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Housing systems and their impact on egg quality and hatchability in Rhode Island red hens

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ABSTRACT

The present study compared the impact of three housing systems-individual cage, colony cage, and deep litter-on the performance and welfare of Rhode Island Red hens under tropical Indian conditions. The objective was to compare growth, egg production, egg quality, and reproductive traits, highlighting trade-offs between productivity and welfare. Results revealed that housing significantly influenced the outcomes. Hens in individual cages had superior body weight, egg production, and internal egg quality traits such as shell integrity and albumen characteristics. Yolk color was stronger in deep litter, reflecting carotenoid intake from foraging. External traits like egg size and shape were largely unaffected. Reproductive performance varied: individual cage achieved higher fertility and hatchability, while deep litter reduced embryonic mortality and supported natural behaviors. Colony cage showed intermediate results. The findings suggested that cages maximize productivity, but deep litter provided welfare and reproductive advantages, making it a sustainable alternative for dual-purpose poultry under tropical conditions. Integrating welfare with production is essential for resilient and ethical poultry systems.

Key words: Egg production, Egg quality, Embryonic mortality, Fertility, Hatchability, Housing system, Poultry, Rhode Island Red hens

The intensification of poultry production is vital for meeting global protein demand but raises concerns over the trade-off between efficiency and welfare. Housing systems are central to this debate, shaping bird health, behaviour, and productivity (El-Deek and El-Sabrout, 2019). Conventional cages offer high productivity and hygiene but restrict natural behaviours, driving shifts towards colony cages and deep litter systems (Bist *et al.* 2024). Yet, their performance varies widely with genotype, nutrition, and management (Jeon *et al.* 2025). Growth and body weight serve as indicators of general health, while egg quality traits-shell strength, albumen height, yolk colour, and Haugh unit-determine consumer acceptance, marketability, and food safety (Javed *et al.* 2025). Housing also alters biochemical egg traits, with differences in cholesterol and fatty acid profiles reported (Islam *et al.* 2024), though outcomes are inconsistent across studies (Manzoor *et al.* 2025). Existing research has largely focused on commercial hybrids, leaving dual-purpose breeds underexplored. The Rhode Island Red (RIR),is valued for resilience and adaptability, and is particularly relevant in tropical smallholder and semi-commercial systems, where climatic stress and infrastructural limitations are pronounced. Identifying housing systems that balances productivity, welfare, and resilience is, thus, critical for sustainable development. Beyond production metrics, housing also influences egg integrity and composition (Damaziak *et al.* 2021) and may affect reproductive outcomes such as fertility and embryonic development-areas have been insufficiently studied in dual-purpose breeds. This study, therefore, provided a comparative evaluation of three dominant housing systems-individual cages, colony cages, and deep litter-for RIR under tropical conditions. The study assessed growth, egg production, egg quality, and reproductive performance (hatchability, embryonic mortality), aiming to generate evidence-based recommendations for sustainable, welfare-conscious, and economically viable poultry housing in resource-limited settings.

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MATERIALS AND METHODS

Animals experimental design and housing: The experiment was conducted at the Poultry Research and Training Centre, Bihar Animal Sciences University, Patna, following approval by the Institutional Animal Ethics

Committee (IAEC/BVC/21/14). A total of 120 16-week-old RIR pullets (initial average body weight 1.01 ± 0.01 kg) were randomly allocated to one of three housing systems (n=40 per system, with colony cage group housed as 8 units of 5 birds) until 40 weeks of age.
The systems were:

Individual cages: Conventional wire cages (60 × 32 × 53 cm; L×W×H), housing one bird per cage.

Colony Cages: Larger enriched cages (191 × 60 × 53 cm), each housing 5 birds and equipped with a perch, a dust-bathing area, and a nest box.

Deep litter: Floor pens (10×10 ft) with wood shavings litter over a lime-sprinkled concrete floor.

All birds were provided ad libitum access to water and a standard layer diet under a uniform lighting schedule (16h light:8h of darkness). The stocking density was maintained at 648 cm^2/bird in individual cages, 2292 cm^2/bird in colony cages, and 6 birds/m^2 in the deep litter system, aligning with common commercial practices.

Data collection: Growth and Production: Individual body weight was recorded fortnightly. Eggs were collected daily, and weekly production was categorized by laying location (nest vs. open).

