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Meat Quality Traits and Blood Biochemistry of Three Chicken Genotypes Reared under Different Production Systems

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Abstract: The objective of the current study was to assess meat quality attributes in different chicken genotypes raised in three distinct housing systems. Fifty-four female birds (52 weeks old) from three genotypes—two crossbreds (Naked Neck × Rhode Island Red [RNN], Naked Neck × Black Australorp [BNN]) and purebred Naked Neck (NN)—were reared in intensive, semi-intensive, and free-range systems. These birds were slaughtered, and their meat samples were analyzed for nutritional, qualitative, and sensory attributes. Significant differences were observed among genotypes, housing systems, and their interactions concerning carcass yield, breast, wings, drumsticks, and neck weight. Significant variations were noted in sensory evaluation among genotypes, housing systems, and their interaction, except for juiciness. In terms of meat proximate analysis, differences were observed in moisture, dry matter, ash, and ether extract among different genotypes, housing systems, and their interactions. Regarding blood biochemistry, birds reared intensively had higher glucose values, whereas globulin was higher in semi-intensively reared birds; among genotypes, BNN showed higher cholesterol levels. In conclusion, carcass traits, sensory evaluation, meat proximate, and mineral composition were influenced by genotypes and housing systems.

Keywords: chicken genotype; carcass traits; proximate analysis; mineral composition; sensory evaluation

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1. Introduction

The global population is gradually increasing, leading to a rising demand for animal proteins. Poultry meat (commonly referred to as white meat) and eggs, renowned for their high-quality protein content, play crucial roles in sustaining human health and nutrition [1]. Rearing poultry in home backyards has been a traditional practice worldwide since ancient times. In many developing nations, various genotypes of local poultry constitute a significant portion, ranging from 80–99%, of the total poultry population [2]. Approximately 80% of households in rural areas of Pakistan are directly or indirectly involved in backyard poultry [3]. Rural poultry plays a crucial role in Pakistan's poultry production, as it demonstrates better adaptability to environmental changes and disease resistance compared to exotic and commercial strains.

The rural poultry in Pakistan predominantly comprises native breeds such as Aseel, Desi, Naked Neck (NN), along with some exotic breeds like Rhodes Island Red (RIR), Black Australorp (BAL), and Fayoumi. Indigenous poultry breeds hold significant genetic, historical, and cultural importance. For example, the Aseel breed, native to this region, has played a pivotal role in the development of various breeds such as the Cornish [4]. Additionally, breeds like CARI-Shyama and CARI-Nirbheek in India have roots in the Aseel breed [5]. There is a growing consumer interest in natural, organic, and antibiotic-free chicken products, leading to a heightened appreciation for indigenous breeds. These breeds are often raised without antibiotics, which are perceived to have positive effects on human health. However, their relatively lower performance and slower growth are primarily attributed to management practices, suboptimal feed quality, and a lack of genetic selection strategies [6].

Crossbreeding native breeds can be an effective strategy to improve the performance of rural poultry, ultimately benefiting poultry producers [7]. This approach, coupled with genetic selection, can lead to improved genetic outcomes [8]. By crossbreeding exotic chicken breeds with indigenous ones, it is possible to produce chickens with better feed conversion ratios, higher growth rates, superior carcass and meat quality, and improved reproductive traits. These chickens can adapt well to local environments [9]. The genetic composition of birds, coupled with an appropriate rearing system, can significantly enhance meat quality, carcass yield, and growth performance [10]. A free-range housing system, for instance, can improve taste and meat quality due to birds having access to pasture and the freedom to exercise. However, this system tends to reduce production performance, resulting in a higher feed conversion ratio and lower body weight [11].

Several studies have compiled management guidelines for crossbred chickens raised in specific housing systems, outlining their effects on growth and reproductive performance. However, documentation regarding meat quality is limited and requires further investigation. Therefore, the present study aimed to explore the meat quality attributes of crossbred chickens (RNN, BNN, and NN) raised under free-range, semi-intensive, and intensive housing systems.

2. Materials and Methods

2.1. Birds Genotypes and Rearing Systems

Three chicken genotypes were utilized in this study, including two crossbreds: Naked Neck × Rhode Island Red (RNN) and Naked Neck × Black Australorp (BNN), as well as the purebred Naked Neck (NN). These genotypes were reared at the Indigenous Chicken Genetic Resource Centre (ICGRC), University of Veterinary and Animal Sciences (UVAS), Ravi Campus, Pattoki, Pakistan. The chickens were raised in three different housing systems: 1) free range, 2) semi-intensive, and 3) intensive housing, for a duration of 52 weeks.

At the conclusion of the 52-week period, fifty-four female chickens, representing three different genotypes raised under three distinct housing systems (with 6 birds per treatment, totaling 6 × 9 = 54), were selected for slaughter. Each bird was considered a replicate, labeled with a metal wing tag, and transported to the processing plant. The slaughtering process took place at the Meat Processing Plant, UVAS, Lahore.

2.2. Carcass Traits

Measurements of live body weight and hot carcass weight were conducted using a digital weighing balance with a capacity of measuring up to 0.5 g accuracy. Carcass yield, breast, wings, drumsticks, neck, ribs, and back weight percentages were calculated as the weight of each parameter divided by the live body weight in grams (g), multiplied by 100.

