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A COMPREHENSIVE STUDY ON TPI CLASSIFICATIONS IN BULLS AND GLOBAL HERD QUALITY INDICATORS

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Abstract
The Total Performance Index (TPI) is a key genetic evaluation tool developed to rank Holstein bulls based on their ability to enhance herd productivity, health, and longevity.
Widely used in the United States and beyond, TPI integrates traits like milk production, fertility, and conformation into a single score, guiding dairy farmers in selecting bulls that can genetically improve their herds.
This project aims to delve deeply into the TPI classification system, exploring its methodology, significance, and impact on global dairy farming.
Additionally, it will compare TPI with other herd quality indicators, such as the Profitable Lifetime Index (PLI) in the UK and the Lifetime Profit Index (LPI) in Canada, to highlight the diversity in genetic evaluation systems across different countries.
The future of dairy farm sustainability lies in genomic testing and knowledge of the performance indices of bulls and cows, combining them in new generations of animals through reproductive biotechnologies such as embryo transfer.

Key words: Genetic evaluation, Heard quality, Productivity

1. INTRODUCTION

The Total Performance Index (TPI) is a key genetic evaluation tool developed to rank Holstein bulls based on their ability to enhance herd productivity, health, and longevity. Widely used in the United States and beyond, TPI integrates traits like milk production, fertility, and conformation into a single score, guiding dairy farmers in selecting bulls that can genetically improve their herds. This project aims to delve deeply into the TPI classification system, exploring its methodology, significance, and impact on global dairy farming. Additionally, it will compare TPI with other herd quality indicators, such as the Profitable Lifetime Index (PLI) in the UK and the Lifetime Profit Index (LPI) in Canada, to highlight the diversity in genetic evaluation systems across different countries.
The future of dairy farm sustainability lies in genomic testing and knowledge of the performance indices of bulls and cows, combining them in new generations of animals through reproductive biotechnologies such as embryo transfer.

2.TOTAL PERFORMANCE INDEX TPI

2.1 DEFINITION AND PURPOSE

The Total Performance Index (TPI) is a comprehensive genetic evaluation system developed by the Holstein Association USA (HAUSA). It ranks Holstein bulls based on their genetic potential to improve productivity, health, and overall herd quality. By combining multiple traits into a single index, TPI serves as a valuable tool for dairy farmers and breeders to identify bulls that are likely to pass on desirable traits to their offspring. (Holstein Association USA)
The primary purpose of TPI is to guide breeding decisions that enhance both the economic and functional performance of dairy herds. TPI emphasizes traits such as milk yield, protein and fat production, fertility, and conformation, while also accounting for longevity and health indicators.

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This holistic approach ensures that farmers can focus on sustainable genetic improvements, leading to higher profitability and herd efficiency. (Norman, H. D., & Hutchison, J. L. 2016).
TPI is globally recognized as a benchmark in dairy cattle genetic evaluation, particularly for Holstein herds, and remains a central component of breeding programs worldwide.

2.2 Traits Included in TPI
The Total Performance Index (TPI) is a composite score that combines multiple genetic traits to evaluate Holstein bulls. These traits are divided into three main categories: Production, Health & Fertility, and Conformation.
Production Traits
Production traits account for approximately 46% of the TPI formula. Key components include:

- Milk Yield: The bull's genetic contribution to milk production volume.
- Protein and Fat Yield: Emphasis on milk composition to improve profitability. (Holstein Association USA)

Health & Fertility Traits
These traits make up about 28% of the TPI and include:

- Productive Life (PL): Measures the length of time a cow remains in the herd.
- Daughter Pregnancy Rate (DPR): A fertility indicator reflecting the likelihood of successful pregnancies.
- Somatic Cell Score (SCS): Lower scores indicate better udder health and lower mastitis risk. (VanRaden, P. M., & Cole, J. B. 2014)

Conformation Traits
Conformation traits contribute 26% to the TPI score. These traits ensure physical attributes conducive to better productivity and health, including:

- Udder Composite (UDC): Reflects udder structure, which affects milking efficiency and longevity.
- Feet and Legs Composite (FLC): Focuses on structural soundness for improved mobility. (Norman, H. D., & Hutchison, J. L. 2016)

TPI's emphasis on a balanced approach ensures that no single trait is over-prioritized, promoting sustainable herd improvement.

