Effect of heat stress on production traits of Holstein cattle in Japan: parameter estimation using test day records of first parity and genome wide markers

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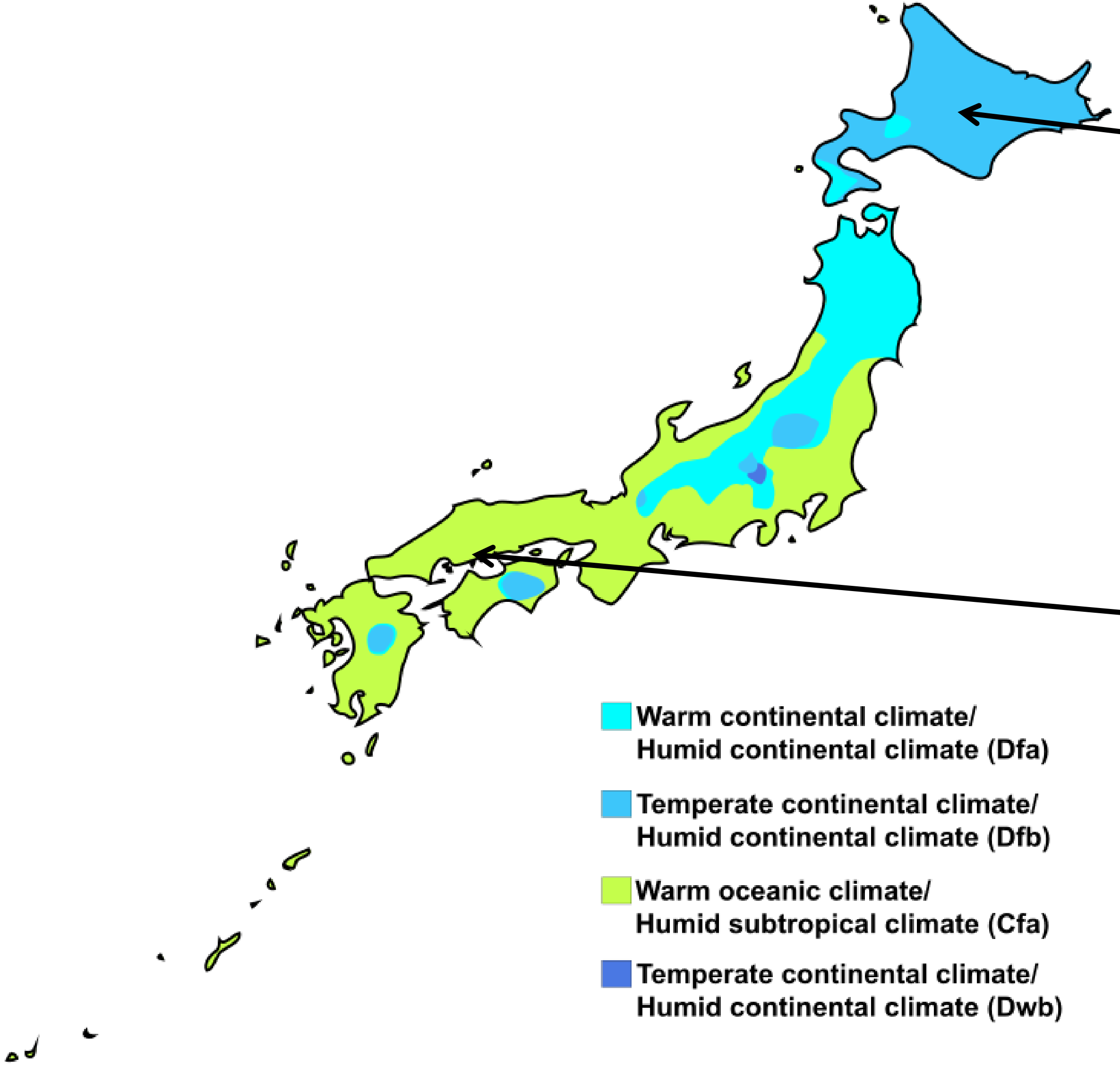
Japan map of Köppen climate classification



