EFFECT OF DIFFERENT HOUSING CONDITIONS ON BEHAVIOR, MORPHOMETRICS, AND CARCASS TRAITS OF THREE GENOTYPES OF NAKED NECK CHICKEN

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ABSTRACT

This study evaluated the effect of housing systems (HS) and chicken genotypes (CG) on the behavior, morphometrics, and carcass traits of Naked Neck cockerels. In total, 405 males between 6 to 16 weeks old were studied. A randomized complete block design in factorial arrangement, with 9 treatments of 3 replicates with 15 birds each, was applied. Treatments consisted of 3 housing systems (Enriched indoor aviary system, Semi-intensive free-range system, and Intensive indoor system) and three chicken genotypes (full feathered (FF), partial feathered (PF), and Naked Neck (NN)). Behavior (walking, jumping, running, drinking, foraging & feeding, standing, sitting, aggressiveness, dust bathing, and wing flapping), morphometrics (body, keel, drumstick, and shank length, wing spread, drumstick and shank circumference), and carcass traits (pre-slaughter, shank, head, empty intestine, empty gizzard, liver, heart, neck, carcass, leg quarter, thigh, drumstick, and breast weight, and carcass yield) were evaluated. Scratching, perching, feeding, and dust bathing behaviors were more pronounced ($p \leq 0.05$) in Semi-intensive free-range system reared birds whereas Naked Neck genotype exhibited higher ($p \leq 0.05$) scratching, preening, jumping, and feeding behaviors. Birds reared under Enriched indoor aviary system revealed higher ($p \leq 0.05$) keel and drumstick length while body, drumstick and shank length, and drumstick and shank circumference were greater ($p \leq 0.05$) in full feathered genotype. Neck and carcass were heavier ($p \leq 0.05$) in birds reared under Enriched indoor aviary system and Semi-intensive free-range system whereas pre-slaughter, carcass, and breast weight were better ($p \leq 0.05$) in full feather genotype. In conclusion, the optimal housing system is genotype specific. The Semi-intensive free-range system is recommended for Naked Neck chickens to best express their natural scratching behavior, and for Partial Feathered chickens to promote dust bathing. The Enriched indoor aviary system is recommended for Full Feathered chickens to maximize carcass yield and muscling. Therefore, matching genotype to housing system is crucial for optimizing both welfare and production outcomes.

Key words: Semi-intensive free-range system, Aviaries, Naked Neck gene, Animal welfare, Genotype-environment interaction.

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INTRODUCTION

Climate change presents a major challenge to animal production. Although indoor housing tends to be perceived as less vulnerable to poultry farming, heat stress is a critical issue because ambient temperatures are high enough to increase house temperatures, which seriously affects the physiology and behavior of chicken. Therefore, effective ways of reducing heat stress are needed (Fernandes et al., 2023). The animal welfare concern of the consumers has contributed to the implementation of free-range housing systems in the developed world. Nonetheless, such outdoor systems are difficult to implement in hot climates especially heat stress. Naked Neck chicken with the Na gene, which decreases the cover of feathers, is best suited to this scenario, as it is better able to withstand heat and work better in humid and hot environments. The Naked Neck phenotype in chickens is an autosomal incompletely dominant gene, Na gene (Naked Neck), which decreases the feather cover especially on the neck. The gene has two allelic forms; the wild-type allele (na+) that carries out normal feathering, and the mutant allele (Na) that carries out reduction of the feathers. Phenotypic expression is based on the genotype: Homozygous recessive (na+/na+): Birds are fully feathered with full neck cover. In this study, they are referred to as Full Feathered (FF) genotypes. Heterozygous (Na/na+): Intermediate phenotype is observed in which birds have a neck feather loss of about 20-30 percent. In this research, these are referred to as Partial Feathered (PF) genotypes.

Homozygous dominant (Na/Na): Birds have about 40 percent loss in the feathers covering, and the neck area remains exposed. In this paper, they are known as Naked Neck (NN) genotypes. The gene is also adequately reported to give heat resistance and birds with Na allele tend to have better behaviour, growth, production and reproduction in hot weather especially in developing nations (Merat, 1986). Beyond the general heat-tolerant properties of the Na gene, phenotypic variation within Naked Neck chickens exists, with dark and light brown phenotypes showing superior morphometric and growth performance compared to black and white-black phenotypes (Shafiq *et al.,* 2022). This suggests that even among birds carrying the Na gene, genetic background influences production traits; a consideration relevant to the present study's comparison of three distinct genotypes (homozygous Na/Na, heterozygous Na/na, and wild type na/na) under different housing systems.

Housing systems (semi-intensive, enriched cages, enriched indoor aviary system, free range, and conventional cages) largely influenced the behavior, growth, and welfare of the birds. To exploit the genetic potential of chicken breeds, behavior assessment is mandatory that enables early detection of challenges and could be helpful for preventive measures. Furthermore, birds perform differently in non-cage and free-range housing systems, especially the domestic chickens (Fiorilla *et al.,* 2024). Study related to fast-growing broiler chickens revealed higher incidences of leg deformities and reduced standing when reared in colony cages than conventional floor housing system however growth performance and thermal regulation were improved. Moreover, conventional floor system rearing exhibited stress related issues in commercial broilers that ultimately influenced meat quality traits. Understanding of different housing systems is crucial towards improvement of bird's welfare, health, and performance (Honig *et al.,* 2024).

