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EVALUATION OF GENETIC INTERVENTIONS AND ECOLOGICAL MANAGEMENT ON GROWTH EFFICIENCY AND MORPHOGENETIC TRAITS IN INDIGENOUS AND EXOTIC CHICKEN GENOTYPES

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Abstract

The genetic selection for balancing feed efficiency, environmental resilience, and ecological management systems (Intensive vs. Free Range) under South Asian environmental conditions in sustainable rural poultry production is most important. A multi-breed assessment across Rhode Island Red (RIR), White Leghorn (WLH), Fayoumi (FO), Desi Normal (DN), and Desi Dwarf (DD) established that introducing dwarf inheritance significantly reduces feed intake by up to 16.8% without diminishing overall weight gain or survival fitness. Concurrently, phenotypic mapping of Desi and Fayoumi lineages shows that Intensive Management Conditions (IMC) unlock superior linear morphology (e.g., maximal body heights of 43.4 ± 3.2 cm in Desi males) compared to harsher Free Range Conditions (FRC). Blending gene-based size reduction with systematic housing upgrades can optimize lean poultry production, lower flock maintenance costs, and conserve robust native genes. Hence, these analyses support a predominantly oligogenic control of environmental adaptations and possible regulation by one or a few genetic elements only. Our study shows that the pre-identification of the key environmental drivers of adaptation, followed by a detailed genomic investigation of the associated genetic mechanisms, provides a powerful new approach for elucidating the effect of natural selection in domestic animals. These results represent new landmarks for informing sustainable improvements in poultry breeding.

Keywords: *Exotic gene, Growth efficiency, Morphological behavior, Poultry improvement*

INTRODUCTION

The conservation and genetic improvement of indigenous poultry stocks are core priorities for safeguarding biodiversity and expanding meat security in rural sectors. Native chickens like the "Desi" breed exhibit high adaptability to fluctuating environments and deliver high-quality products. However, their growth rates are traditionally slow, and their production parameters are poorly standardized. Crossbreeding indigenous stocks with high-yielding exotic breeds such as Rhode Island Red (RIR), White Leghorn (WLH), and Fayoumi (FO) serves as a baseline strategy to amplify commercial vitality.

The investigation of nutrition-consumption dynamics and morphological adaptability should be combined in order to maximize economic performance. In terms of biochemistry, feed is the largest expense in poultry production. The discovery of an autosomal recessive dwarf gene (adw) in Desi chickens provides a way of limiting the maintenance of adult chickens by reducing the size of the overall scaling of the chicken and the length of its shanks. At the same time, the expression of genes is dynamically controlled by environmental factors such as temperature, space and nutrients. A comparison of these parameters for both Intensive Management Conditions (IMC) and Free Range Conditions (FRC) provides a comprehensive picture on the interactions between genetic traits and different rearing conditions. Similarly, plumage color has been associated with a variety of adaptive functions, including temperature regulation, camouflage, and mate choice (1). Bright feather coloration has been linked with better fertility and indicates semen characteristics that influence fertility (2). It has also been suggested that naked-neck chickens have greater body weight in the hot season due to genes that cause a reduction in the number of feathers in their neck region. This could result in increased growth and productivity (3, 4). However, naked-neck cocks have

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complained of lower packed sperm volume, lower sperm motility, and higher abnormal sperm counts, and higher coiled tail defects. On the other hand, the weights of the egg, yolk, albumen, and eggshell were significantly greater in the non-feathered shank hens compared to the shank-feathered hens (5).

Due to natural and artificial selection, mutation, and genetic drift, indigenous chickens have been said to be highly adaptable to the prevailing ecological conditions in the country (6). As a result, different ecotypes of indigenous chickens with distinguishable morphometric characteristics have been reported (7). In Kenya, these ecotypes derive their names from their geographical locations. As listed by studies on genetic diversity using microsatellite markers (8). Pakistani indigenous chickens were classified into 10 distinct ecotypes. Using MHC- linked markers indigenous poultry were classified into three clusters consisting of birds from different ecotypes (9). The wide genetic diversity exhibited by indigenous chicken represents a rich genetic resource for the exploitation of potential hybrid vigor for improved productivity in Pakistan. To enhance the productivity of indigenous poultry, improved crossbreeds from various indigenous chicken ecotypes were developed by the defunct Pakistan Agricultural Research Institute (PARI) Four improved indigenous chicken breeds namely Desi, Australop, Fayoumi, and Aseel are accessible to farmers. The improved indigenous chicken breeds are largely dual-purpose with the capacity of producing more eggs and meat compared to the pure-line indigenous chicken (10). Due to their higher growth rate as well as their adaptive capacity, the rearing of improved indigenous chicken has been shown to be more profitable compared to typical indigenous chicken (11).

