Research

Predicting Crossbred Performance in Chicken: A Genomic Simulation Study on Jharkhand Native × Commercial Breed Combinations

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ABSTRACT

Systematic crossbreeding between indigenous and commercial poultry breeds is a key strategy for enhancing productivity while retaining valuable adaptive traits. This study utilized genomic simulation to predict and evaluate the effects of heterosis in F_1 crosses between the resilient Jharkhand native chicken and three specialized commercial breeds: White Leghorn, Rhode Island Red, and Cornish. A simulated population of 1,200 purebred individuals was generated based on breed-specific performance parameters and a genomic architecture of 1,000 SNP markers. Crossbreeding simulations were conducted to produce 250 F_1 offspring per combination. The Jharkhand × Rhode Island Red cross exhibited the highest heterosis for both egg production (14.9%) and body weight (18.2%), making it an optimal dual-purpose choice. The Jharkhand × White Leghorn cross showed significant heterosis for egg production (10.7%), suiting layer-focused systems. The Jharkhand × Cornish cross yielded the highest body weight heterosis (11.7%), demonstrating its potential for specialized meat production. The results provide data-driven recommendations for targeted crossbreeding programs, highlighting the critical role of indigenous genetic resources in sustainable poultry improvement.

Keywords: Crossbreeding simulation, Jharkhand chicken, Heterosis, Body weight, Egg production

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INTRODUCTION

The sustainable development of poultry production systems requires a strategic balance between improving performance traits and preserving genetic diversity, particularly through the integration of indigenous genetic resources with modern breeding approaches. India, recognized as one of twelve mega-biodiversity countries globally, harbors extensive poultry genetic diversity with over 22 registered native chicken breeds that have evolved under diverse agro-climatic conditions (Chatnallikar *et al*., 2025). Among these valuable genetic resources, Jharkhand native chickens represent an important indigenous population adapted to the challenging environmental conditions of eastern India, exhibiting remarkable resilience to heat stress, disease resistance, and local environmental variations (Agarwal *et al*., 2020). Indigenous chicken breeds play a multifaceted role in rural economies, contributing significantly to livelihood security, nutritional provision, and socio-economic development, particularly among marginalized communities. These breeds have evolved through natural selection over centuries, developing unique adaptive traits that enable survival and production under low-input management systems characteristic of smallholder farming operations. However, despite their valuable adaptive characteristics, indigenous breeds typically exhibit lower production performance compared to commercial strains, with Jharkhand native chickens producing approximately 45-60 eggs annually compared to over 300 eggs from modern commercial layers (Agarwal *et al*., 2022; Kamal *et al*., 2024). Crossbreeding strategies between indigenous and commercial breeds, such as White Leghorn, Rhode Island Red, and Cornish, have emerged as a promising approach to combine the adaptive advantages of local breeds with the superior production capabilities of commercial lines. The fundamental principle underlying successful crossbreeding programs is the exploitation of heterosis or hybrid vigor, which represents the superior performance of crossbred offspring compared to the average of their parental breeds. Research has demonstrated that heterosis effects in poultry can range from -14% to +30% for growth traits and significantly improve egg production, feed efficiency, and survival rates in crossbred populations (Tyasi *et al*., 2019; Mancinelli *et al*., 2023).

Genomic simulation approaches have revolutionized modern animal breeding by enabling precise prediction of crossbreeding outcomes without the time and resource investments required for traditional breeding trials. These methodologies integrate quantitative genetics principles with advanced computational models to simulate complex genetic interactions, predict heterosis effects, and optimize breeding strategies for specific production objectives (Mancinelli *et al*., 2023). The integration of single-nucleotide polymorphism (SNP) markers in genomic simulations allows for accurate representation of genetic diversity and prediction of crossbred performance across multiple generations (Nayak *et al*., 2023; Kanaka *et al*., 2023). Previous research has established the potential of crossbreeding programs involving indigenous × commercial breed combinations to achieve substantial improvements in production performance while maintaining adaptive characteristics. Studies have reported heterosis values ranging from 5-25% for body weight and 10-20% for egg production in various indigenous × commercial crosses (Padhi, 2016; Mancinelli *et al*., 2023). However, systematic evaluation of Jharkhand native chicken crosses with major commercial breeds using genomic simulation approaches remains limited, representing a significant knowledge gap in optimizing breeding strategies for this important genetic resource. This study addresses the critical need for systematic evaluation of heterosis effects in crosses between Jharkhand native chickens and three major commercial breeds (White Leghorn, Rhode Island Red, and Cornish) using advanced genomic simulation methodologies.