Improving behavior and welfare of Naked Neck chickens positively influenced growth performance, morphometric traits, and meat quality characteristics. Studies supported that there exit genotypes × environment interaction in commercial broilers and Naked Neck chicken that positively influence growth and carcass traits. Presence of Naked Neck chicken gene either in heterozygous (Na/na+) or homozygous (Na/Na) condition markedly improved growth, livability, and carcass traits. Fast growing broilers, when provided with outdoor access exhibited natural behaviors and improve welfare traits where it adversely affects growth and meat tenderness (Adomako *et al.,* 2014; Zhao *et al.,* 2014). Provision of free-range housing system to chickens revealed beneficial behavioral aspects that ultimately improve welfare i.e., birds can show sunbathing behavior in response to direct sunlight; however, this behavior is not evident in artificial lighting (Zelnter and Maurer, 2009).

Despite having several studies on Naked Neck chicken regarding its improved performance, behavior, and welfare under heat stress conditions (Fernandes *et al.,* 2023) and housing systems that significantly influenced behavior and welfare of birds (Fiorilla *et al.,* 2024); interactive study regarding three Naked Neck genotypes (normal feather, partial feather, and Naked Neck) under three housing system (Enriched indoor aviary system, Semi-intensive free-range system, and Intensive indoor system) on behavior, morphometrics, and carcass traits remain silent specially in warm climatic conditions.

The aim of this study was to evaluate the behavior, morphometric, and carcass traits in three genotypes of Naked Neck cockerels kept under different housing systems. We hypothesized that the partial-feathered genotype in the Semi-intensive free-range system would show a more balanced profile, optimizing both natural behavior expression and carcass yield. This hypothesis was based on the premise that partial-feathered (PF) birds, being heterozygous for the Na gene (Na/na+), possess an intermediate phenotype, retaining sufficient heat tolerance to cope with outdoor conditions while maintaining growth potential comparable to full-feathered birds. In contrast, we anticipated that fully feathered (FF) birds might experience heat stress in Semi-intensive free-range system systems, reducing performance, while homozygous Naked Neck (NN) birds might prioritize foraging activity over weight gain. The Semi-intensive free-range system system's complexity was expected to allow PF birds to express natural behaviors without excessive energy expenditure, thereby optimizing the trade-off between welfare and production.

MATERIALS AND METHODS

This study was conducted at Avian Research and Training (ART) Centre, University of Veterinary and Animal Sciences, Ravi Campus, Pattoki, Pakistan. This area has a typically hot and humid tropical climate, with temperatures ranging from 13°C in winter to 45°C in summer and an average relative humidity of 53–71% (Pakistan Meteorological Department, 2023).

Ethics: The care and use of birds were conducted in accordance with the laws and regulations of Pakistan and were approved by the Ethical Review Committee (No. DR/161, Dated: 20-05-2024) at the University of Veterinary and Animal Sciences (UVAS), Lahore, Pakistan.

Experimental birds: A total of 405 cockerels were set up as 3 × 3 factorial arrangements of treatments having 3 replicates of 15 birds each according to randomized complete block design. Treatments consisted of three housing systems (Enriched indoor aviary system, Semi-intensive free-range system, and Intensive indoor system) and three chicken genotypes based on their Naked Neck (Na) gene status i.e., Full feathered (FF): Wild-type birds homozygous recessive for the normal feathering allele (na+/na+), with complete feather coverage including the neck region. Partial feathered (PF): Heterozygous carriers of the Naked Neck gene (Na/na+), exhibiting approximately 20-30% reduction in neck feathers. Naked Neck (NN): Homozygous dominant for the Naked Neck gene (Na/Na), showing approximately 40% feather reduction on the neck (Merat, 1986). The three genotypes were the same in terms of base population, and they were managed in the same way before the experimentation. Three housing systems were used to carry out the experiment:

1. **Intensive indoor system (INT):** A traditional open sided house of 20 × 20 ft, which offers 1.5 sq ft per bird and has no exit to the outside. This was the control system that was used as a standard intensive management.
2. **Semi-intensive free-range system (SIR):** A 20ft ×10ft building that consists of a mud room (1.5 sq ft/bird) and an uncovered outdoor area (5 sq ft/bird). The open area was equipped with drinkers, feeders, perches, and dust bathing facilities and the mud room was equipped with lighting. Birds had daily outdoor access throughout the experimental period.
3. **Enriched indoor aviary system (AVI):** A specifically designed Enriched indoor aviary system including two roof fans for ventilation, supplemental lighting, and provisions for dust bathing and perching. Each bird was provided with covered space (1.5 ft × 2.5 ft) and open space (3.5 ft × 2.5 ft), encouraging vertical movement and exercise.

Birds were maintained at the ART Centre for a duration of 10 weeks, from 6-16 weeks of age. The chicks were brooded until 6 weeks of age in a well-ventilated, Intensive indoor housing system under standard management conditions, with a photoperiod of 8 hours per day. Throughout the experimental period (6-16 weeks), all birds were provided *ad libitum* access to water and a commercial grower diet formulated according to Leeson and Summers (2005). The composition of the diet is presented in Table 1. No feed restriction was applied to any treatment group. During this period, birds received vaccinations against Newcastle Disease (ND) and Infectious Bronchitis (IB) following the local schedule.

Parameters evaluated

Behavioral aspects: Behavioral observations were conducted daily using the focal observer method, as described by Ahmad *et al.* (2021). Two trained observers conducted the observations, and inter-rater reliability was assessed prior to data collection (Cohen's kappa = 0.85), ensuring consistency between observers. Observations took place between 11:00 AM and 1:00 PM daily, which corresponded to the period of peak ambient temperature. This timing was chosen to capture potential heat stress-related behaviors, but we acknowledge that this narrow window may not represent the full daily behavioral repertoire of the birds; moreover, we did not evaluate corticosterone or H:L ratio. Percentage of time budget of the following behaviors was recorded: scratching, preening, perching, standing, drinking, running, jumping, walking, sitting, aggression, foraging and feeding, wing flapping, and dust bathing (Table 2).