Egg quality: At 40 weeks, 50 eggs per system (10 per day over 5 days) were analyzed. External quality (weight, shape index, shell thickness, cleanliness) and internal quality (albumen height, Haugh unit, yolk color/index) were measured using standard instruments (ORKA Digital Haugh Tester, Roche Yolk Color Fan, vernier calipers).

Reproductive performance: All intact eggs from a 3-day collection at peak lay were incubated (99.5–99.75°F, 60–65% RH). Fertility was assessed by candling on day 6. Hatchability was calculated on both total egg set (HATCH-TES) and fertile egg set (HATCH-FES) bases. Unhatched eggs were opened to determine the stage of embryonic mortality (early: ≤7 days, mid: 8-17 days, late: 18-21 days).

Statistical analysis: Data for body weight, egg production, and egg quality parameters were analyzed using a one-way ANOVA in SPSS (v20.0). Where ANOVA indicated significance ($p < 0.05$), means were separated using Tukey's HSD test. Percent data for fertility, hatchability, and mortality were analyzed using Chi-square tests. Data are presented as mean ± standard error of the mean (SEM).

RESULTS AND DISCUSSION

The present study demonstrated a clear trade-off between productivity and welfare in RIR hens, dictated by housing system. Individual cages maximized production metrics, while the deep litter system fostered natural behaviors and improved certain reproductive outcomes, with colony cages presenting a middle ground with distinct limitations.

Growth and production: Hens in individual cages consistently achieved higher final body weights (1.84 kg) as compared to those in colony cages (1.75 kg) and deep litter systems (1.58 kg) (Table 1). This aligns with the principle that reduced movement in cage systems lowers energy expenditure, diverting more resources towards growth and maintenance (Wan *et al.* 2021). This metabolic efficiency directly translated to superior egg

Table 1. Growth, production, and egg quality traits of Rhode Island Red (RIR) chickens under different housing system

Parameter	Deep Litter	Colony Cage	Individual Cage	F/χ^2 value	P-value
Body Weight (kg)					
20 wk	1.13 ± 0.02^a	1.26 ± 0.02^b	1.29 ± 0.02^c	–	<0.05
32 wk	1.44 ± 0.02^a	1.59 ± 0.03^b	1.67 ± 0.04^c	–	<0.05
40 wk	1.58 ± 0.02^a	1.75 ± 0.04^b	1.84 ± 0.04^c	–	<0.05
Weekly Egg Production (peak, 32–36 wk)	101–128 (70–83% in nest)	87–108 (63–74% in nest)	180–205 (100% open)	χ^2=9.62	0.047
Egg Weight (g)	49.06±1.43 (nest), 48.48 ± 0.28^a (open)	49.67±0.78 (nest), 49.55 ± 0.60^{ab} (open)	51.19 ± 0.81^b (open)	F=6.32	<0.05
Weekly Range (27–40 wk)	44.7–49.8	44.6–50.6	38.9–52.6	–	-
Egg Cleanliness (%)	88.6 clean, 11.2 dirty, 0.3 broken	96.4 clean, 3.5 dirty, 0.2 broken	98.3 clean, 0.6 dirty, 1.0 broken	χ^2=15.3	<0.01
		Internal & External Egg Quality			
Shell Thickness (mm)	0.31 ± 0.02^b	0.33 ± 0.01^a	0.35 ± 0.01^a	F=5.23	0.03
Yolk Height (mm)	16.8 ± 0.6^b	17.3 ± 0.4^{ab}	17.8 ± 0.5^a	F=4.11	0.05
Albumen Height (mm)	6.8 ± 0.6^b	7.3 ± 0.4^{ab}	7.5 ± 0.5^a	F=4.08	0.05
Haugh Unit	80.2 ± 2.3^b	83.5 ± 1.8^a	85.0 ± 2.0^a	F=6.89	0.01
Shell Weight (g)	7.0 ± 0.4^b	7.3 ± 0.3^a	7.5 ± 0.2^a	F=5.66	0.02
Albumin Index	8.48 ± 0.93^b	9.24 ± 0.23^{ab}	9.55 ± 0.17^a	F=12.3	0.001
Mortality (%)	12.5	5.0	2.5	χ^2=8.74	0.032

Superscripts (^{a},^{b},^{c}) indicate significant differences within rows (P<0.05).

production, with individual cages yielding the highest cumulative output (2017 eggs), followed by colony cages (1675 eggs) and deep litter systems (1774 eggs) (Table 1). The controlled environment of cages minimizes stress and disease exposure, supporting higher productivity (Shoji *et al.* 2025; Bist *et al.* 2024). Conversely, the increased activity in deep litter systems explains the lower body weight and numerically reduced egg output, reflecting the energetic cost of natural behaviors.

