UNIVERSITÀ DEGLI STUDI DI PADOVA

DAFNAE Dipartimento di Agronomia, Alimenti, Risorse naturali, Animali e Ambiente

From fertility to longevity and climate adaptability: genetics of fitness traits in horses

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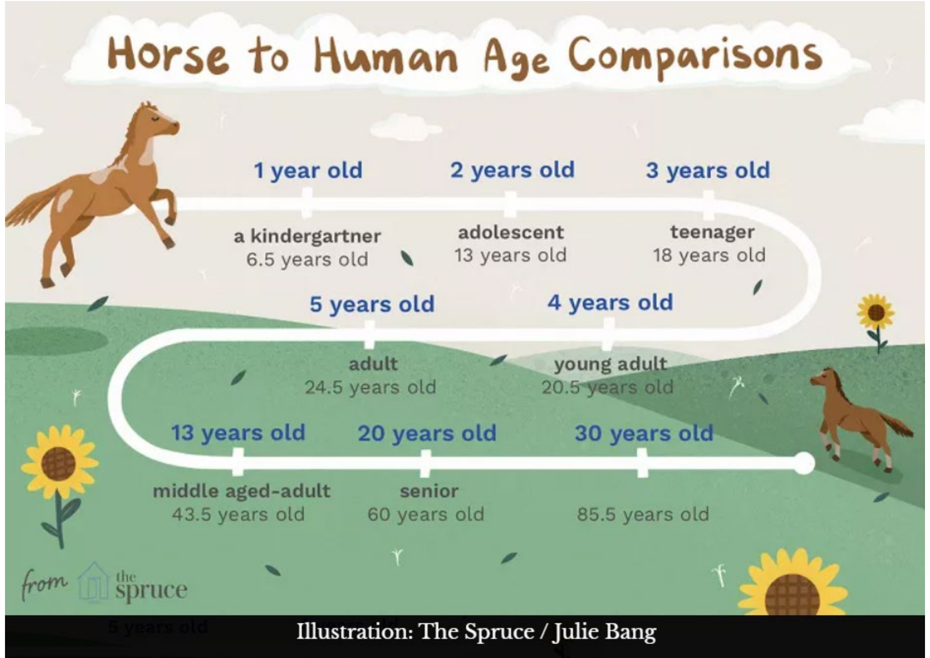
Intro: fitness traits in horses

Horses have a long productive life → many moneys are invested

Longer-lived animals → more desirable to breeders:

- less prone to contracting diseases → reduce replacement costs
- good reproductive ability → regular fertility, good annual foal productivity



Intro: fitness traits in horses

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...but

Horses show a low reproductive capacity → fertility is of great economic importance in equine industry

...but
- **Fertility not accounted** for in horse breeding programs → not crucial for the development of leisure, sport, work, or meat
- **Few studies** on estimating genetic components of fertility

Intro: fitness traits in horses

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Analysis of fitness traits is not an easy job:

Longevity
- Records of culling and death are **rarely available** for analytical purposes
- It should be not a simply measure of career length but it should account for the animal ability to avoid voluntary culling by breeders → **functional longevity**
- Ongoing careers should be considered → **censored animals**

Fertility
- Influenced by **many environmental and management factors**: method of insemination, season, age, racing activity when present → estimation of genetic parameters is challenging
- **Inbreeding** → inbreeding depression
- Possible influence of **genotype by environment interaction** (GxE) → re-ranking of individual performances

Relationships with traits under selection (e.g., morphology) should be considered

Aim of the study

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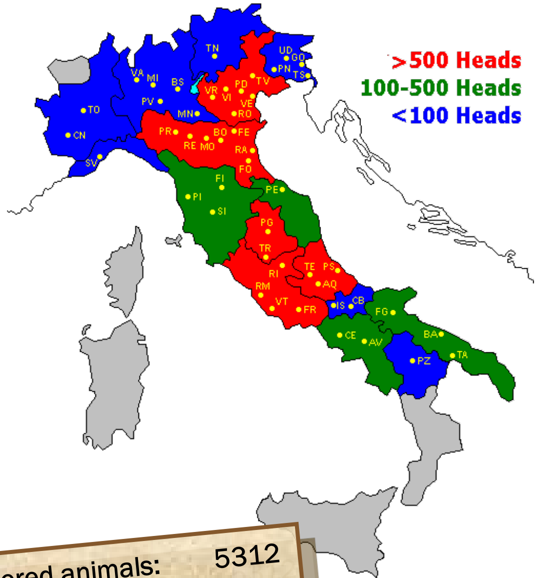
To estimate:

- **genetic parameters for fitness traits** in Italian Heavy Draught Horse breed: functional longevity, lifetime fertility rate, foaling event (this latter also including GxE)
- **Genetic correlations** among fitness traits
- Genetic correlations with **morphological traits** used for selection
- **Multi-trait response to selection**