MATERIALS AND METHODS

SAMPLE DESIGN

A partial dialer crossing program was executed utilizing RIR, WLH, FO, DN, and DD parent lines. This design produced 709 chicks distributed across eight genetic combinations: RIR (*n=75*), WLH (*n=130*), FO (*n=100*), DN (*n=70*), DD (*n=66*), RIR × DD (*n=80*), WLH × DD (*n=80*), and FO × DD (*n=108*). Chicks were individually weighed, wing-banded, and brooded under strict microclimate management (starting at 35°C during week one, decreasing 3°C weekly) up to 4 weeks. Feed was provided *ad libitum* across developmental periods: a starter diet (20% Crude Protein [CP], 2798 Kcal/kg ME) up to 6 weeks, followed by a grower diet (16.7% CP, 2700 Kcal/kg ME). Performance evaluations spanned 18 weeks. At 19 weeks of age, crossbred offspring were phenotypically separated into distinct normal and dwarf clusters based on automated shank metrics.

- **The ecological context and phenotype:** The environmental influences were investigated by comparing the performance of flocks of pure and F_1 crossbred Desi and Fayoumi lines in two different ecological backgrounds based on a 90-day phase.
- **Intensive Management Conditions (IMC):** Birds were segregated by genotype into standard modern wire cages and fed strictly controlled feeds as specified in the NRC and ISA and were thoroughly vaccinated.
- **Free Range Conditions (FRC):** flocks were let free in domesticated habitats created in rural environments, and a mating allocation of 3:1 (females: male) was maintained. For this group, standard commercial rations and veterinary vaccinations were not provided at all, and this is to see what baseline environmental pressure is.

Technical machines for measuring the textile properties were used to measure quantitative linear properties. The total body height was taken from the digital edge to the tip of the skull; the length of the shank was from the hock joint to the digital edge; the beak length was from the basal edge to the tip of the beak; and the wingspan was taken from the humeral junction to the end of the spinal extremity.

STATISTICAL ANALYSIS

Growth performance data were analyzed by completely randomized design. Analysis of variance (ANOVA) was done by using the software packages MSTAT-C and separation of means was calculated by Duncan's New Multiple Range Test (DMRT). Linear morphometric were logged as mean values accompanied by standard deviation (± SD) parameters.

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RESULTS AND DISCUSSION

Initial day-old body mass was significantly affected by genetic configuration (*p<0.05*). Pure exotic breeds achieved the highest mass (RIR: 36.1g, WLH: 34.5g, FO: 34.0g), while pure Desi Dwarf chicks showed the lowest initial weight (27.5g). Introduction of the DD sire line into exotic dam lines caused explicit drops in day-old chick weight: RIR crossed with DD fell by 7.0%, WLH by 8.7%, and FO by 15.3%. Pure DD chicks displayed a 9.2% reduction in initial weight relative to Desi Normal. However, as the birds matured toward weeks 4 and 18, absolute live body-weight differences between the genotypes narrowed significantly, with daily weight gains stabilizing across all groups (*p>0.05*) (Table I).

Table I. Growth performance, feed intake, and feed conversion ratio (0–18 Weeks)

Parameters	Age	RIR	WLH	FO	DN	DD	RIR×DD	WLH×DD	FO×DD	Sig.
Day-old weight (g/bird)	0	36.1	34.5	34.0	30.3	27.5	33.7	31.5	28.8	*p<0.05*
Daily weight gain (g/bird)	0–4	1.9	1.8	1.9	1.5	2.5	2.0	2.3	1.8	NS
	5–18	11.0	9.9	9.7	8.7	6.8	10.7	9.0	7.8	NS
	0–18	8.8	8.1	8.0	7.3	5.6	8.8	7.5	6.5	NS
Daily feed intake (g/bird)	0–4	11.5	10.5	10.7	8.7	7.7	8.15	8.6	7.8	*p<0.05*
	5–18	39.28	30.3	37.9	34.0	28.4	36.6	34.7	31.7	*p<0.05*
	0–18	33.1	32.1	31.84	28.3	23.8	30.36	28.9	26.5	*p<0.05*
Feed conversion ratio (FCR)	0–4	6.4	6.0	5.7	5.5	3.6	4.1	3.8	4.3	NS
	5–18	3.6	3.9	3.9	3.9	4.2	3.5	3.9	4.1	NS
	0–18	3.8	4.0	4.0	3.9	4.4	3.5	3.9	4.1	NS
Mortality (%)	0–18	25.0	20.8	25.9	15.2	16.7	13.6	14.1	21.8	NS