- Hokkaido, the biggest domestic dairy production area
- Heat stress is minimal

- Heat stress affects dairy production in South west of Japan

From Wikipedia on 8Feb, 2018

Record processing

- phenotypes (Apr1987-Nov2015)
  - in 233 dairy farms with genotyped cows
- genotype
  - impute 20,411 cow LD records using Beagle 3
  - with 50K records (2849 bulls and 2598 cows)
- farms were linked with meteorological offices based on their areas for the announcement of weather forecasts
- calculate Temperature-Humidity Index (THI) at meteorological offices

$$THI = (1.8 \times T_d + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T_d - 26)$$

T_d : dry bulb temperature (Celsius), RH : relative humidity (%)

- each phenotype was linked to the average (THI) up to 4 days before test day
- Heat stress
  - defined as decreased production at THI > 60

Summary of records

Traits	Chip used for genotyping	Milk, Fat and Protein	SCS
Test day records, n	-	820,573	752,514
Cows (female with records)	Total	93,725	86,435
	HD	807	
	LD*	363	
	-	92,555	85,265
Bulls (Sire of cows)	HD	3,126	
	-	2,229	
Females with genotypes but without records	HD	1,791	
	LD*	1	
Males other than bulls with genotypes	HD	2,313	
Other animals in a pedigree	-	106,843	101,777

*LD genotypes: only cows with records and their dams to reduce equation size

Random regression test day model

$$y_{ijklmno} = HTDT_i + M_j w + A_k w + hy_l v + pe_m z + peh_m \cdot f(THI) + u_m z + uh_m \cdot f(THI) + e_{ijklmno}$$

- $y_{ijklmno}$: test day milk, fat, protein (kg), Somatic Cell Score
- $HTDT_i$: fixed effect of herd*test day*milking frequency
- M_j : fixed regression coefficients of calving month
- A_k : fixed regression coefficients of calving age
- hy_l : random regression coefficients of herd*calving year (HY) effects
- pe_m : random regression coefficients of general permanent environment (PE) effects
- peh_m : random linear regression coefficient of PE effect of heat tolerance
- u_m : random regression coefficients of general additive genetic (AG) effects
- uh_m : random linear regression coefficient of AG effects of heat tolerance
- $e_{ijklmno}$: random residuals at DIM: 6-35, 36-65, 66-95, 96-125, 126-215, 216-305
- $w' = \begin{bmatrix}\phi_0(t) & \phi_1(t) & \phi_2(t) & \phi_3(t) & \phi_4(t) & e^{-0.05t}\end{bmatrix}, v' = \begin{bmatrix}\phi_0(t) & \phi_1(t)\end{bmatrix}, z' = \begin{bmatrix}\phi_0(t) & \phi_1(t) & \phi_2(t)\end{bmatrix}$
- $\phi_p(t)$: Legendre polynomials

$$f(THI) = \begin{cases} 0 \;\; if \;\; THI \le 60 \\ THI - 60 \;\; if \;\; THI \ge 60 \end{cases}$$

Covariance components

$$\mathrm{var}\begin{bmatrix} hy \\ pet \\ ut \\ e \end{bmatrix} = \begin{bmatrix} I \otimes Q & 0 & 0 & 0 \\ 0 & I \otimes P & 0 & 0 \\ 0 & 0 & H \otimes G & 0 \\ 0 & 0 & 0 & R \end{bmatrix}$$

- I : identity matrix
- Q : 2×2 matrix of (co)variances for HY effects
- H :a matrix combining additive relationship and genomic relationship
- P, G : 4×4 of (co)variances for total (general + heat tolerance) PE and AG effects
- R : diagonal matrix with residual variance corresponding to DIM category

AG (co)variances and heritability

- General AG (co)variance at DIM t and t':

$$\operatorname{cov}\left(u(t),u(t')\right)=\operatorname{cov}\left[u_{m0}\phi_0(t)+u_{m1}\phi_1(t)+u_{m2}\phi_2(t),u_{m0}\phi_0(t')+u_{m1}\phi_1(t')+u_{m2}\phi_2(t')\right]$$
$$=\sum_{i,j}\operatorname{cov}\left(u_{mi}\phi_i(t),u_{mj}\phi_j(t')\right)$$
$$=\sum_{i,j}\phi_i(t)\phi_j(t')\operatorname{cov}\left(u_{mi},u_{mj}\right)$$