2.3. Physicochemical Properties

The color of the breast samples was assessed at 2 hours and 24 hours post-slaughter using a Minolta® CR-410 colorimeter (Konica Minolta® CR-410, Japan). Color parameters included Lightness (L*), Redness (a*), Yellowness (b*), Chroma (c), and Hue angle (h). Additionally, the pH of the breast samples (pectoral major muscle) was measured using a pH meter with a penetrating probe (WTW, pH 3210 SET 2, Germany) at 2 hours and 24 hours post-slaughter.

Drip loss was measured by hanging meat samples inside plastic bags (without touching them) for 24 hours at 0–4°C. Samples were weighed both at the time of hanging and after 24 hours to calculate drip loss percentage using the formula:

Drip loss % = [(Initial weight - Final weight) / (Initial weight)] × 100

For cooking loss measurement, meat samples were placed in plastic bags and heated in a water bath to achieve a core temperature of 72°C. Subsequently, cylindrical pieces of meat (3 cm long, diameter 12mm, and parallel to fiber) were cut from the breast. Shear force value was determined for breast meat samples using a Warner-Bratzler shear force texture analyzer [11].

2.4. Sensory and Proximate Analysis Properties

Breast meat was selected for the sensory analysis test. Meat samples were cooked without the use of spices and salt [12]. A nine-point hedonic scoring scale was employed for scoring the meat samples, with 1 indicating "dislike extremely" and 9 indicating "like extremely". The scale also included intermediate points for varying degrees of liking or disliking. The sensory assessment was conducted by a panel of 10 assessors [13]. The sensory analysis took place at the Sensory Analysis Lab, Ravi Campus, UVAS. The parameters assessed included texture, aroma, taste, flavor, juiciness, and overall acceptability.

The Proximate Analysis of meat samples was done at the laboratory of the Department of Animal Nutrition, UVAS, following the protocols outlined by AOAC [14]. The analysis included determining dry matter (%), moisture (%), ash (%), crude protein (%), and ether extract (%).

Macro-mineral analysis (calcium, Ca; phosphorus, P; sodium, Na; and potassium, K) of the breast meat samples was conducted following the protocols outlined by AOAC [14].

2.5. Blood Biochemistry

For blood biochemistry analysis, 5 mL of blood was drawn from the jugular vein of each of 6 birds per treatment and placed in a vacutainer without any anticoagulant. The serum was then separated and stored at -20°C. Subsequently, the samples were analyzed using commercially available kits (Bio-Med®), and the spectral absorption was measured at a wavelength of 540 nm at the Biochemistry Lab, Ravi Campus, UVAS. Various blood metabolites including glucose, cholesterol, total protein, serum albumin, serum globulin, and uric acid were determined.

2.6. Statistical Analyses

The collected data were analyzed using factorial ANOVA through GLM Procedure in SAS (SAS; Version 9.1). Housing systems and chicken genotypes were treated as fixed effects. The interaction of genotype and housing system was also assessed. Comparison of means was done using Tukey's test, with a significance level set at $p \leq 0.05$.

3. Results and Discussion

The present study aimed to evaluate the meat quality attributes of different chicken genotypes raised in various housing systems. The study successfully identified significant differences in several meat quality parameters across the different genotypes and housing systems.

3.1. Carcass Traits

The RNN genotype birds reared in intensive housing systems were heavier in body weight at slaughter and had the highest wing and neck percentages compared to other treatment groups (Table 1; $p \leq 0.05$). RNN chickens in the free-range production system showed better carcass yield ($p \leq 0.05$). BNN chickens reared in intensive housing systems had a higher percentage of drumstick ($p \leq 0.05$). The difference in body weight might be due to the activity levels of these birds. Several factors affected free-range and semi-intensive birds, such as photoperiod, light intensity, increased exercise in yards, and fluctuating temperatures, which increased their energy requirements. This led to the lower body weight observed in free-range and semi-intensive chickens. Contrary to current findings, Santos et al. [15], found that chickens reared in semi-intensive housing systems had higher live body weight.

Significant differences were noted in dressed weight among different housing systems, genotypes, and their interactions. However, Jaturasitha et al. [16] reported contradictory findings, with no clear differences in dressing percentage between Thailand's local breed and exotic chickens.

Table 1. Effect of housing system and genotype on carcass traits as a percentage of live body weight.