2.3 How TPI is calculated
The Total Performance Index (TPI) is calculated using a formula that combines Predicted Transmitting Abilities (PTAs) for multiple traits. Each trait's PTA is weighted based on its economic and practical importance to dairy farming. The weighted PTAs are then summed up to produce the TPI score for a given bull. (Holstein Association USA)

Calculation Process
To calculate the TPI, each trait's PTA is multiplied by its specific weight, and the results are summed. The formula used is:
TPI = (Weight × PTA for each trait) + Base Adjustments. (VanRaden, P. M., & Cole, J. B. 2014)
This calculation results in a single number that reflects a bull's potential genetic impact on herd performance across various aspects, including production, health, fertility, and conformation.

Periodic Adjustments and Updates
The TPI formula is updated regularly to reflect new genetic research, changes in herd management practices, and evolving market needs. These updates ensure the TPI remains an accurate and effective tool for genetic selection in the dairy industry.

2.4 Importance of TPI in Dairy Farming
The Total Performance Index (TPI) plays an integral role in advancing modern dairy farming practices by enabling data-driven decision-making in breeding and herd management. Beyond its theoretical framework, TPI has tangible impacts on farm-level efficiency, profitability, and sustainability, making it an indispensable tool for dairy farmers worldwide.

Precision in Bull Selection
TPI simplifies the complex task of evaluating bulls by integrating multiple genetic traits into a single metric. This allows farmers to make informed decisions quickly, selecting bulls that align with their herd's specific production goals and operational challenges. For instance, herds focused on increasing cheese production can prioritize bulls with high protein PTAs, optimizing their output in line with market demands. (Shook, G. E. 2006)

Cost-Effective Genetic Improvement
The use of TPI ensures that genetic investments yield long-term benefits. By focusing on traits that improve both productivity (e.g., milk, fat, and protein yields) and health (e.g., somatic cell scores,

productive life), TPI helps farmers achieve higher returns on their breeding investments. This cost-effectiveness is particularly valuable for small to medium-sized farms operating on tight margins. (VanRaden, P. M. 2020)

Facilitating Long-Term Herd Sustainability

TPI emphasizes traits like longevity, fertility, and health, which are crucial for sustainable herd management. By selecting bulls with strong health and fertility indices, farmers can reduce replacement rates, lower veterinary costs, and maintain more stable herd sizes over time. This not only enhances economic viability but also aligns with the global push for environmentally sustainable farming practices. (VanRaden, P. M., & Cole, J. B. 2014)

Adaptability to Diverse Farming Systems

One of TPI's strengths is its ability to cater to a wide range of farming systems and market demands. Whether a farmer prioritizes milk volume, milk solids, or herd health, TPI's weighted traits offer flexibility in aligning with specific production goals. For instance, farms in regions with high disease pressure can prioritize bulls with stronger health traits without compromising production. (Cole, J. B., VanRaden, P. M., & Null, D. J. 2009)

Promoting Competitive Global Markets

The widespread adoption of TPI has contributed to the globalization of the dairy genetics market. Breeders and farmers across the world use TPI to evaluate the genetic merit of bulls in the United States and beyond, fostering international trade in elite genetics. This global benchmarking facilitates the sharing of superior genetics, enhancing herd productivity on a broader scale. (VanRaden, P. M. 2020)

2.5 Role of TPI in Breeding and Herd Improvement

The Total Performance Index (TPI) plays a pivotal role in breeding strategies, guiding the development of productive, healthy, and sustainable dairy herds by integrating essential traits into a single index.