MATERIAL AND METHODS

Breed-specific Parameters

Breed-specific parameters were established based on an extensive literature review and field performance data from Indian poultry production systems. The Jharkhand native chicken parameters were based on performance records from indigenous breeding programs, with a mature body weight of 1520 ± 30g and annual egg production of 45 ± 0.61 eggs (Agarawal *et al*., 2022). White Leghorn parameters reflected commercial layer performance with high egg production capacity (300 ± 30 eggs/72wk) and moderate body weight (1497g ± 150) (Chatterjee & Rajkumar, 2015). Rhode Island Red characteristics were set for dual-purpose performance with 2000g ± 180 body weight and 240 ± 25 eggs/72wk annually, representing balanced meat and egg production traits (Annual Report, 2019). Cornish breed parameters emphasized meat production characteristics with the highest body weight (3629g ± 250) but lower egg production (160 ± 30 eggs/72wk), reflecting their specialization for broiler parent stock (https://livestockconservancy.org/cornish-chicken/).

Genomic Architecture Simulation

The simulation incorporated 1000 SNP markers per individual, distributed across the genome to capture major quantitative trait loci (QTL) effects for egg production and body weight. Genomic values were calculated using additive genetic effects, where each SNP contributed to the overall breeding value through allelic substitution effects. The genetic effects were breed-specific, with different allele frequency distributions reflecting breed-specific selection histories. Additive genetic variance components were partitioned according to trait heritabilities: egg production (h^2 = 0.25), body weight (h^2 = 0.35), and feed conversion ratio (h^2 = 0.30) (Wolc *et al*., 2011).

Crossbreeding Simulation Protocol

Crossbreeding simulations followed Mendelian inheritance principles, with each F_1 offspring receiving one randomly selected allele from each parent at every locus. Mating systems were designed as terminal crossbreeding programs, with Jharkhand native chickens as the dam line crossed with commercial sire lines (White Leghorn, Rhode Island Red, and Cornish). Parent selection was implemented using selection index methodology, combining standardized breeding values for egg production (weight = 0.4) and body weight (weight = 0.3). Selection intensity was set at 15% of the population, representing practical breeding program parameters for small-scale operations.

Heterosis Estimation Methodology

Heterosis effects were estimated using the standard formula: Heterosis (%) = [(F_1 performance - Mid-parent value) / Mid-parent value] × 100, where mid-parent value represents the average performance of the two parental breeds. This approach has been extensively validated in poultry crossbreeding studies and provides direct estimates of hybrid vigor expression. Heterosis coefficients were established based on literature meta-analysis of indigenous × commercial crossbreeding studies. Research has demonstrated significant heterosis effects in crosses between local and commercial chicken strains, particularly for production traits. The heterosis values implemented were: Jharkhand × White Leghorn (12% egg production, 8% body weight), Jharkhand × Rhode Island Red (15% egg production, 18% body weight), and Jharkhand × Cornish (5% egg production, 25% body weight).

Statistical Analysis

Population simulation involved 300 individuals per pure breed (1,200 total) and 250 F_1 crossbred offspring per cross combination (750 total). This sample size provided adequate statistical power for detecting significant heterosis effects while maintaining computational efficiency. The ChromaX (Younis *et al*., 2023) library was used for simulation purposes. All analyses were conducted using Python 3.8 with NumPy, Pandas, and Scikit-learn libraries for data manipulation and statistical modeling.

RESULTS AND DISCUSSION

The genomic simulation successfully generated distinct purebred populations and their F_1 crosses, allowing for a detailed analysis of performance traits and the expression of heterosis. The findings provide valuable insights into optimal breeding strategies for improving poultry production by leveraging the genetic diversity of Jharkhand native chickens.

Simulated Pure Breed Performance and Genetic Variation

The simulation realistically captured the documented performance characteristics of each breed, confirming the model's validity. As expected from their selection history for commercial egg production, White Leghorns demonstrated superior laying performance (303.5 ± 85.7 eggs) with a moderate body weight of 1953 ± 258g (Chatterjee and Rajkumar, 2015). In contrast, the Cornish breed, selected for meat, exhibited the highest body weight (3999 ± 656g) but the lowest egg production (109.8 ± 32.4 eggs), consistent with its role as a broiler parent stock. The Rhode Island Red breed displayed a balanced, dual-purpose profile with substantial body weight (1833 ± 455g) and moderate egg production (213.9 ± 69.2 eggs), aligning with its common use in systems where both meat and eggs are valued (Annual Report, 2019).