Housing System	Genotype [1]	Live Weight (g)	Carcass Yield (%)	Breast (%)	Wings (%)	Drumstick (%)	Neck (%)	Ribs & Back (%)
Free-range		1181.86^{c}	58.06^{a}	14.30^{a}	5.91^{b}	4.81^{b}	3.08^{a}	6.65
Semi-intensive		1477.94^{b}	53.21^{b}	12.32^{b}	4.98^{c}	4.39^{b}	2.41^{b}	5.76
Intensive		1925.64^{a}	55.71^{ab}	13.41^{a}	6.93^{a}	6.13^{a}	3.01^{a}	6.47
	RNN	1494.45^{b}	57.51^{a}	14.29^{a}	5.99	5.31	3.25^{a}	6.40
	BNN	1689.74^{a}	54.12^{b}	13.51^{a}	5.96	4.99	2.52^{b}	6.58
	NN	1401.25^{b}	55.35^{ab}	12.23^{b}	5.87	5.03	2.73^{b}	5.90
Free-range	RNN	1167.92^{ef}	59.59^{a}	15.26	5.67^{b}	5.26^{cd}	3.12^{b}	6.24
Free-range	BNN	1328.34^{def}	57.55^{b}	14.18	6.02^{b}	4.31^{ef}	3.12^{b}	6.83
Free-range	NN	1049.31^{f}	57.05^{abc}	13.47	6.05^{b}	4.86^{ced}	3.01^{bc}	6.88
Semi-intensive	RNN	1379.80^{e}	53.26^{bc}	12.78	4.52^{c}	4.51^{efd}	2.62^{cd}	6.04
Semi-intensive	BNN	1616.50^{cd}	51.94^{c}	12.93	4.79^{c}	3.87^{f}	2.30^{ed}	6.14
Semi-intensive	NN	1437.51^{cde}	54.43^{abc}	11.24	5.62^{b}	4.79^{ecd}	2.30^{ed}	5.11
Intensive	RNN	1935.63^{ab}	59.69^{a}	14.83	7.77^{a}	6.18^{ab}	4.00^{a}	6.92
Intensive	BNN	2124.37^{a}	52.87^{bc}	13.43	7.08^{a}	6.78^{a}	2.15^{e}	6.78
Intensive	NN	1716.92^{bc}	54.58^{abc}	11.98	5.94^{b}	5.44^{abc}	2.89^{bc}	5.72
SEM		57.61	0.16	0.24	0.16	0.15	0.09	0.18
Source of Variation				***p* Value**				
Housing system		<0.0001	0.0047	0.0005	<.0001	<.0001	<0.0001	0.1171
Genotype		<0.0001	0.0581	0.0003	0.8739	0.3052	<0.0001	0.2951
Interaction		<0.0001	0.3164	0.5761	0.0001	0.0016	<0.0001	0.4965

$^{a–f}$ Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$.
[1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

Additionally, another study highlighted considerable variability in dressing percentages among Italian breeds, such as the Padovana, which exhibited slightly lower dressing percentages compared to commercial broilers [12]. The study results revealed significant differences in breast meat, wing, and neck percentage among different housing systems and genotypes. These findings align with those of Batkowska et al. [17], who also reported significant differences in breast meat and wing percentage among different genotypes and housing systems.

The study results showed significant differences in drumstick percentage among housing systems and genotypes (Table 1). These findings agree to Rizzi et al. [18] who found a higher percentage of thigh and drumsticks in 44-week-old local Italian breed chickens compared to hybrid hens. Regarding housing systems, Batkowska et al. [17] found similar results, showing a higher drumstick percentage in chickens from intensive housing systems than in those from free-range housing systems.

The study results indicated non-significant differences in ribs & back percentage among different housing systems, genotypes, and their interactions. This is consistent with the findings of Hassen et al. [19], who also found no significant difference in ribs and back percentage among local ecotypes of birds (Table 1).

3.2. Meat Quality

The results of different meat quality traits are presented in Table 2 to Table 4. RNN chickens reared in a free-range housing system exhibited more yellow meat (b*) and a higher Hue angle ($p \leq 0.05$). BNN chickens in a semi-intensive housing system showed greater lightness (L*). Meat from RNN birds in an intensive housing system was more reddish (a*) and had a higher Chroma (C) value (Table 2; $p \leq 0.05$). NN chickens reared in a semi-intensive housing system exhibited higher yellowness ($p \leq 0.05$).

Table 2. Effect of housings system and genotype on meat color at 2 (h) post slaughtering.

Housing System	Genotype [1]	L*	a*	b*	C	H
Free-range		53.20^{b}	10.93^{c}	10.62^{b}	15.24^{c}	44.54^{a}
Semi-intensive		55.34^{a}	12.90^{b}	11.46^{a}	16.77^{b}	44.77^{a}
Intensive		49.11^{c}	14.83^{a}	9.60^{c}	17.76^{a}	34.34^{b}
	RNN	52.45	12.51	10.65	16.75	40.22
	BNN	52.93	13.44	10.60	16.73	41.84
	NN	52.26	12.71	10.42	16.28	41.58
Free-range	RNN	53.02	9.67^{d}	11.89^{a}	15.75	50.49^{a}
Free-range	BNN	53.92	11.33^{cd}	10.45^{b}	15.26	42.71^{bc}
Free-range	NN	52.65	11.78^{cd}	9.52^{b}	14.72	40.42^{bc}
Semi-intensive	RNN	55.22	12.42^{bc}	10.46^{b}	16.28	38.80^{c}
Semi-intensive	BNN	54.78	14.86^{a}	11.72^{a}	17.34	44.83^{b}
Semi-intensive	NN	56.03	11.41^{cd}	12.20^{a}	16.69	50.67^{a}
Intensive	RNN	49.13	15.43^{a}	9.61^{b}	18.24	31.37^{e}
Intensive	BNN	50.10	14.12^{ab}	9.63^{b}	17.59	37.99^{cd}
Intensive	NN	49.33	14.95^{a}	9.56^{b}	17.26	33.66^{ed}
SEM		0.39	0.28	0.20	0.18	0.93
Source of Variation				***p* Value**		
Housing system		<.0001	<.0001	<0.0001	<.0001	<.0001
Genotype		0.2990	0.8243	0.3339	0.4161	0.596

Interaction		0.0864	0.0127	<0.0001	0.1373	<.0001

[a–d] Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

Color is the main appearance factor involved in the choice of food when it comes to consumers and consumers frequently reject or select a product based merely on its visual presence [20]. The three major causative factors to poultry meat color are pH of the meat, chemical state of the heme structure, and myoglobin content [21]. Quentin et al. [22] observed that birds granted outdoor access and fed with green forage displayed more deeply pigmented skin.