Morphometric traits: Throughout the 6 to 16-week growth phase, the morphometric traits were measured using a measuring tape (FT-070, China), with data recorded for body length, keel length, drumstick length, shank length, wingspread, shank circumference, and drumstick circumference.

Carcass characteristics: At 16 weeks, a total of 90 birds (3×3 = 9 × 10 birds per treatment group) were randomly selected and subjected to halal slaughter. Carcass traits were subsequently measured, including pre-slaughter live weight, carcass weight and yield, and the weights of major organs (heart, liver, empty gizzard, empty intestine) and commercial cuts (breast, thigh, drumstick, leg quarter, neck, head, and shank).

Statistical analysis: The normality and homogeneity of variance of the data for behavior, morphometrics, and carcass traits were confirmed using the Kolmogorov-Smirnov and Levene tests, respectively. Subsequently, the data were subjected to a Factorial ANOVA using PROC GLM in SAS (Version 9.1). The model included the housing system, chicken genotypes, and their interaction as fixed effects. Tukey HSD test was used to determine significant differences between means of treatments at the $p \leq 0.05$ significance level. All statistical analyses were based on the experimental unit, which was the pen since the chicks in a pen were treated and in the same environment. The data of each bird were averaged per pen before analysis. The research was a 3 × 3 factorial in a Randomized Complete Block Design (RCBD) with three replicates (pens) to each treatment combination. The level of replication offers 18 degrees of freedom of error in the ANOVA model, which is consistent with the norms of the poultry research and is adequate to identify the important main effects and interactions of the key traits of interest. A post-hoc power analysis on the key variable of carcass yield, using the observed effect size and variance, confirmed the achieved statistical power was >0.80. The following statistical model was employed:

$$Y_{ijk} = \mu + \beta_i + \tau_j + (\beta \times \tau)_{ij} + \epsilon_{ijk}$$

Where,

Y_{ijk} = Observation of dependent variable recorded on j^{th} Housing System in i^{th} Block
μ = Overall population mean
β_i = Effect of i^{th} Block (i = 1, 2, 3)
τ_j = Effect of j^{th} Housing System (j = 1, 2, 3)
$(\beta \times \tau)_{ij}$ = Interaction between the block and housing system
ϵ_{ijk} = Residual error of k^{th} observation on j^{th} treatment in i^{th} block NID ~ 0, σ^2

RESULTS

Behavioral Repertoires: Birds reared under Semi-intensive free-range system (SIR) spent most of their time scratching ($p < 0.0001$), perching ($p = 0.0070$), feeding ($p < 0.0001$), and dust bathing ($p < 0.0001$) compared to Intensive indoor system and Enriched indoor aviary system. Preening behavior was more pronounced in Enriched indoor aviary system and Intensive indoor system reared birds than Semi-intensive free-range system ($p = 0.0070$). Birds in Intensive indoor system exhibited more standing behavior compared to Semi-intensive free-range system ($p = 0.0006$); however, birds in Enriched indoor aviary system remained intermediate. Drinking behavior was higher in Intensive indoor system than Enriched indoor aviary system and Semi-intensive free-range system ($p = 0.0419$). Feeding ($p < 0.0001$) and dust bathing ($p < 0.0001$) behaviors were noticeable in birds in Semi-intensive free-range system compared to Enriched indoor aviary system and Intensive indoor system. However, running, jumping, walking, sitting, aggressiveness, and wing flapping behaviors did not differ among treatment groups.

Scratching behavior was more prevalent in NN genotype followed by PF and FF ($p < 0.0001$). Preening behavior was prominent in NN genotype than FF ($p = 0.0458$) whereas PF remained intermediate. Standing behavior was distinct in FF and PF genotypes compared to NN ($p <0.0001$). Drinking behavior was noticeable in FF genotype compared to PF ($p = 0.0325$) while NN behaved intermediately. Jumping behavior was more pronounced in PF and NN genotypes than FF ($p = 0.0227$). Feeding behavior was higher in FF and NN genotypes than PF ($p = 0.0010$); dust bathing was more prevalent in PF genotypes compared to NN ($p = 0.0467$) where FF genotype was intermediate. However, perching, running, walking, sitting, aggressiveness, and wing flapping behaviors did not differ among treatment groups (Table 3). The interaction between housing system and chicken genotype were significant regarding scratching ($p < 0.0001$), preening ($p = 0.0070$), perching ($p = 0.0008$), standing ($p = 0.0006$), drinking ($p = 0.0419$), feeding ($p < 0.0001$), and dust bathing ($p < 0.0001$) behaviors (Table 4). Based on behavioral parameters, the optimal housing system is genotype-specific: the Semi-intensive free-range system best supports the high scratching behavior of Naked-Neck (NN) chickens and the pronounced dust bathing of Partially-Feathered (PF) chickens, while the Intensive indoor system best accommodates the increased standing and drinking behaviors characteristic of Normally-Feathered (FF) chickens. Matching each genotype to its behaviorally suited environment is therefore key to promoting their natural behavioral welfare.

Morphometric traits: Keel ($p = 0.004$) and drumstick ($p = 0.007$) length were higher in birds in Enriched indoor aviary system compared to those in Semi-intensive free-range system and Intensive indoor system. However, body and shank length, drumstick and shank circumference, and wing spread did not differ ($p > 0.05$) among treatment groups.

FF and PF genotype birds exhibited increased body ($p < 0.0001$) and drumstick ($p = 0.014$) length compared to NN. Keel length was maximum in PF genotype than FF ($p = 0.029$) whereas NN remained intermediate. FF genotype birds had the large shank length followed by the PF and NN genotypes ($p = 0.001$). Greater wing spread was noted in PF genotype as compared to FF and NN ($p <0.0001$). Drumstick ($p = 0.001$) and shank ($p = 0.002$) circumference were maximum in FF genotype compared to PF and NN (Table 3). However, the interaction between housing system and chicken genotype did not differ ($p > 0.05$) among all the treatment groups regarding all parameters of morphometric traits.

