

IMPACT OF VARIOUS HOUSING SYSTEMS ON PRODUCTIVE PERFORMANCE, EGG QUALITY, AND HATCHING TRAITS IN NORMAL FEATHER, PARTIAL FEATHER, AND NAKED NECK CHICKEN GENOTYPES

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ABSTRACT

Present study evaluated the performance, egg quality, and hatching results of three chicken genotypes (full feather, partial feather, and Naked Neck) reared in three different housing systems (open sided, aviary, and backyard system) during the production period (26-48 weeks). A total of 405 birds (81 males & 324 females) were randomly distributed into 9 treatment groups, each replicated 3 times with 15 birds in each (3 males and 12 females) under randomized complete block design. Data were recorded regarding productive performance, egg geometry and quality characteristics, and hatching results. Partial feather chickens exhibited better ($p \leq 0.05$) productive performance, including body weight, egg weight, production percentage, egg number, and egg mass. Full feather birds were better ($p \leq 0.05$) in egg quality traits regarding egg weight, surface area, volume, yolk index, and shell pores number. Naked neck chicken had higher ($p \leq 0.05$) Haugh unit values and better ($p \leq 0.05$) egg shell breaking strength. Full feather and partial feather birds revealed better ($p \leq 0.05$) hatchability and fertility and had lower infertile eggs. Birds reared under aviary and open-sided houses were more ($p \leq 0.05$) heavier at week 48. The yolk index of open-sided reared bird's egg was better ($p \leq 0.05$). The hatchability and fertile eggs rate were better ($p \leq 0.05$) in backyard reared birds. It was concluded that partial-feathered chicken genotypes demonstrated superior productive performance, while full-feathered genotypes exhibited better egg quality traits. Both partial- and full-feathered chickens achieved favorable hatching results. Birds reared in open-sided houses showed higher body weights and yolk index values, whereas backyard birds exhibited superior hatching traits.

Key words: Chicken genotypes, Housing systems, Productive performance, Feathering, Hatchability.

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INTRODUCTION

In Pakistan, three indigenous poultry breeds are recognized: Desi (non-descriptive), Naked Neck, and Aseel. Additionally, farmers in rural areas also rear some exotic breeds and their crossbreeds (Sadef *et al.*, 2015). The Naked Neck (NN) chicken is a common breed of *Gallus gallus domesticus* characterized by its lack of feathers on the neck and vent. They are active foragers and productive birds, and their bare necks and reduced plumage are not a problem, especially in warm climates. It is commonly reared in Europe and Africa; however, its numbers are lower in America (Allonby and Wilson, 2019). The naked-neck trait in chickens is an incompletely dominant characteristic determined by the Na gene, and significant differences in feather quantity and distribution have been observed between homozygous (Na/Na; reduce feather mass 30 to 40%) and heterozygous individuals (Na/na; reduce feather mass 15

to 20%) (Deeb and Cahaner, 1999; Cai *et al.*, 2025). The NN chicken breed, due to its superior adaptability to the harsh environments of rural areas makes it a suitable choice to be developed as a dual-purpose (for both meat and egg production) (Ahmad *et al.*, 2021; Riaz *et al.*, 2024). In Pakistan, the Naked Neck chicken has an average egg production potential of 140 eggs over 52 weeks, with an average body weight of 1.1 kg for females and 1.5 kg for males (Shafiq *et al.*, 2018). Traditionally, dual purpose breeds are reared by the family household without any proper housing and nutritional management (Pal *et al.*, 2020).

In rural areas of Pakistan, backyard poultry production system is one of the most commonly adopted rearing system. Its contribution is about 20% to the total poultry production outputs (Shafiq *et al.*, 2018). The backyard poultry production system is usually defined as a system where most of the feed requirements of the bird are met by foraging and the birds usually have low

production. Mostly chicks are hatched by natural incubation, and reared without proper brooding arrangements (Singh *et al.*, 2021). To fully harness the genetic potential, provision of a suitable environment and proper management are essential (Menge *et al.*, 2005). Poultry farming in backyards is gaining popularity because of its potential in improving economics. Moreover, it can also provide a source of nutritious diet for the poor rural community. This farming system has higher adaptability as compared to other farming systems for the poor community because of financial return in a shorter time (Chakrabarti *et al.*, 2014). From the consumer point of view, poultry products obtained from the backyard poultry are usually healthier and more nutritious as compared to commercial poultry (Rehman *et al.*, 2016).

