Use of genomics to optimize breeding decisions for beef and sexed semen

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Notes:

Paper and PowerPoint slides on following pages

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The importance of genetic selection

Dairy cattle selection programs aim to improve the profitability and sustainability of the dairy industry, either by targeting traits that increase revenues or traits that reduce expenses. Contrary to improvements in nutrition, management or cow comfort, changes achieved through selection are incremental, cumulative, and permanent, which makes genetic improvement a very cost-effective strategy. In fact, genetic selection is a very powerful tool for achieving lasting gains in dairy cattle performance. For instance, the current dairy cow produces more than twice as much milk as the dairy cow of 60 years ago, and more than half of that improvement is due to genetic selection.

The best selection tool: economic selection index

There are a large number of traits, including production traits (such as milk yield and milk composition) and functional traits (such as fertility, health, and longevity), that directly impact the profitability of any dairy production enterprise. The best approach for selecting animals considering multiple traits is the use of an economic selection index. This method combines multiple traits into a single value, greatly facilitating the identification of the best animals. Individual traits are weighted based on relevant genetic information, such as heritabilities and genetic correlations, and their economic importance. The Council on Dairy Cattle Breeding currently report four different economic selection indices, namely Lifetime Net Merit (NM$), Cheese Merit (CM$), Fluid Merit (FM$), and Grazing Merit (GM$). These indices are updated periodically in order to include new traits and to reflect price trends. It should be noted that the focus of dairy cattle selection programs has evolved over time, from an initial emphasis on increasing milk yield and physical appearance, to a current interest in improving production efficiency, milk composition, health, and fertility.

Genomic selection: the latest revolution

Genomic selection refers to selection decisions based on genomic-estimated breeding values. These genomic breeding values are calculated using genetic markers across the entire genome. This technology has revolutionized dairy cattle breeding, enabling more rapid genetic progress, particularly for low heritable traits, such as health and fertility. Indeed, genomic selection in dairy cattle has doubled the annual rates of genetic gain for production traits but has increased from 3-fold to 4-fold for fitness traits, including longevity, fertility, and health.

Effective use of genomics: replacement heifer selection

Genomic testing allows farmers to make accurate selection (culling) decisions at an early age. The identification of genetically inferior heifer calves allows early culling of these animals, significantly reducing the cost of rearing replacements. Alternatively, these genetically inferior heifers can be inseminated with beef semen to produce high-value crossbred beef calves. On the other hand, the identification of superior heifers can be combined with the use of advanced reproductive technologies to rapidly propagate these animals and generate superior replacements.

For instance, high-genetic-merit heifers can be used as donors in an embryo transfer program or can be inseminated using sexed semen from top sires. Note that genotyping replacement heifers has extra benefits other than making proper selection and mating decisions, including parentage verification, controlling inbreeding, and avoiding the spread of genetic disorders. Arguably, these benefits add value to genomic testing.

Novel traits in the genomics era

Genomics facilitates the selection for novel traits that are critically important, but too difficult or expensive to measure on the entire population. These relevant traits can be measured only on a relatively small group of genotyped animals, and this reference population can then be used to predict genomic breeding values for the entire population, including young selection candidates. This could allow the selection for new traits, such as methane emissions and resilience, among others.

Final remarks

The success of dairy cattle genetic programs is based on the collection and analysis of performance records and pedigree information, the use of assisted reproductive technologies, and more recently, the incorporation of genomic data. Indeed, genomics has transformed dairy cattle breeding programs, increasing the rate of genetic gain. Selection objectives have evolved over time, from increasing milk yield to improving milk solids and enhancing health and fertility traits, following the needs and concerns of producers, milk processors, and consumers. The widespread implementation of on-farm sensors and monitoring systems, such as activity and rumination monitors, automated calf feeders, and in-line milk sensors, among others, provide huge amounts of data, generating opportunities to incorporate new traits into genetic selection programs. In addition, new genomic technologies, such as whole-genome sequencing and genome editing, will provide new tools for genetic improvement. Health and fertility traits, as well as environmental sustainability traits, such as feed efficiency and methane emissions, are very important given the increasing concerns of society about dairy cow welfare and the environmental impacts of dairy farming.

