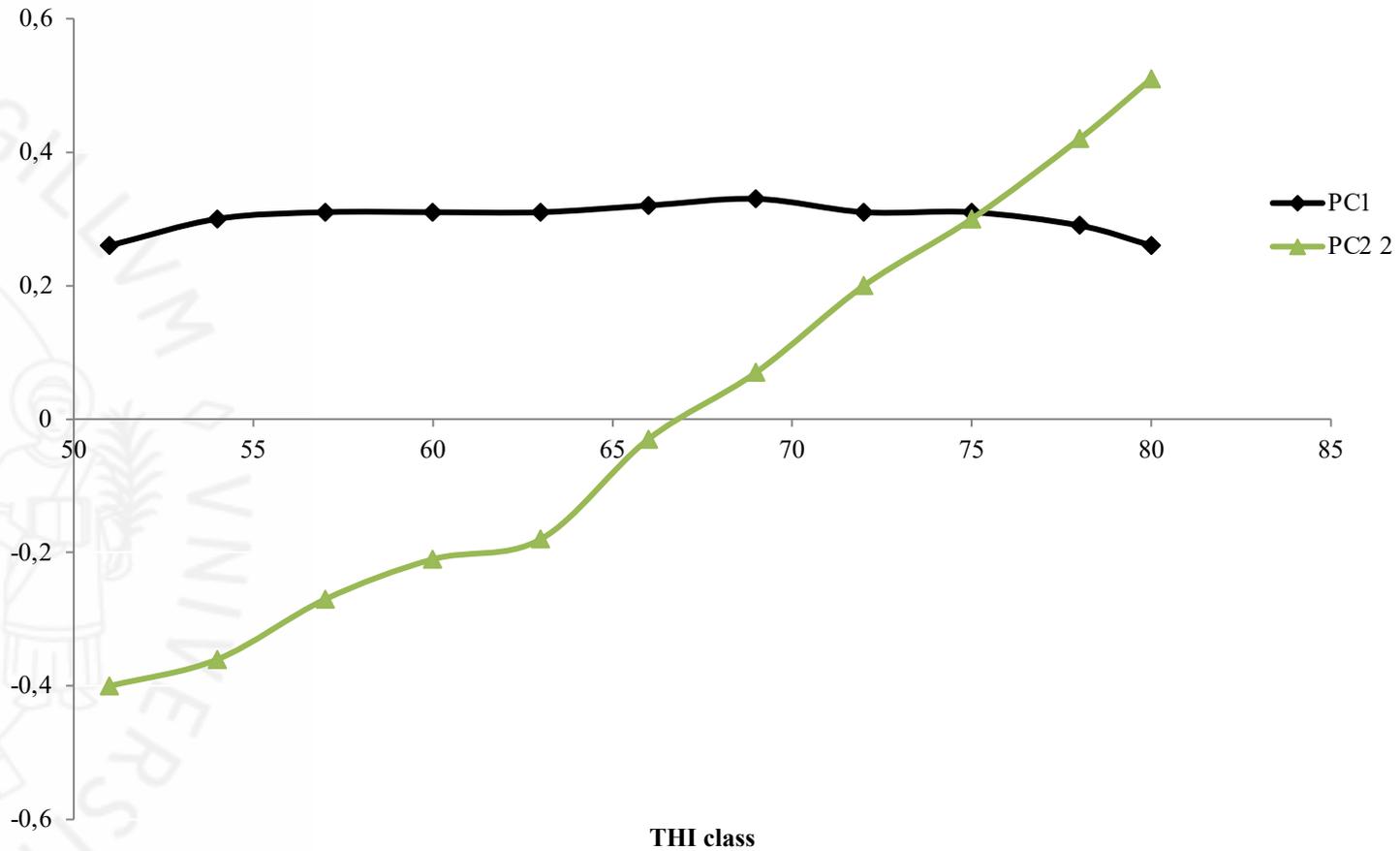
✓ Variance component estimation of PC scores