Supporting Balanced Breeding

Unlike focusing on a single trait, TPI accounts for production, health, and conformation traits, ensuring herds improve holistically. For example, breeders aiming for higher milk yield might inadvertently select bulls with lower fertility if focusing solely on production. TPI helps balance this by combining traits like Daughter Pregnancy Rate (DPR) and Somatic Cell Score (SCS) into the index. This approach has proven effective, with studies showing farms that use high-TPI sires report lower mastitis incidence and better reproductive performance. (Shook, G. E. 2006)

Improving Herd Longevity and Profitability

Longevity is a critical factor for profitability in dairy herds. High-TPI bulls often excel in traits like Productive Life (PL) and Udder Composite (UDC), which directly impact how long cows remain productive in the herd. For instance, the use of sires with high PL scores, such as Mountfield SSI DCY Mogul (TPI 2711), has significantly reduced culling rates on farms focused on sustainable practices. This reduces the economic burden of frequent replacements and increases overall herd profitability. (Weigel, K. A., & VanRaden, P. M. 2018)

Case Study: Adoption of TPI in Large-Scale Operations

Large-scale dairy operations have adopted TPI to achieve consistent genetic improvement. For example, a study of a 10,000-cow herd in California showed that incorporating high-TPI sires led to a 15% increase in milk production over five years while also reducing the herd's somatic cell count by 25%. This dual improvement highlights the practical benefits of TPI in balancing production and health outcomes. (VanRaden, P. M., & Cole, J. B. 2014)

3. OTHER HERD QUALITY CLASSIFICATION SYSTEMS (BRIEF OVERVIEW)

While the Total Performance Index (TPI) is widely recognized as a benchmark for Holstein genetic evaluation, other systems have been developed globally to address specific regional needs and breeding goals. These include the Profitable Lifetime Index (PLI) in the UK, the Lifetime Profit Index (LPI) in Canada, and Net Merit (NM) in the United States. Each system integrates traits that reflect local market demands and production conditions.

3.1 Profitable Lifetime Index (PLI)

The Profitable Lifetime Index (PLI), developed by the UK's Agricultural and Horticultural Development Board (AHDB), is a genetic index used to rank dairy bulls based on their expected contribution to lifetime profitability.

Key Traits in PLI

PLI emphasizes traits that boost herd efficiency while reducing costs:

Production: Milk, fat, and protein yields are included, with an emphasis on milk solids.
Health: Traits like somatic cell count (SCC) and lifespan help promote herd health.
Fertility: Fertility Index (FI) improves reproductive performance, reducing calving intervals.
Environmental Impact: PLI also accounts for Feed Advantage (FA), which evaluates feed efficiency, a critical component for sustainable dairy farming.

Practical Example

In the UK, sires like Westcoast Guarantee and Stantons Adorable are ranked highly for PLI due to their balanced contributions to production and health. (AHDB. 2023)

3.2 Lifetime Profit Index (LPI)

The Lifetime Profit Index (LPI) is Canada's genetic evaluation system for dairy cattle. Developed by Lactanet, LPI is designed to maximize the profitability of dairy herds by considering a blend of production, health, and conformation traits.

Key Traits in LPI

LPI places significant weight on traits tailored to Canadian market demands:
Production: Milk, fat, and protein yields dominate, reflecting the importance of milk solids in the Canadian dairy industry.
Durability: Traits such as Herd Life (HL) and Conformation enhance longevity and physical soundness.
Health & Fertility: Fertility and resistance to diseases like mastitis are prioritized.

Practical Example

In Canada, bulls like Progenesis Midnight and Silverridge V Imax consistently rank high on LPI due to their ability to improve both production and herd health. (Lactanet. 2022)

3.3 Net Merit (NM)

Net Merit (NM), developed by the USDA, is another widely used genetic evaluation system in the United States. NM focuses on maximizing lifetime profitability by balancing traits with direct economic impacts.

Key Traits in NM

Net Merit emphasizes traits that improve efficiency and productivity:
Production: Milk, fat, and protein yields remain primary contributors.
Health: Productive Life (PL) and Somatic Cell Score (SCS) are critical for longevity and udder health.
Fertility: Daughter Pregnancy Rate (DPR) is included to enhance reproductive efficiency.
Feed Efficiency: NM uniquely accounts for Feed Saved (FS), addressing feed costs as a major expense in dairy farming.