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progress, challenges and perspectives

"Dairy Girls"

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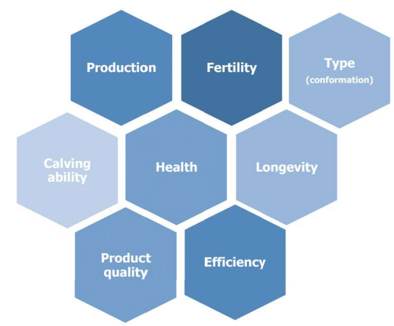
What's the goal of a breeding program?

improve traits that **increase revenues** or traits that **reduce expenses**

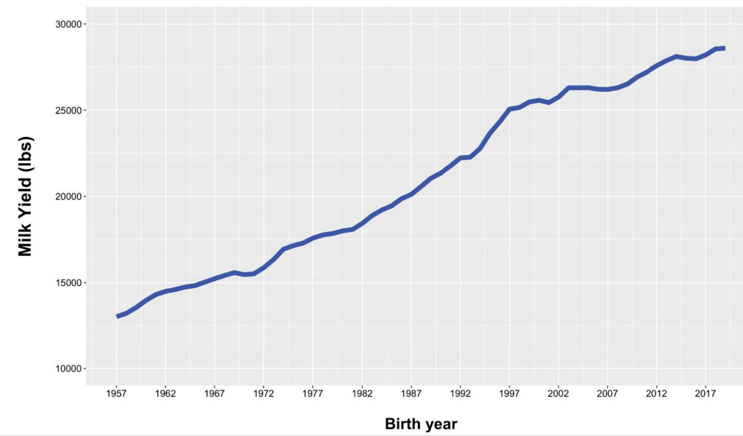


Current traits under selection

Production	milk yield | protein yield & percentage | fat yield & percentage
Fertility	daughter pregnancy rate | heifer/cow conception rate | age at first calving
Longevity	productive life | cow livability | heifer livability
Health	SCS | mastitis | ketosis | retained placenta | metritis | DA | milk fever
Calving ability	calving ease | stillbirth rate | gestation length
Conformation	body weight composite | feet and leg composite | udder composite
Feed efficiency	residual feed intake | feed saved

How important is genetic selection?

Change in milk yield in the last 60 years



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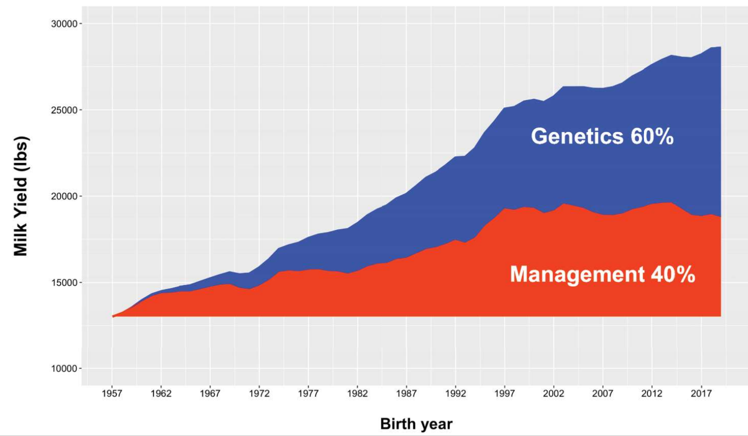
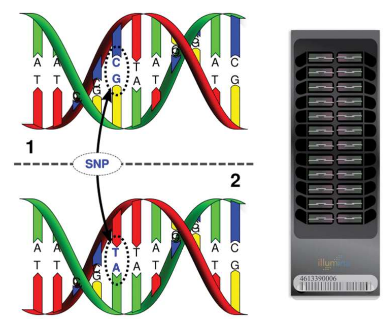