- AG variance of heat tolerance: $f(THI)^2\,\sigma_{uh}^2$
- AG covariance and correlation between general and heat tolerance at DIM t:

$$Co\mathrm{v}\left(u(t),f(THI)\cdot uh\right)=f(THI)\cdot\operatorname{cov}\left[u_{m0}\phi_0(t)+u_{m1}\phi_1(t)+u_{m2}\phi_2(t),uh_m\right]$$
$$=f(THI)\cdot\sum_i\phi_i(t)\operatorname{cov}\left(u_{mi},uh_m\right)$$

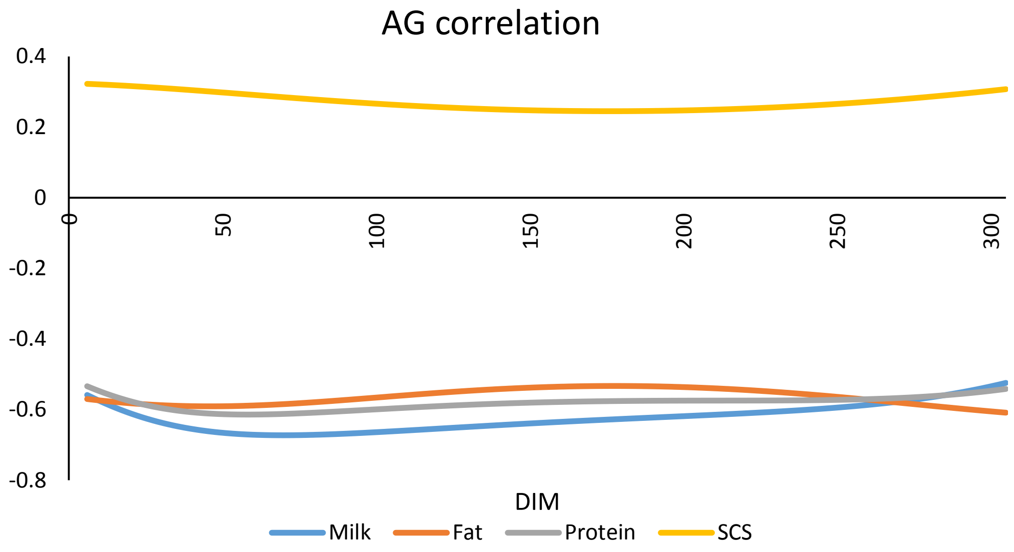
$$Correlation:\frac{\sum_i\phi_i(t)\operatorname{cov}\left(u_{mi},uh_m\right)}{\sqrt{\sum_i\phi_i(t)^2\operatorname{cov}\left(u_{mi},u_{mi}\right)\cdot\sigma_{uh}^2}}$$

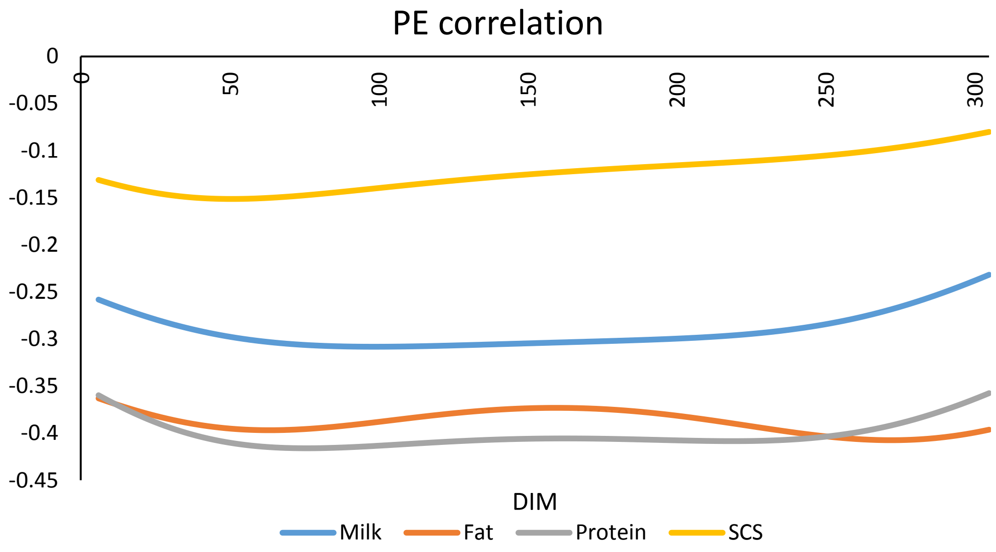
- Total AG variances and heritability at DIM t and THI:

$$\sigma_{u_{total}}^2=\sum_i\phi_i(t)^2\operatorname{cov}\left(u_{mi},u_{mi}\right)+f(THI)^2\sigma_{uh}^2+2f(THI)\sum_i\phi_i(t)\operatorname{cov}\left(u_{mi},uh_m\right)$$

$$h^2=\frac{\sigma_{u_{total}}^2}{\sigma_{u_{total}}^2+\sigma_{pe_{total}}^2+\sigma_{hy}^2+\sigma_e^2}$$

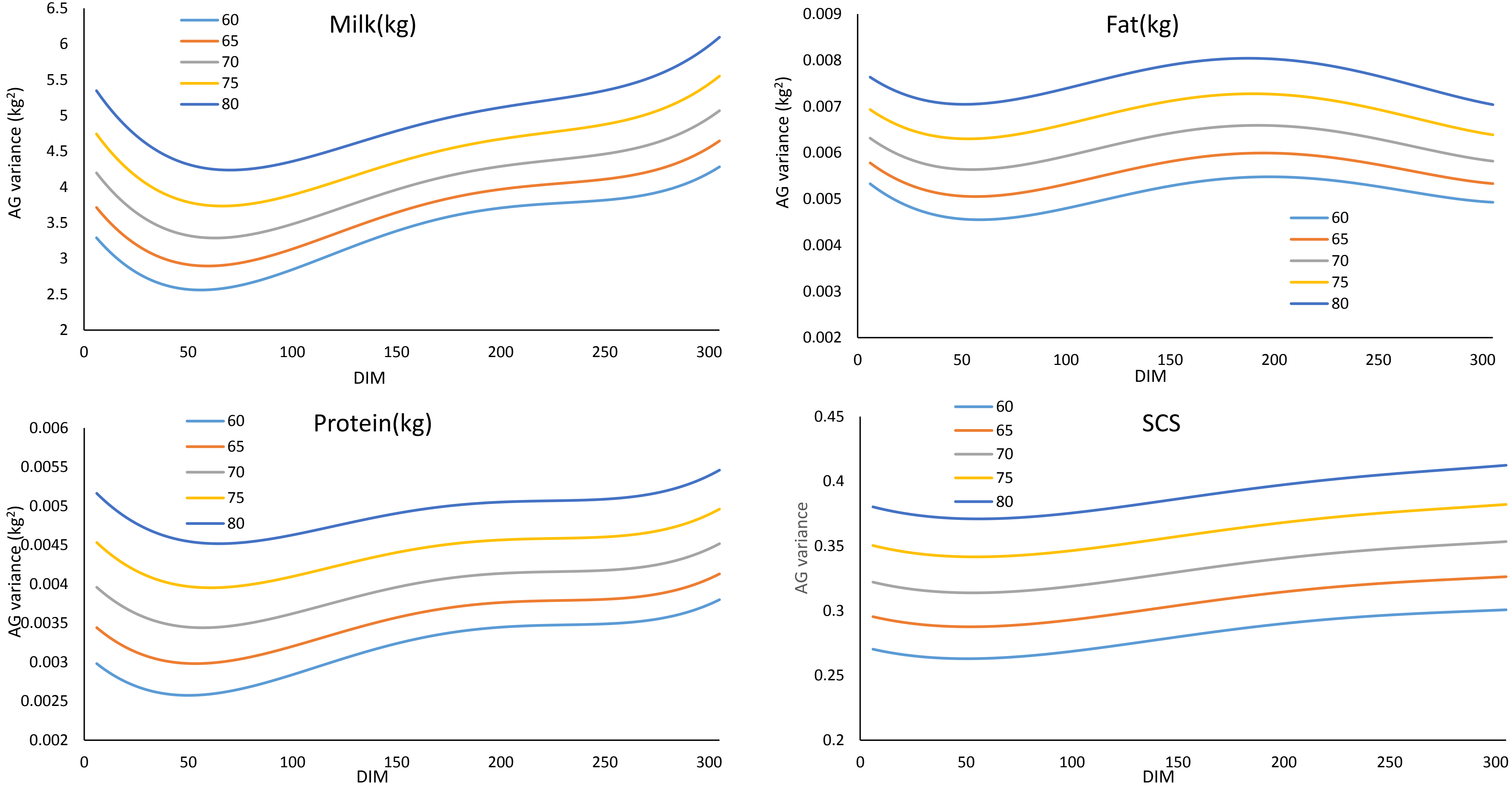
AG / PE correlation





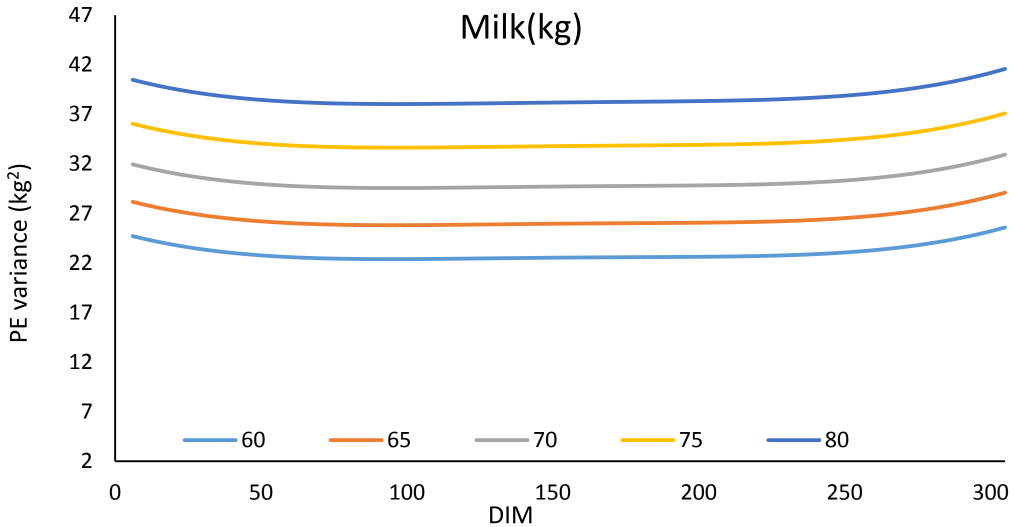
- AG correlations were negative, except for SCS.
- PE correlations were negative and weaker than the AG correlations.