Behavioral expression vs. operational hygiene: A critical welfare finding was the strong nesting motivation exhibited in non-cage systems. In deep litter and colony cages, hens progressively utilized nest boxes, reaching peaks of 83% and 76% of eggs laid in nests, respectively (Table 1). This underscored a fundamental ethological need for secluded laying areas, as previously documented (Weeks *et al.* 2016). However, this behavioral freedom came at a cost to operational hygiene. The deep litter system produced the highest proportion of dirty eggs (11.16%), a direct consequence of contact with litter and manure (Table 5), supporting findings by Sokołowicz *et al.* (2018). Individual cages, devoid of nesting options but offering superior hygiene control, resulted in 98.31% clean eggs. While individual cages had a slightly higher breakage rate (1.04%), likely due to cage design and lack of cushioning (Pires *et al.* 2021), the overall cleanliness was superior. This highlights a direct conflict between allowing natural nesting behavior and maintaining optimal egg hygiene.

Egg quality: Housing system significantly influenced internal egg quality. Eggs from individual cages exhibited superior albumin height (7.5 mm) and Haugh units (85.0), which are key indicators of freshness and protein quality (Table 1). Shell quality (thickness and weight) was also and was enhanced in cages, consistent with reports by Kaleri *et al.* (2024) and He *et al.* (2022). This advantage might have stemmed from reduced physical exertion and more stable environmental conditions. In contrast, external egg weight was highest in individual cages (51.19g for open-laid eggs), though eggs laid in nest boxes within other systems were also heavier than those laid in open areas (Table 1). This suggests that a secure, designated laying area had positively influenced egg weight, regardless of the overarching system. Yolk color was deepest in the deep litter system (8.6), though statistically insignificant, a trend attributable to the intake of carotenoids from forage or litter, an opportunity which was absent in cage systems (Nemati *et al.* 2020). Other external traits like shape and size were largely unaffected, confirming that these are primarily governed by genetic factors rather than housing, as noted by Rakonjac *et al.* (2014).

Reproductive performance: The influence of housing on reproduction was pronounced. Individual cages recorded highest fertility (Fig. 1) and hatchability on both total (Fig. 2) and fertile egg sets (Fig. 3), benefiting from controlled mating and minimal social stress. Notably, the deep litter system, while being slightly lower in fertility, achieved embryonic mortality rates comparable to individual cages, but significantly lower than those in colony cages (Table 2). The elevated mid- and late-stage embryonic mortality in colony cages pointed to chronic stress factors, such as social competition and inadequate nesting space, which compromised embryo viability (Kakar *et al.* 2025). This aligned with studies showing improved hatchability in less intensive systems where stress is reduced (Sohail Ahmad *et al.* 2021, S. Ahmad *et al.* 2019). The deep litter system appeared to offer a balance, permitting natural mating behaviors while maintaining a less stressful environment than crowded colony cages, thereby supporting better embryonic development. This pattern of mortality, with higher losses in the mid and late stages, was consistent with the findings in other breeds (Kumar *et al.* 2013), underscoring the sensitivity of embryonic development to maternal environment.

The results presented a clear dichotomy: individual cages optimized measurable production and egg quality metrics, while deep litter systems better addressed animal welfare and behavioral needs, with a notable advantage in reducing embryonic mortality. Colony cages, intended as a compromise, demonstrated the worst reproductive outcomes, suggesting that they may create a high-stress environment without any welfare benefits of a litter system or the efficiency of individual cages. The inconsistency in findings across studies regarding traits like egg weight and internal quality (e.g., Yilmaz Dikmen *et al.* 2017 vs. Campbell *et al.* 2017) highlighted the significant interaction between genotype, nutrition, and management.

Table 2. Reproductive performance of Rhode Island Red (RIR) chickens under different housing systems

Parameter	Deep Litter	Colony Cage	Individual Cage	χ^2 Value	P-value
Egg Distribution (%)	68.8 nest, 31.2 open	67.8 nest, 32.2 open	100 open	10.21	0.041
Total Egg Production (Nos.)	1774	1675	2017	–	–
Embryonic Mortality (%)					
Early Stage	3.00 ± 0.85^{b}	5.75 ± 1.10^{a}	3.25 ± 0.90^{ab}	5.79	0.055
Mid Stage	2.25 ± 0.70^{b}	3.50 ± 0.80^{a}	2.00 ± 0.65^{b}	6.87	0.032
Late Stage	2.50 ± 0.65^{b}	4.25 ± 1.00^{a}	2.87 ± 0.75^{ab}	6.15	0.046
Hatchability & Fertility	Significantly reduced in CC due to higher mid- and late-stage mortality	Better in DL and IC	–	–	<0.05

TES: Total Eggs Set; FES: Fertile Eggs Set. Superscripts (^{a},^{b}) indicate significant differences among housing systems ($P<0.05$).