Genomic selection: the latest revolution



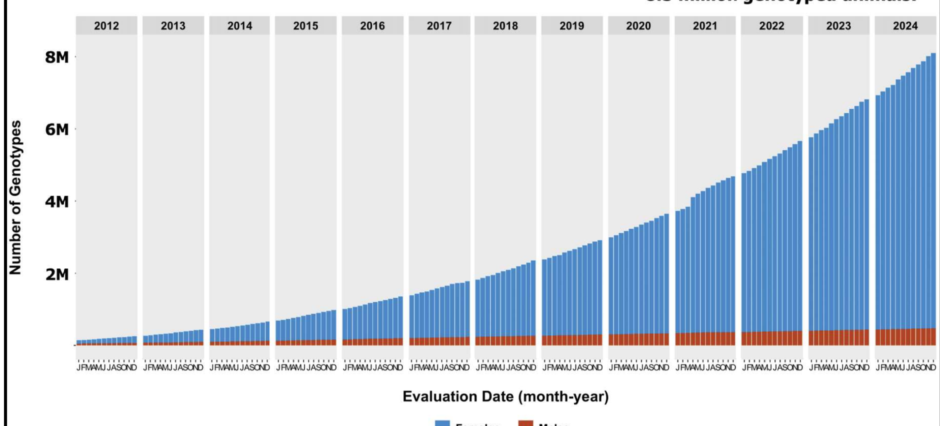
the use of genetic markers across the genome to predict breeding values

allows to select animals at an early age

all relevant traits are sex limited
and cannot be measured until females begin lactating

US Holstein genotypes

8.3 million genotyped animals!



source: https://www.uscdcb.com

Genomic selection: benefits

main goal: maximize the genetic gain per unit of time

$$\Delta G_{year} = \frac{\sqrt{\text{reliability}} \cdot \text{selection intensity} \cdot \sqrt{\text{genetic variance}}}{\text{generation interval}}$$

- **reliability**: how accurate genetic merits are estimated (↑ **genomics**)
- **selection intensity**: how superior are the parents of next generation
- **generation interval**: time between generations (↓ **genomics**)
- **genetic variance**: variation due to genetic factors

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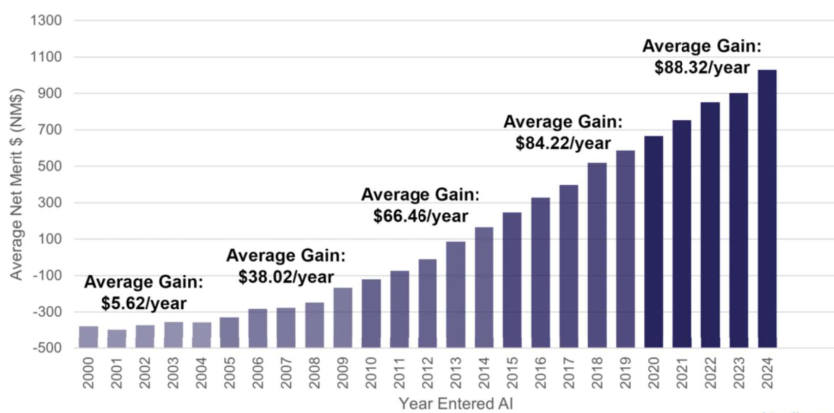
Genetic gain

genetic merit of marketed Holstein bulls



source: https://www.uscdcb.com

Genomics increases reliability

reliability: how accurate genetic merits are estimated

estimate **as precisely as possible** the **genetic merit** of a newborn calf

selection decisions are based on **parent average**

reliability ranges from **0** to **0.35**

genomic testing

selection decisions are based on **genomic breeding values**

reliability ranges from **0.65** to **0.80**

↑ reliability → ↑ annual genetic gain

Genomic vs traditional reliabilities

CDCB — COUNCIL ON DAIRY CATTLE BREEDING

3966 Holstein Genomics bulls (Dec 2024)

Traits	PTA			Reliability (%)		
	Genomic average	Traditional average	Difference	Genomic average	Traditional average	Difference
Milk	1269	1168	101	81	34	**47**
Fat	93.1	83.2	9.9	81	34	**47**
Protein	58.1	52.9	5.2	81	34	**47**
Productive life	4.2	3.2	1.0	76	26	**50**
Cow Livability	0.5	-0.3	0.8	73	19	**54**
Daughter pregnancy rate	-0.9	-1.1	0.2	76	26	**50**
Mastitis	1.7	1.2	0.5	72	22	**50**
Early First Calving	3.0	1.8	1.2	73	21	**52**

gains in reliability are greater for fertility and health traits

source: https://www.uscdcb.com

Does genomics work?