The practice of keeping backyard poultry is being followed by 80% of the rural families of Pakistan (Achakzai *et al.*, 2019). Conventional confined cages restrict the locomotor activities of birds, while the lack of natural habitat inhibits the expression of innate behaviors such as roosting and nesting (Dal Bosco *et al.*, 2014). To address the reduced expression of natural behaviors, conventional cages have been banned by the European Union, and alternative housing systems are increasingly gaining popularity. Alternative housing systems benefit birds by allowing the expression of natural behaviors and also enhance economical egg production (Ferguson, 2021). Higher expenditure associated with higher income and reduced prices of Animal-derived foods drawn the attention of the consumers regarding the management and housing conditions of animal farmed in intensive production systems. Intensification in poultry production system was swifter as compared to other livestock species (Bessei, 2018). Nest boxes, perches, and dust-bathing areas in furnished cages help retain the benefits of providing a more natural habitat for birds (Appleby, 1998). In developing countries like Pakistan, small scale and backyard type farming is still a source of rural household livelihood and women empowerment; however, it still demands better performing chickens and the selection of most suitable yet economical farming systems with low input and running costs. Literature on the performance of different Naked Neck chicken genotypes under aviary, open-sided houses, and backyard poultry farming systems is limited and needs further exploration. Therefore, this study focused on performance of three chicken genotypes (Naked Neck, full-feathered, and partial-feathered) reared in different housing systems (backyard, aviary, and open-sided) during the production period (26-48 weeks).

MATERIALS AND METHODS

The experiment was performed on three different chicken genotypes [full feather (FF) a crossbred

of Rhode Island Red × Naked Neck chickens, partial feather (PF) a heterozygous Naked Neck chicken, and a homozygous Naked Neck (NN) chicken; average male body weight 1784 ± 24 g and female body weight 1305 ± 17 g at week 26] reared in backyard, aviary, and open housing system during the production phase (26-48 weeks).

Experimental design: A total of 405 birds ($n = 81$ males & 324 females; 27 males and 108 females from each chicken genotype) were randomly distributed into 9 treatments with three replicates of 15 birds (3 males and 12 females) in each, according to the randomized complete block design. A 3×3 factorial arrangement of treatments (3 housing systems × 3 genotypes) was applied. Treatments consisted three chicken genotypes i.e., full feather, partial feather, and naked neck that were reared under three housing systems i.e., aviary, backyard, and open sided (Figure 1). Detailed description of different housing systems is provided in Table 1.

Experimental ration: The backyard housing system allowed the bird's access to range area and water during the day (08:00 AM to 05:00 PM), as adopted by Zahid *et al.* (2024). The breeder ration was formulated based on the guidelines of Leeson and Summers (2005), with 60% of it provided to the birds during the production phase. A 100 g serving of succulent fodder (seasonal legumes, beans, herbs, and shrubs) and a layer breeder ration (only 25% of the standard requirements) were provided to laying hens kept in the free-range system twice daily. The same 100 g of succulent fodder and a layer breeder ration (only 50% of the standard requirements) were provided to the birds housed in backyard system. The birds kept under open sided system were only offered layer breeder diet according to the Leeson and Summer (2005) without offering fodder. The backyard and free-range systems allowed birds access to range areas, where they could supplement their diet with natural forages, insects, and other available resources. In contrast, birds in the open-sided system were provided a formulated layer breeder diet without additional fodder. The feeding strategies in each system were designed to reflect real-world production practices.

Productive Performance: Eggs were collected daily; on a weekly basis, indicators of laying hen productivity, including egg weight, hen day egg production (HDEP), and egg mass, were evaluated. Egg weight was recorded using an electronic weighing balance with a precision of 0.01 g, while egg mass was calculated by adding the weight of all eggs collected from each replicate across different production systems. The HDEP was calculated on weekly basis using the following formula (Bell and Weaver, 1990):

$$\text{HDEP}(\%) = \frac{\text{Total number of eggs produced on a day}}{\text{Total number of hens present on that day}} \times 100$$

Egg Characteristics: At the end of the experiment (48 weeks of age), five eggs from each treatment were collected. A total of 45 eggs examined for egg quality parameters. Egg weight (EW) was recorded using an electronic weighing balance with a capacity to measure up to 0.1 g. The average egg mass was calculated using the following formula (Bell and Weaver, 1990):

$$\text{Average egg mass (g)} = \text{Production percentage} \times \text{Average egg weight (g)}$$

The egg length and width were measured using a Vernier caliper to calculate the egg surface area (ESA) and egg volume (EV). The ESA and EV were calculated (Sreenivasiah, 2006) following the formula:

$$\text{Egg surface area} = kW^{0.67}$$

$$\text{Whereas, } K = 4.588 \text{ and Egg volume} = \pi L W^2 / 6$$

where, $k = 0.929$, L = length of egg (cm), W = width of egg (cm).