Study subject: Italian Heavy Draught Horse (IHDH)

Local breed (Italy)
Dual purpose: meat & draught

IHDH is bred in different **areas** (North, Centre, South) & under different **rearing systems** (Stable, Semi-feral, Feral)



Registered animals:	5312
- Mares	2983
- Stallions	390
Registered stud farms	748

(update: 29 Aug 2023, fao.org/dad-is)

Selection aims:

- Rapid Draught for Agriculture, as in the past
- Activities of Holidays Farms
- Meat Production

Traits & Models

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Longevity:

Editing of mares’ careers (e.g., animals not more in herd-book due to selling, stoled, disappeared)

Adaptation of data for the following ***fixed*** effects:
Environmental unit* – Birth Year (EU-BY, 163 levels)
Quintiles of Lifetime fertility within EU-BY in 5 year period (5 levels)
Age at first foaling (3 or 4 years)

Y = μ + *fixed* + a + e

2566 obs., 2566 mares, 757 censored (30%), 6786 animals in pedigree

220,000 iteration of Gibbs sampler (Gibbsf90+;Misztal et al., 2014); burn-in: 20,000 iterations; thinning: each 100 samples (2,000 chains for posterior analysis)
Posterior distribution analysis (POSTGIBBSF90 Misztal et al., 2008) → the same for all traits

***Environmental units**
(geographical region by stud system):
1. North Italy, Stable
2. Centre-South Italy, Stable
3. North Italy, Feral
4. North-Centre Italy, Feral
5. South Italy, Feral
6. North-Centre, Semi-feral
7. South, Semi-feral

Traits & Models

Fertility:

Lifetime foaling rate (LFR):
the actual or estimate of foal production at the 6th reproductive season on the basis of the age at first foaling and the previous foal produced after 3, 4 or 5 reproductive seasons

Fixed effects: **Environmental unit***-Birth Year (163 levels), age at first foaling (3 or 4 years)

Y = μ + *fixed* + a + e

3823 obs., 3823 mares, 8172 animals in pedigree

***Environmental units**
(geographical region by stud system):

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(Mantovani et al 2020, Animals 10(6), 1085)

Traits & Models

Fertility:

Foaling event: 1 successful (81%); 0 elsewhere (19%; e.g., absence of pregnancy 16%, abortion 3%);

Fixed effects: **Environmental unit**-Birth Year (163 levels), age at foaling (cov), Year (30 levels), Inbreeding (7 classes), **THI at conception** (cov)*

Single-trait threshold animal models:

- No THI included:

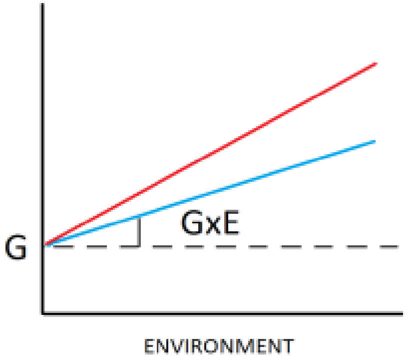
$$\mathbf{Y = \mu + \mathit{fixed} + a + Pe + e}$$

- THI as just environmental covariate:

$$\mathbf{Y = \mu + \mathit{fixed} + \Sigma_{k=0,1}\phi_o + a + Pe + e}$$

- THI also in GxE interaction (reaction norm model):

$$\mathbf{Y = \mu + \mathit{fixed} + \Sigma_{k=0,1}\phi_o + \Sigma_{k=0,1}\phi_o\, a + Pe + e}$$



22318 foaling events in 30 years, 3308 mares, 7697 animals in pedigree

(Sartori et al 2023, EAAP congress; in prep.)

*THI at conception

11 to 12 months (averaged) before the foaling event

Standardized as 1st order Legendre Polynomial ($\Sigma_{k=0,1}\phi_o$)

Data obtained from OpenStreetMap (https://openstreetmap.org) & NASA weather stations (https://power.larc.nasa.gov)

Traits & Models

Linear type traits:

1 to 5 scale, including half points

Scored at 6 months → 11 traits, 5 of which in total selection index ➡ (Head size & expression; temperament; fleshiness; fore diameters; rear diameters)

