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Growth Performance and Adaptive Traits of F_1 Backcross Progenies Derived from Normal-Feathered, Naked-Neck, and Frizzle Crossbred Chickens under Humid Tropical Conditions

By

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Abstract

The development of poultry genotypes capable of sustaining high productivity under humid tropical conditions remains a major challenge in sub-Saharan Africa, where elevated temperature and humidity impose chronic environmental stress. This study evaluated the growth performance and adaptive traits of F_1 backcross progenies derived from normal-feathered (NF), naked-neck (Na), and frizzle (F) indigenous chickens crossed with an exotic broiler breeder strain (Anak), under humid tropical conditions. The experiment was conducted at the Poultry Unit of the Teaching and Research Farm, Michael Okpara University of Agriculture, Umudike, Nigeria, characterised by high ambient temperature (27–36°C maximum), relative humidity (57–91%), and annual rainfall of approximately 2,177 mm. A total of 90 parental birds (48 weeks old), comprising 45 indigenous genotypes and 45 exotic broiler breeders, were used to generate F_1 progenies through main and reciprocal crosses using artificial insemination. The resulting crossbreds, each containing 50% exotic genetic background, were reared from day-old to 18 weeks of age under standard management conditions. Growth performance traits (body weight, average daily feed intake [ADFI], feed conversion ratio [FCR], and mortality percentage) and linear body measurements (body length, wing length, keel length, shank length, breast width, drumstick length) were recorded. Data were analysed using analysis of variance in a completely randomised design, with genotype and cross direction as fixed effects. Genotype significantly influenced ($P < 0.05$) body weight, ADFI, FCR, morphometric traits, and mortality rates across ages. Reciprocal crosses consistently outperformed main crosses in growth performance. At 18 weeks, final body weights were highest in the frizzle × exotic (F × E) reciprocal cross (1666.67 g), followed by normal-feathered × exotic (NF × E) and naked-neck × exotic (Na × E). Main crosses recorded comparatively lower body weights. Average daily feed intake was significantly higher in reciprocal crosses, corresponding with improved growth. Feed conversion ratio values were consistently lower ($P < 0.05$) in reciprocal crosses, indicating superior feed efficiency, with F × E exhibiting the most favourable efficiency across evaluation periods. Linear body measurements at 18 weeks further confirmed genotype effects. Reciprocal crosses demonstrated significantly greater body length, keel length, wing length, breast width, and drumstick length compared with main crosses. The F × E genotype showed superior musculoskeletal development in both cockerels and pullets, suggesting enhanced meat-type potential under humid tropical conditions. Mortality patterns revealed significant genotype differences. Naked-neck crosses exhibited higher brooding, rearing, and laying mortality rates, indicating reduced early-life viability under the prevailing environmental conditions. In contrast, frizzle-bearing crosses recorded comparatively lower mortality, suggesting improved environmental adaptability, possibly due to enhanced heat dissipation associated with reduced plumage density. Overall, the results demonstrate that both genotype and cross direction exert significant influence on growth performance and adaptive capacity in tropical poultry production systems. Reciprocal crossing, particularly involving frizzle males and exotic females (F × E), produced progenies with superior growth rate, feed efficiency, morphometric development, and survivability. These findings underscore the importance of strategic crossbreeding and gene interaction in developing climate-resilient meat-type chickens suitable for humid tropical environments.

Keywords: *F_1 backcross; frizzle gene; naked-neck gene; reciprocal cross; feed efficiency; morphometric traits; humid tropics; poultry breeding; genotype × environment interaction.*

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INTRODUCTION

Poultry production plays a pivotal role in food security, income generation, and livelihood sustainability in sub-Saharan Africa. In Nigeria, the poultry sector contributes substantially to national animal protein supply, with an estimated standing population of approximately 180 million birds and annual outputs of meat and eggs that significantly support the country's rapidly growing population (ASL 2050, 2018). Beyond commercial production, indigenous chickens remain central to rural economies, where they serve as an accessible source of high-quality protein and supplemental household income (Gueye, 2003; Alabi et al., 2006).