The Haugh unit (HU) (Haugh, 1937) and yolk index (YI) (Sreenivasiah, 2006) were calculated using the following formulas:

$$\text{HU} = 100 \text{ Log} [(H+7.57) - (1.7) \times (W/0.37)]$$

$$H = \text{Albumen height (mm); } W = \text{egg weight (g)}$$

$$\text{YI} = \text{Yolk height (mm) / Yolk width (mm)} \times 100$$

The shell attributes including shell breaking strength, shell thickness, and shell pore number (SPN) were also recorded. Eggshell thickness (EST) was measured using a screw gauge after removing the eggshell membrane, while shell strength was determined using an egg force reader. The SPN was calculated using the following equation (Rahn and Paganelli, 1990):

$$\text{SPN (N)} = 304M^{0.767} \quad \text{where, } M = \text{egg weight (g)}$$

Hatching traits: To analyze hatching parameters, including hatchability, fertility, percentage of infertile eggs, and early and late embryonic mortality, eggs were placed in a Victoria Incubator at the Avian Research and Training Centre, UVAS, Ravi Campus, Pattoki, Pakistan. Standard incubation practices were followed and at the end of incubation parameters regarding hatchability, fertility, infertile eggs, and embryonic mortality were collected by using following formulas (Sreenivasiah, 2006):

$$\text{Hatchability (\%)} = \frac{\text{Number of chick hatch}}{\text{Number of eggs set}} \times 100$$

$$\text{Fertility (\%)} = \frac{\text{Number of fertile eggs}}{\text{Number of eggs set}} \times 100$$

$$\begin{aligned} \text{Embryonic mortality (\%)} \\ = \frac{\text{Number of dead embryos}}{\text{Number of fertile eggs}} \times 100 \end{aligned}$$

Statistical Analysis: The data on production performance, egg geometry and quality characteristics,

and hatching traits were analyzed using two-way ANOVA, considering housing systems and chicken genotypes as fixed effects, along with their interaction using SAS software (version 9.1). For the comparison of significant treatment means, Tukey's HSD test (Tukey, 1953) was applied considering significance level at $p \leq 0.05$.

RESULTS

Productive performance: Significant differences were observed in productive performance traits among three chicken genotypes reared under different production systems (Table 2, 3). Initial body weight (26 weeks) of male and female birds was similar with average weight of male and female was $1784 \pm 24\text{g}$ and $1305 \pm 17\text{g}$, respectively. At the end of trial (48 weeks), birds reared under open sided and aviary housing systems were heavier than backyard birds (1970.67 , 1969.67 vs. 1899.17g ; $p = 0.0027$); similar trend was observed in female birds (1647 , 1641 vs. 1526g ; $p = 0.0001$). Egg weight ($p = 0.2683$), egg production rate ($p = 0.1620$), egg number ($p = 0.1620$), egg mass ($p = 0.1755$), and livability ($p = 0.0840$) were similar across the production systems. Regarding genotypes, FF and PF were heavier at week 48 than NN chickens (1966.17 , 1956 vs. 1917.33g ; $p = 0.0374$); similar trend was observed in female body weight (1651 , 1619.67 vs. 1544.33g ; $p = 0.0006$). Egg production rate and egg number were higher ($p = 0.0004$) in PF birds followed by the NN and FF. PF and NN chickens had the highest egg weight compared to FF (45.48 , 45.33 vs. 44.73kg ; $p = 0.0361$). PF and NN birds had the highest egg mass than FF birds (3.81 , 3.62 vs. 3.23kg ; $p = 0.0004$). However, bird's livability was similar ($p = 0.6930$) among genotypes. The interaction between production systems and genotypes were significant regarding body weight of male ($p = 0.0108$) and female ($p = 0.0004$) birds at 48 weeks, egg number ($p = 0.0054$), production % ($p = 0.0054$), and egg mass ($p = 0.0057$).

Egg quality traits: Egg quality traits of three chicken genotypes reared under different production systems differed significantly (Table 4, 5). FF birds exhibited better egg quality traits regarding egg weight (52.92 vs. 50.17 , 48.93g ; $p = 0.0005$), surface area (65.07 vs. 62.80 , 61.76cm^2 ; $p = 0.0006$), volume (48.31 vs. 48.80 , 44.67cm^3 ; $p = 0.0005$), yolk index (42.04 vs. 41.70 , 41.70 ; $p = 0.0541$), and shell pore numbers (6378.38 vs. 6123.90 , 6007.84 ; $p = 0.0006$) than PF and NN. Haugh unit score was higher (89.34 vs. 87.97 , 97.11 ; $p = 0.0010$) in NN eggs compared to PF and FF. Egg shell breaking strength was higher (43.40 vs. 43.20 , 42.60 N; $p = 0.0035$) in NN eggs than FF and PF. However, shell thickness ($p = 0.2937$) and egg shape index ($p = 0.2912$) did not differ among chicken genotypes. Regarding

production systems, egg yolk index was higher in birds reared under open sided housing system than aviary and backyard housing reared birds (42.05 vs. 41.70, 41.70; $p = 0.0531$). However, egg weight ($p = 0.2293$), surface area ($p = 0.2329$), shape index ($p = 0.2971$), volume ($p = 0.2293$), Haugh units ($p = 0.9205$), shell thickness ($p = 0.9544$), shell breaking strength ($p = 0.5221$), and shell pores number ($p = 0.2318$) were similar across the production system. Production systems and chicken genotypes interaction were significant regarding egg weight ($p = 0.0020$), volume ($p = 0.0020$), surface area ($p = 0.0022$), Haugh units ($p = 0.0159$), yolk index ($p = 0.0102$), shell breaking strength ($p = 0.0307$), and shell pores number ($p = 0.0021$).