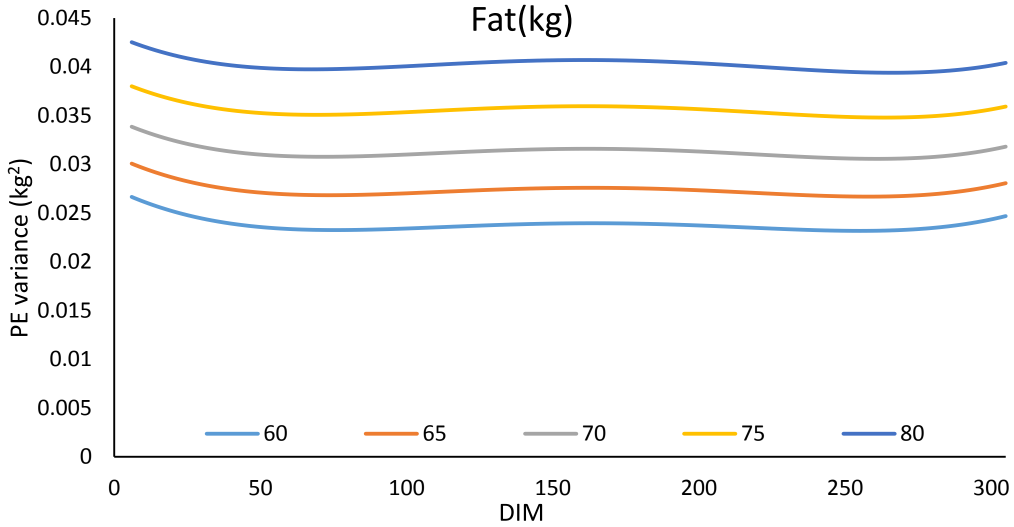
Total AG variance

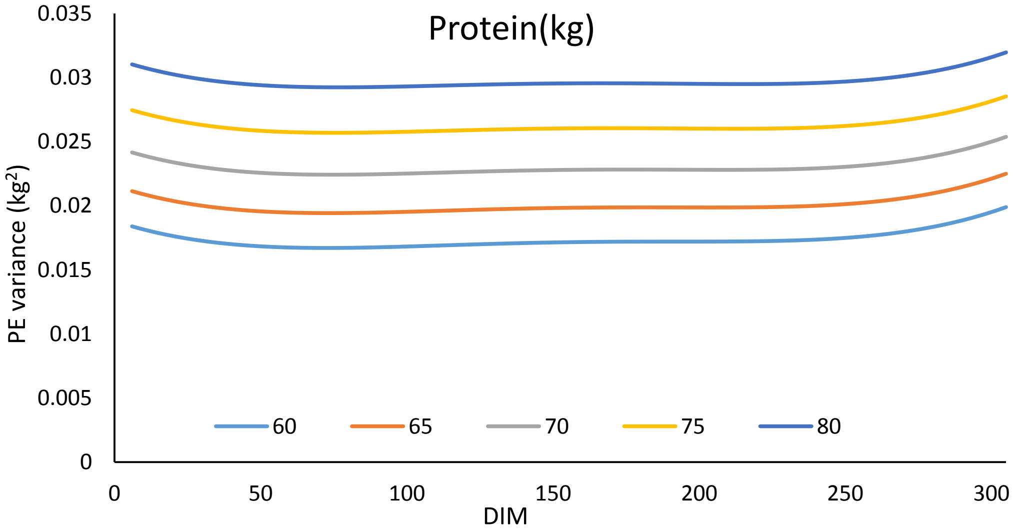


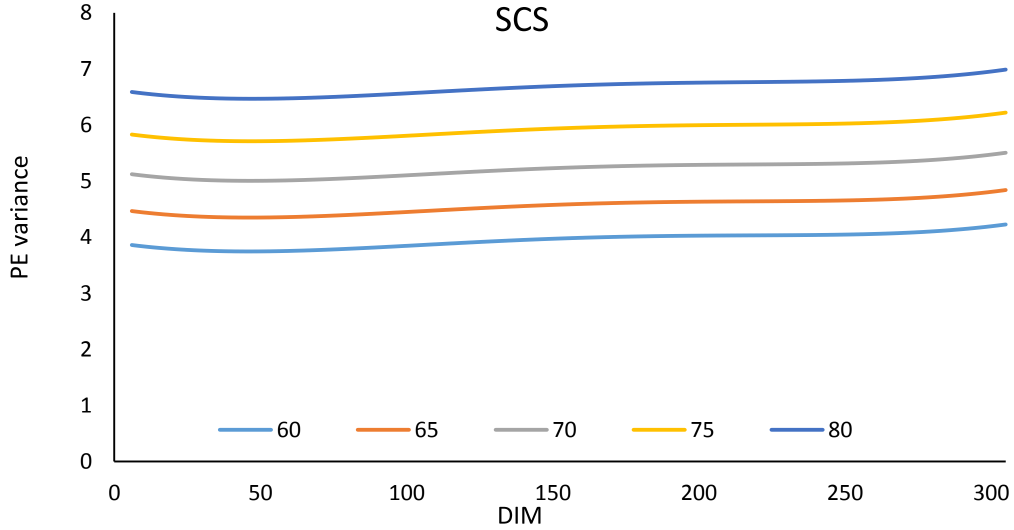
- The higher the THI, the larger the total AG variances.
- Change in Fat looked different at later stage of lactation.