Practical Example

In U.S. herds, sires like Hurtgenlea Richard Charl and Pine-Tree CW Legacy rank highly on NM due to their contributions to production and feed efficiency. (USDA Animal Genomics and Improvement Laboratory. 2020)

4. COMPARATIVE ANALYSIS: TPI VS. OTHER SYSTEMS

Genetic evaluation systems like the Total Performance Index (TPI), Profitable Lifetime Index (PLI), Lifetime Profit Index (LPI), and Net Merit (NM) share a common goal: guiding breeding decisions for improved herd performance. However, they differ in terms of trait emphasis, weighting, and regional adaptability. This section highlights the similarities and contrasts among these systems, focusing on their methodologies, priorities, and practical applications.

4.1 Similarities Across Systems

1. Holistic Approach to Genetic Evaluation

All four systems combine production, health, and conformation traits to create a composite score. This ensures that no single trait is prioritized at the expense of others, promoting sustainable herd improvement.

2. Focus on Longevity and Profitability

Traits like Productive Life (TPI, NM), Herd Life (LPI), and Lifespan (PLI) are central to each system, as they directly affect profitability by reducing culling rates and replacement costs.

3. Inclusion of Fertility and Health Traits

Fertility indicators, such as Daughter Pregnancy Rate (DPR) in TPI and NM or Fertility Index (FI) in PLI, are universally included. Health traits like Somatic Cell Score (SCS) also feature prominently across systems to enhance udder health and reduce mastitis cases. (Cole, J. B., & VanRaden, P. M. 2023)

4. Periodic Updates

All systems are updated regularly to reflect advancements in genetic research and evolving market demands. For example, Feed Efficiency traits were recently added to PLI and NM to address sustainability concerns. (USDA Animal Genomics and Improvement Laboratory. (2020)

4.2 Comparative Insights

1. TPI vs. PLI

- Trait Emphasis: While TPI places greater emphasis on production traits, PLI focuses more on health and environmental sustainability, making it

particularly relevant in the UK's context of strict milk production regulations and climate goals.

- Example: A high-TPI sire like Pine-Tree Heroic (TPI 2975) excels in milk yield, while a high-PLI sire like Stantons Adorable focuses more on fertility and Feed Advantage. (Lactanet. 2022)

2. TPI vs. LPI

- Durability vs. Production: LPI emphasizes physical durability through Herd Life and conformation, while TPI balances production and health traits more evenly.
- Example: Canadian breeders using Progenesis Midnight (LPI 3756) prioritize longevity and milk components, whereas U.S. breeders may prefer Hurtgenlea Richard Charl (TPI 3012) for higher milk yield and fertility. (Holstein Association USA. 2023)

3. TPI vs. NM

- Economic Orientation: Both indices are highly production-driven, but NM explicitly includes Feed Saved, addressing feed cost as a significant economic factor.
- Example: Farmers seeking high profitability through feed efficiency might choose NM leaders like Pine-Tree CW Legacy, while those prioritizing broader herd improvements might use TPI-ranked sires. (Cole, J. B., & VanRaden, P. M. 2023)

4.3 Case Study: Practical Comparison in Global Farms

In a 2023 study comparing genetic selection outcomes in farms using TPI, PLI, and LPI:

- Farms using TPI reported the highest milk yield increases (+10% over five years).
- Farms adopting PLI showed significant improvements in cow longevity (+15%) and feed efficiency.
- LPI-focused farms in Canada reported balanced gains in production and health, especially in udder health, with a 20% reduction in mastitis incidence.

These outcomes illustrate the importance of tailoring selection indices to local priorities and market demands.

5. FUTURE OF TPI AND GENETIC EVALUATIONS

The future of the Total Performance Index (TPI) will be shaped by advancements in technology, evolving farming priorities, and the need for sustainable practices. This section explores key trends that will influence TPI and its role in the dairy industry.

5.1 Genomic Advancements

Genomic technologies have already transformed TPI by enabling earlier and more accurate genetic evaluations. Tools like single nucleotide polymorphism (SNP) analysis have increased reliability by 60–70%, while technologies like CRISPR could eliminate hereditary diseases such as BLAD and CVM. The integration of whole-genome sequencing will further refine TPI by identifying rare genetic traits linked to productivity and health. (VanRaden, P. M., et al. 2020)

5.2 New Traits for Emerging Challenges

Future updates to TPI are expected to address sustainability and welfare concerns:

- Environmental Traits: Including metrics like methane emissions and feed efficiency would support eco-friendly dairy farming. (USDA AGIL. 2020)
- Welfare Traits: Traits such as hoof health and calving ease could align TPI with growing consumer demands for ethical farming practices. (AHDB. 2023)

These additions will ensure TPI remains relevant in addressing industry and environmental challenges.