Hatching traits: There were several differences in the hatching traits of the three chicken genotypes reared under aviary, backyard, and open-sided housing systems (Table 6,7). Regarding production systems, backyard reared birds had the highest ($p < 0.0001$) hatchability

than open sided and aviary housing systems. Fertility rate was also better in birds reared under backyard system compared to open sided and aviary housing systems (88.80 vs. 83.11, 82.87%; $p = 0.0050$). Infertile eggs were lower in backyard reared birds than aviary and open sided housing birds (11.20 vs. 17.13, 16.895%; $p = 0.0012$). However, early ($p = 0.7046$) and late ($p = 0.9084$) embryonic mortality pattern were similar across the production systems. Regarding chicken genotypes, FF and PF birds had the highest hatchability (73.07, 71.65 vs. 65.09%; 0.0003) and fertility (87.72, 86.89 vs. 80.17%; $p = 0.0012$) than NN birds. Infertile eggs were lower in FF and PF than NN birds (12.72, 13.11 vs. 19.83%; $p = 0.0012$). However, embryonic mortality pattern [early ($p = 0.7046$) and late ($p = 0.9084$)] was similar among chicken genotypes. The interaction between the production system and chicken genotypes was significant for fertility ($p = 0.0028$), hatchability ($p = 0.0001$), and the percentage of infertile eggs ($p = 0.0028$).

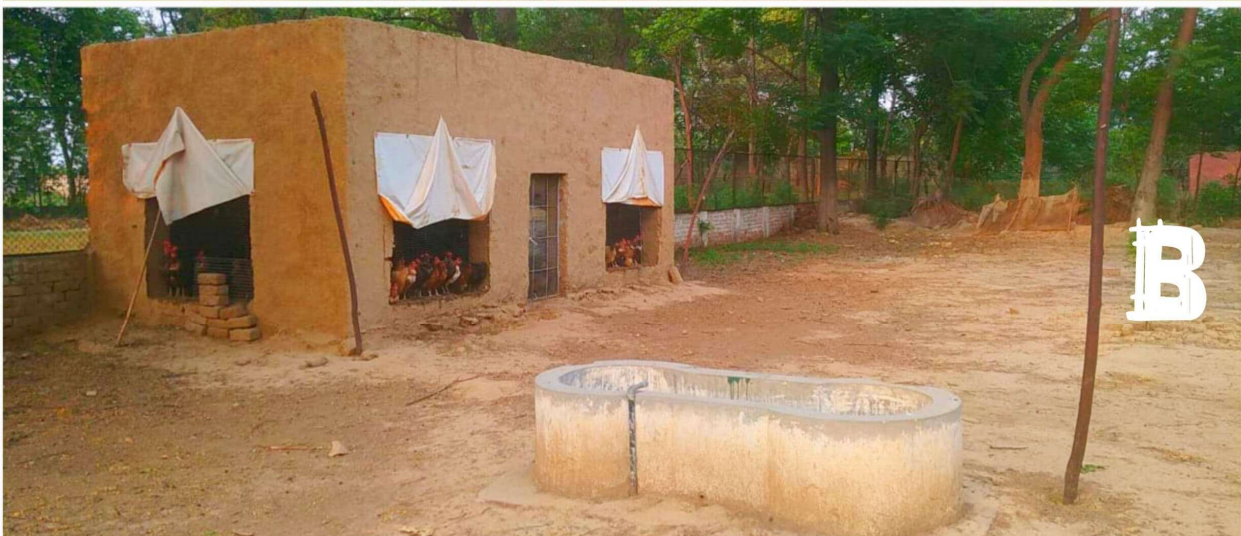




Figure 1. Housing systems used for experimental birds: Aviary (A), Backyard (B), and Open-Sided (C).

Table 1. Description of different housing systems.

Specifications	Aviary	Backyard	Open sided
Dimensions Covered area	304.8 × 304.8 × 304.8	548.64 × 304.8 × 243.84	609.6 × 609.6 × 365.76
Length × width × height (cm)			
Dimensions open area	579.12 × 304.8 × 274.32	1249.68 × 548.64	--
Production system + Replicates + Birds (each replicate)	3 × 06 × 30	3 × 06 × 30	3 × 06 × 30
Stocking density	15 birds/replicate	15 birds/ partition	15 birds/replicate
Sex ratio (male: female)	3:12 (each replicate)	3:12 (each replicate)	3:12 (each replicate)
Space per bird (cm ²)	1548.38 (open area) 2941.93 (closed area)	2787.09 11427.07 (each partition)	6193.54
Litter	Rice husk/wheat straw	--	Rice husk/wheat straw
Nesting			
Number of nests	3	3	3
Nesting dimension (cm)	25.4 × 22.86 × 22.86	25.4 × 22.86 × 22.86	25.4 × 22.86 × 22.86
Perches			
Number of perches	3	6	--
Material	Wooden	Wooden	--
Shape	Round	Round	--
Diameter (cm)	2.5	2.5	--
Length (cm)	91.44	152.4	--
Height from floor (cm)	45.72 - 60.96	45.72 - 60.96	--
Perching space/bird (cm)	11.43	38.1	--

Table 2. Production traits of chicken genotypes (26-48 weeks) reared under different production systems.