The Jharkhand native chickens, known for their resilience and adaptability to local tropical conditions, showed characteristic indigenous traits with low egg production (51.8 ± 12.5 eggs) and moderate body weight (2223 ± 92g). These simulated values are in line with performance records from indigenous breeding programs (Agarawal *et al*., 2022; Kamal *et al*., 2024). The significant standard deviations observed in production traits across all simulated breeds underscore the substantial genetic variation present within each population. This inherent variation is a critical resource, providing the raw material for genetic improvement through both within-breed selection and, as demonstrated, crossbreeding programs (Wolc*et al*., 2011).

Heterosis and Performance in F_1 Crosses

All three crossbreeding combinations resulted in positive heterosis for both egg production and body weight (Table 1), confirming the well-documented principle that crossing genetically distant lines can unlock significant hybrid vigor. This highlights the potential of systematic crossbreeding to enhance the productivity of indigenous poultry systems.

Table 1: Comparison of mid-parent values and F1 production of egg production and body weight in different crosses

Cross	Mid-parent egg production (eggs)	F1 simulated egg production (eggs)	Mid-parent body weight (g)	F1 simulated body weight (g)
Jharkhand Native x White Leghorn	183.7	203.4	2083	2252
Jharkhand Native x Rhode Island Red	133.9	153.9	2036	2406
Jharkhand Native x Cornish	80.6	82.6	3088	3449

Jharkhand × White Leghorn cross

This cross yielded significant heterosis for egg production (10.7%) and a moderate effect for body weight (7.4%). The resulting F_1 generation achieved an average performance of 203.4 eggs and a 2252g body weight, substantially outperforming the mid-parent average of 183.7 eggs and 2083g. This outcome exemplifies effective breed complementarity, where the high production capacity of the White Leghorn is successfully combined with the adaptive traits of the Jharkhand native breed. The strong positive heterosis suggests excellent combining ability and aligns with previous research demonstrating that crossing local and commercial layer strains is a highly effective strategy for improving egg-related traits.

Jharkhand × Rhode Island Red cross

The cross with the dual-purpose Rhode Island Red exhibited the highest heterosis for both egg production (14.9%) and body weight (18.2%). The F_1 offspring produced 153.9 eggs and weighed 2406g, far exceeding the mid-parent expectation of 133.9 eggs and 2036g. This exceptional combining ability is consistent with studies showing that crossing indigenous lines with balanced, dual-purpose breeds often yields the most significant and well-rounded hybrid vigor. The balanced genetic background of the Rhode Island Red appears to complement the Jharkhand native traits more effectively than highly specialized breeds, making this cross an excellent candidate for farmers seeking simultaneous improvements in both egg and meat output.

Jharkhand × Cornish cross

As anticipated, this cross produced the most pronounced heterosis for body weight (11.7%) but the lowest for egg production (2.5%). The F_1 offspring reached an impressive average weight of 3449g, a significant increase over the 3088g mid-parent value. Egg production remained minimal (82.6 eggs), showing only a slight improvement over the expected 80.6 eggs. This result clearly demonstrates that while heterosis can enhance performance, its expression is ultimately constrained by the genetic potential of the parent breeds; the poor laying ability of the Cornish parent limits the potential for improvement in the F_1 generation. Nonetheless, the exceptional growth makes this cross highly suitable for specialized meat production systems, a finding supported by studies on crossing indigenous chickens with terminal broiler sires.

CONCLUSION

The simulation results offered clear, data-driven recommendations for breeding programs tailored to specific production goals. For farmers prioritizing egg numbers, the Jharkhand × White Leghorn cross is optimal. For those operating dual-purpose systems, the Jharkhand × Rhode Island Red cross provides the best-balanced improvement. Where meat production is the primary objective, the Jharkhand × Cornish cross is the superior choice. These findings highlight the critical importance of conserving indigenous genetic resources like the Jharkhand native chicken. However, the study's limitations must be acknowledged. The heterosis coefficients were derived from a literature meta-analysis and not from empirical crosses involving the specific Jharkhand strain. Future research should prioritize controlled crossbreeding experiments to validate these simulated predictions. Furthermore, investigating advanced strategies like developing synthetic lines or back crossing would provide crucial insights into sustaining hybrid vigor over multiple generations. Integrating economic analyses and evaluating genotype-by-environment interactions across different regions would further refine these recommendations for practical, on-farm adoption.

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