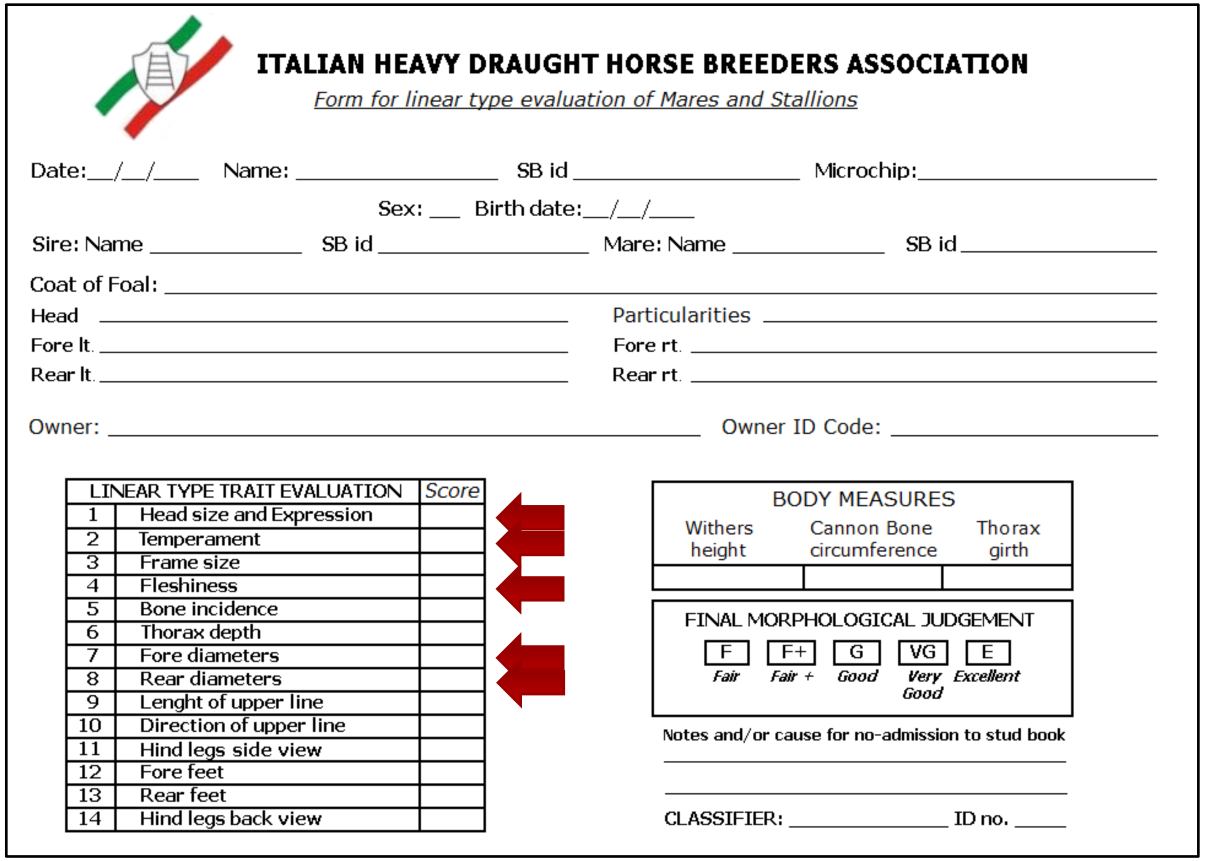
Fixed effects: environmental unit of stud groups-Year (163 levels); sex (2 levels); age of foal at scoring (9 classes); age of mare at scoring (5 classes);

$$Y = \mu + \textit{fixed} + a + e$$

16996 obs., 16996 foals, 23614 animals in pedigree

Notes:
Type traits also scored at **30 months** (14 traits)
4 new type traits & BCS (PSRN funding, see Mancin et al., 2021 EAAP congress)

(Folla et al 2019, Livest Sci 219, 91-96;
Folla et al 2020, Animals 10(6), 1099)



ITALIAN HEAVY DRAUGHT HORSE BREEDERS ASSOCIATION

Form for linear type evaluation of Mares and Stallions

Date:__/__/____ Name: ________ SB id ________ Microchip:________

Sex: __ Birth date:__/__/____

Sire: Name ________ SB id ________ Mare: Name ________ SB id ________

Coat of Foal: ________

Head ________ Particularities ________

Fore lt. ________ Fore rt. ________

Rear lt. ________ Rear rt. ________

Owner: ________ Owner ID Code: ________

	LINEAR TYPE TRAIT EVALUATION	*Score*
1	Head size and Expression	
2	Temperament	
3	Frame size	
4	Fleshiness	
5	Bone incidence	
6	Thorax depth	
7	Fore diameters	
8	Rear diameters	
9	Lenght of upper line	
10	Direction of upper line	
11	Hind legs side view	
12	Fore feet	
13	Rear feet	
14	Hind legs back view	