Traits	Production System			Chicken Genotype			SEM	p-value	
	Aviary	Backyard	Open Sided	FF	PF	NN		PS	GT
MBW-26	1772.00	1788.72	1791.26	1787.26	1787.81	1776.91	8.56	0.2750	0.6140
MBW-48	1969.67 ^a	1899.17 ^b	1970.67 ^a	1966.17 ^a	1956.00 ^a	1917.33 ^b	11.71	0.0027	0.0374
FBW-26	1313.13	1300.52	1300.55	1302.68	1304.59	1306.92	7.90	0.4600	0.9310
FBW-48	1641.00 ^a	1526.00 ^b	1647.00 ^a	1651.00 ^a	1619.67 ^a	1544.33 ^b	12.71	0.0001	0.0006
PROD	54.15	56.72	54.73	50.86 ^c	59.05 ^a	55.69 ^b	0.90	0.1620	0.0004
EW	45.04	45.44	45.07	44.73 ^b	45.48 ^a	45.33 ^a	0.18	0.2683	0.0361
EN	83.60	87.56	84.50	78.54 ^c	91.15 ^a	85.97 ^b	1.38	0.1620	0.0004
CEM	3.49	3.66	3.51	3.23 ^b	3.81 ^a	3.62 ^a	0.07	0.1755	0.0004
LIV	90.97	91.01	90.93	90.91	91.00	91.00	0.09	0.8040	0.6930

Superscripts on different means within row differ significantly at $p \leq 0.05$. PS = production system; GT = genotype; FF = full feathered; PF = partial feather; NN = naked neck; MBW = male body weight (g); FBW = female body weight (g); PROD = production %; EW = egg weight (g); EN = egg number; CEM = cumulative egg mass (kg); LIV = livability %

Table 3. Interaction effect between production systems and chicken genotypes on productive performance

Traits	Aviary			Backyard			Open Sided			SEM	p-value
	FF	PF	NN	FF	PF	NN	FF	PF	NN		
MBW-26	1794.91	1747.67	1773.43	1771.97	1814.59	1779.62	1794.92	1801.17	1777.69	14.82	0.1140
MBW-48	2002.00 ^a	1972.00 ^{ab}	1935.00 ^{abc}	1900.00 ^c	1892.00 ^c	1905 ^c	1996.00 ^a	2003.00 ^a	1912.00 ^b	20.28	0.0108
FBW-26	1299.83	1315.78	1323.80	1301.02	1293.54	1306.99	1307.20	1304.47	1289.99	13.69	0.6050
FBW-48	1680 ^a	1675 ^a	1570 ^a	1565 ^b	1515 ^b	1500 ^b	1710 ^a	1669 ^a	1563 ^b	22.01	0.0004
PROD	49.73 ^c	58.00 ^{ab}	54.25 ^{bc}	52.73 ^c	58.34 ^{ab}	59.09 ^{ab}	50.14 ^c	60.34 ^a	53.73 ^{bc}	1.56	0.0054
EW	44.52	45.25	45.35	45.29	45.47	45.56	44.38	45.73	45.09	0.31	0.1403
EN	76.79 ^c	90.27 ^{ab}	83.76 ^{bc}	81.41 ^c	90.06 ^{ab}	91.21 ^{ab}	77.42 ^c	93.14 ^a	82.92 ^{bc}	2.40	0.0054
CEM	3.17 ^c	3.76 ^{ab}	3.57 ^{abc}	3.36 ^c	3.76 ^{ab}	3.85 ^{ab}	3.15 ^c	3.90 ^a	3.46 ^{bc}	0.11	0.0057
LIV	90.80	91.11	91.01	91.02	90.98	91.03	90.91	90.91	90.97	0.15	0.9160

Superscripts on different means within row differ significantly at $p \leq 0.05$. FF = full feathered; PF = partial feather; NN = naked neck; MBW = male body weight (g); FBW = female body weight (g); PROD = production %; EW = egg weight (g); EN = egg number; CEM = cumulative egg mass (kg); LIV = livability %

Table 4. Egg quality traits of chicken genotypes (at 48 weeks) reared under different production systems.