In our study, the relatively elevated levels of skin and breast meat yellowness, in contrast to several findings in the literature, could be attributed to outdoor access and the presence of natural pigments found in legume-based pastures [23]. Conversely, literature suggests that birds raised in extensive production systems tend to produce meat with higher a* values (redder) and lower L* values (lighter) compared to intensively raised chickens, likely due to the higher content of myoglobin red type fibers resulting from increased physical activity in outdoor birds [24].

Table 3. Effect of housings system and genotype on meat color at 24(h) post slaughtering.

Housing System	**Genotype** [1]	**L***	**a***	**b***	**C**	**H**
Free-range		54.91^{a}	12.26^{c}	12.95^{b}	17.75^{c}	47.19^{a}
Semi-intensive		55.46^{a}	13.74^{b}	13.66^{a}	19.15^{b}	47.50^{a}
Intensive		50.59^{b}	16.09^{a}	12.31^{c}	20.47^{a}	36.78^{b}
	RNN	53.92^{ab}	14.04	13.19^{a}	19.14	44.07
	BNN	54.22^{a}	14.22	13.07^{a}	19.25	44.13
	NN	52.83^{b}	13.83	12.65^{b}	18.98	43.27
Free-range	RNN	55.79^{ab}	11.17^{e}	14.28^{a}	17.98^{ef}	52.30^{a}
Free-range	BNN	54.32^{bc}	13.11^{cd}	12.78^{b}	17.87^{ef}	46.02^{bc}
Free-range	NN	54.63^{abc}	12.49^{ed}	11.78^{c}	17.39^{f}	43.26^{c}
Semi-intensive	RNN	56.15^{ab}	14.40^{bc}	12.68^{b}	18.48^{ed}	43.58^{c}
Semi-intensive	BNN	56.62^{a}	13.94^{cd}	14.13^{a}	19.91^{bc}	48.82^{ab}
Semi-intensive	NN	53.62^{cd}	12.87^{cd}	14.16^{a}	19.07^{cd}	50.10^{ab}
Intensive	RNN	49.80^{e}	16.56^{a}	12.62^{b}	20.97^{a}	36.34^{d}
Intensive	BNN	51.72^{ed}	15.61^{ab}	12.30^{bc}	19.96^{abc}	37.55^{d}
Intensive	NN	50.24^{e}	16.12^{a}	12.01^{bc}	20.49^{ab}	36.46^{d}
SEM		0.39	0.28	0.15	0.19	0.90
Source of Variation				***p* Value**		
Housing system		<.0001	<.0001	<.0001	<.0001	<.0001
Genotype		0.0391	0.645	0.0238	0.6317	0.7244
Interaction		0.0348	0.021	<.0001	0.0136	<.0001

[a–f] Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

In our study, significant differences in color after 24 hours were observed among different housing systems and interactions between housing systems and genotypes (Table 3). Color might be affected by pre-slaughter management and genetics. Similarly, Quentin et al. [22] noted significant differences in lightness (L*), redness (a*), and yellowness (b*) of breast meat among chicken genotypes. The three major causative factors to poultry meat color are pH of the meat, chemical state of the heme structure, and myoglobin content [21]. Quentin et al. [22] observed that birds granted outdoor access and fed with green forage displayed more deeply pigmented skin. BNN chickens raised in intensive housing systems had the highest pH at 2 hours post-slaughter, while both NN and BNN birds in intensive housing systems had a higher ultimate pH (Table 4; $p \leq 0.05$).

Table 4. Effect of housing system and genotype on physicochemical properties of meat.

Housing System	**Genotype** [1]	**Shear Force Value (N)**	**Drip Loss (%)**	**pH(2h)**	**Ultimate pH(24h)**
Free-range		18.21	3.46^{b}	5.89^{b}	5.51^{b}
Semi-intensive		18.37	3.51^{a}	5.89^{b}	5.47^{b}
Intensive		20.10	3.52^{a}	5.99^{a}	5.54^{a}
	RNN	18.57	3.49	5.86^{b}	5.47^{b}
	BNN	18.57	3.50	6.02^{a}	5.52^{a}
	NN	19.53	3.51	5.90^{b}	5.54^{a}
Free-range	RNN	16.99	3.45	5.85^{cde}	5.47^{b}
Free-range	BNN	17.75	3.48	5.90^{bcd}	5.47^{b}
Free-range	NN	19.89	3.46	5.93^{bc}	5.57^{a}
Semi-intensive	RNN	18.01	3.51	5.80^{e}	5.44^{b}
Semi-intensive	BNN	17.91	3.50	6.05^{a}	5.51^{ab}
Semi-intensive	NN	19.18	3.53	5.84^{ed}	5.46^{b}
Intensive	RNN	20.72	3.52	5.93^{bc}	5.48^{b}
Intensive	BNN	20.06	3.52	6.11^{a}	5.58^{a}
Intensive	NN	19.51	3.53	5.94^{b}	5.58^{a}
SEM		0.36	0.01	0.02	0.01
Source of Variation			***p* Value**		
Housing system		0.0596	0.0028	<0.0001	0.0008
Genotype		0.4411	0.7254	<0.0001	0.0011
Interaction		0.4110	0.7926	0.0007	0.0094