Carcass traits: Among different housing systems, pre-slaughter weight was higher in Semi-intensive free-range system birds compared to the Enriched indoor aviary system ($p = 0.0128$); while Intensive indoor system birds were intermediate. Intestine weight was heavier in birds in Intensive indoor system than those of Enriched indoor aviary system and Semi-intensive free-range system ($p = 0.0334$). Neck ($p = 0.0020$) and carcass ($p <0.000$) weight were higher in Enriched indoor aviary system and Semi-intensive free-range system than Intensive indoor system birds. Carcass yield was better in Enriched indoor aviary system compared to Intensive indoor system birds ($p <0.000$); birds in Semi-intensive free-range system were intermediate. However, shank, head, empty gizzard, liver, heart, leg quarter, thigh, drumstick, and breast weight did not differ ($p > 0.05$) among housing systems.

FF birds had the highest body weight compared to PF and NN ($p = 0.0010$). Carcass weight was greater in FF and PF than NN ($p = 0.0001$); whereas carcass yield was superior in PF chickens followed by FF and NN birds ($p = 0.0004$). FF chickens had the heaviest breast compared to NN ($p = 0.0143$) while PF remained intermediate. However, shank, head, empty intestine, gizzard, liver, heart, neck, leg quarter, thigh, and drumstick weight did not differ ($p > 0.05$) among chicken genotypes (Table 3). The interaction between housing systems and genotypes was significant regarding pre-slaughter ($p = 0.0016$), neck ($p = 0.0154$), and carcass weight ($p = 0.0002$) and carcass yield ($p = 0.0002$) (Table 5).

Table 1. Composition of experimental rations

Feed Ingredient (%)	Starter (0-6 weeks)	Grower (7-16 weeks)
Corn	59.63	61.55
Soybean Meal	32.50	31.70
Fish Meal	2.00	0.00
Soybean Oil	2.00	3.00
DCP	1.50	1.70
NaCl	0.30	0.30
Methionine	0.23	0.12
Total	100	100
Nutrient Levels		
DM	89.3	89.5
Crude Protein	21.54	20.02
ME (Kcal/Kg)	2960	3020
Calcium	1.02	0.91
Phosphorus	0.45	0.35
Lysine	1.21	1.09
Methionine	0.57	0.43

Table 2. Ethogram of behavioral repertoires

Activity	Definition
Scratching	The bird scratches and pecks at the litter in a backward motion to search for food.
Preening	The bird uses its beak in a rotating motion to straighten its feathers, repeatedly pecking, nibbling, and combing through its plumage.
Perching	The bird exhibits roosting behavior on an elevated structure.
Standing	Feet on the ground, rest of the body parts are not touching the floor, bird standing in upright site.
Drinking	Drinking activity / Bird's beak in contact with water or drinker.
Running	Running activity with assistance of wings.
Jumping	Bird bounces back by jumping and feet are not in contact with ground
Walking	Forward movement of bird at least two steps with the exception of feet scratching.
Sitting	Bird's ventral region is in contact with the ground. Knee bending in the legs. The tibia and fibula bones are in contact with the surface.
Aggressiveness	An unpleasant response towards other birds, forceful pecking behavior, the beak of the aggressive bird hitting receiver's head.
Foraging & feeding	Bird's head inside feeder ingesting feed / foraging, pecking, and manipulating feed once or in a repeated manner.
Wing Flapping	Horizontal extension of the wings, leaving a space between the underside of the wing and the bird's body surface.
Dust Bathing	Sitting position in the substrate with use of the wings, head, neck, and legs is observed in either a free-range or an open system. wing trembling

Note: traits were evaluated as percentage of time spent in different behavioral activities

Table 3. Main effects of housing system and chicken genotype on behavior (%), morphometric traits (cm), and carcass traits (g) of Naked Neck cockerels.