Despite their socio-economic importance, Nigerian indigenous chickens are generally characterized by small body size, slow growth rate, low egg production, and relatively small egg size when compared with specialized commercial broiler and layer strains (Pedersen, 2002; Gondwe, 2004). However, these local populations possess considerable genetic variability and adaptive attributes, particularly tolerance to harsh environmental conditions, endemic diseases, and fluctuating feed resources (Msoffe et al., 2001; Fayeye et al., 2005). The absence of formal breed classification (Ibe, 2001) does not negate the existence of distinct genetic variants within indigenous populations, including major genes that influence economically important traits (Fayeye et al., 2006). Among these are plumage-reducing genes such as the naked-neck (Na) and frizzle (F) genes, which are associated with improved thermoregulatory capacity under heat stress conditions (Peters, 2000).

High ambient temperature, particularly when combined with elevated relative humidity, constitutes one of the most critical constraints to poultry productivity in tropical and subtropical environments. Heat stress negatively affects feed intake, growth rate, feed efficiency, egg production, egg quality, carcass yield, and survivability (Mahrous et al., 2003; Chen et al., 2009; Fathi et al., 2013). In humid tropical climates, birds experience reduced capacity for sensible heat dissipation due to limited evaporative cooling efficiency. Consequently, genetic strategies aimed at enhancing heat tolerance have received increasing research attention.

The naked-neck (Na) and frizzle (F) genes reduce feather coverage and alter plumage structure, thereby increasing exposed body surface area and facilitating improved heat dissipation. Birds carrying the Na gene exhibit reduced feather mass, particularly in the neck region, resulting in enhanced sensible heat loss (Yahav et al., 1998). The frizzle gene modifies feather structure through outward curling, thereby reducing feather insulation and promoting thermoregulation (Fathi et al., 2013). Additionally, reduced feather development may spare dietary protein that would otherwise be utilized for feather synthesis, potentially reallocating nutrients toward growth or egg production (Adomako, 2009).

Physiologically, these genes have been associated with endocrine and metabolic adjustments, including alterations in triiodothyronine (T3) concentration (Decuypere et al., 1993), which may partly explain their pleiotropic effects on growth and productivity. Several studies have reported that the Na and F genes exert favorable effects on growth performance, egg production, feed efficiency, and carcass traits under high ambient temperatures (Galal, 2000; El-Safty, 2006; Mahrous, 2008). Their incorporation into breeding programs has therefore been proposed as a strategic approach for developing poultry lines adapted to tropical production systems (Horst, 1988; Thiruvenkadan et al., 2010; Rajkumar et al., 2011).

Crossbreeding represents a practical genetic improvement strategy for harnessing additive and non-additive genetic effects, including heterosis and breed complementarity. Indigenous chickens often exhibit low heritability estimates for growth traits at conventional broiler market ages (6–8 weeks), reflecting strong environmental influence and non-additive gene action. Strategic crossing with improved or selected stocks can enhance growth rate, carcass yield, and reproductive performance while retaining adaptive resilience. The incorporation of plumage-reducing genes into crossbreeding schemes may therefore provide a synergistic advantage, particularly in humid tropical environments where genotype × environment interactions significantly influence productivity.

Despite extensive research on the naked-neck and frizzle genes individually, comparatively fewer studies have comprehensively evaluated the performance of F_1 and subsequent crossbred generations carrying these genes under humid tropical conditions. Understanding their growth, carcass, and early laying performance, as well as the relationships between body weight at first egg and reproductive traits, is essential for designing breeding programs tailored to tropical production systems.

Poultry production in humid tropical regions is constrained by persistent heat stress, which adversely affects growth performance, feed efficiency, reproductive output, and carcass quality. Per capita poultry meat consumption in many tropical countries remains below global averages, partly due to suboptimal productivity and limited availability of heat-tolerant, high-performing genotypes.

Indigenous chicken populations, while well adapted to local environmental stressors, are characterised by slow growth, low egg production, small body size, and modest carcass yield. Conversely, improved commercial strains exhibit superior growth and egg production but are often less adapted to high temperature and humidity. There is therefore a need to develop genetically improved stocks that combine environmental adaptability with enhanced productive performance.

The strategic utilisation of thermoregulatory plumage-modifying genes within crossbreeding programs offers a promising approach to sustainable poultry improvement in tropical climates. The naked-neck and frizzle genes reduce feather coverage, increase effective heat dissipation, and may improve productivity under thermal stress conditions. Given that modern fast-growing birds generate substantial metabolic

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heat, especially under high ambient temperatures, reduced plumage insulation can mitigate heat load and improve overall physiological stability.