Results

Estimated correlation matrix for milk yield


$$\begin{bmatrix} 1 & 0.43 & 0.38 & 0.35 & 0.35 & 0.34 & 0.32 & 0.28 & 0.27 & 0.23 & 0.18 \\ & 1 & 0.44 & 0.41 & 0.40 & 0.39 & 0.37 & 0.35 & 0.30 & 0.27 & 0.22 \\ & & 1 & 0.43 & 0.44 & 0.42 & 0.41 & 0.38 & 0.35 & 0.33 & 0.22 \\ & & & 1 & 0.41 & 0.42 & 0.41 & 0.40 & 0.36 & 0.27 & 0.26 \\ & & & & 1 & 0.42 & 0.43 & 0.37 & 0.39 & 0.31 & 0.26 \\ & & & & & 1 & 0.40 & 0.41 & 0.39 & 0.37 & 0.34 \\ & & & & & & 1 & 0.39 & 0.44 & 0.43 & 0.34 \\ & & & & & & & 1 & 0.42 & 0.42 & 0.41 \\ & & & & & & & & 1 & 0.47 & 0.41 \\ & & & & & & & & & 1 & 0.43 \\ & & & & & & & & & & 1 \end{bmatrix}$$

Eigenvectors MY

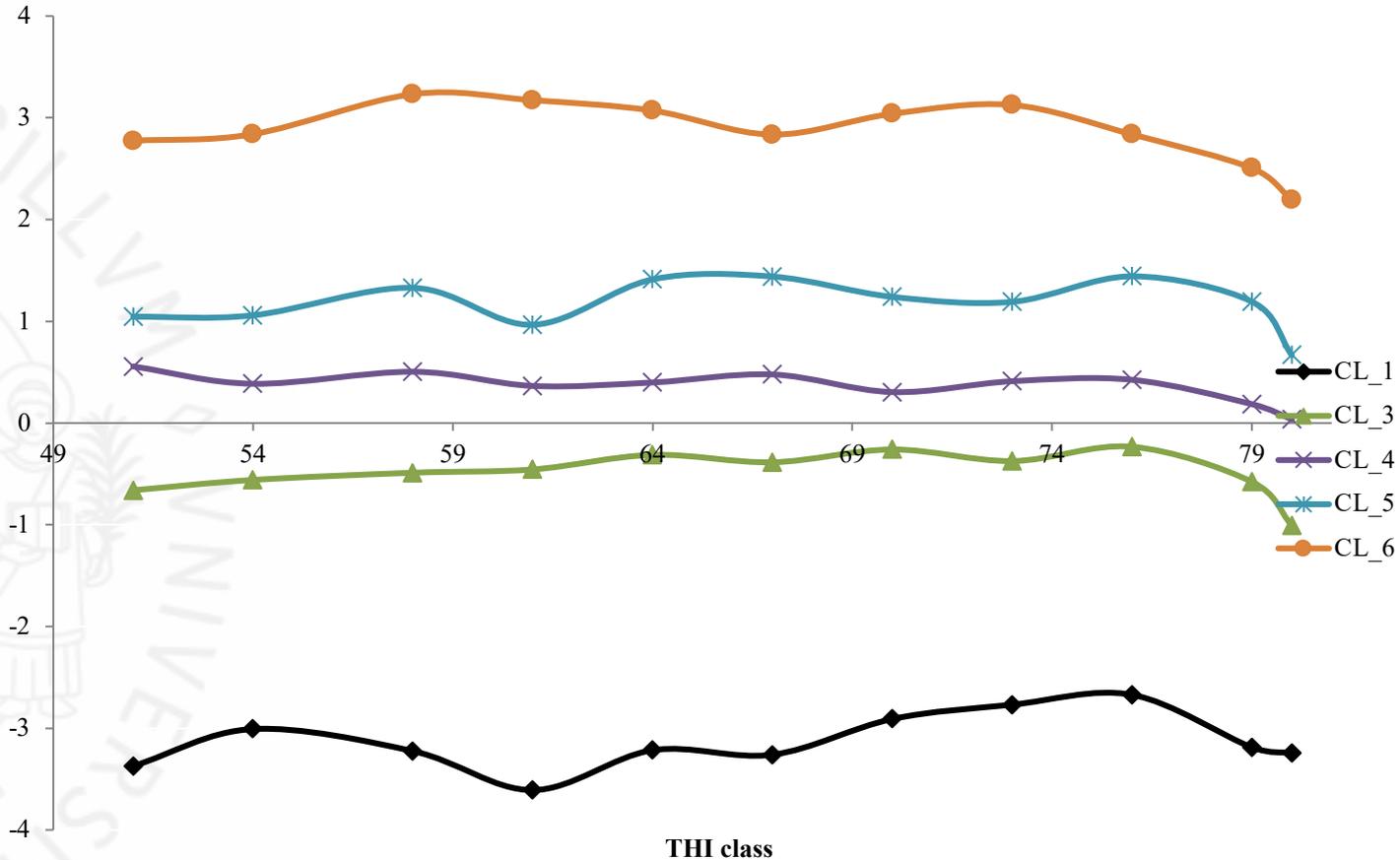


Results

Eigenvectors

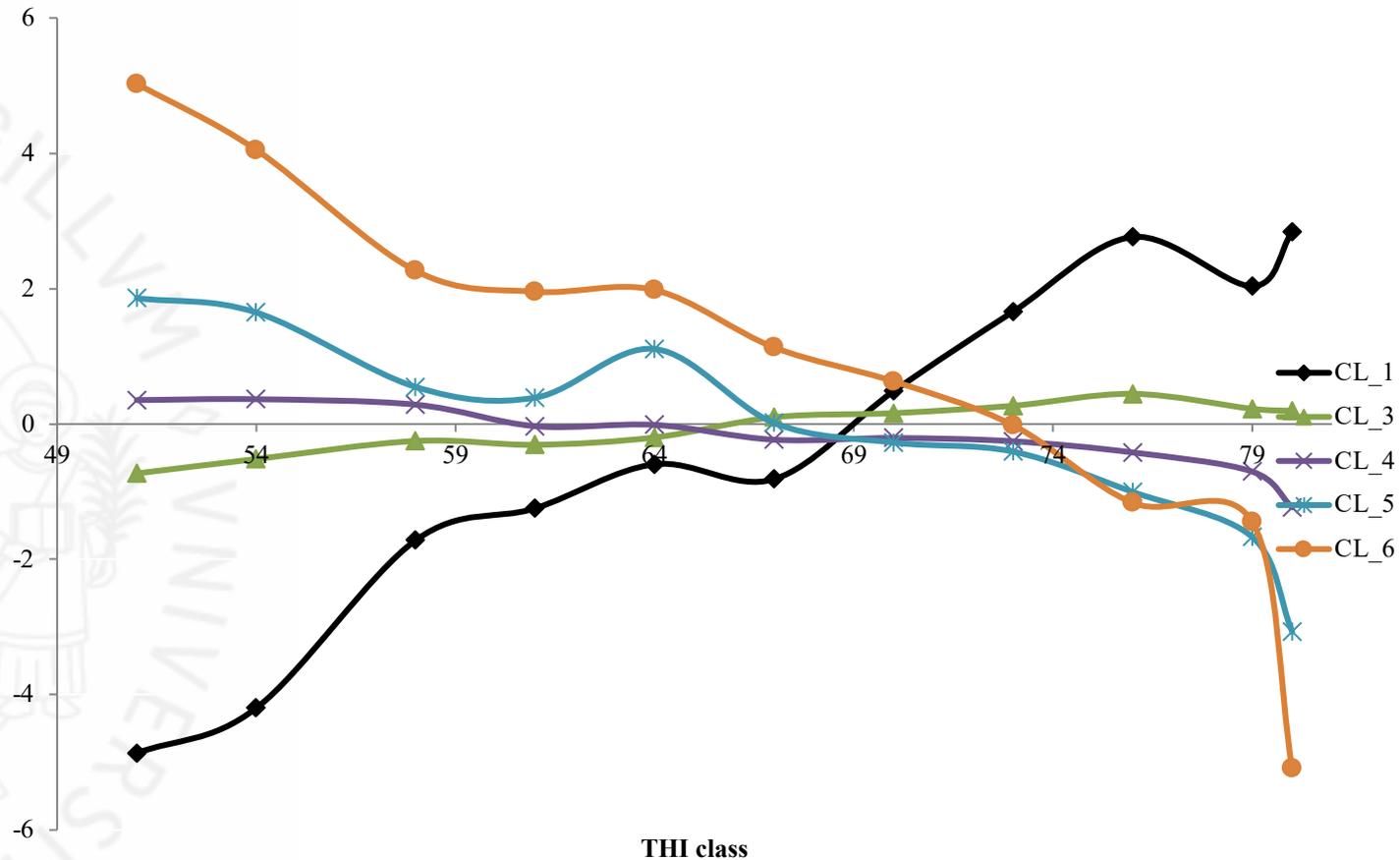
	MY		FP		PP		PY		SCS	
THI class	PC1	PC2								
50-52	0.26	-0.40	0.27	-0.37	0.27	-0.34	0.26	-0.41	0.27	0.42
53-55	0.30	-0.36	0.29	-0.36	0.29	-0.34	0.29	-0.36	0.26	0.57
56-58	0.31	-0.27	0.31	-0.30	0.32	-0.29	0.31	-0.23	0.30	0.27
59-61	0.31	-0.21	0.31	-0.23	0.31	-0.22	0.31	-0.22	0.30	0.10
62-64	0.31	-0.18	0.30	-0.17	0.31	-0.19	0.31	-0.16	0.31	0.09
65-67	0.32	-0.03	0.32	-0.06	0.34	-0.06	0.32	0.01	0.31	0.02
68-70	0.33	0.07	0.32	0.08	0.32	0.10	0.32	0.04	0.31	-0.16
71-73	0.31	0.20	0.33	0.20	0.31	0.20	0.32	0.16	0.33	-0.23
74-76	0.31	0.30	0.29	0.38	0.30	0.29	0.32	0.23	0.31	-0.25
77-79	0.29	0.42	0.30	0.39	0.28	0.43	0.29	0.41	0.30	-0.25
>79	0.26	0.51	0.26	0.47	0.24	0.53	0.25	0.57	0.29	-0.44
Eigenv.	0.42	0.11	0.39	0.10	0.38	0.12	0.45	0.09	0.40	0.08