$^{a–e}$ Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

The results of our study revealed significant differences in ultimate pH among various housing systems, genotypes, and their interactions (Table 4). Consistent with previous research, lower pH levels were observed in meat from free-range birds compared to those reared indoors [12,23,25]. This difference was attributed to reduced pre-slaughter stress in free-range birds, resulting in higher glycogen levels in the muscles [23]. However, there are contradictory findings regarding pH differences between outdoor and indoor chickens, as noted by Ponte et al. [23] and Almasi et al. [26]. Free-range access may influence muscle size and fiber density, potentially impacting postmortem pH decline [27].

In this study, no significant differences were found among housing systems, genotypes, or the interaction between housing systems and genotypes regarding the shear force value of breast meat (Table 4). Similarly, López et al. [28] observed no differences in mean shear force between different breeds of chicken. However, contrary findings were reported by Pripwai et al. [29], who found that Baetong and Praduhangdum breast meat exhibited lower shear force values compared to Black-boned breast meat. Additionally, slow-growing genotypes displayed higher shear values than fast-growing genotypes [16]. Thai Indigenous breeds' breast meat was noted to be tenderer than that of other indigenous breeds from Spain [30].

A significant difference was obtained in drip loss among different housing systems (Table 4). Similar to the current findings, Batkowska et al. [17] found that there was a significant difference in drip loss of chicken meat reared in different housing systems. Similarly, Stadig et al. [14] also found that chickens reared in intensive housing systems had higher drip loss than birds from free-range. In the case of genotype, a significant difference was observed by Batkowska et al. [17] regarding drip loss which is contrary to the current study.

3.3. Proximate Analysis

RNN chickens reared in semi-intensive housing systems had the highest moisture percentage (Table 5; $p \leq 0.05$). NN chickens reared in intensive housing systems showed higher values of crude protein, ether extract, and dry matter ($p \leq 0.05$). BNN chickens reared in semi-intensive housing systems had the highest ash percentage ($p \leq 0.05$).

Table 5. Effect of housing system and genotype on meat proximate analysis.

Housing System	**Genotype** [1]	**Moisture (%)**	**Crude Protein (%)**	**Ether Extract (%)**	**Ash (%)**	**Dry Matter (%)**
Free-range		71.50^{b}	22.95^{b}	0.12^{b}	1.06^{a}	28.50^{b}
Semi-intensive		72.40^{a}	22.90^{b}	0.88^{a}	0.98^{b}	27.60^{c}
Intensive		71.21^{c}	24.39^{a}	0.89^{a}	0.99^{b}	28.78^{a}
	RNN	72.28^{a}	22.96^{b}	0.87^{a}	0.98^{b}	27.73^{c}
	BNN	71.32^{c}	23.70^{a}	0.89^{a}	1.06^{a}	28.68^{a}
	NN	71.52^{b}	23.58^{a}	0.81^{b}	0.99^{b}	28.48^{b}
Free-range	RNN	71.42^{c}	23.20^{cd}	0.86	1.05^{bc}	28.58^{c}
Free-range	BNN	71.48^{c}	22.79^{d}	0.86	1.00^{cd}	28.52^{cd}
Free-range	NN	71.60^{c}	22.86^{d}	0.70	1.14^{ab}	28.40^{ed}
Semi-intensive	RNN	73.86^{a}	21.69^{e}	0.84	0.91^{ed}	26.14^{g}
Semi-intensive	BNN	71.09^{d}	24.22^{b}	0.93	1.17^{a}	28.91^{b}
Semi-intensive	NN	72.25^{b}	22.80^{d}	0.85	0.87^{e}	27.75^{f}
Intensive	RNN	71.55^{c}	23.99^{bc}	0.92	0.98^{cd}	28.46^{e}
Intensive	BNN	71.38^{c}	24.08^{b}	0.88	1.02^{c}	28.62^{c}
Intensive	NN	70.70^{e}	25.10^{a}	0.88	0.98^{cd}	29.27^{a}
SEM		0.17	0.20	0.02	0.02	0.17
Source of Variation			***p* Value**			
Housing system		<0.0001	<0.0001	0.0164	0.0158	<0.0001
Genotype		<0.0001	0.0070	0.0253	0.0126	<0.0001
Interaction		<0.0001	0.0001	0.0628	<.0001	<0.0001

$^{a–e}$ Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

The present study revealed significant differences in dry matter among different housing systems, genotypes, and their interactions. According to Fletcher [31], alterations in dry matter content may be because free-range chickens had a greater exercise than indoor confined birds. However, Fanatico et al. [32] found that there was no significant difference in different chicken genotypes, housing systems, and interaction between housing systems and genotypes. Poultry meat quality can be influenced by various factors including rearing conditions, genotype, and feeding practices, all of which can impact muscle metabolism and chemical composition. However, Fanatico et al. [25] found that the protein content of breast meat was influenced by genotype. In terms of housing systems, Alvaredo et al. [33] reported no significant difference in crude protein content between the free-range and the intensive housing systems, contrary to the findings of the present study. Similarly, Fanatico et al. [32] reported that the production system and genotype had effects on the intramuscular fat of chicken meat. According to the present research, indoor birds had higher fat than free-range birds. This aligns with other studies indicating that the additional space provided in free-range systems leads to increased leanness in poultry, likely due to increased physical activity [34]. However, contradictory findings have also been reported, with some studies indicating that the fat percentage of breast muscle does not differ significantly among chicken genotypes [16,35].