Furthermore, these genes exhibit pleiotropic effects, meaning their influence extends beyond thermoregulation to include growth, carcass traits, and reproductive performance. Crossbreeding schemes incorporating Na and F genes can exploit heterosis and breed complementarity while maintaining adaptability traits inherent in indigenous stocks.

As poultry production continues to expand in tropical and subtropical regions, identifying genetic combinations that enhance resilience and productivity under humid conditions becomes increasingly important. This study, therefore, provides empirical evidence to support breeding strategies aimed at developing heat-tolerant, high-performing crossbred chickens suitable for sustainable poultry production in the humid tropics.

MATERIALS AND METHODS

Study Location

The experiment was conducted at the Poultry Unit of the Teaching and Research Farm, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria (Latitude 05°29′N; Longitude 07°33′E; altitude ≈122 m above sea level). The area lies within the humid rainforest agro-ecological zone of south-eastern Nigeria and is characterised by a hot-humid tropical climate.

Mean daily temperatures range from 20–26°C (minimum) to 27–36°C (maximum), with relative humidity between 57–91% and an average annual rainfall of approximately 2,177 mm. These climatic conditions typify the humid tropics and present environmental challenges relevant to poultry genetic adaptation and performance evaluation.

Experimental Design and Parent Stock Management

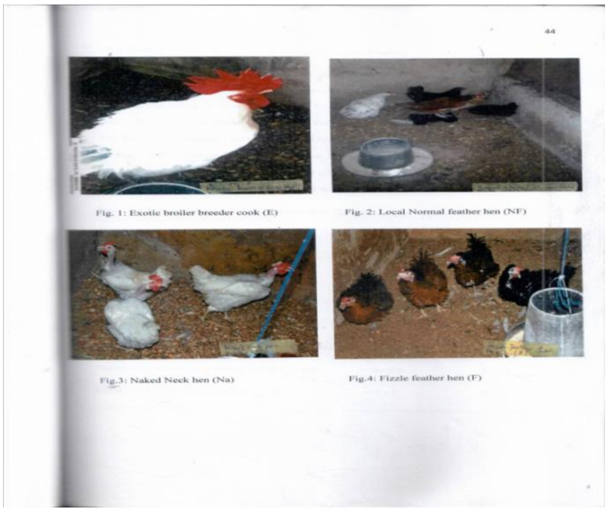
Parent Stock

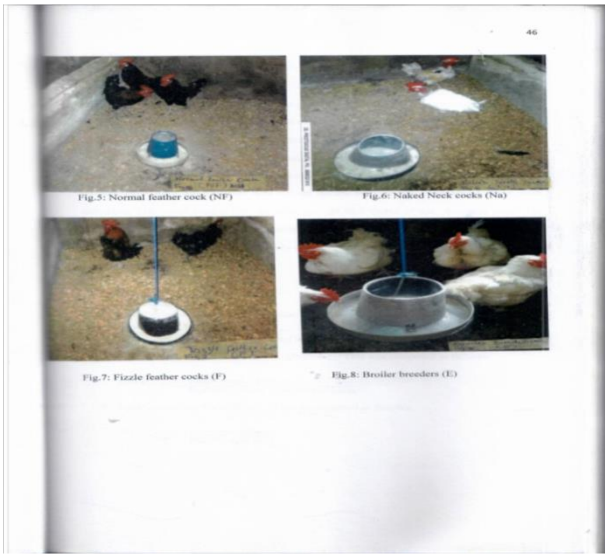
A total of 90 adult chickens (48 weeks old) were used as the parental population, comprising:

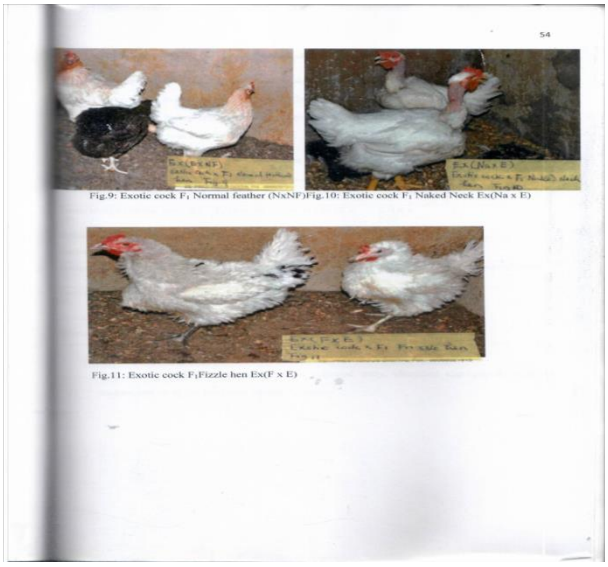
i. 45 indigenous genotypes (normal-feathered, naked-neck, and frizzle)

ii. 45 exotic broiler breeder birds (Anak strain)