Traits	Production System			Chicken Genotype			SEM	p-value
	Aviary	Backyard	Open Sided	FF	PF	NN		
EW	50.58	49.89	51.50	52.92 ^a	50.17 ^b	48.93 ^b	0.67	0.2293
ESI	73.34	73.34	73.15	73.15	73.34	73.34	0.10	0.2971
ESA	63.14	62.47	63.90	65.07 ^a	62.80 ^b	61.76 ^b	0.56	0.2329
EV	46.18	45.45	47.02	48.31 ^a	45.80 ^b	44.67 ^b	0.61	0.2293
YI	41.70 ^b	41.70 ^b	42.05 ^a	42.04 ^a	41.70 ^b	41.70 ^b	0.11	0.0531
HU	88.16	88.23	88.21	87.11 ^b	87.97 ^b	89.34 ^a	0.38	0.9205
ST	0.40	0.40	0.40	0.39	0.40	0.40	0.004	0.9544
SBS	43.50	43.30	43.50	43.20 ^b	42.60 ^b	43.40 ^a	0.03	0.5221
SPN	6162.30	6087.49	6247.05	6378.38 ^a	6123.90 ^b	6007.84 ^b	62.31	0.2318

Superscripts on different means within row differ significantly at $p \leq 0.05$. PS = production system; GT = genotype; FF = full feathered; PF = partial feather; NN = Naked Neck; EW = egg weight (g); ESI = egg shape index; ESA = egg surface area (cm²); EV = egg volume (cm³); YI = yolk index; HU = Haugh unit score; ST = shell thickness (mm); SS = shell breaking strength (N); SPN = shell pore numbers.

Table 5. Interaction effect between production systems and chicken genotypes (at 48 weeks) on egg quality traits.

Traits	Aviary			Backyard			Open Sided			SEM	P-value
	FF	PF	NN	FF	PF	NN	FF	PF	NN		
EW	53.50 ^{ab}	50.00 ^c	48.25 ^c	49.75 ^c	50.75 ^{bc}	49.17 ^c	55.50 ^a	49.75 ^c	49.25 ^c	1.15	0.0020
ESI	73.34	73.34	73.34	73.34	73.34	73.34	72.77	73.34	73.34	0.17	0.2957
ESA	65.57 ^{ab}	62.67 ^c	61.19 ^c	62.43 ^c	63.28 ^{bc}	61.97 ^c	67.21 ^a	62.46 ^c	62.03 ^c	0.97	0.0022
EV	48.85 ^{ab}	45.65 ^c	44.05 ^c	45.42 ^c	46.33 ^{bc}	44.89 ^c	50.67 ^a	45.42 ^c	44.70 ^c	1.05	0.0020
YI	41.70 ^b	41.70 ^b	41.70 ^b	41.70 ^b	41.70 ^b	41.70 ^b	42.73 ^a	41.70 ^b	41.70 ^b	0.19	0.0102
HU	86.51 ^d	88.29 ^{abcd}	89.67 ^a	87.29 ^{cd}	87.20 ^{cd}	89.54 ^{ab}	87.52 ^{bcd}	88.42 ^{abcd}	88.70 ^{acd}	0.66	0.0159
ST	0.39	0.40	0.40	0.39	0.40	0.40	0.39	0.40	0.40	0.007	0.9000
SBS	43.10 ^{ab}	42.80 ^{ab}	44.50 ^a	42.40 ^b	42.40 ^b	44.40 ^a	44.20 ^{ab}	42.60 ^b	43.90 ^{ab}	0.57	0.0307
SPN	6434.14 ^{ab}	6108.64 ^c	5944.12 ^c	6082.94 ^c	6177.46 ^{bc}	6030.54 ^c	6618.06 ^a	6085.60 ^c	6037.51 ^c	107.93	0.0021

Superscripts on different means within row differ significantly at $p \leq 0.05$. FF = full feathered; PF = partial feather; NN = Naked Neck; EW = egg weight (g); ESI = egg shape index; ESA = egg surface area (cm²); EV = egg volume (cm³); YI = yolk index; HU = Haugh unit score; ST = shell thickness (mm); SS = shell breaking strength (N); SPN = shell pore numbers.

Table 6. Hatching traits of chicken genotypes reared under different production systems.

Traits	Production System			Chicken Genotype			SEM	p-value	
	Aviary	Backyard	Open Sided	FF	PF	NN		PS	GT
HATCH	65.58 ^c	75.15 ^a	69.88 ^b	73.07 ^a	71.65 ^a	65.09 ^b	0.79	<0.0001	0.0003
FERT	82.87 ^b	88.80 ^a	83.11 ^b	87.72 ^a	86.89 ^a	80.17 ^b	1.06	0.0050	0.0012
IE	17.13 ^a	11.20 ^b	16.89 ^a	12.72 ^b	13.11 ^b	19.83 ^a	1.06	0.0050	0.0012
EEM	8.05	7.17	6.47	7.45	7.46	6.77	0.66	0.2886	0.7046
LEM	9.24	6.48	6.76	7.20	7.79	7.50	0.94	0.1260	0.9084

Superscripts on different means within row differ significantly at $p \leq 0.05$. PS = production system; GT = genotype; FF = full feathered; PF = partial feather; NN = Naked Neck; HATCH = hatchability %; FERT = fertility %; IE = infertile egg %; EEM = early embryonic mortality%; LEM = late embryonic mortality %

Table 7. Interaction effect between production systems and chicken genotypes on hatching traits.

