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Artificial intelligence in animal breeding: Transforming breeding prediction for sustainable livestock improvement

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Abstract

Artificial intelligence (AI) has emerged as a transformative technology in livestock breeding, enabling rapid and accurate prediction of breeding values. Conventional genetic evaluation methods such as BLUP have served breeding programs for decades but often require complete performance records and assume linear relationships. Modern machine learning algorithms including Random Forest, Support Vector Machine, Artificial Neural Networks, Gradient Boosting and XG-Boost can capture complex nonlinear interactions and improve prediction accuracy. AI-assisted breeding value estimation enables earlier identification of genetically superior animals, reduces generation intervals and accelerates genetic gain.

Keywords: Artificial intelligence, machine learning, breeding value, XG-Boost, genomic selection, livestock

1. Introduction

Genetic improvement is one of the most economical methods for increasing productivity and profitability in livestock production. Estimation of breeding value (EBV) is fundamental to selection because it predicts the additive genetic merit transmitted to the next generation. Traditional approaches such as BLUP have been highly successful but generally require complete records and assume linear relationships. Advances in artificial intelligence, precision livestock farming, and genomic technologies have generated large datasets that are ideal for machine learning. These methods can model complex interactions, improve prediction accuracy and support earlier selection decisions, thereby reducing generation interval and accelerating genetic gain.

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2. Artificial Intelligence in Animal Breeding

AI applications include breeding value prediction, genomic selection, disease diagnosis, fertility prediction, milk yield forecasting, heat detection, feed efficiency evaluation and precision herd management. Ensemble learning algorithms have become especially popular because they provide high predictive performance on structured livestock datasets.

3. Machine Learning Algorithms

Random Forest combines many decision trees for robust prediction. Support Vector Machine models nonlinear relationships using kernel functions. Artificial Neural Networks learn complex patterns through interconnected layers. Gradient Boosting builds sequential models to improve performance. XGBoost enhances boosting with regularization, efficient computation and excellent prediction accuracy.

3.1 Machine Learning Algorithms Used for Breeding Value Prediction

Several machine learning techniques have demonstrated promising results in livestock breeding.

3.1.1 Random Forest

Random Forest constructs numerous decision trees and combines their predictions. It effectively handles nonlinear relationships, noisy datasets, and interactions among variables while reducing overfitting.

3.1.2 Support Vector Machine (SVM)

SVM identifies an optimal decision boundary that maximizes prediction accuracy. Kernel functions enable SVM to model complex nonlinear biological relationships.

3.1.3 Artificial Neural Networks (ANN)

ANNs imitate the functioning of biological neurons through interconnected layers. They are capable of modeling highly complex relationships between genetic, environmental, and production variables.

3.1.4 Gradient Boosting

GB sequentially develops weak prediction models while correcting errors from previous iterations. It generally provides high predictive accuracy for structured livestock datasets.

3.1.5 Extreme Gradient Boosting

XG-Boost is one of the most efficient boosting algorithms currently available. It includes regularization techniques, automatic handling of missing values, and parallel computation, making it particularly suitable for large livestock databases. Several recent studies have shown that XG-Boost frequently outperforms conventional statistical approaches for predicting breeding values and production traits.

4. Advantages of AI over Conventional Genetic Evaluation: AI enables earlier prediction, captures nonlinear relationships, integrates diverse datasets, improves prediction accuracy, reduces generation interval and supports precision breeding decisions.

- Compared with traditional approaches, AI provides several advantages:
- Earlier prediction of breeding values before complete lactation.

- Better handling of nonlinear relationships.
- Automatic identification of important predictive variables.
- Improved prediction accuracy using large datasets.
- Integration of genomic, pedigree, production, and environmental information.
- Reduced generation interval leading to faster genetic gain.
- Support for precision breeding decisions.

However, AI should complement rather than completely replace established genetic evaluation systems. Traditional statistical models remain valuable because of their interpretability and strong theoretical foundation.

5. Applications in Dairy Cattle and Buffalo

- Artificial intelligence has been successfully applied across several livestock species.
- Dairy Cattle and Buffalo
- Researchers have applied machine learning for:
 - Genomic prediction
 - Milk yield forecasting
 - Mastitis detection
 - Fertility prediction
 - Feed efficiency estimation
 - Early lactation milk yield prediction
 - Breeding value estimation
 - Reproductive performance prediction
 - Disease diagnosis
 - Precision herd management

These developments are particularly valuable for improving Cattle and Buffalo breeding programs, where early identification of elite animals can substantially enhance genetic progress.

6. Recent Literature (2022-2026)

- Recent studies increasingly compare ensemble learning algorithms (XGBoost, LightGBM and CatBoost) with BLUP and GBLUP for prediction of economically important traits.
- Scientific Reports (2024) ^[6] benchmarked machine learning and parametric methods for genomic prediction of feed-efficiency traits in Nellore cattle, showing competitive performance of ML methods.
- Crossa *et al.* (2025) ^[7] reviewed modern machine learning and deep learning approaches for genomic prediction and emphasized integration with multi-omics and environmental information.
- Explainable AI techniques such as SHAP are being adopted to interpret model predictions and identify influential variables.
- Deep learning and graph neural networks are emerging tools for large genomic datasets.

8. Applications

AI has been used successfully for genomic prediction, milk yield, fertility, disease resistance and feed efficiency in dairy cattle. In buffalo breeding, machine learning supports early lactation prediction, breeding value estimation and decision support for selection. Combining AI with genomic and sensor data is expected to improve national breeding programmes.

9. Future Perspectives

Future research should integrate AI with genomic selection, precision phenotyping, wearable sensors, IoT, explainable AI, digital twins and federated learning. Hybrid approaches combining BLUP/GBLUP with machine learning are expected to provide robust and interpretable predictions.

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7. Comparison of Machine Learning Algorithms

Algorithm	Advantages	Limitations	Data Need	Typical Use	Relative Accuracy
Random Forest	Robust, nonlinear	Large model size	Medium	Trait prediction	High
SVM	Good for small datasets	Kernel tuning	Low-Medium	Regression	High
ANN	Learns complex patterns	Needs more data	High	Complex traits	High
Gradient Boosting	Excellent structured data	May overfit	Medium	Production traits	Very High
XGBoost	Fast, regularized	Hyperparameter tuning	Medium	EBV prediction	Excellent

10. Conclusion

Artificial intelligence complements conventional genetic evaluation by improving prediction accuracy, enabling earlier selection and supporting sustainable livestock improvement. Continued collaboration between geneticists, data scientists and breeders will accelerate practical adoption.

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