Trait	Housing System (HS)			Chicken Genotype (CG)			SEM	p-value	
	AVI	SIR	INT	FF	PF	NN		HS	CG
Behavior (%)									
Scratching	14.54[b]	20.45[a]	15.02[b]	10.13[c]	17.15[b]	22.73[a]	1.58	<0.0001	<0.0001
Preening	16.37[a]	9.26[b]	17.57[a]	11.55[b]	13.89[ab]	17.75[a]	1.77	0.0070	0.0458
Perching	5.35[b]	11.51[a]	3.40[b]	9.22	6.27	4.77	1.54	0.0008	0.1188
Standing	14.38[ab]	9.71[b]	15.63[a]	17.28[a]	16.09[a]	6.34[b]	1.79	0.0006	<0.0001
Drinking	6.76[b]	5.48[b]	9.54[a]	10.36[a]	4.79[b]	6.62[ab]	1.52	0.0419	0.0325
Running	7.38	6.34	7.22	4.54	7.75	8.66	1.46	0.2990	0.1144
Jumping	8.22	5.19	5.95	3.40[b]	8.59[a]	7.36[a]	1.38	0.1538	0.0227
Walking	10.86	8.38	10.42	11.27	11.85	6.53	1.70	0.3887	0.0552
Sitting	9.63	3.51	8.38	8.44	6.30	6.78	1.61	0.1528	0.6158
Aggressiveness	1.37	3.36	1.55	2.22	1.27	2.80	0.87	0.5707	0.4564
Feeding	1.27[b]	9.37[a]	0.81[b]	5.29[a]	0.97[b]	5.19[a]	0.92	<0.0001	0.0010
Wing flapping	3.61	2.04	4.28	4.72	1.71	3.50	1.07	0.2705	0.1376
Dust bathing	0.28[b]	5.42[a]	0.23[b]	1.62[ab]	3.36[a]	0.97[b]	0.70	<0.0001	0.0467
Morphometric (cm)									
Body length	63.3	62.87	63.31	66.35[a]	64.75[a]	58.38[b]	0.67	0.871	<0.0001
Keel length	10.20[a]	9.82[b]	9.53[b]	9.64[b]	10.10[a]	9.81[ab]	0.10	0.004	0.029
Drumstick length	11.47[a]	10.84[b]	10.48[b]	11.13[a]	11.23[a]	10.42[b]	0.17	0.007	0.014
Shank length	10.12	9.77	9.86	10.68[a]	9.97[b]	9.10[c]	0.20	0.459	0.001
Wing spread	9.21	9.18	9.50	9.06[b]	10.11[a]	8.73[b]	0.11	0.136	<0.0001
Drumstick circumference	6.95	7.28	6.83	7.55[a]	6.85[b]	6.67[b]	0.12	0.056	0.001
Shank circumference	4.05	3.60	3.70	4.42[a]	3.60[b]	3.33[b]	0.15	0.148	0.002
Carcass (g)									
Pre slaughter weight	1063.33[b]	1086.67[a]	1075.00[ab]	1095.00[a]	1065.00[b]	1065.00[b]	4.30	0.0128	0.0010
Carcass weight	597.65[a]	594.61[a]	565.59[b]	595.83[a]	595.56[a]	566.46[b]	3.16	<0.0001	0.0001
Carcass yield (%)	56.21[a]	54.74[ab]	52.62[b]	54.44[b]	55.93[a]	53.20[c]	0.30	<0.0001	0.0004
Shank weight	21.34	22.62	21.70	23.89	21.15	21.15	0.75	0.4858	0.1024
Head weight	62.87	65.17	63.15	64.89	63.83	62.47	1.02	0.2712	0.2924
Intestine weight	26.20[b]	25.17[b]	29.44[a]	27.23	27.94	26.38	0.87	0.0334	0.4779
Gizzard weight	23.48	24.56	24.60	24.33	23.86	24.45	0.51	0.2658	0.7046
Liver weight	27.94	29.01	27.12	28.58	27.94	27.55	0.72	0.2337	0.6102
Heart weight	9.41	10.25	8.46	10.23	9.45	8.44	0.53	0.1087	0.1055
Neck weight	56.08[a]	55.30[a]	50.75[b]	55.44	53.93	52.77	0.78	0.0020	0.1056
Leg quarter weight	172.11	175.16	175.30	178.00	173.82	170.13	2.37	0.5811	0.0873
Thigh weight	78.92	77.81	78.85	79.98	79.65	76.43	1.89	0.8983	0.4124
Drumstick weight	93.20	97.35	96.44	98.65	94.65	93.70	1.41	0.1474	0.0770
Breast weight	209.18	214.63	214.03	218.82[a]	212.81[ab]	206.21[b]	2.37	0.2572	0.0143

AVI = Enriched indoor aviary system, SIR = Semi-intensive free-range system, INT = Intensive indoor system; FF = full feathered (na/na), wild-type with complete feathering; PF = partial feathered (Na/na), heterozygous Naked Neck with ~20-30% neck feather reduction; NN = Naked Neck (Na/Na), homozygous with ~40% feather reduction;

Means with different superscripts within row (within main effect) differ significantly at $p \leq 0.05$.

Behavioral traits were presented as percentage of time spent in different behavioral activities.

Table 4. Interaction effect between housing systems and Naked Neck chicken genotypes on male behavior

Traits (%)	AVI			SIR			INT			SEM	p-value
	FF	PF	NN	FF	PF	NN	FF	PF	NN		
Scratching	7.34^{cd}	15.21^{bc}	20.97^{ab}	0.00^{d}	20.63^{ab}	25.76^{a}	0.00^{d}	15.62^{bc}	21.46^{ab}	2.74	<0.0001
Preening	14.24^{abc}	17.43^{ab}	17.43^{ab}	0.00^{c}	6.18^{bc}	13.68^{abc}	0.00^{c}	18.06^{b}	22.15^{a}	3.07	0.0070
Perching	10.56^{ab}	3.61^{bc}	1.88^{c}	8.76^{abc}	14.17^{a}	11.60^{ab}	0.00^{e}	1.04^{cd}	0.83^{d}	2.67	0.0008
Standing	17.85^{ab}	16.81^{abc}	8.47^{bcd}	13.16^{abc}	13.06^{abc}	2.92^{d}	0.00^{d}	18.40^{a}	7.64^{cd}	3.10	0.0006
Drinking	7.64^{abc}	6.04^{abc}	6.60^{abc}	12.68^{a}	1.04^{c}	2.71^{bc}	10.76^{ab}	7.29^{abc}	10.56^{ab}	2.63	0.0419
Running	5.21	9.86	7.08	5.97	6.46	6.60	2.43	6.94	12.29	2.54	0.2990
Jumping	5.69	8.61	10.35	1.04	8.13	6.39	3.47	9.03	5.35	2.39	0.1538
Walking	10.42	14.17	7.99	9.51	9.93	5.69	13.89	11.46	5.90	2.95	0.3887
Sitting	14.03	6.39	8.47	2.96	3.82	3.75	8.33	8.68	8.13	2.79	0.1528
Aggressiveness	1.39	0.00	2.71	2.78	3.82	3.47	2.43	0.00	2.22	1.50	0.5707
Feeding	1.74^{b}	0.00^{b}	2.08^{b}	12.75^{a}	1.88^{b}	13.47^{a}	1.39^{b}	1.04^{b}	0.00^{b}	1.60	<0.0001
Wing flapping	0.00	1.04	5.97	3.40	1.67	1.04	6.94	2.43	3.47	1.85	0.2705
Dust bathing	0.00^{c}	0.83^{bc}	0.00^{c}	4.10^{b}	9.24^{a}	2.92^{bc}	0.69^{bc}	0.00^{c}	0.00^{c}	1.21	<0.0001