Traits	Aviary			Backyard			Open Sided			SEM	p-value
	FF	PF	NN	FF	PF	NN	FF	PF	NN		
HATCH	70.34 ^{cd}	65.49 ^{ef}	60.92 ^f	79.71 ^a	74.21 ^{bc}	71.54 ^{bcd}	69.15 ^{de}	75.24 ^{ef}	65.26 ^{ef}	1.37	0.0001
FERT	87.49 ^a	86.68 ^a	74.44 ^b	90.39 ^a	88.45 ^a	87.57 ^a	85.29 ^a	85.55 ^a	78.50 ^b	1.83	0.0028
IE	12.52 ^b	13.32 ^b	25.56 ^a	9.62 ^b	11.55 ^b	12.44 ^b	14.71 ^b	14.46 ^b	21.51 ^a	1.83	0.0028
EEM	7.71	10.31	6.13	5.72	6.97	8.81	8.93	5.11	5.37	1.15	0.0939
LEM	9.44	10.89	7.40	4.96	7.27	7.23	7.21	5.20	7.88	1.62	0.3501

Superscripts on different means within row differ significantly at $p \leq 0.05$. FF = full feathered; PF = partial feather; NN = Naked Neck; HATCH = hatchability %; FERT = fertility %; IE = infertile egg %; EEM = early embryonic mortality%; LEM = late embryonic mortality %.

DISCUSSION

This study evaluated the performance of three chicken genotypes (FF, PF, and NN) reared under three different production systems: aviary, backyard, and open-sided.

Productive performance: Birds (males and females) reared under aviary and open sided housing systems were heavier at week 48 compared to the birds reared under backyard housing system. Most likely explanation of this finding is that these systems typically offer a more controlled environment compared to backyard housing. Birds expend less energy on thermoregulation and stress

responses, allowing more nutrients to be allocated toward growth and body maintenance. Ahmad *et al.* (2019) reported higher body weight of chicken genotypes when reared under intensive housing systems than semi-intensive and free-range system. Another study on Aseel chicken noted higher body weight under confinement and semi-intensive housing systems (Rehman *et al.*, 2016). However, a study reported higher body weights in chicken genotypes under enriched cages than conventional cages and aviary housing systems (Usman *et al.*, 2020). Higher feed intake was also noted in chicken reared under aviary and barn system compared to conventional cages in Korea (Ahammed *et al.*, 2014). Xianju chickens from conventional cage rearing system

had an advantage in terms of productivity parameters, but exhibited higher levels of serum lipids and glucose compared to flat net-rearing system, and free range system in China (Dong *et al.* 2017).

Partial feather birds (male and females) were heavier at week 48 and exhibited better egg production, egg weight, egg number, and egg mass. The heavier body weights and production traits of partial feathered birds can be attributed to the lower energy expenditure, efficient nutrient allocation, and potentially higher genetic growth potential. Naked Neck chickens, while adapted for specific environmental conditions, may face physiological trade-offs that limit their growth under certain production systems. Moreover, the physiological trade-offs in Naked Neck chickens mean that while they are well-adapted for heat stress, their energy and nutrient allocation toward thermoregulation and potential stress resistance may limit their growth and production performance. In contrast, Partial Feather birds maintain a better balance, leading to higher body weight and production traits. Similarly, a study related to Aseel chicken revealed variation in production performance among Peshawari, Mushki, Sindhi, and Lakha Aseel chicken varieties with highest egg rate in Sindhi and Peshawari Aseel chickens (Rehman *et al.*, 2016). Higher body weight of BNN (Black Australorp × Naked Neck) chicken crossbred were also reported compared to the Rhode Island Red × Naked Neck crossbred and purebred Naked neck chickens (Ahmad *et al.*, 2019). Gebreslassie (2024) reported significant differences among the performance of four chicken genotypes in Ethiopia and found higher body weight in Koekoe chickens, whereas higher survival rate in Indigenous and Improved Horro chickens. Ahmed *et al.* (2012) found better performance of Naked neck chickens in terms of body weight, egg weight, and egg production compared to indigenous normal feather chickens in Bangladesh. Sözcü *et al.* (2021) reported variation in Turkish chicken genotype regarding production performance; Atabey hens showed a higher egg production rate with better feed utilization than Atak-S. Tadele *et al.* (2023a) found better performance of exotic chicken genotype (Tetra H chicken) than the other chicken genotypes (Naked Neck and Normal Feathered) in terms of age at first egg and body weight, egg production, and egg mass in Ethiopia.

Egg quality traits: Better egg yolk index in bird reared under open sided housing system compared to the aviary and backyard housing system might be attributed to their balanced environmental conditions, controlled feeding, reduced stress levels, and efficient metabolic processes. These factors collectively enhance yolk deposition and structural integrity, leading to superior egg quality. Similarly, better egg quality traits of chicken genotypes were reported when reared under enriched cages compared to conventional cages and aviary housing

systems (Usman *et al.*, 2020). Svobodová *et al.* (2014) revealed that housing system (conventional cages vs. deep litter) significantly affected the most parameters of egg quality especially egg weight and albumen in chicken genotypes (Czech hen and Lohmann) in Czech Republic. Egg quality traits of the new Turkish laying hen hybrid Akbay were better in the free-range production system than in convention cages (Baylan *et al.*, 2024). However, a contradictory study by Ahmad *et al.* (2019) reported no significant differences in egg quality traits among crossbred chickens reared under intensive, free-range, and semi-intensive housing systems.