Total PE variance



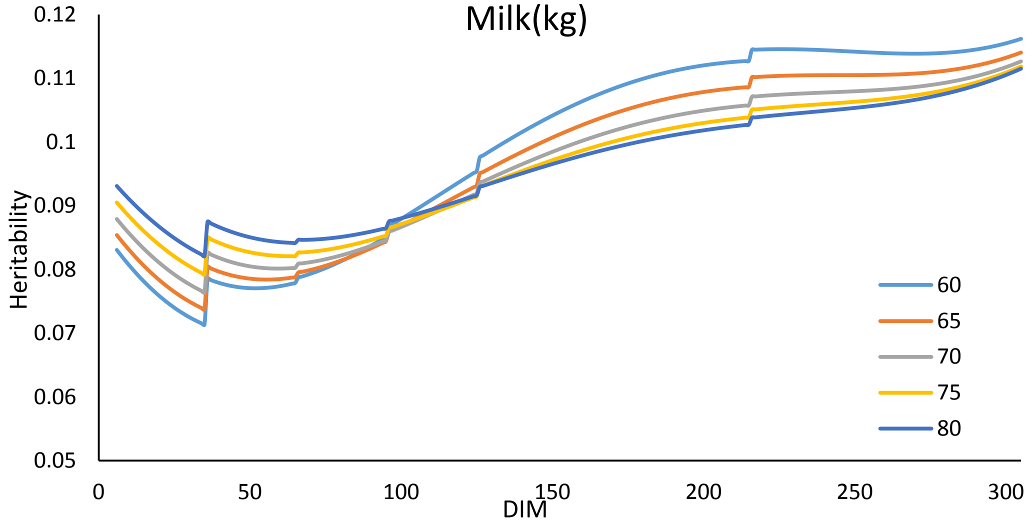


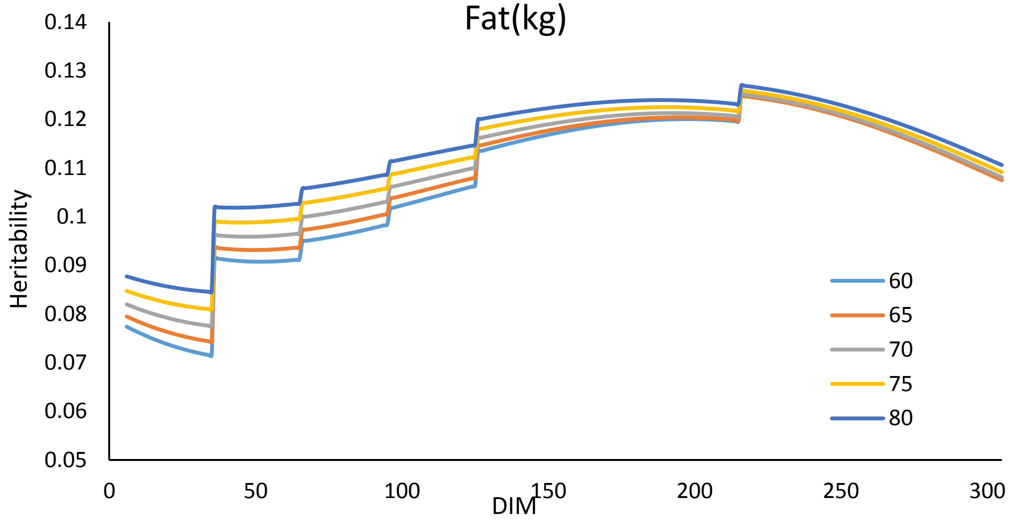


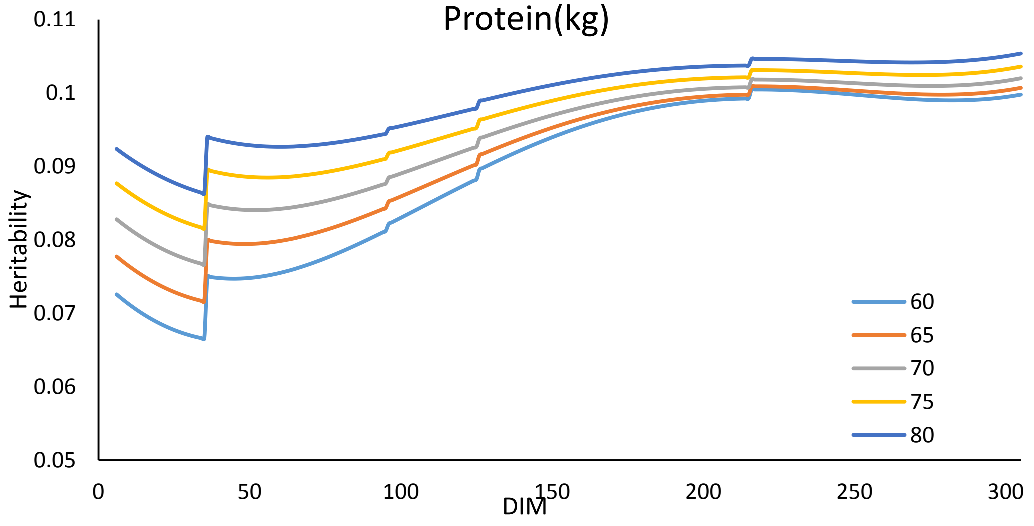


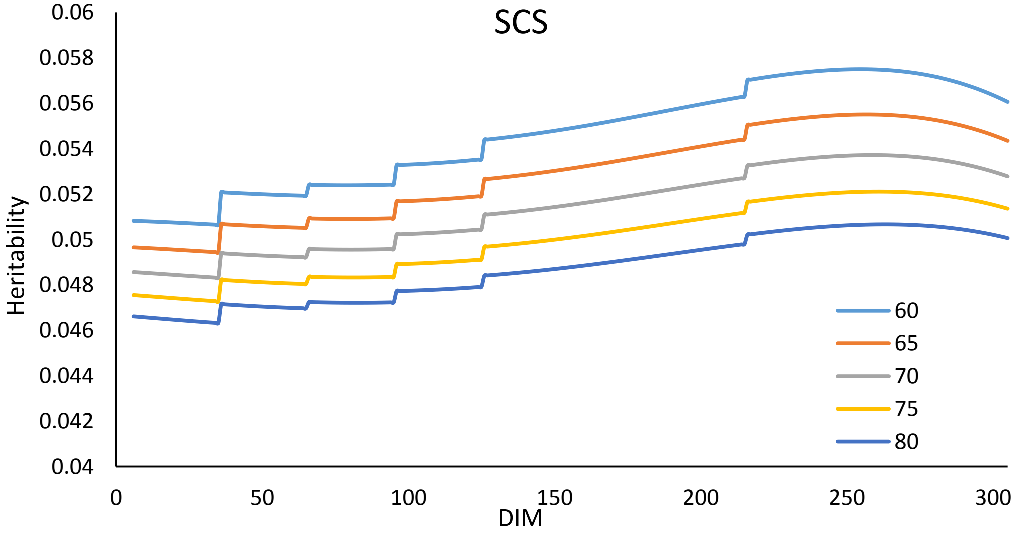
- The higher the THI, the larger the total PE variances.
- PE variances were bigger than AG variances.

Heritability









- h^2 (Fat, Protein) were larger for higher THI.
- h^2 (SCS) was smaller for higher THI due to larger difference of PE variances.

Summary

- PE variances of heat tolerance were larger than AG variances.
  - ➢ Various non-AG factors affect.
- Negative genetic correlation (general effect vs heat tolerance) should be considered carefully.
  - ➢ Use total AG effect.
- AG variances were smaller, whereas PE variances were larger than national genetic evaluation.
  - ➢ Further study is required.
- Heat stress affects more in later parities.
  - ➢ Later parities to be included.
- Variance components were successfully estimated. Genetic evaluation of heat tolerance would be feasible.

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