*Note: RIR = Rhode Island Red; WLH = White Leghorn; FO = Fayoumi; DN = Desi Normal; DD = Desi Dwarf; NS = Non-Significant (*p>0.05*)

The autosomal dwarf gene (*adw*) exerted a strong regulatory effect on feed consumption throughout the 18-week study (*P<0.05*). Dwarf-inherited crossbreds consistently consumed less feed. During the early brooding phase (0–4 weeks), RIR, WLH, and FO dwarf-crossed chicks consumed 29.6%, 18.2%, and 27.2% less daily feed than their pure exotic counterparts. For the full growth period (0– 18 weeks), dwarf-crosses maintained lower consumption rates: RIR × DD ate 8.3% less, WLH × DD ate 10.0% less, and FO × DD ate 16.8% l less than their corresponding pure breeds.

Pure Desi Dwarf chickens consumed 16.0% less feed over 18 weeks compared to Desi Normal (23.8 g/bird/day vs. 28.3 g/bird/day). Because daily weight gains did not drop significantly alongside this reduction in feed intake, the Feed Conversion Ratio (FCR) remained stable across all groups (*P>0.05*), with RIR × DD showing a highly efficient FCR of 3.5. Total mortality rates showed no significant variation between genotypes (*P>0.05*), proving that dwarf-gene modifications do not reduce biological viability or survival fitness.

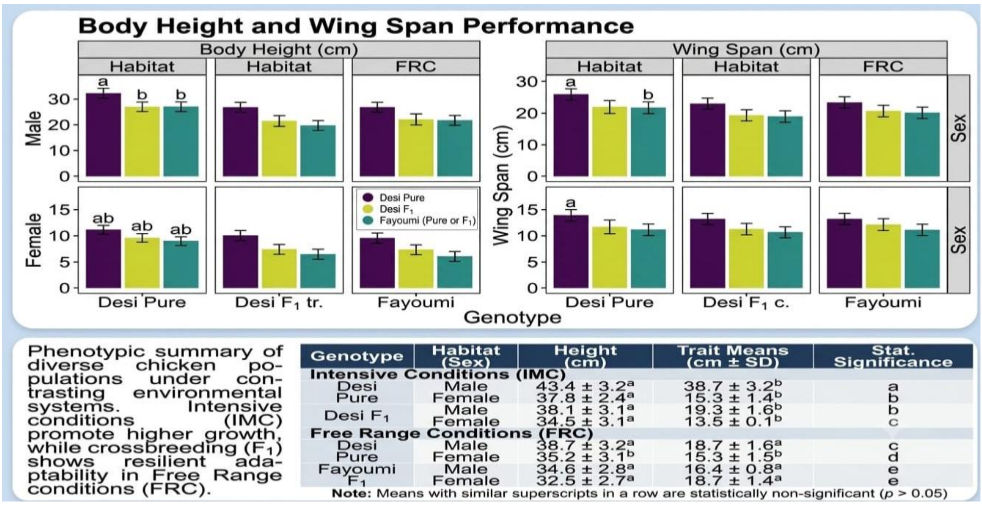

Fig. 1. Phenotype summary of diverse chicken population with various traits

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Environmental Influence (G × E Interaction): The body height of almost all the genotypes has a definite decreasing trend from "Desi Pure" to "FRC" environment. This means the "Desi Pure" habitat is probably the best in terms of maximizing physical growth (height), while the "FRC" habitat is a more limiting habitat. The highest dark blue line is the Cross (probably males). The mean value of its body height is the highest and most consistent in all habitats ranging from 43.4 cm to 38.3 cm. This is a heterosis (hybrid vigor) in which the crossbred offspring are superior to both the two purebred parents. The Fayoumi (brown line) on the average has a slightly higher body height than the Desi (yellow line) in most habitats; however, the difference is not significant in the FRC environment (34.2 cm vs. 32.4 cm). The lower groups of lines (purple and light teal lines – from about 27cm to 34cm) are females. These are much smaller than males, and show the same habitat-specific decline (Fig. 1).