can genomic testing predict future performance?

genomic testing

Production
Health
Reproduction

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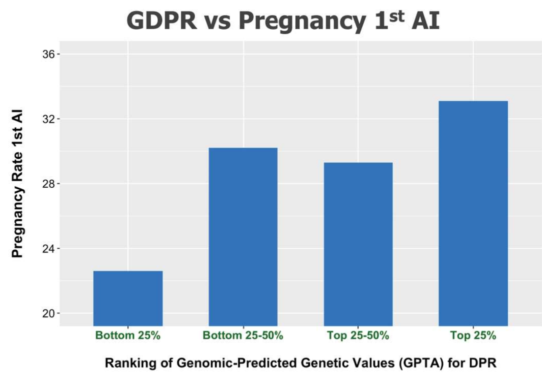
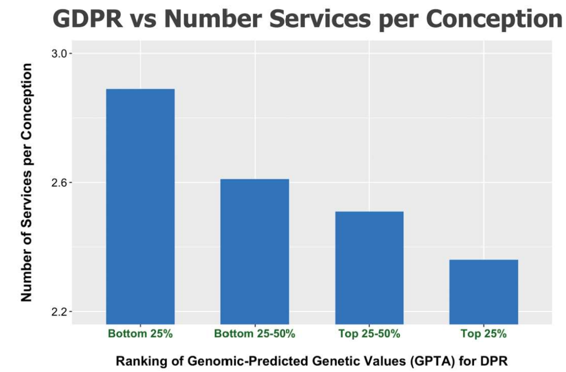
Predicting fertility using genomic testing



Lima et al. (2020) Journal of Dairy Science 103: 3312-3324

Predicting fertility using genomic testing



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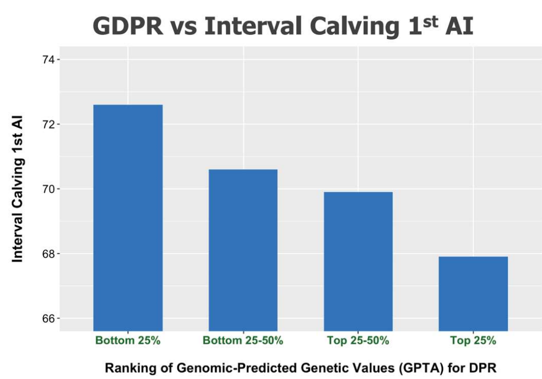
Predicting fertility using genomic testing



Lima et al. (2020) Journal of Dairy Science 103: 3312-3324

Does genomics work?

can genomic testing predict future performance?

Genomic testing

- can be effectively used to predict performance
- more accurate than using sire's PTA values
- can be used to make proper selection decisions

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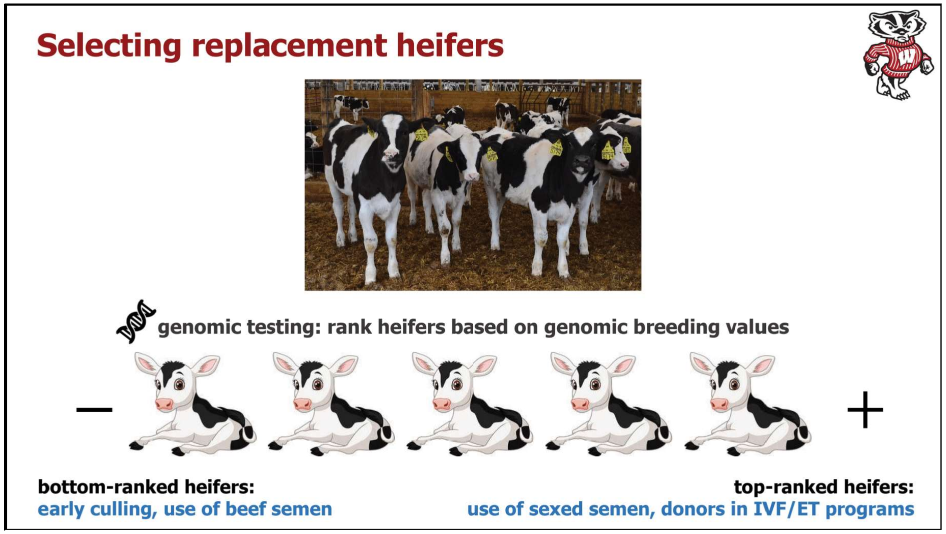