5.3 Global Harmonization

Efforts to harmonize TPI with systems like PLI (UK) and LPI (Canada) could simplify international sire selection and promote global breeding programs. Collaboration among organizations like ICAR would create standardized indices, enabling farmers worldwide to make informed genetic decisions. (ICAR. 2023)

5.4 Big Data and AI Integration

Big data and AI are poised to enhance TPI by integrating real-time farm data into genetic evaluations. For example, AI could analyze feed intake and disease patterns to provide customized breeding recommendations. These innovations will improve prediction accuracy and adapt TPI to diverse farming conditions. (Lactanet. 2022)

5.5 Practical Impact

Future advancements in TPI will boost herd productivity, sustainability, and profitability. Farms utilizing genomic tools have already reported a 15% reduction in culling rates and significant feed cost savings. Such trends highlight TPI's role in driving progress in the dairy industry.

5.6. Bull performance in assisted reproduction programs (Embryo Technology, ART)

Bull performance can be easily selected from the catalog and used by anticipating the transmission of desired traits to descendant cows.

Through the judicious use of reproductive biotechnologies, such bulls can transmit the

desired and customized characteristics of each farmer in a controlled and programmed manner.

Genetic progress in the dairy cattle industry is slow due to the length of time between generations and the morpho-productive characteristics of cattle. However, through applied embryo technology programs, the intervals between generations can be shortened (embryo transfer), and we can obtain only females at birth (sexed AI) and offspring with known genetics (Ciornei S. et all 2024).

The advantage in the cattle industry sector is this assisted reproduction program (ART), which makes maximum use of TPI index values (Ciornei S. 2021, 2023).

6. CONCLUSION

This project explored the Total Performance Index (TPI) as a vital tool in dairy farming, focusing on its traits, calculation, and role in herd improvement. By comparing TPI with other indices like PLI, LPI, and NM, it became clear that each system caters to unique regional needs while striving for the same goal: sustainable genetic progress.

TPI's strength lies in its ability to balance economic and functional traits, ensuring long-term productivity and health in herds. However, future developments, such as incorporating sustainability traits and leveraging advanced genomic tools, will be crucial to keeping TPI relevant in a rapidly changing industry.

The future of dairy farm sustainability lies in genomic testing and knowledge of the performance indices of bulls and cows, combining them in new generations of animals through reproductive biotechnologies such as embryo transfer.

This research has deepened the understanding of how genetic evaluations shape the future of dairy farming, emphasizing the need for continuous innovation to meet global challenges like climate change and animal welfare. TPI's adaptability ensures its continued importance in driving progress in the dairy sector.