Table II. Linear body sizes of Desi and Fayoumi breeds under diverse ecological conditions

Habitat & genotype	Sex	Body height (cm)	Neck length (cm)	Shank length (cm)	Beak length (cm)	Wing span (cm)
Intensive Management Conditions (IMC)						
Desi Pure	Male	43.4 ± 3.2	20.4 ± 1.9	12.5 ± 0.82	3.6 ± 0.21	23.7 ± 1.6
	Female	37.8 ± 2.4	15.3 ± 1.4	10.3 ± 0.68	3.2 ± 0.17	20.3 ± 1.4
Desi F_1 Cross	Male	38.1 ± 3.4	19.3 ± 1.6	10.2 ± 0.87	3.3 ± 0.21	21.3 ± 1.9
	Female	34.5 ± 3.1	13.5 ± 1.4	8.7 ± 0.65	3.2 ± 0.18	18.4 ± 1.6
Fayoumi Pure	Male	33.7 ± 3.2	16.5 ± 1.4	8.3 ± 0.72	2.7 ± 0.16	18.3 ± 1.5
	Female	32.4 ± 2.8	15.2 ± 1.4	7.8 ± 0.64	2.4 ± 0.16	17.4 ± 1.6
Fayoumi F_1 Cross	Male	34.2 ± 2.8	17.4 ± 1.6	8.6 ± 0.72	2.9 ± 0.17	19.4 ± 1.7
	Female	33.7 ± 2.7	16.7 ± 1.4	8.3 ± 0.75	2.8 ± 0.18	18.7 ± 1.6
Free Range Conditions (FRC)						
Desi Pure	Male	38.7 ± 3.2	18.7 ± 1.6	10.3 ± 0.97	3.3 ± 0.24	20.4 ± 1.5
	Female	35.2 ± 3.1	15.3 ± 1.2	8.7 ± 0.92	3.1 ± 0.25	19.7 ± 1.07
Desi F_1 Cross	Male	38.5 ± 3.3	18.2 ± 1.5	10.2 ± 0.94	3.2 ± 0.23	20.2 ± 1.6
	Female	35.4 ± 3.1	15.3 ± 1.3	8.6 ± 0.87	3.1 ± 0.21	19.6 ± 1.5
Fayoumi Pure	Male	34.6 ± 3.1	16.4 ± 1.3	7.4 ± 0.94	2.7 ± 0.18	18.5 ± 1.4
	Female	32.5 ± 2.8	12.7 ± 1.2	9.2 ± 0.82	2.4 ± 0.18	18.7 ± 1.4
Fayoumi F_1 Cross	Male	36.1 ± 3.1	17.8 ± 1.4	9.8 ± 0.83	2.8 ± 0.16	19.3 ± 1.5
	Female	35.4 ± 2.9	13.2 ± 1.2	9.5 ± 0.87	2.3 ± 0.16	18.7 ± 1.3

Both Desi and Fayoumi lines were greatly influenced by environmental conditions during physical development. All intensive housing (IMC) had larger physical growth and body parts than free range housing.

There was a significant increase in the overall dimensions of the pure desi male reared under IMC with 43.4 ± 3.2 cm body height, 20.4 ± 1.9 cm neck length and 12.5 ± 0.82 cm shank lengths. The body height of pure Desi males under free range condition (FRC) was smaller, 38.7 ± 3.2 cm compared to 41.2 ± 3.2 cm in crossbreds. Shank length of Desi males under FRC was 10.3 ± 0.97 cm while it was 10.8 ± 0.95 cm in crossbred.

The Desi birds exceeded the exotic Fayoumi lines in all aspects under both environments; the latter were still smaller than the Desi birds. The height of the Pure Fayoumi males recorded under IMC was 33.7 ± 3.2 cm while the recorded shank length was 8.3 ± 0.72 cm, and under FRC, their body height was adjusted to 34.6 ± 3.1 cm and the shank length was decreased to 7.4 ± 0.94 cm (Table II).