Birds were managed under a deep-litter system and fed a commercial layer mash. Clean drinking water was provided *ad libitum*. A photoperiod of 18 hours (12 h natural daylight + 6 h artificial light) was maintained to stimulate reproductive performance. Standard vaccination and biosecurity protocols were implemented, including Newcastle disease, infectious bursal disease (IBD), and routine prophylactic treatments where necessary.







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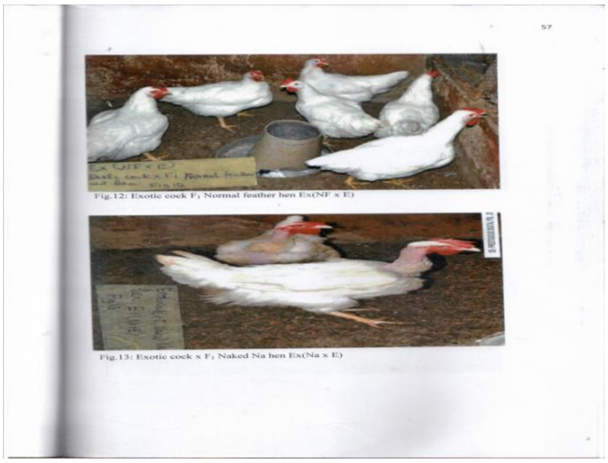

Mating Scheme and Production of F_1 Crossbreds

F_1 progenies were generated through main and reciprocal crosses using artificial insemination, following the procedure described by Lake et al. (1985). Artificial insemination was adopted to minimise fertility bias due to body size differences between indigenous and exotic birds.

Birds were randomly allocated to mating pens at a ratio of 2 females: 1 male. The mating design is summarised below:

Main Cross

i. Exotic cock (E) × Normal-feathered hen (NF)

ii. Exotic cock (E) × Naked-neck hen (Na)

iii. Exotic cock (E) × Frizzle hen (F)

Reciprocal Cross

i. Normal-feathered cock (NF) × Exotic hen (E)

ii. Naked-neck cock (Na) × Exotic hen (E)

iii. Frizzle cock (F) × Exotic hen (E)

All F_1 progenies contained 50% exotic genetic background.

Fertilised eggs were collected daily, stored for ≤7 days at 10–14°C and 75–80% relative humidity, fumigated, and incubated under standard hatchery conditions.

Management of F_1 Progenies (0–12 Weeks)

The experimental evaluation of F_1 progenies was conducted from day-old to 12 weeks of age**.**

Brooding Phase (0–6 Weeks)

Day-old chicks were individually wing-tagged for identification and brooded in genotype-specific pens under a deep-litter system. Supplemental heat was provided using kerosene brooders and 60-W electric bulbs as required.

Birds were fed a commercial starter diet containing approximately 23% crude protein from 0–6 weeks. Clean water was provided *ad libitum*.

Vaccination schedule are Newcastle disease (Day 7 and Day 28) and Infectious Bursal Disease (Day 14 and Day 21). Routine health monitoring and biosecurity practices were strictly maintained.

Grower Phase (7–12 Weeks)

At 6 weeks of age, birds were transitioned to a grower diet containing approximately 15–16% crude protein and maintained under similar management conditions.

Vaccinations administered during this phase included fowl pox vaccine (via wing web at Week 6) and Newcastle disease (Komarov strain at Week 8)

Prophylactic treatments were administered only when necessary based on veterinary assessment.