Full feather chicken exhibited better quality regarding egg volume and surface area, egg weight, shell pore number, and yolk index compared to partial feather and naked neck birds. The most likely explanation of improve egg quality of full feather birds is that full-feathered chickens can use nutrients more effectively for egg production due to reduced energy loss from stress and thermoregulation. Nutrients like calcium, phosphorus, and proteins are more efficiently channeled into eggshell formation, yolk development, and overall egg quality. In addition, Full-feathered birds exhibit better control over eggshell pore number, which balances gas exchange without compromising shell strength. This is critical for embryo viability and overall egg quality. Stress in other genotypes may disrupt the process of shell mineralization and pore formation. Similarly, better egg yolk index was reported in RNN and BNN crossbred chickens than Naked Neck chickens (Ahmad *et al.*, 2019). Lower yolk index in Naked neck chicken eggs were also reported when compared with full feather birds (Rajkumar *et al.*, 2021). In study of Naked neck and frizzle feather chicken, variation in yolk index was also reported in India (Dunga, 2013). Sözcü *et al.* (2021) noted better yolk, albumen, and eggshell quality in Atabey hens than those of Atak-S hens in Türkiye. Another study stated that except for yolk width and color, the Tetra H genotype (exotic chicken) was found to have significantly higher internal and external egg quality traits than the other genotypes (Naked Neck and normal feathered) in Ethiopia (Tadele *et al.*, 2023a).

Hatching traits: Backyard chicken revealed better hatching results in terms of hatchability and fertility while reducing the number of infertile eggs compared to the birds reared under open sided or aviary housing systems. The backyard chickens often forage and consume a varied diet, which can provide diverse nutrients, potentially enhancing fertility and egg quality. The availability of natural micronutrients in the backyard system may positively influence embryo development. Moreover, backyard systems typically have fewer birds in a given area, reducing competition and stress among chickens. Lower stocking densities provide better opportunities for mating and improve the overall fertility

and hatchability of eggs. Similarly, higher fertility and hatchability of chicken genotypes were noted those reared under free range system than intensive and semi-intensive housing (Ahmad *et al.*, 2019). However, study on Botswana chicken genotypes, revealed higher semen quality and fertility when birds were reared in an intensive housing system (Mothibedi *et al.*, 2016). Moreover, higher fertility and hatchability of chicken genotypes were noted when reared under aviary housing system than conventional and enriched cage systems (Usman *et al.*, 2020). Damaziak *et al.* (2021) evaluated the hatching performance of ISA brown laying hens in closed and open aviary systems and found that rate of fertilization, rate of hatching, and quality of chick did not depend on the flock rearing systems.

Full feather and partial feather birds exhibited better hatching results regarding hatchability and fertility and had lower infertile eggs than naked neck chicken. Most likely explanation of this improve hatching result is that full-feathered and partial-feathered birds might have genetic traits favoring better fertility and embryo development. These traits may include superior sperm motility, egg viability, and overall reproductive fitness. In addition, full-feather and partial-feather birds experience less stress from temperature extremes, enabling better hormonal balance (e.g., estrogen and testosterone), which directly influences reproductive success. Similarly, RNN and BNN chicken genotypes exhibited better hatchability and fertility than purebred Naked Neck chickens (Ahmad *et al.*, 2019). Adeleke *et al.* (2012) reported variation in hatching traits among different chicken genotypes (Naked neck, frizzled, normal feather, and Anak Titan). Rhode Island Red and Black Australorp crosses revealed better fertility and hatchability compared to other genotypes (Usman *et al.*, 2020). Improved hatching traits of Normal feathered chickens were also reported by Moreki *et al.* (2014) in Botswana when compared to Naked Neck Tswana chickens. Tadele *et al.* (2023b) compared hatching performance of exotic and indigenous chickens in Ethiopia and found that fertility and hatchability of indigenous naked-neck and normal-feathered chicken genotypes demonstrated superiority over the Tetra H chicken genotype.

Conclusion: This study highlights significant variations among chicken genotypes across different production systems, with notable genotype-production system interactions. Partial-feathered genotypes outperformed others in productive traits, whereas full-feathered genotypes excelled in egg quality. Both genotypes exhibited favorable hatching outcomes. Birds raised in open-sided houses attained higher body weights and yolk index values, while backyard-reared birds demonstrated superior hatching traits. These findings offer practical guidance for farmers in selecting optimal genotypes and

production systems to align with their specific production objectives.

Author's contribution: AHK conducted this study as part of his Ph.D. research work under the supervision of SM, SA, and AJ. AHK conducted the data collection and wrote the manuscript. SA helped in the statistical analysis and formatting of the manuscript. SM, SA, and AJ helped in reviewing the manuscript. All authors read and approved the final manuscript.

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