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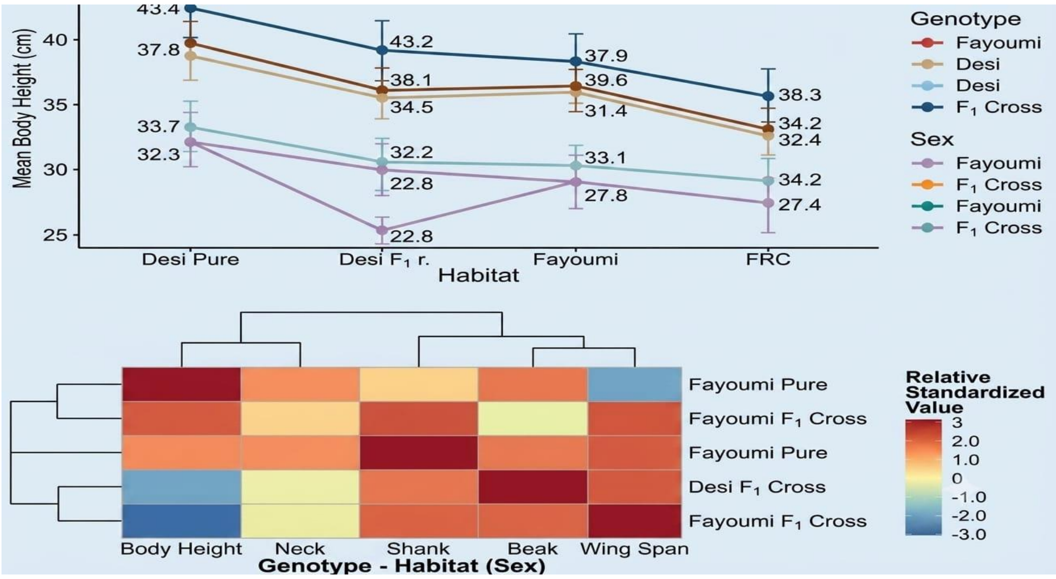

Fig. 2. Highlights genotype-environment interaction between different traits

In both studies, sexual dimorphism was striking; in every single case in both studies, the body dimensions of males developed more elongated and larger than those of females, in the same genetic group exposed to the same environment. As expected in F_1 generations, the body metrics of the crossings were meshed. This medium growth is the result of blending exotic linear traits with the native structural frame of local birds, with this growth being the medium between the two extremes (Fig. 2).

The physical development of chicken lines is closely related with genetics, gender and environmental factors. Body height (mean) decreases across all habitats from "Desi Pure" to "FRC" but the sexual dimorphism is very strong and always males are taller than females. The line graph clearly shows the phenomenon of hybrid vigor (heterosis): the male Cross shows the highest overall body height in all environments. The heat map suggests however that crossbreeding has an effect of changing overall body proportions as pure breed Fayoumi lines had a tall, upright body with short wings while crosses tended to be of shorter body height with much longer wings, beaks and shanks (Fig. 3).