In this study, a significant difference was observed in breast meat moisture percentage among different housing systems, genotypes, and their interactions. Moisture content may be influenced by diet, bird age, and breeding environment. Regarding genotype, higher moisture percentages were recorded in broiler breeders, followed by broilers and Aseel chickens [36]. Conversely, no significant variation in moisture content among different genotypes was observed by Jaturasitha et al. [16]. This study also revealed significant differences ($p \leq 0.05$) in ash percentage among various housing systems, genotypes, and their interactions. Minerals play a crucial role as they are linked with organic compounds essential for muscle contraction, and their levels typically rise as birds mature. Similar findings were reported by Siddiqi et al. [37], who noted that ash content in the meat of Lyallpur Silver Black birds was notably higher compared to White Leghorn, White Plymouth Rock, and Desi birds (Table 5).

3.4. Meat Mineral Profile

The NN birds reared in intensive housing systems showed a higher ($p \leq 0.05$) value of calcium compared to other treatment groups (Table 6). Siddiqi et al. [37] reported a low value of calcium in the meat of the Desi breed when compared with Lyallpur Silver Black. The present study revealed significant differences ($p \leq 0.05$) in phosphorus content among different housing systems and non-significant differences among different genotypes. However, Silva et al. [38] reported variation in phosphorus content among different poultry species. Moreover, some other studies also reported a significant effect of breeds and varieties on the phosphorus content of meat [39].

Table 6. Effect of housing system and genotype on meat microminerals (mg/L).

Housing System	Genotype [1]	Sodium	Phosphorus	Potassium	Calcium
Free-range		519.38	429.61[a]	2951.60[a]	4797.91[c]
Semi-intensive		523.15	443.94[a]	2915.39[a]	4849.37[b]
Intensive		532.55	466.98[b]	3086.60[b]	4892.97[a]
	RNN	523.57	440.23	2986.68	4847.74
	BNN	522.87	439.73	2980.05	4847.73
	NN	528.66	460.57	2986.86	4844.79
Free-range	RNN	518.48	426.05	2944.02	4807.74[de]
Free-range	BNN	520.30	427.58	2944.66	4788.28[e]

Free-range	NN	519.36	435.19	2966.13	4797.72[de]
Semi-intensive	RNN	527.03	440.25	2913.44	4835.95[cd]
Semi-intensive	BNN	511.66	442.59	2936.99	4870.39[abc]
Semi-intensive	NN	530.77	448.99	2895.74	4841.78[bcd]
Intensive	RNN	525.19	454.38	3102.59	4899.52[a]
Intensive	BNN	536.63	449.03	3058.50	4884.51[ab]
Intensive	NN	535.84	497.54	3098.71	4894.88[a]
SEM		3.01	5.37	16.59	8.83
Source of Variation			***p* Value**		
Housing system		0.2297	0.0092	<.0001	<.0001
Genotype		0.7115	0.1149	0.9402	0.9589
Interaction		0.6268	0.4611	0.5539	<.0001

[a–e] Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

In the current experiment, non-significant differences ($p \leq 0.05$) were noted regarding meat sodium content among different housing systems, genotypes, and their interactions. However, contradictory findings were reported in different breeds regarding sodium content in meat [37]. Regarding potassium, significant differences ($p \leq 0.05$) were shown among different housing systems and non-significant differences among different genotypes. Species, breeds, and strains differences in potassium percentage have also been reported [39].

3.5. Sensory Evaluation

The results of meat sensory evaluation are presented in Table 7. Meat from NN chickens reared in free-range systems had significantly higher ($p \leq 0.05$) texture values (Table 8). NN and BNN chicken genotypes reared in free-range housing systems exhibited higher ($p \leq 0.05$) ratings for taste, flavor, aroma, and overall acceptability. RNN chickens reared in free-range housing systems showed the highest ($p \leq 0.05$) juiciness values. The study also revealed significant differences in flavor among different housing systems, genotypes, and their interactions. Other studies examining genotype [40,41] have suggested that the unique flavors of indigenous chickens are preferred in Chinese or Korean cuisine. Furthermore, Bogosavljevic-Boskivic et al. [24] found that the chicken products from semi-intensive systems had better flavor compared to conventionally raised broiler chickens.

In the present study, meat from free-range birds exhibited better flavor. However, another study found no significant variations among different chicken genotypes regarding appearance and flavor [42]. The current study identified significant differences in juiciness among various housing systems and interactions between housing systems and genotypes. These variations in juiciness could be explained by higher water and intramuscular fat content. Similarly, research on genotype has suggested that broilers demonstrate the highest juiciness compared to Amarela roosters [43]. Furthermore, breast meat from broiler chickens raised in intensive systems demonstrated enhanced juiciness compared to those from semi-intensive systems [44].