BODY MEASURES		
Withers height	Cannon Bone circumference	Thorax girth

FINAL MORPHOLOGICAL JUDGEMENT

F	F+	G	VG	E
Fair	*Fair +*	*Good*	*Very Good*	*Excellent*

Notes and/or cause for no-admission to stud book

CLASSIFIER: ________ ID no. ____

Traits and models



Genetic trend of trait

Bi-trait analyses

- among fitness traits
- fitness vs. linear type traits
- among type traits (Folla et al. 2019)

Multi-trait selection response

- **R = G·P⁻¹·S** (Lande, 1979; Kause et al., 2015)



$R = (i/\sigma_i)\cdot b'\cdot P^{-1}$

$\sigma_i=(b'Pb)^{1/2}$

$b=P^{-1}Ga$

$Rds_i = R/\sigma_{Pi}$

P= Phenotypic variance matrix

G = Genetic variance matrix

σ_i = Trait's phenotypic standard dev.

i = Selection intensity (here i = 1.755)

a = **economic weight of traits**

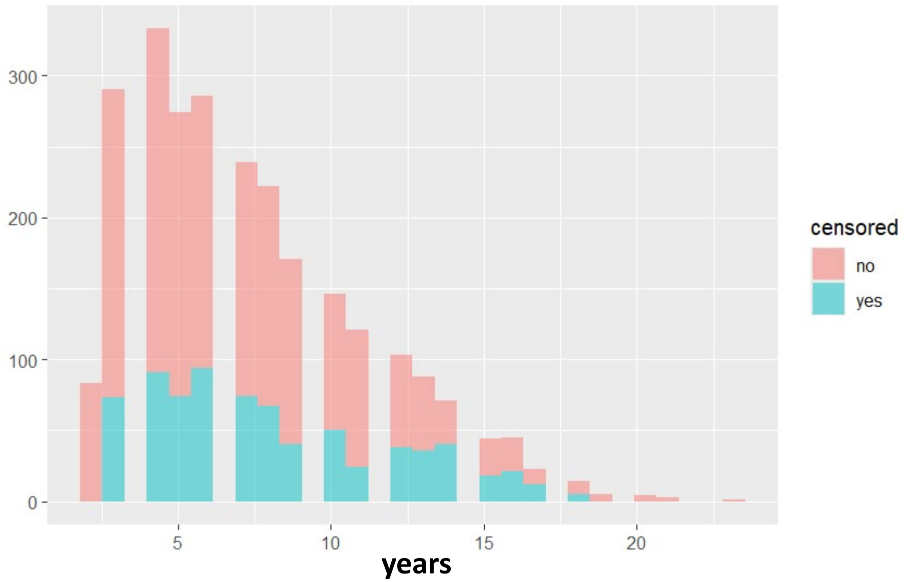
economic weight of traits:

1. Current selection (100% linear type traits):	2. Inclusion of fitness (20% fitness, 80% type traits)
0.25 Head size & expression 0.15 temperament 0.25 fleshiness 0.15 fore diameters 0.2 rear diameters	(let's see the Results!)

Results

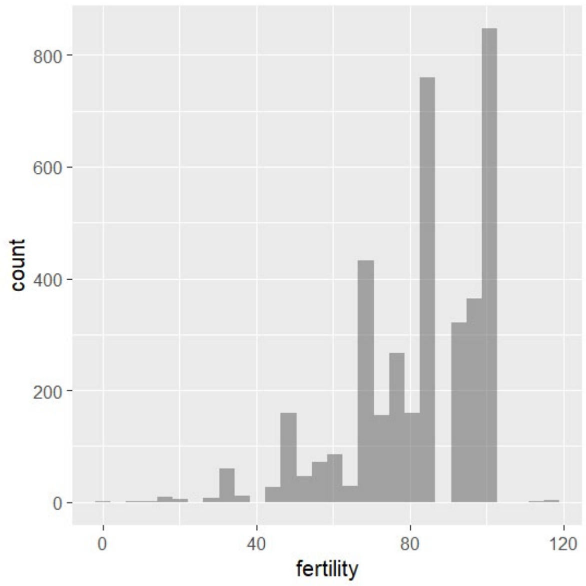
Descriptive statistics

Longevity



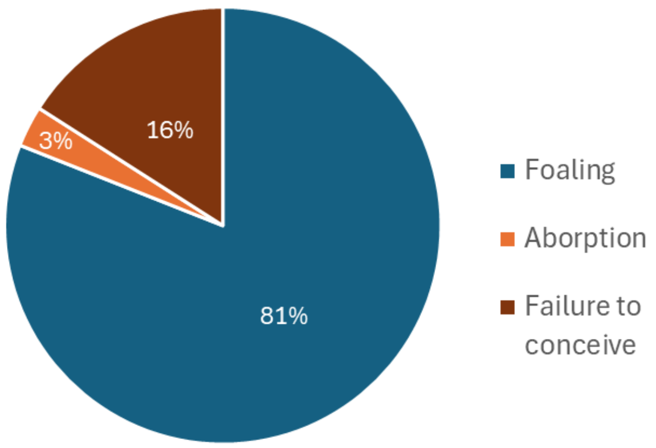
Censored:	yes	No
Median	7	6
Mean	8.03	7.08
Std. Dev.	3.90	3.90
Min.	3	2
Max.	18	23
n.	757	1809