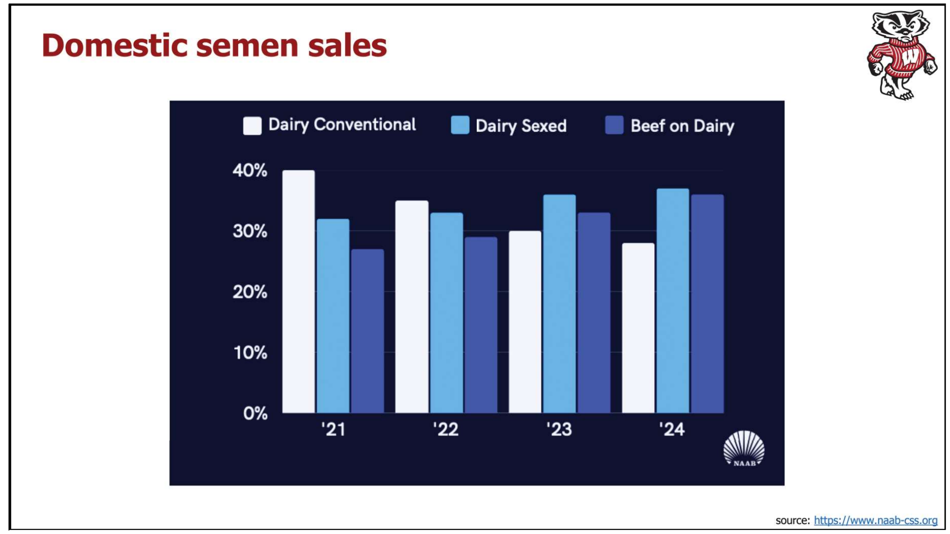

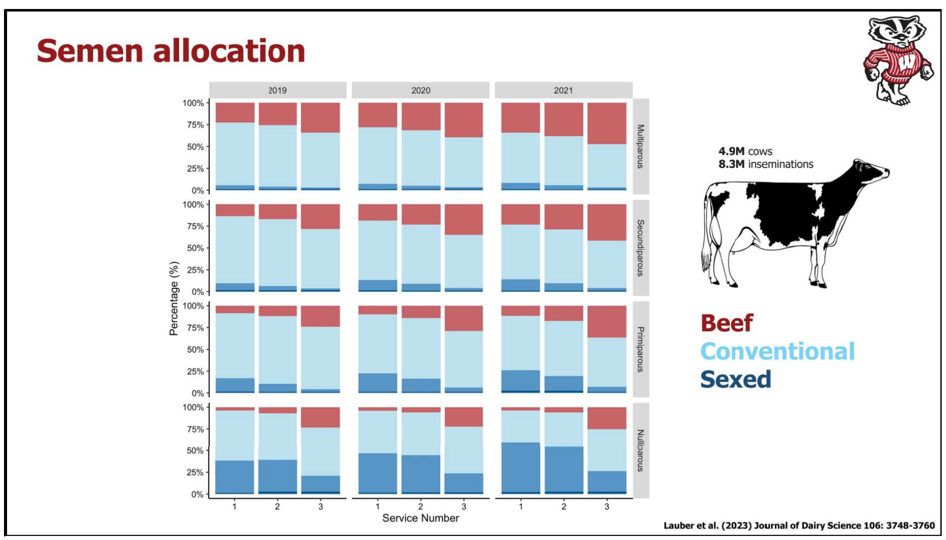

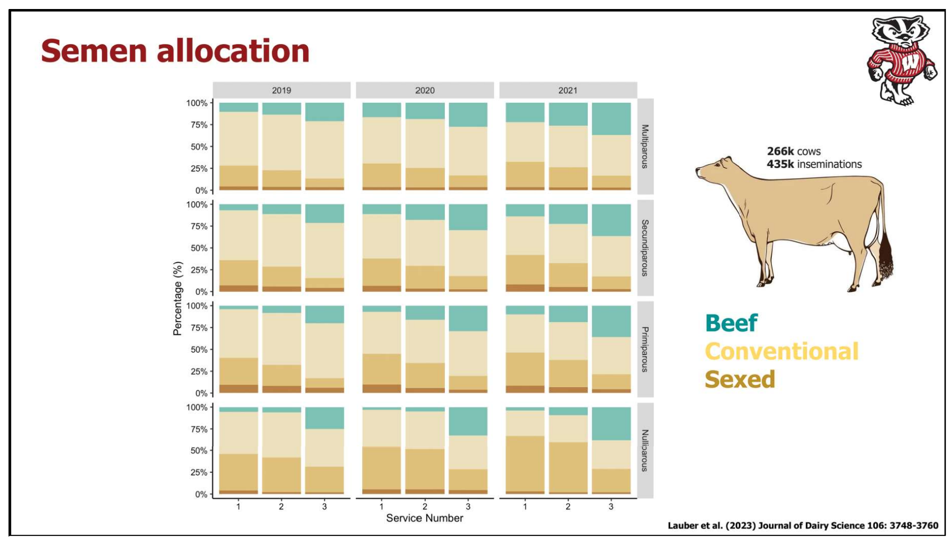

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Tracking genetic disorders

- tracking known recessive defects

  BLAD, CVM, DUMPS, Mulefoot, Brachyspina, among others

- tracking haplotypes affecting fertility

  - haplotypes that are never observed as homozygous
  - absence of homozygous indicates a recessive deleterious effect
  - if two carriers are mated: 25% chance of embryonic/fetal loss

Recessive haplotypes

Breed[1]	Haplo[2]	OMIA ID[3]	Functional/gene name[4]	Haplotype frequency (%)	BTA	Location (bp)[5]	Timing[6]
AY	AH1	001934	PIRM/*UBE3B*	13.0	17	65,921,497	W
BS	BH1	001825	—	6.67	7	42,811,272 – 47,002,161	E
	BH2	001939	*TUBD1*	7.78	19	10,617,246 – 11,726,846	B, W
	BHD	001247	SDM/*SPAST*	2.19	11	14,742,058	W