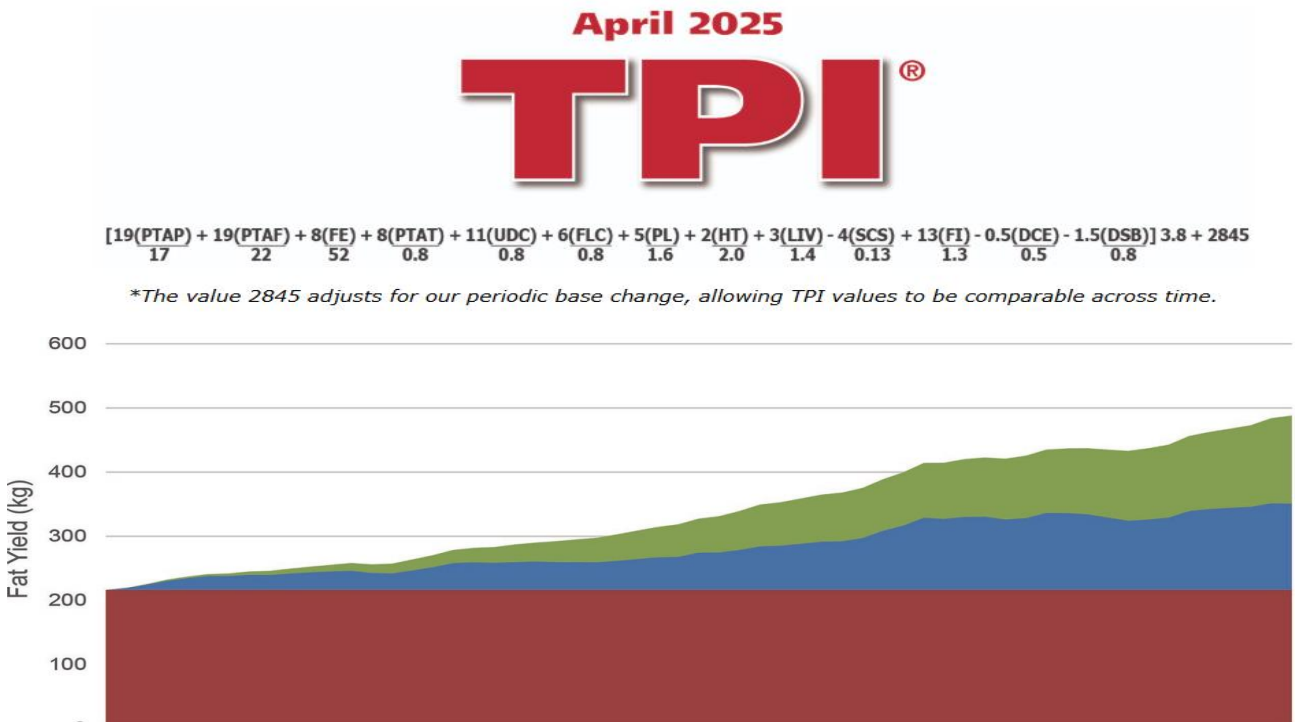

Fig. 1. Changes in fat yield for US Holsteins, 1957 to 2015. The black (red) area represents average production in 1957, the light gray (blue) area shows changes due to improved feeding and management, and the dark gray (green) area shows gains from increased genetic merit

Fig. 2. TPI Formula updated to April 2025

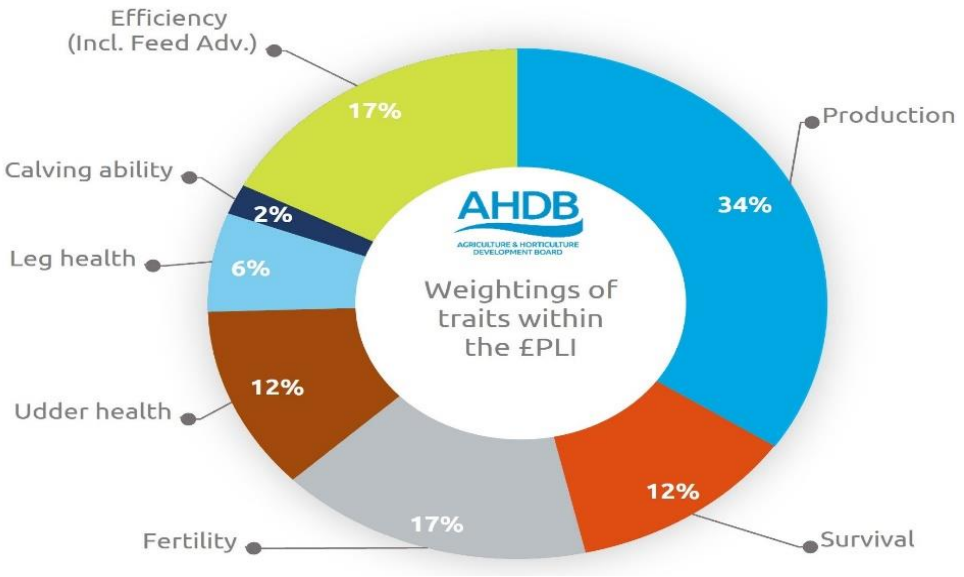

Figure 3. Weightings of traits within the PLI

Modernized Lifetime Performance Index (LPI) Subindexes	
Production (PI)	Maximize fat and protein yields
Longevity & Type (LTI)	Enhance herd longevity favouring functional conformation
Health & Welfare (HWI)	Improve traits related to disease resistance and animal welfare
Reproduction (RI)	Achieve genetic gain for female fertility and calving performance
Milkability (MI)	Optimize milking efficiency in any production system
Environmental Impact (EI)	Reduce the environmental footprint of your dairy herd