AVI = Enriched indoor aviary system, SIR = Semi-intensive free-range system, INT = Intensive indoor system; FF = full feathered (na/na), wild-type with complete feathering; PF = partial feathered (Na/na), heterozygous Naked Neck with ~20-30% neck feather reduction; NN = Naked Neck (Na/Na), homozygous with ~40% feather reduction.
^{abc}Means with different superscripts within row differ significantly at $p \leq 0.05$. Behavioral traits were presented as percentage of time spent on different behavioral activities.

Table 5. Interaction effect between Housing system and Naked Neck chicken genotypes on male carcass traits

Traits	AVI			SIR			INT			SEM	p-value
	FF	PF	NN	FF	PF	NN	FF	PF	NN		
PSW	1065.00^{bc}	1060.00^{c}	1065.00^{bc}	1130.00^{a}	1070.00^{bc}	1060.00^{c}	1090.00^{b}	1065.00^{bc}	1070.00^{bc}	7.45	0.0016
SW	23.28	20.39	20.37	24.22	22.68	20.97	22.62	20.37	22.10	1.29	0.3840
HW	64.02	64.07	60.53	65.73	65.14	64.65	64.94	62.28	62.23	1.77	0.5402
EIW	23.86	28.54	26.19	27.67	25.59	24.46	30.15	29.69	28.85	1.51	0.1252
EGW	22.70	23.30	25.45	24.79	23.85	25.05	25.51	24.45	23.85	0.89	0.5012
LvW	27.36	29.71	26.77	30.56	26.75	29.71	27.83	27.35	26.17	1.25	0.2578
HrW	9.89	9.91	8.77	10.96	10.47	9.32	9.86	7.98	7.56	0.91	0.2512
NW	59.36^{a}	54.75^{ab}	54.13^{bc}	56.50^{ab}	55.24^{ab}	54.67^{bc}	50.45^{c}	51.80^{bc}	50.01^{c}	1.36	0.0154
CW	602.34^{a}	614.46^{a}	576.15^{c}	608.25^{a}	596.07^{ab}	579.51^{bc}	576.26^{c}	576.15^{c}	543.74^{d}	5.47	0.0002
CY	56.55^{ab}	57.97^{a}	54.10^{cd}	53.83^{d}	55.71^{cd}	54.64^{cd}	52.93^{d}	54.09^{cd}	50.82^{e}	0.51	0.0002
LQW	172.84	171.24	172.27	186.79	176.79	161.92	176.26	173.43	176.20	4.11	0.0955
TW	76.99	80.67	79.09	85.15	78.75	69.54	77.81	78.10	80.65	3.26	0.2460
DW	95.85	90.57	93.18	101.65	98.05	92.37	98.45	95.33	95.55	2.45	0.1741
BW	214.17	209.68	203.69	221.97	218.07	203.85	220.32	210.68	211.10	4.11	0.0890

AVI = Enriched indoor aviary system, SIR = Semi-intensive free-range system, INT = Intensive indoor system; FF = full feathered (na/na), wild-type with complete feathering; PF = partial feathered (Na/na), heterozygous Naked Neck with ~20-30% neck feather reduction; NN = Naked Neck (Na/Na), homozygous with ~40% feather reduction.; PSW = pre slaughter weight (g); SW = shank weight (g); HW = head weight (g); EIW = empty intestine weight (g); EGW = empty gizzard weight (g); LvW = liver weight (g); HrW = heart weight (g); NW = neck weight (g); CW = carcass weight (g); CY = carcass yield (%); LQW = leg quarter weight (g); TW = thigh weight(g); DW = drumstick weight (g); BW = breast weight (g). ^{abcde}Means with different superscripts within row differ significantly at $p \leq 0.05$.

DISCUSSION

Behavioral Repertoires: The interaction between housing system and chicken genotype were more pronounced regarding grooming and maintenance behaviors indicate that the effect of the housing system on behavior is not uniform; it depends on the bird's genotype. A Semi-intensive free-range system might allow the NN genotype to fully express its scratching instinct, while the same system might not elicit the same level of response from the FF genotype, which is behaviorally less active. This underscores the importance of matching genotype to housing system for optimal welfare and performance.