Lifetime fertility



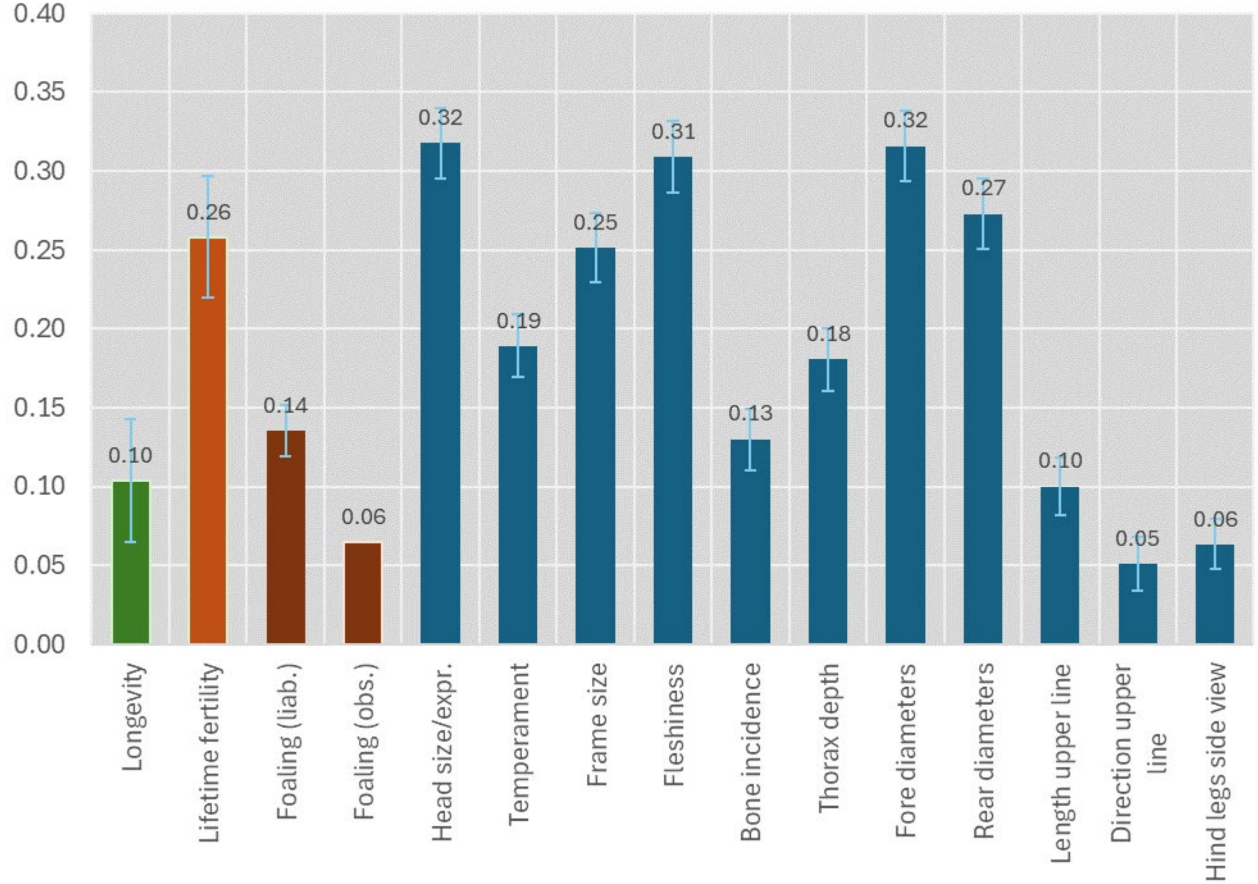
Stat:	Lifetime fert.
Median	83
Mean	81.67
Std. Dev.	17.00
Min.	0
Max.	117
n.	3823

Foaling event



Variable	Successful foaling	Unsuccessful f.
Average Mean T°C	14.68 (5.69)	18.88 (6.61)
Average Max T°C	19.65 (6.05)	24.05 (7.29)
Average Min T°C	9.94 (5.30)	14.25 (5.87)
Relative Humidity %	71.20 (7.18)	67.34 (12.01)
Average Mean THI	57.97 (8.53)	63.80 (9.47)
Average Max THI	65.38 (8.77)	71.27 (9.89)