Data Collection

Growth Performance Traits

Data were collected weekly from 0 to 12 weeks.

i. **Body Weight (g):** Measured individually using a digital weighing scale.

ii. **Average Daily Feed Intake (ADFI; g/bird/day):**

$$\text{ADFI} = \frac{\text{Feed Given} - \text{Left over}}{\text{Number of days} \times \text{Number of birds}}$$

Feed Conversion Ratio (FCR): This was computed as follows:

$$\text{FCR} = \frac{\text{Daily feed intake}}{\text{Daily weight gain}}$$

Mortality per cent (M %): This was computed as follows:

$$\text{M\%} = \frac{\text{Total number dead at the end of the brooding phase}}{\text{Total number of birds at the beginning of the experiment}} \times 100$$

Body Conformation Traits

Linear body measurements were obtained weekly using a flexible measuring tape and digital callipers where appropriate. Measurements included:

i. Breast girth (cm)

ii. Keel length (cm)

iii. Shank length (cm)

iv. Thigh length (cm)

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v. Wing length (cm)

vi. Body length (cm; beak tip to longest toe, excluding claw)

vii. Drumstick length (cm)

All measurements were taken on live birds following standard morphometric procedures.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using a completely randomised design (CRD). The statistical model included the fixed effects of genotype and cross type (main vs reciprocal). Where significant differences ($p < 0.05$) were detected, means were separated using Duncan's Multiple Range Test (or Tukey's HSD, depending on your final choice of software).

All statistical analyses were performed using appropriate statistical software.

RESULTS AND DISCUSSION

Growth Performance of F_1 Crossbred Chickens

Mean Body Weight

The mean body weights of the F_1 crossbred chickens from week 2 to week 18 are presented in Table 1. Genotype significantly influenced ($P < 0.05$) body weight at all ages evaluated. Across weeks, reciprocal crosses consistently outperformed the main crosses. At week 2, body weights ranged from 67.04 ± 4.12 g to 91.74 ± 7.95 g among the main crosses and from 82.11 ± 3.09 g to 129.74 ± 0.95 g among the reciprocal crosses.

This superiority of reciprocal crosses persisted up to week 18, where final body weights reached 1415.43 ± 97.00 g (NF × E), 1314.23 ± 65.33 g (Na × E), and 1666.67 ± 77.86 g (F × E). The F × E genotype recorded the highest body weight at market age, indicating enhanced growth potential.

The observed genotype-dependent variation in body weight corroborates previous findings that growth traits in chickens are strongly influenced by genetic constitution. Studies have reported significant effects of sire and dam lines on progeny growth performance, particularly when indigenous genotypes are crossed with exotic meat-type strains. The superior performance of reciprocal crosses suggests the presence of maternal effects and favourable gene interactions, possibly reflecting heterosis and better adaptability to the humid tropical environment.

Although some reports indicate growth advantages of naked neck or frizzle genotypes under heat stress conditions, results remain inconsistent across environments. In the present study, the reciprocal frizzle cross (F × E) demonstrated superior growth, suggesting that combining the frizzle gene with exotic germplasm may enhance growth efficiency under humid tropical conditions.

The consistently higher body weights recorded in reciprocal crosses suggest improved adaptation and genetic complementarity when the exotic strain was used as the dam line. These findings highlight the importance of cross-direction in designing breeding strategies for meat-type development in indigenous poultry populations.

Table 1: Mean Body Weight (g) of F_1 Crossbred Normal feathered, Naked neck and Frizzle Chickens (sex combined)

Genetic groups	Main crosses →		Reciprocal crosses →		
E x NF	E x Na	E x F	NF x E	Na x E	F x E
$67.04±4.12^{e}$	$76.54±4.48^{d}$	$91.74± 7.95^{ab}$	$82.11±3.09^{c}$	$101.29±1.20^{b}$	$129.74±0.95^{a}$
$91.53± 4.95^{e}$	$98.00±11.97^{d}$	$121.17±12.30^{c}$	$162.91±0.33^{b}$	$176.81±2.50^{3ab}$	$178.48±3.98^{a}$
$192.91±4.30^{e}$	$195.81±4.38^{d}$	$192.44±4.20^{e}$	$255.58±9.40^{c}$	$313.15±13.90^{b}$	$339.87±22.90^{a}$
$223.75±6.23^{e}$	$245.58±11.96^{d}$	$275.13±10.80^{c}$	$355.00±52.02^{b}$	$371.92±60.35^{ab}$	$426.29±52.97^{a}$
$343.26±23.34^{f}$	$364.00±19.05^{e}$	$395.13±31.00^{d}$	$475.65±10.97^{c}$	$541.11±22.01^{b}$	$596.09±9.97^{a}$
$474.11±21.22^{e}$	$495.80±33.43^{d}$	$586.88±10.09^{c}$	$635.66±21.51^{b}$	$741.21±46.14^{ab}$	$756.32±22.43^{a}$
$564.90±20.09^{f}$	$585.97±31.22^{e}$	$676.35±54.55^{d}$	$835.84±29.87^{c}$	$904.45±49.90^{b}$	$956.81±51.08^{a}$
$730.29±49.85^{e}$	$751.33±48.90^{d}$	$842.17±39.02^{c}$	$1015.51±66.06^{b}$	$1114.04±42.87^{b}$	$1166.33±112.08^{a}$
$875.05±61.95^{d}$	$896.72±44.86^{d}$	$987.65±121.87^{c}$	$1415.43±97.00^{a}$	$1314.23±65.33^{b}$	$1666.67±77.86^{a}$