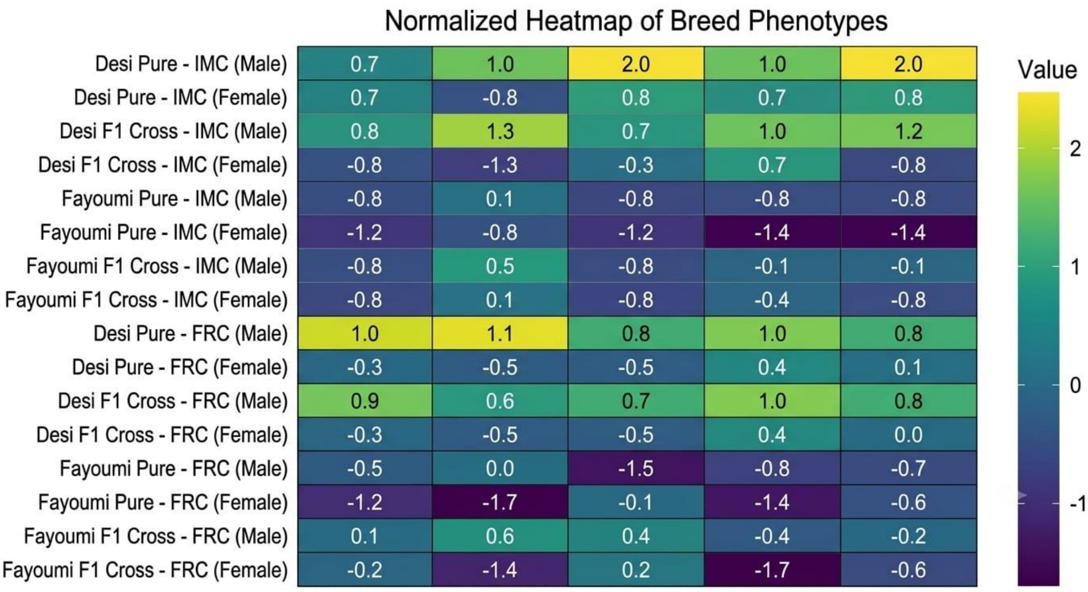

Fig. 3. Represents statistical heat map of breed phenotype

Here, the different breed phenotypes are compared to one another for several combinations of genotype, habitat (IMC vs. FRC), and sex, with brighter yellow denoting significantly higher trait values and dark purple denoting significantly lower trait values (12). The most remarkable result is the consistently high positive phenotypic values for all measured traits in the case of Desi Pure IMC (Male), which indicates that this group is the most physically vigorous under the environmental conditions measured. Strong sexual dimorphism was observed, especially within the Fayoumi breed as groups of females scored very low

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sometimes as low as -1.7 (Female) and Fayoumi Pure - FRC (Female) in particular. Secondly, the data indicated that the IMC environment generally produced more extreme (highly positive and highly negative) phenotypic values than the FRC environment, which tends to moderate the value of the phenotypic extremes and thus produce more moderate to intermediate values, both within the purebreds and the F1crosses.

The findings of this study affirm the significant potential of integrating the autosomal dwarf gene (*adw*) from indigenous Desi lines into exotic germplasm to enhance feed efficiency without compromising growth or viability. This aligns with recent research on sex-linked dwarf genes, which have been shown to improve feed conversion ratio (FCR) in layer-type chickens (13). The observed stability in FCR and weight gain despite reduced feed intake is a critical economic advantage, echoing studies that report improved feed efficiency in dwarf crossbreds (14). Furthermore, the clear demonstration of genotype-environment interaction (G×E), where intensive management (IMC) promoted superior linear growth over free-range conditions (FRC), underscores the necessity of considering environmental context in breeding strategies. This interaction is a well-documented phenomenon in poultry science, with significant implications for optimizing performance in diverse production systems (15). The heterosis observed in crossbreds, particularly in male body height, further validates crossbreeding as a tool for enhancing adaptive traits and productivity.

The strategic use of the *adw* gene, combined with improved management, presents a sustainable pathway for poultry production in South Asia. By reducing feed costs—a major input in poultry farming—this genetic intervention directly addresses economic and environmental sustainability. Recent studies continue to explore the integration of molecular markers, such as the growth hormone (GH) gene, with quantitative traits to accelerate genetic improvement in crossbred chickens (16, 17). Such approaches could further refine the efficiency of breeding programs that utilize the *adw* gene and other adaptive traits. The conservation and utilization of indigenous genetic resources, like the Desi Dwarf, are not only vital for maintaining biodiversity but also offer practical solutions for developing resilient and cost-effective production systems tailored to local environmental challenges (18).

CONCLUSION

To optimize sustainable poultry production in South Asia, genetic selection and strategic environmental management are crucial. Use of the autosomal recessive dwarf gene (adw) available in native Bangladeshi Desi lines in indigenous/exotic crossbreeding will be a useful method to increase the efficiency of production. This genetic manipulation is able to significantly reduce overall daily feed consumption by up to 16.8% as well as metabolic maintenance in adulthood. Most importantly, this decrease in feed intake doesn't affect absolute live weight gain, feed conversion ratio or biological survival viability, so it's a highly economical trait in lean poultry production. At the same time, the research sheds light on the role of rearing conditions in the regulation of the morphological potential and structural frames of these lineages. Controlled Intensive Management Conditions (IMC) promotes superior linear growth and larger body dimensions in all genotypes when compared to more challenging Free Range Conditions (FRC), which has a built-in limitation and compression of phenotype. Purebred lines are very sensitive to environmental deterioration, but strategic crossbreeding (F1) produces a potent hybrid vigor effect on total height in males and a shift in antero-posterior proportions to longer wings and beaks. Finally, the (adw) dwarf gene selection coupled with improved, high-density rearing systems can offer a practical, synergistic route to reduce the cost of keeping the structures, increase the plant growth, and protect the native resilient genetic resources.

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Conflict of interest:

Authors declared no conflict of interest.

Authors' contribution:

SAJ Laboratory experiments, data collection, statistical analysis, tables and figure, data interpretation and manuscript writing; SG Conceptualization, study design and methodology, lab experiment, follow-up assessment; MAJ Data curation and formal analysis.

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