Birds reared under Semi-intensive free-range system spent most of their time in scratching, perching, feeding, and dust bathing. This is a typical sign of enhanced behavioral expression and well-being. Semi-intensive free-range system in which they have their more natural litter-based floors furnish the substrate and the opportunity, to which these strongly motivated, natural foraging and comfort behaviors are devoted. The upper systems imply that the birds within this system are less constrained and can undertake a broader area of natural behaviors than the more structured Enriched indoor aviary system and open-sided systems in which floor space and substrate quality may be restrictive. Aviary and intensive indoor systems had stronger preening behavior. In as much as preening is normal maintenance behavior, when high levels occur it can also be an indication of redirected behavior in unfavorable environments; as an example, when the foraging opportunity is scarce, birds can redirect the motivation back to feather maintenance. The reduced preening of the semi-intensive system may be merely because birds were busier on the ground (scratching, dust bathing) and less likely to preen, as opposed to different welfare conditions. The Intensive indoor system of birds depicted more standing behavior than Semi-intensive free-range system; nevertheless, birds reared in Enriched indoor aviary system were intermediate. A higher position in the intensive indoor system can be taken in different ways. It may be an indication of increased vigilance owing to the changes in the environment (temperature, noise) as postulated by earlier research. Nonetheless, there is another possible reason, namely that the sterile environment of the intensive system (the absence of litter, perches, or other stimulating materials) simply provides fewer chances to express other behaviors like foraging or dust bathing, and birds are forced to stand in a passive position. In the absence of physiological stress indicators, the two interpretations are both feasible and additional studies that would involve corticosterone levels would aid in the differentiation of the two. Drinking behavior was higher in Intensive indoor system. This could be linked to environmental factors. Higher temperatures or lower humidity in the Intensive indoor system might have increased the birds' water consumption to maintain thermoregulation. As a non-genetic factor, housing system significantly influences bird's behavior, growth, and slaughter traits (El-Deek and El-Sabrout, 2019; Attia et al., 2024). Findings of this study correspond with the study of Aseel pullets indicating more pronounced behavioral response when reared in part time free range system compared to free range and caged (Rehman *et al.,* 2018). Similarly, another study reported differences in behavioral repertoire among crossbred chickens reared under intensive, semi intensive, and free range housing systems. Maintenance and explorative behaviors were more pronounced in free range birds whereas longer standing and aggressive behaviors were higher in intensive birds (Ahmad *et al.,* 2021). However, contradictory study reported that outdoor housing system facilitates the expression of natural behaviors of broiler chickens but negatively affects performance of the birds (Zhao *et al.,* 2014).

The NN genotype appears to exhibit more "active" or "natural" foraging behaviors. This suggests a stronger expression of ancestral behavioral traits, possibly because they are less selected for rapid growth and feed conversion compared to the FF and PF genotypes. Standing behavior was distinct in FF and PF genotypes. This is in line with the high-yield paradox in animal production. Fast-growing and heavy-muscling genotypes (FF, PF) develop weaknesses or overall discomfort of the legs because their body weight is too large. This may increase their resistance to movement and cause a lot of time standing in one position instead of walking or running. The drinking behavior was conspicuous in FF genotype this may be because heavy and fast growing birds have a higher metabolic rate and generate more metabolic heat. This likely increases their water requirement for thermoregulation and metabolic processes. Jumping behavior was more pronounced in PF and NN genotypes. This is a behavior requiring agility and energy. The FF genotype, being heavier and potentially less mobile, performs this behavior less. The lighter NN and intermediate PF genotypes are more agile and capable of expressing this active behavior. The findings of this study correspond with the study reported differences in behavioral repertoire among slow growing (Ancona, Leghorn, and Crossbred - Cornish × Leghorn), medium growing (Gaina, Robusta Maculata, Kabir, and Naked Neck) and fast growing (Ross 308) chicken strains. Slow growing chickens exhibited more natural behaviors followed by medium growing birds, whereas fast growing birds were mostly involved in inactive behaviors (Castellini *et al.,* 2016). Similarly, another study reported better expression of natural behaviors in slow growing chicken compared to fast growing chicken strains (Ghayas *et al.,* 2021). Another study confirms the difference among chicken genotypes regarding behavior and welfare traits and reported that Hubbard RedJA and Rowan Ranger genotypes exhibited more adaptability and active behaviors compared to CY5XJA87, CY5XJA87, Ranger Classic, and Ranger Gold genotypes (Mancinelli *et al.,* 2020). In study of crossbred chickens (Rhode Island Red × Naked Neck and Black Australorp × Naked Neck), better exploratory and maintenance behavior revealed compared to purebred Naked

Neck chicken (Ahmad *et al.,* 2021). A limitation of this study is the restricted behavioral observation window (11:00 AM - 1:00 PM), which may not capture behaviors expressed during cooler morning or evening hours. Future research ought to employ more than one observation time of the day in order to have a more holistic behavioral profile.

Morphometric traits: The implication that morphometric traits showed no significant interaction with housing system implies that the genetic potential of body frame and muscle attachment points is to a large extent fixed. While activity in the Enriched indoor aviary system improved some measures, the fundamental genetic differences between FF, PF, and NN were the dominant factors determining overall body conformation.

Keel and drumstick length was higher in birds reared under Enriched indoor aviary system. The most likely explanation of this increase is that the Enriched indoor aviary system with its multi-tiered structure encourages more vertical movement, flying, and jumping. This increased physical activity, particularly the use of breast muscles for flight and leg muscles for jumping and perching, likely promotes the development of the keel and drumstick muscles. This corresponds with the study of crossbred chickens reported higher body and keel length in birds reared under enriched cage system than Enriched indoor aviary system and conventional cage system (Usman *et al.,* 2020). Another study supported this argument and reported maximum keel length in birds reared under semi-intensive housing system compared with free range and intensive housing system (Ahmad *et al.,* 2019).

FF and PF genotype birds exhibited increased body and drumstick length. This result is directly linked to genetics. The FF and PF genotypes have been selectively bred for improved growth rate and meat yield. This selection manifests significantly greater body length, drumstick length, shank length, and circumference; all traits associated with a larger frame and higher muscle mass. Greater wing spread was noted in PF genotype. This is an interesting finding that may indicate a specific anatomical trait of the PF genotype or a retained ability for flight compared to the heavier FF genotype. It warrants further investigation into the specific genetic background of these birds. The findings of this study correspond to study of Naked Neck phenotypes, reported that light and dark brown Naked Neck chicken exhibited superior morphometric traits than black and black white phenotypes (Shafiq *et al.,* 2022). Another study reported differences in keel length among Frizzled feathered, normal feathered, Naked Neck, crossbreds, and exotic Giri Raja chickens (Fadare *et al.,* 2014). Similarly, another study indicated differences in normal and Naked Neck chickens regarding shank circumference (Oleforuh-Okoleh *et al.,* 2017). Another study supported this argument that variation exists among different genotypes of chicken and reported higher body and keel length, breast width, and shank circumference in Tetra H chickens compared to Naked Neck and normal feathered chickens (Tadele *et al.,* 2023).