	BHM	000939	SMA/*KDSR* (*FVT1*)	3.61	24	62,118,139 – 62,156,760	W
	BHW	000827	Weaver/*PNPLA8*	1.56	4	49,616,352 – 49,738,691	W
HO	HCD	001965	Cholesterol deficiency/*APOB*	2.5	11	77,953,380 – 78,040,118	W
	HH0	000151	Brachyspina/*FANCI*	2.76	21	21,184,869 – 21,188,198	E, B
	HH1	000001	*APAF1*	1.92	5	63,150,400	E
	HH2	001823	—	1.66	1	94,860,836 – 96,553,339	E
	HH3	001824	*SMC2*	2.95	8	95,410,507	E
	HH4	001826	*GART*	0.37	1	1,277,227	E
	HH5	001941	*TFB1M*	2.22	9	92,350,052 – 93,910,957	E
	HHB	000595	BLAD/*ITGB2*	0.25	1	145,119,004	W
	HHC	001340	CVM/*SLC35A3*	1.37	3	43,412,427	E, B
	HHM[9]	000963	Mulefoot/*LRP4*	0.07	15	77,663,790 – 77,701,209	B
JE	JH1	001697	*CWC15*	12.10	15	15,707,169	E
	JH2	001942	—	1.3	26	8,812,759 – 9,414,082	E

E = embryonic or fetal loss
B = calf death at birth
W = calf death few weeks after birth