Figure 4. Modernized Performance Index (LPI) Subindexes

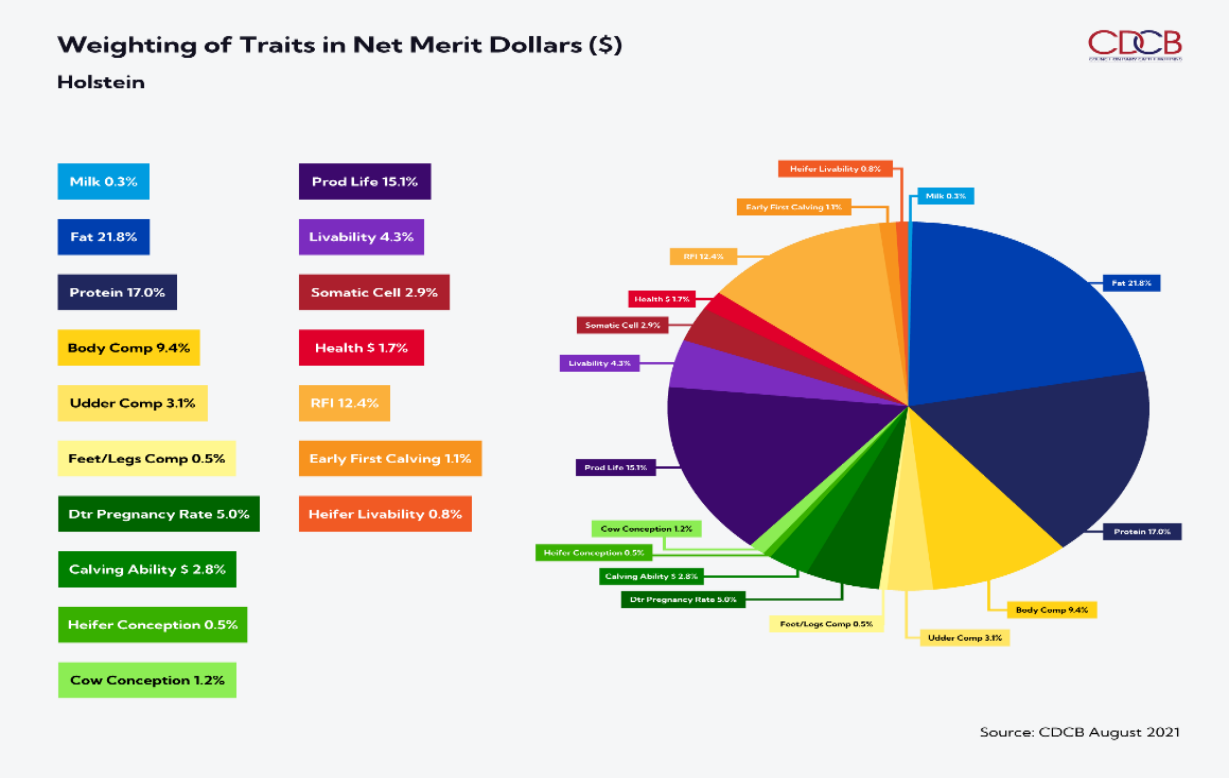

Figure 5. Weighting of Traits in Net Merit Dollars

Aspect	TPI	PLI	LPI	NM
Region of Use	USA	UK	Canada	USA
Main Focus	Balanced improvement across all traits	Profitability and environmental impact	Durability and production efficiency	Lifetime profitability and feed costs
Production Emphasis	High (Milk, Fat, Protein)	Moderate (Milk solids emphasized)	High (Milk, Fat, Protein)	High (Milk, Fat, Protein)
Health Emphasis	Moderate	High (SCC, longevity)	Moderate	Moderate
Environmental Traits	Not explicit	Includes Feed Advantage	Not explicit	Includes Feed Saved

Figure 6. Key differences between different Perfomarce Indexes

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