Heritability & correlations among fitness traits



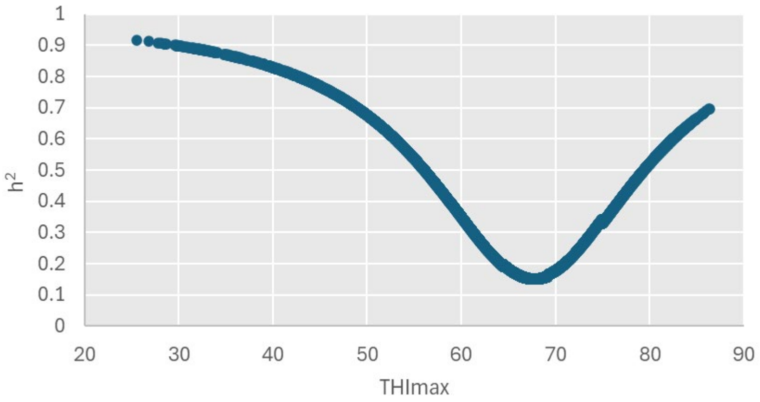
	Longevity	Lifetime fertility	Foaling
Longevity		0.558	0.784
Lifetime fertility	0.269		0.999
Foaling	0.120	0.549	

GxE in foaling event, yes vs. not

Variance components & heritability

analysis	Pe	G	covGxE	GxE	R	h²
noTHI	0.012	0.143	-	-	1.002	0.124
THIenv	0.022	0.161	-	-	1.004	0.135
THIgen	0.025	0.184	-0.073	0.537	1.000	0.115

Above: Variance components & heritability of traits (posterior means, liability scale)
Below: Plot of heritability by THI (GxE model)



EBV rank correlation

Mares / Stallions	noTHI	THIenv	THI GxE
no THI	-	0.917	0.684
		<0.001	<0.001
THI env	0.879	-	0.781
	<0.001		<0.001
THI GxE	0.698	0.821	-
	<0.001	<0.001	

Above: Spearman correlations between EBVs ranks of mares (above diagonal, n=3308) and stallions (below diagonal, n=1464)

Variance for GxE detected

Reranking of animals:

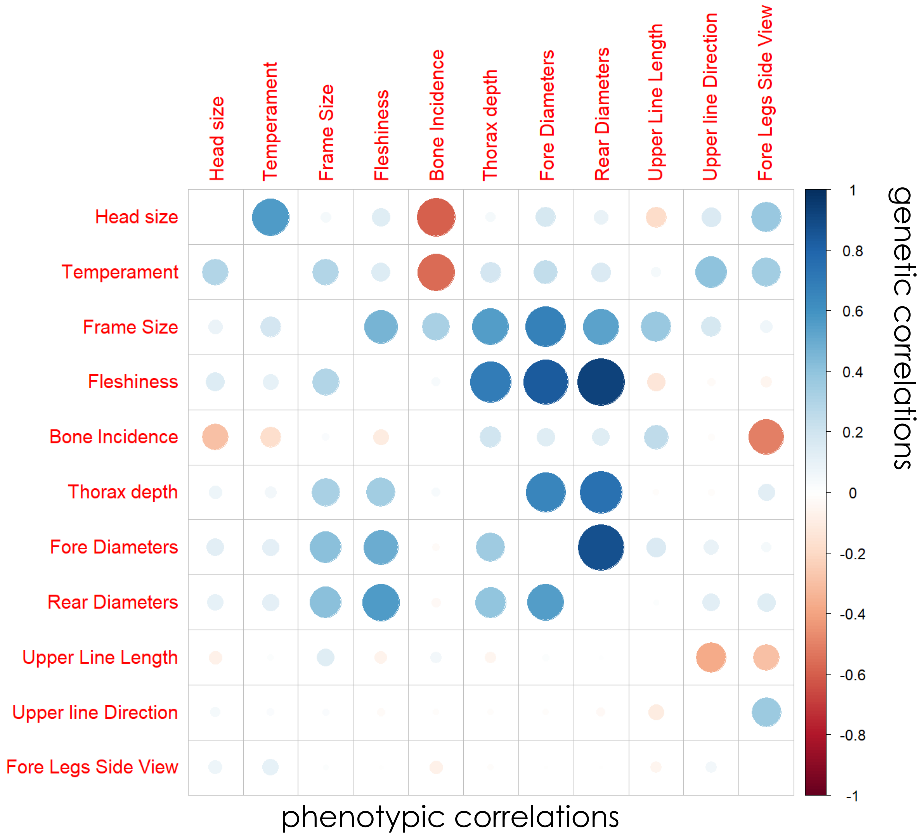
- under THI → importance of the environmental covariate
- under GxE → it should be considered in selection