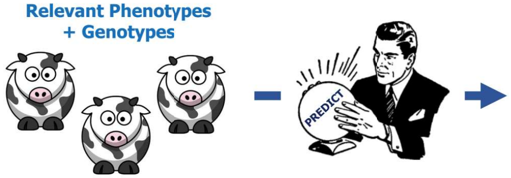
Cole et al. (2016) Journal of Dairy Science 99: 7274-7288

Novel traits in the genomics era

Genomics has created opportunities to improve traits that are critically important,

but too difficult or expensive to measure on the entire population

Relevant Phenotypes + Genotypes

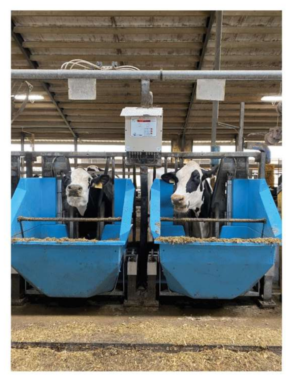


genomic PTAs for the entire population
(including young selection candidates)

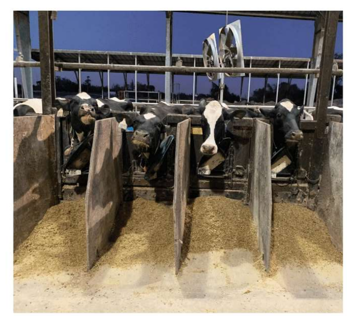
small reference population

e.g., feed efficiency, methane emissions, blood calcium profiles, thermoregulation, adaptive immune response, …

Novel traits: feed efficiency



Insentec Gates



Calan Gates

Tie Stalls

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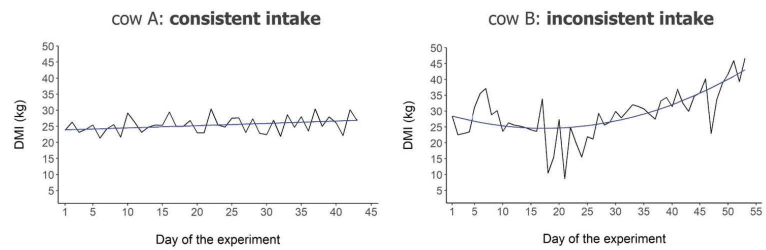
Novel traits: methane emissions

Novel traits: consistency, resilience

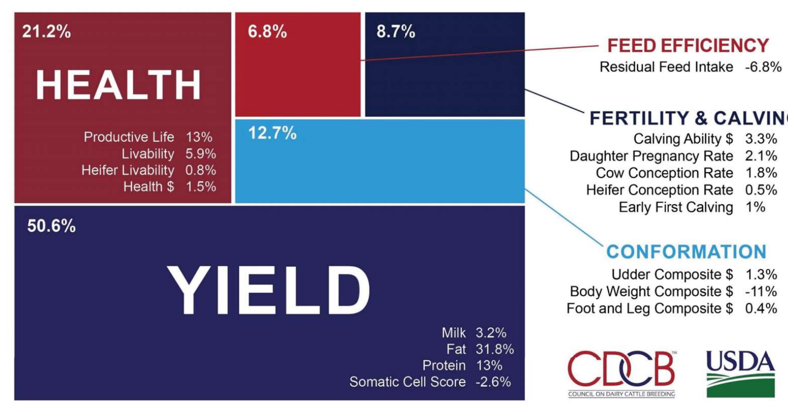


Best selection tool!

Trait	NM$	FM$	CM$	GM$
Milk	3.2	17.6	-2.7	3.0
Fat	31.8	31.7	30.0	30.3
Protein	13.0	0.0	17.4	12.3
PL	13.0	13.0	12.3	6.9
SCS	-2.6	-1.5	-3.2	-2.5
BWC	-11.0	-11.0	-10.4	-13.0
UDC	1.3	1.3	1.3	1.5
FLC	0.4	0.4	0.4	0.4
DPR	2.1	2.1	2.0	5.6
CA$	3.3	3.3	3.2	3.4
HCR	0.5	0.5	0.5	0.9
CCR	1.8	1.8	1.7	5.2
LIV	5.9	5.9	5.6	4.4
HTH$	1.5	1.5	1.4	1.5
RFI	-6.8	-6.8	-6.4	-7.6
EFC	1.0	1.0	1.0	0.8
HLIV	0.8	0.7	0.7	0.6

source: https://www.uscdcb.com

Net Merit Index ($NM)



