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Phenomics In Animal Breeding

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Introduction:

Genomic selection has been used on an industrial scale for the past 20 years thanks to advancements in genotyping and sequencing technology that have surpassed even the most optimistic predictions. Although genomics is a developed technology today, its momentum may be receding at a noticeable rate. Unless the causing mutations are found, increasing marker density follows the law of diminishing returns. When genome sequencing data is used in place of high-density genotyping data, simulation and empirical studies have demonstrated that only slight improvements in genetic prediction accuracy may be anticipated (Choudhary et al., 2024). When the additional expense of computer power and storage that sequence analyses demand in comparison to genotyping, arrays is taken into consideration, this minor benefit will most likely disappear. With the advent of various technological gadgets and the availability of the internet, phenomics—defined as "the acquisition of high-dimensional phenotypic data on an organism wide scale". Large-scale, continuous phenotyping is now feasible because to sensors that can record photos, videos, sounds, and a variety of environmental factors at a low cost.

Importance of Phenotyping:

Phenomics, broadly defined, is the large-scale study and measurement of phenotypes. It involves not just the traditional traits like milk yield or body weight, but also a wide array of physiological, behavioral, and welfare-related parameters such as feed intake, temperature regulation, disease resistance, reproductive efficiency, and even temperament. What distinguishes phenomics from classical phenotyping is the scale, precision, and technological integration.

Phenomics = Phenotyping + Big Data + Technology

All genetic improvement initiatives are based on the phenotype, a measurement of an individual's trait or feature, however definitions are occasionally scarce and its meaning is frequently inferred (sLush, 1994).

Although livestock breeders have long employed complex selection indices that aggregate multiple traits into a single performance metric (Cole and VanRaden, 2017), environmental concerns (Grossi et al., 2019), and promising new technologies for low-cost phenotyping (e.g., Halachmi et al., 2019) have sparked a renewed interest in gathering high-dimensional data on individual animals.

Applications:

- **Feed Efficiency**: One of the key areas where phenomics is showing promise is in the measurement of feed efficiency. Traditionally, measuring how much feed an animal consumes compared to the weight it gains or milk it produces was time-consuming and labour-intensive. Today, with the help of automatic feeding systems equipped with tags and load cells, it is possible to monitor individual feed intake across hundreds of animals with great precision. This data can then be analyzed to select animals that do more with less producing higher output per unit of feed, which is crucial in regions where feed costs are high or availability is limited. Such selection can significantly reduce the carbon footprint of livestock production and improve the economic viability for smallholder farmers (Steibel et al., 2023).
- **Heat Stress**: Another application is in the domain of heat stress and thermal tolerance. With global temperatures rising and heat waves becoming more frequent, especially in the Indian subcontinent, heat stress has emerged as a silent killer in dairy and meat production systems. Phenomics offers new ways to measure how animals cope with heat through thermal imaging, respiration sensors, and rectal temperature monitors. These technologies can non-invasively detect early signs of stress and help identify animals that maintain stable physiological responses under extreme conditions (Upadhyay et al., 2024).

- **Animal Welfare**: Phenomics also supports improved animal welfare and health monitoring. Automated systems now allow continuous tracking of animal behavior—how much time a cow spends lying down, walking, ruminating, or feeding. Sudden changes in these patterns often signal discomfort, illness, or reproductive events. When combined with artificial intelligence, these systems can generate alerts for farmers, prompting timely interventions and reducing dependency on antibiotics or emergency veterinary care. In poultry and piggery units, video-based behavioral tracking is being used to detect lameness, aggression, and even social stress, leading to more humane and productive farming environments (Brito et al., 2020).
- **Genomic Selection**: One of the most transformative impacts of phenomics is its ability to complement and enhance genomic selection. Genomics tells us which genes are present, but

phenomics tells us how those genes are being expressed under actual farm conditions. When both datasets are combined—genotype and high-resolution phenotype—it becomes possible to create more accurate selection indices, predict future performance more reliably, and identify gene-by-environment interactions. This synergy of genomics and phenomics marks the next frontier in animal breeding, often referred to as "precision breeding." It promises faster genetic gains, reduced generation intervals, and customized breeding strategies tailored to specific agro-climatic zones (Ding et al., 2025).

In India, the integration of phenomics into breeding programs is still in its early stages but gaining momentum. The National Dairy Development Board (NDDB), through platforms like INAPH (Information Network for Animal Productivity and Health), has begun digitalizing performance records of millions of dairy animals, creating a foundation for integrating phenomics into future breeding programs. Similarly, ICAR institutes like the Central Sheep and Wool Research Institute (CSWRI) and the Central Institute for Research on Goats (CIRG) are piloting projects involving tagging, biometric data collection, and environmental sensors to build phenomic databases for indigenous breeds like Malpura sheep and Barbari goats. These efforts are not only helping conserve valuable genetic resources but also demonstrating that high-tech breeding can be farmer-inclusive and grassroots-driven (ICAR, 2023).

Challenges:

These new data have a lot of potential, but the farming and scientific sectors also face a lot of obstacles. Dairy producers are being given a lot of new technology, many of which are proprietary, and their processes might not have independent validation. Land-grant institutions' agricultural experiment stations have undergone institutional changes that have made it more difficult to find the personnel and resources necessary to conduct validation studies, either independently or in partnership with industry. Because computation methods are regarded as trade secrets, they are frequently either not documented at all or only partially. Data silos or being locked away in proprietary software are also frequent occurrences. Last but not least, the dairy industry is incredibly opaque.

Conclusion:

In conclusion, phenomics is not just a scientific buzzword—it represents a paradigm shift in how we observe, understand, and improve livestock. By capturing the full complexity of animal performance in real-world settings, phenomics empowers breeders to make smarter, faster, and more sustainable decisions. In a country like India, where livestock is intertwined with rural livelihoods, food security, and cultural heritage, embracing phenomics can ensure that the future of breeding is not only more productive but also more humane, resilient, and locally adapted. Innovative technologies based on low-cost sensors and cutting-edge data analysis tools will be necessary to meet those objectives. Close collaboration between dairy producers, scientists, and allied industry will be essential to convert these

technologies into practical solutions.

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