Correlations with linear type traits

Fitness vs. type traits

	Lifetime fertility		Longevity	
	r_a	r_P	r_a	r_P
Head size/expr.	**0.164**	0.033	0.224	-0.003
Temperament	**0.198**	0.025	**0.360**	0.012
Frame size	0.125	0.011	0.138	0.015
Fleshiness	**0.251**	**0.059**	**0.255**	**0.009**
Bone incidence	-0.149	-0.013	0.084	0.059
Thorax depth	**0.192**	0.015	0.231	0.024
Fore diameters	**0.255**	0.038	**0.259**	0.010
Rear diameters	**0.262**	**0.067**	0.206	0.001
Upper line length	0.032	0.044	**-0.617**	**-0.062**
Upper line direction	-0.017	-0.010	-0.026	-0.006
Fore legs side view	0.011	0.046	0.077	0.038

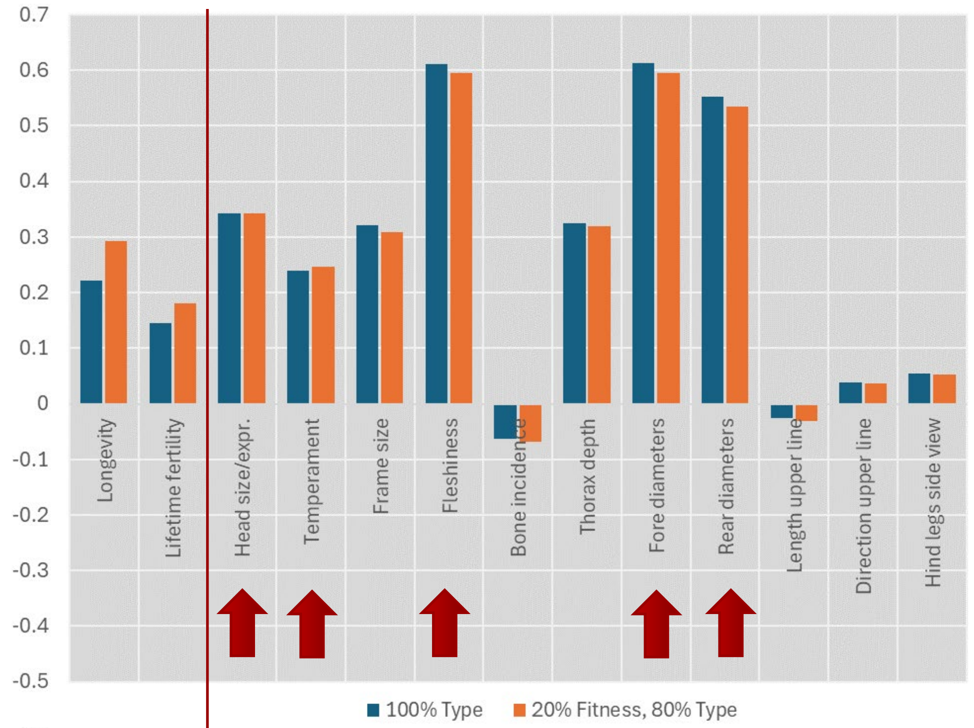
Type traits vs. type traits

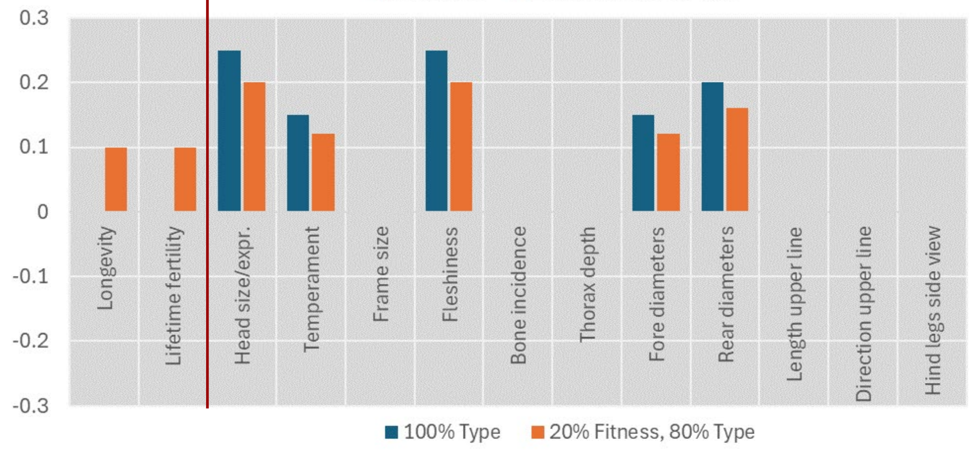


Traits under selection

Significant correlations are **bolded**

Response to selection & genetic trend





Standardized selection response

100% Type

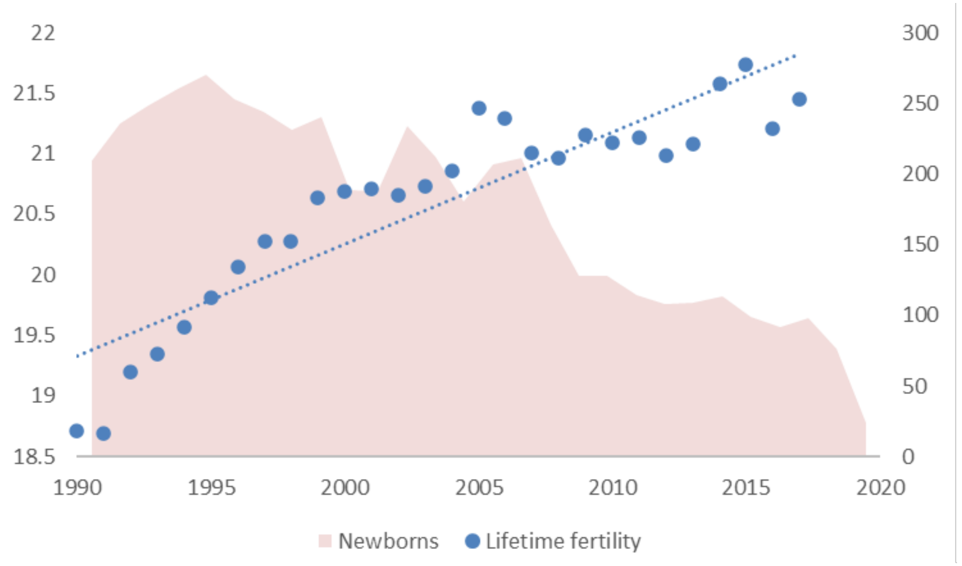
Current selection index, only type traits considered

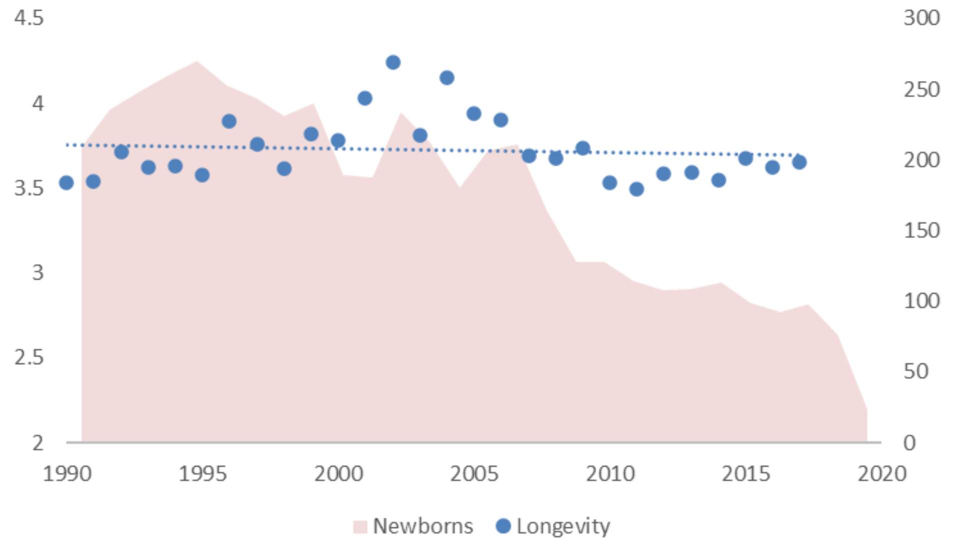
20% Fitness, 80% Type

20% of economic weight to fitness traits

Economic weights of traits

Genetic trend of traits





Conclusions & Perspectives

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Conclusions:

- **Variance components & heritability** estimated for fitness traits in horses (Italian Heavy Draught Horse):
- **Functional longevity, Lifetime fertility, Foaling events**
- Effects of **THI** on foaling events (environmental covariate & **GxE**): important to consider robustness in selection
- **High genetic correlations** among fitness traits & **linear type traits** currently under selection (5 traits for draught and meat improvement)
- **Positive response to selection** for fitness traits under current genetic improvement
- **Even more positive** response if **fitness traits are included in selection index**
- Should be a good option for longevity, which genetic trend is almost zero (lifetime fertility is increasing)
- Results suggest the importance of accounting for fitness traits and climate information in horse breeding, especially in local populations exposed to various rearing systems and management conditions

Perspectives:

- To evaluate how **to consider robustness** in selection
- **To implement the inclusion** of fitness traits in routine breeding practices

Thanks to ANACAITPR for data