CDCB USDA

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Evolution Net Merit Index

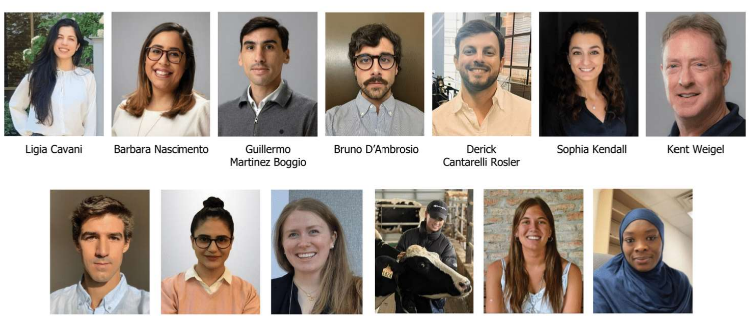
Traits	PD$ (1971)	MFP$ (1976)	CY$ (1984)	NM$ (1994)	NM$ (2000)	NM$ (2003)	NM$ (2006)	NM$ (2010)	NM$ (2014)	NM$ (2017)	NM$ (2018)	NM$ (2021)	NM$ (2025)
Milk	52	27	−2	6	5	0	0	0	−1	−1	−1	0	3
Fat	48	46	45	25	21	22	23	19	22	24	27	29	32
Protein	---	27	53	43	36	33	23	16	20	18	17	20	13
Productive Life	---	---	---	20	14	11	17	22	19	13	12	16	13
Somatic Cell Score	---	---	---	−6	−9	−9	−9	−10	−7	−7	−4	−3	−3
Body Weight Composite	---	---	---	---	−4	−3	−4	−6	−5	−6	−5	−9	−11
Udder Composite	---	---	---	---	7	7	6	7	8	7	7	3	1
Feet & Legs Composite	---	---	---	---	4	4	3	4	3	3	3	0	0
Daughter Pregnancy Rate	---	---	---	---	---	7	9	11	7	7	7	4	2
CA$ (calving trait sub-index)	---	---	---	---	---	---	6	5	5	5	5	3	3
Heifer Conception Rate	---	---	---	---	---	---	---	---	1	1	1	1	1
Cow Conception Rate	---	---	---	---	---	---	---	---	2	2	2	1	1
Livability	---	---	---	---	---	---	---	---	---	7	7	4	6
HTH$ (health trait sub-index)	---	---	---	---	---	---	---	---	---	---	2	1	2
Residual Feed Intake	---	---	---	---	---	---	---	---	---	---	---	−4	−7
Early First Calving	---	---	---	---	---	---	---	---	---	---	---	1	1
Heifer Livability	---	---	---	---	---	---	---	---	---	---	---	1	1

source: https://www.uscdcb.com

Take home messages

- **genetic selection is a very powerful tool**
- **best selection tool: economic selection index**
- **focus of selection has evolved:** from only production to fitness traits and efficiency
- **genomics has transformed dairy cattle breeding,** enabling faster genetic gain
- **benefit of genomics is greatest for low h^2 traits,** e.g. fertility and health
- **genomics facilitates the selection for novel traits**, e.g. feed efficiency
- **genomic predictions can effectively predict future performance**
- **genomic testing allows tracking of genetic recessive effects**
- **how to balance rapid genetic progress and adequate genetic diversity?**

Team



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Acknowledgments

Dairy Innovation Hub; FFAR Foundation for Food and Agriculture Research; USDA NIFA United States Department of Agriculture National Institute of Food and Agriculture; College of Agricultural & Life Sciences University of Wisconsin-Madison; Greener Cattle Initiative; Gerstner Philanthropies; C-LOCK Measure and Control Feed Intake and Emissions; CDCB Council on Dairy Cattle Breeding; DMI Dairy Management Inc.

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Thanks for your attention!

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