Carcass traits: The significant interactions for pre-slaughter, neck, and carcass weight/yield mean that the "best" housing system for producing a heavy, high-yielding carcass depends on the genotype of the chicken. For instance, the FF genotype might perform best in one system, while the NN genotype might achieve its potential in another. This is a powerful conclusion for making tailored management recommendations.

Among different housing systems, pre slaughter weight was higher in bird reared under Semi-intensive free-range system. Despite potentially lower feed efficiency, birds in the Semi-intensive free-range system may have achieved higher final weights due to a longer growing period, less stocking density, or access to a more diverse diet (e.g., insects, greens) that supplemented their intake. Intestinal weight was heavier in birds reared in Intensive indoor system. A heavier intestine can be an adaptation to a higher-fiber diet or less digestible feed, requiring a larger digestive organ to process the same amount of nutrients. The reason for this in the Intensive indoor system needs to be linked to the specific diet or management practices. Neck and carcass weight and carcass yield were higher in Enriched indoor aviary system and Semi-intensive free-range system. The Enriched indoor aviary system, through increased activity, seems to have promoted lean muscle development, leading to a higher yield. The Semi-intensive free-range system, though gave heavier live weight, also reflected this into good carcass weight. The intensive indoor system having lower carcass yield with equal pre-slaughter weights could be theorized to be due to greater energy usage on maintenance behaviors like standing which may be at the cost of tissue deposition. Nevertheless, this interpretation is hypothetical without direct indicators of physiological stress (e.g., corticosterone levels, heterophil: lymphocyte ratio). Future studies incorporating such measures would help establish whether behavioral differences observed in this system translate into meaningful stress responses that affect carcass composition. Findings of the present study corresponds with the study related to medium growing cockerels (Hubbard JA757) exhibited better meat quality traits when housed in mobile boxes on pasture (Englmaierová *et al.,* 2021). Another study reported higher breast muscles in chicken when reared under grass paddock (Castellini *et al.,* 2002). Another supported this argument that housing system significantly influence meat composition traits of local Chinese broiler chicken where caged reared birds exhibited more carcass and abdominal fat percentage compared to the birds reared under pen systems might be attributed to energy expenditure between different housing systems (Zhao *et al.,* 2012).

FF and PF birds had the highest body, carcass, and breast weight, and carcass yield. As expected, the genotypes selected for meat production (FF, PF) had higher body weight, carcass weight, and breast weight. This is the direct result of genetic selection for these commercial traits. The superior carcass yield in PF over FF is a nuanced finding that could point to a more favorable fat-to-lean ratio or better efficiency in the PF genotype. The finding of this study corresponds with the study of commercial chicken strains indicating differences in carcass traits; breast proportion was higher in fast growing strain (Ross 308), intermediate in medium growing strain (Hubbard JA 757) whereas lower proportion was observed in slow growing strains (ISA dual chicken) (Tůmová *et al.,* 2021). Similarly, another study reported better breast weight, carcass yield, and cooking loss in crossbred chicken than those of Padovana Camosciata local breed and an Italian commercial slow-growing line Berlanda-Gaina (Cassandro *et al.,* 2015). In other study, differences in carcass traits were noted where Aseel chicken was comparable with broiler chicken whereas broiler breeder exhibited superior carcass quality traits (Khan *et al.,* 2019) and different broiler genotype (Attia et al., 2016). A study from Ethiopia reported the differences in carcass weight among normal feather local chicken (LL), Sasso-RIR, and their crossbred (LSR) where carcass weight was higher in crossbred chicken compared to LL and Sasso-RIR (Wolde *et al.,* 2022). Moreover, the study regarding Ethiopian chicken genotypes (NaT = Naked-neck × Tetra H; NfT = Normal feathered × Tetra H; ThH = Tetra H × Tetra H) the NaT cross (Naked-neck × Tetra H) generally demonstrated superior growth performance, higher dressing percentage, improved breast yield, and more favorable blood lipid profiles compared to the NfT (Normal-feathered × Tetra H) and pure ThT (Tetra H × Tetra H) genotypes. However, genotype alone showed less consistent effects (Tadele *et al.,* 2024). In drawing these results against the literature, we must put our genotypes into perspective in the larger scheme of growth types. The genotype of our FF (na+/na+), with full feathering and highest body and breast weights, fits into the category of fast-growing strains described by Castellini *et al.* (2016) and Tumova *et al.* (2021) of the strains like Ross 308. The PF type (Na/na+), which has intermediate feather loss and high carcass yield, is associated with medium-growing varieties. The NN genotype (Na/Na), which emphasizes foraging activity overweight gain, is like the behavioral profile of slow-growing strains, but with distinct adaptations to heat. This typology assists in balancing our results with the prior studies on genotype x environment interactions.

Conclusions: Finally, the experiment reveals that there is a strong genotype-by-housing interaction, which requires specific recommendations. For NN chickens, the Semi-intensive free-range system is optimal to facilitate their strong expression of natural foraging behaviors. For FF chickens, the Enriched indoor aviary system is recommended to maximize their genetic potential for breast muscling and high carcass yield. PF chickens performed well in both systems, allowing producers to choose the Enriched indoor aviary system for superior yield or the Semi-intensive free-range system to promote specific natural behaviors. Therefore, matching genotype to housing system is a key management strategy to simultaneously address welfare and production goals.

Author's contribution: AHK conducted this study as part of his Ph.D. research work under the supervision of SM, SA, and AJ. AHK did 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 approve the final manuscript.

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