In this study, a significant difference was observed in meat texture among various housing systems, genotypes, and their interactions. Meat texture can be influenced by factors such as species, diet, type of muscle fiber, and the level of physical activity of the bird. Regarding overall acceptability, a significant difference was revealed among different housing systems, genotypes, and their interactions. Wattanchant et al. [45] reported higher acceptability in native chicken meat than in commercial broilers. Contrarily, Olaifa et al. [44] found that the overall acceptability of meat from chickens raised in intensive systems was significantly higher, but in the present study, breast meat from free-range chickens had greater overall acceptability. Castellini et al. [46] demonstrated that lower intramuscular fat content correlated with reduced meat juiciness in slow-growing broilers. However, Rajkumar et al. [42] reported non-significant differences in appearance and juiciness among chicken genotypes and weight groups.

Table 7. Effect of housing system and genotype on meat sensory characteristics (Score 1–9).

Housing System	Genotype [1]	Texture	Aroma	Taste	Flavor	Juiciness	Overall Acceptability
Free-range		6.40[a]	6.07[a]	6.33[a]	6.24[a]	6.05[a]	6.11[a]
Semi-Intensive		5.58[b]	5.69[c]	5.99[c]	5.67[c]	5.40[b]	5.76[c]
Intensive		5.64[b]	5.90[b]	6.16[b]	5.86[b]	4.66[c]	5.84[b]
	RNN	5.67[c]	5.77[b]	6.13[b]	5.75[c]	5.39	5.80[b]
	BNN	5.90[b]	5.82 [b]	6.02[c]	5.93[b]	5.34	5.96[a]
	NN	6.06[a]	6.07[a]	6.33[a]	6.07[a]	5.39	5.94[a]
Free-range	RNN	5.85[c]	5.74[bc]	6.09[cd]	5.83[bc]	6.31[a]	5.94[bc]
Free-range	BNN	6.49[b]	6.16[a]	6.40[a]	6.41[a]	6.07[b]	6.21[a]
Free-range	NN	6.88[a]	6.30[a]	6.50[a]	6.47[a]	5.77[c]	6.18[a]
Semi-intensive	RNN	5.54[d]	5.84[b]	6.12[cd]	5.66[cd]	5.39[d]	5.75[de]
Semi-intensive	BNN	5.57[d]	5.56[c]	5.71[e]	5.54[d]	5.39[d]	5.67[e]
Semi-intensive	NN	5.64[cd]	5.66[bc]	6.15[cd]	5.80[bc]	5.42[d]	5.85[bcd]
Intensive	RNN	5.62[d]	5.73[bc]	6.18[bc]	5.76[bc]	4.47[f]	5.72[ed]
Intensive	BNN	5.66[cd]	5.73[bc]	5.97[d]	5.86[bc]	4.54[f]	6.00[b]
Intensive	NN	5.66[cd]	6.24[a]	6.33[ab]	5.94[b]	4.98[e]	5.81[cde]
SEM		0.07	0.04	0.04	0.05	0.08	0.03
Source of Variation		***p* Value**					
Housing system		<.0001	<.0001	<.0001	<.0001	<.0001	0.0005
Genotype		<.0001	<.0001	<.0001	<.0001	0.3904	<.0001
Interaction		<.0001	<.0001	<.0001	0.0002	<.0001	0.0008

[a–f] Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

In the current experiment, a significant difference in taste was observed among different housing systems, genotypes, and their interactions. Another study suggested that semi-intensive systems yield products with superior taste compared to conventionally produced broiler chickens and free-range alternatives [10]. Similarly, another study noted that native chicken meat possesses a unique taste compared to commercial broilers [45].

Regarding aroma, a significant difference was observed among different housing systems, genotypes, and their interaction in the current experiment. Variations in aroma may arise from the release of volatile fatty acids during the cooking of meat. Another study [47] highlighted that lipid oxidation serves as an indicator of the formation of aldehydes and other low molecular weight.

3.6. Blood Biochemistry

The results of blood metabolites are presented in Table 8. BNN chickens reared in free-range housing systems had higher serum cholesterol levels ($p \leq 0.05$) (Table 6). NN chickens reared in free-range housing systems showed higher albumin levels ($p \leq 0.05$).

RNN chickens in free-range housing systems had higher serum uric acid levels ($p \leq 0.05$). Birds reared in intensive housing systems exhibited the highest glucose levels, with BNN chickens having the highest glucose levels, followed by RNN and NN. The differences in blood glucose levels among different breeds might be attributed to genetic factors as well as the metabolic rates of different genotypes. Additional exercise in birds under the free-range housing system likely caused a decrease in plasma glucose levels. However, Gunes et al. [48] found that different housing systems influenced serum glucose levels, whereas Kumar et al. [49] reported no such effect of housing systems on serum glucose levels.

Table 8. Effect of housing system and genotype on blood plasma biochemistry parameters.