Meaning of extracted PC



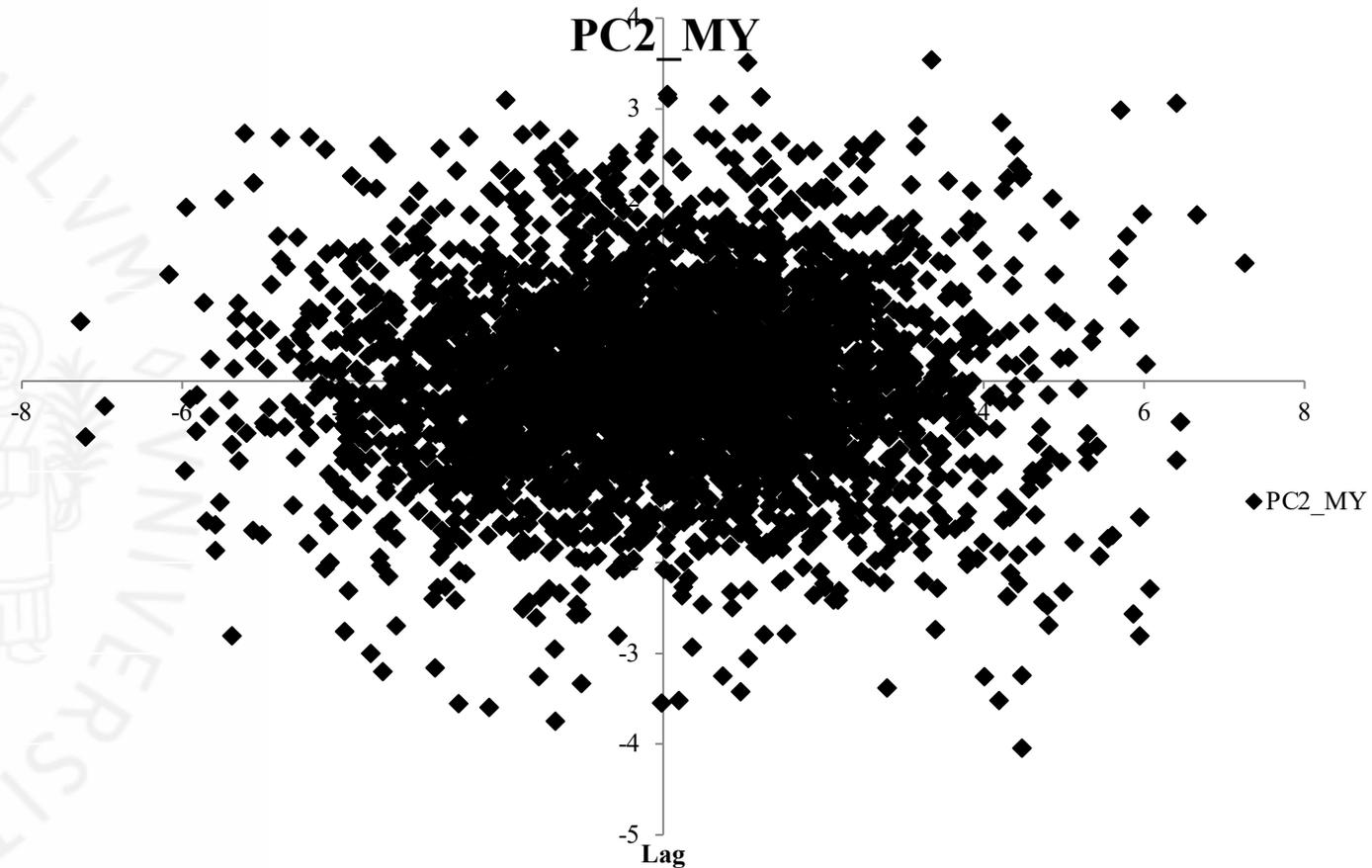
PC1 for MY

Meaning of extracted PC



PC2 for MY

Distributions of PC scores



Correlations among PC scores

	PC1 MY	PC2 MY	PC1 FP	PC2 FP	PC1 PP	PC2 PP	PC1 SCS	PC2 SCS
PC1 MY	1	0.03	-0.33	-0.01	-0.36	-0.01	-0.06	-0.03
PC2 MY		1	-0.01	-0.23	0.03	-0.23	-0.02	0.15
PC1 FP			1	0.05	0.51	0.01	0.01	0.01
PC2 FP				1	0.02	0.28	-0.03	-0.11
PC1 PP					1	0.04	0.06	0.01
PC2 PP						1	0.02	-0.16
PC1 SCS							1	-0.02
PC2 SCS								1



Results: h^2

	PC1	PC2
Milk yield	0.39	0.07
Fat percentage	0.44	0.05
Protein percentage	0.41	0.05
SCS	0.37	0.06

Results: genetic correlations

	$r_{PC1, PC2}$
Milk yield	0.24
Fat percentage	0.19
Protein percentage	0.25
SCS	0.39



Considerations

- ✓ Unstructured correlation matrix estimated by mixed model similar to original data
- ✓ PCA extracts two new variables related to the level and shape of production across different THI levels
- ✓ The extracted variables exhibit a very low degree of phenotypic correlation

Considerations

✓ PC scores show large to moderate pseudo heritabilities for LEVEL and low for SHAPE

✓ PC scores can be calculated from data currently recorded in breeding programs for dairy cattle

Use of PCA for managing correlated data

- ✓ Joint analysis of the effect of THI_max and THI_min in the first or the second half of pregnancy of the great granddam on cattle performances
- ✓ Variables highly correlated ($r > 0.75$), collinearity problems
- ✓ PCA could yield uncorrelated variables

Use of PCA for managing correlated data

	PC1	PC2	PC3	PC4
THI_max_1 st	-0.513799	0.176500	0.760750	0.355130
THI_min_1 st	-0.474466	0.740191	-0.333203	-0.340551
THI_max_2 nd	0.513257	0.306885	0.548332	-0.584569
THI_min_2 nd	0.497453	0.571652	-0.097810	0.645125
Eigenvalues %	86	9	3	2