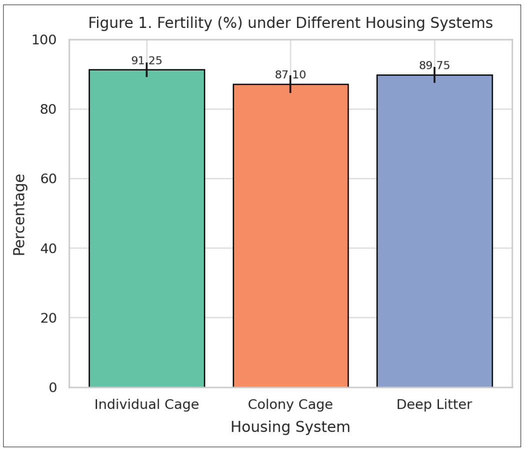

Fig. 1. Effect of different housing system on fertility (%) in the RIR birds

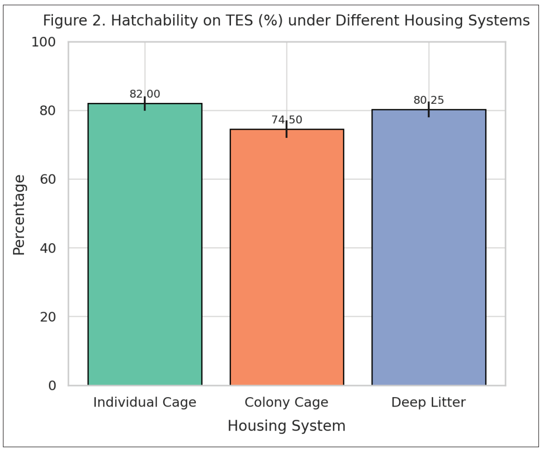

Fig. 2. Effect of different housing system on hatchability on total egg set (%) in the RIR birds

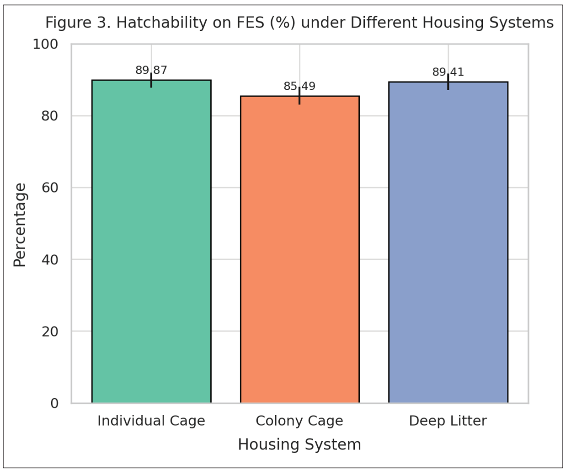

Fig. 3. Effect of different housing system on hatchability on fertile egg set (%) in the RIR birds

For dual-purpose poultry in tropical settings, the deep litter system emerges as a sustainable alternative that aligns with evolving welfare standards without drastically compromising productivity. The future lies in developing hybrid or enriched systems that intelligently integrate the efficiency of controlled environments with the ethical imperative of providing for the hens' behavioral needs.

The present study confirmed that housing systems substantially affect the productivity, welfare, and reproductive traits of Rhode Island Red hens, a key dual-purpose breed for sustainable smallholder poultry. Individual cages yielded higher reproductive efficiency, while deep litter systems enhanced natural behaviors, reduced embryonic mortality, and aligned better with welfare priorities. Colony cages performed moderately but carried inherent limitations. With global shifts toward cage-free, welfare-oriented poultry farming in regions such as India, deep litter and enriched systems emerge as viable, ethical options for tropical poultry production. Future research should focus on integrating behavioral analytics, climate-resilient housing designs, and hybrid systems that combine the efficiency of cages with the welfare advantages of litter-based housing to achieve optimal outcomes in changing production environments.

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