Housing System	Genotype [1]	Albumin (mg/dl)	Globulin (mg/dl)	Uric Acid (mg/dl)	Glucose (mg/dl)	Cholesterol (mg/dl)
Free-range		5.20	2.02	7.78[a]	96.96[b]	202.54
Semi-Intensive		5.10	2.03	7.85[a]	102.42[a]	202.11
Intensive		5.11	1.98	7.38[b]	105.57[a]	201.03
	RNN	5.14	2.03	7.68[b]	96.17[b]	198.78[b]
	BNN	5.15	2.01	7.44[c]	110.23[a]	206.91[a]
	NN	5.12	1.99	7.89[a]	98.55[b]	199.99[b]
Free-range	RNN	5.20[ab]	2.02	8.18[a]	94.31[d]	201.18[abc]
Free-range	BNN	5.11[bc]	2.03	7.21[c]	103.57[bc]	208.91[a]
Free-range	NN	5.30[a]	2.01	7.96[ab]	92.99[d]	197.53[bcd]
Semi-intensive	RNN	5.18[ab]	2.07	7.67[b]	96.58[d]	190.74[d]
Semi-intensive	BNN	5.14[abc]	2.01	7.93[ab]	113.34[a]	207.79[ab]
Semi-intensive	NN	4.98[c]	2.00	7.95[ab]	97.36[cd]	207.80[ab]
Intensive	RNN	5.04[bc]	1.99	7.19[c]	97.63[cd]	204.42[abc]
Intensive	BNN	5.21[ab]	1.99	7.19[c]	113.79[a]	204.02[abc]
Intensive	NN	5.08[bc]	1.96	7.77[b]	105.30[b]	194.66[cd]
SEM		0.02	0.01	0.06	1.20	1.32
Source of Variation				***p* Value**		
Housing system		0.0635	0.2256	<.0001	<.0001	0.8524
Genotype		0.7558	0.0636	<.0001	<.0001	0.0099
Interaction		0.0063	0.8065	<.0001	<.0001	0.0033

[a–d] Means in the same column labeled with different letters are significantly different at a significance level of $p \leq 0.05$. [1] RNN is the crossbreed of Naked Neck and Rhode Island Red; BNN is the crossbreed of Naked Neck and Black Australorp; NN refers to Naked Neck. Traits were assessed at 52 weeks of age. The values represent least square means and pooled standard error of the mean.

In the present experiment, higher cholesterol levels were found in BNN chickens, followed by NN and RNN, while the housing system had no significant effect on serum cholesterol. The variation in cholesterol levels among different chicken genotypes is attributed to their genetic makeup. The differences in cholesterol levels of indigenous poultry breeds might be due to different levels of body activity and variable energy demands [50]. These results are consistent with the studies of Gunes et al. [48] and Sekeroglu et al. [51], which also found no significant effect of housing systems on serum cholesterol. However, Rehman et al. [50] reported contrary findings, indicating that housing systems did have a notable effect on serum cholesterol.

In this study, chickens from semi-intensive housing systems showed the highest total serum protein levels compared to those from free-range and intensive housing systems. The lower serum total protein levels in free-range birds might be due to their higher activity levels, which are associated with nitrogen loss, increased adrenal function, and protein synthesis, thereby causing an increase in total blood protein [52]. Conversely, Diktas et al. [53] found that plasma protein content was not affected by housing systems, suggesting that total protein content is related to protein intake and quality. The present study aligns with the findings of Gunes et al. [48], who reported that confinement had a notable effect on serum total protein with birds reared under intensive housing systems exhibited higher plasma total protein levels compared to those under semi-intensive and free-range systems. In our experiment, genotype did not affect the total serum protein level. Elagib et al. [52], studying the blood profiles of three different genotypes (Bare neck, Betwil, and Large Beladi), found significantly higher total protein values ($p \leq 0.05$) in Large Beladi compared to Betwil and Bare neck.

In this experiment, neither genotype nor housing system significantly affected serum albumin levels. According to Rehman et al. [50], blood albumin levels were not significantly different among birds reared under different systems, although significant differences were observed among different genotypes. Several other studies on various breeds or strains [54,55] also reported differences in albumin levels. This study found no significant differences in globulin levels among different housing systems, genotypes, or their interactions, which contrasts with the findings of Rehman et al. [50].

Significant differences were observed in uric acid levels among different housing systems, genotypes, and their interactions in this experiment. Similar results were reported by Dutta et al. [56], who found significant differences among different genotypes. Another study comparing the blood biochemical profile of Sudanese indigenous chicken breeds also showed that uric acid levels were significantly ($p \leq 0.05$) higher in Large Beladi than in the rest of the genotypes [52]. Serum creatine is a waste product linked to muscle metabolism [57]. Peters et al. [58] also found significant differences in creatinine levels among different genotypes of chickens.

5. Conclusions

In conclusion, this study demonstrated that meat quality attributes in different chicken genotypes were significantly influenced by the housing systems. Notable differences were observed in carcass yield, breast, wings, drumsticks, and neck weight across genotypes and housing systems. Sensory evaluations varied significantly, except for juiciness. Proximate analysis of meat showed variations in moisture, dry matter, ash, and ether extract among genotypes and housing systems. Blood biochemistry results revealed that intensively reared birds had higher glucose values, while semi-intensively reared birds had higher globulin levels. Among genotypes, BNN chickens exhibited higher cholesterol levels. Overall, both genotypes and housing systems had a significant impact on carcass traits, sensory evaluation, and meat proximate and mineral composition.

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