$^{a-f}$Means±Standard Error of mean with different superscripts in the same row are significantly different ($P<0.05$)

Average Daily Feed Intake (ADFI)

Average daily feed intake (ADFI) is presented in Table 2. Genotype significantly affected ($P < 0.05$) feed intake at all ages evaluated.

Across weeks, reciprocal crosses consumed more feed than the main crosses. At week 2, ADFI ranged from 8.76–11.14 g among the main crosses and 18.87–19.56 g among the reciprocal crosses. By week 18, feed intake increased to 68.34–74.05 g in the main crosses and 92.06–94.01 g in the reciprocal crosses.

The higher feed intake observed in reciprocal crosses likely contributed to their superior body weights. Increased voluntary feed intake may reflect enhanced metabolic demand and growth capacity. However, higher intake alone does not indicate efficiency unless accompanied by improved feed conversion, as observed in this study.

Previous studies have reported inconsistent effects of naked neck and frizzle genes on feed intake. While some authors observed no genotype effect on feed intake, others reported higher consumption in normal-feathered birds. The present findings indicate that cross-direction exerts a stronger influence on feed intake than feather genotype alone.

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Table 4.2: Average Daily Feed Intake (ADFI) of F₁ Crossbred Normal feathered, Naked neck and Frizzle Chickens

Genetic groups	Main crosses			Reciprocal crosses		
Age (weeks)	E x NF	E x Na	E x F	NF x E	Na x E	F x E
2	11.14±0.81[b]	9.17±0.01[b]	8.76±0.21[b]	18.87±0.86[a]	19.33±0.64[a]	19.56±0.39[a]
4	19.45±0.98[c]	15.22±0.87[d]	14.76±0.75[d]	28.04±1.07[b]	29.53±1.15[a]	30.96±1.87[a]
6	25.97±1.97[d]	23.16±1.02[c]	20.87±0.88[c]	40.98±1.59[c]	43.45±1.90[b]	46.91±1.18[a]
8	34.14±1.54[b]	31.76±1.90[b]	31.95±1.91[b]	59.32±1.68[a]	62.01±2.09[a]	64.19±3.86[a]
10	44.11±0.14[c]	40.55±1.88[d]	39.05±2.11[d]	64.90±3.12[b]	67.44±2.97[ab]	69.10±2.89[a]
12	53.00±1.11[b]	52.24±1.94[b]	52.87±1.89[b]	75.80±3.90[a]	76.77±3.54[a]	75.98±2.98[a]
14	61.02±1.80[b]	59.96±2.95[b]	56.90±2.98[b]	79.90±2.54[a]	82.33±2.09[a]	80.65±2.57[a]
16	67.17±0.60[b]	64.54±1.97[b]	63.90±3.07[b]	85.55±3.30[a]	87.89±3.80[a]	84.47±2.22[a]
18	74.05±1.88[b]	69.23±0.37[c]	68.34±3.14[c]	92.06±2.98[a]	94.01±1.86[a]	93.88±1.77[a]

[a–d]Means±Standard Error of mean with different superscripts in the same row are significantly different (P<0.05)

Feed Conversion Ratio (FCR)

Feed conversion ratio (FCR) values are presented in Table 3. Significant differences (P < 0.05) were observed among genotypes at all ages except week 8.

Reciprocal crosses exhibited significantly lower FCR values compared to the main crosses, indicating superior feed efficiency. Among all genotypes, the F × E reciprocal cross consistently recorded the lowest FCR, corresponding with its highest body weight.

FCR is a key performance indicator reflecting the efficiency with which birds convert feed into body mass. Lower numerical FCR values indicate superior efficiency. The improved FCR observed in frizzle-bearing reciprocal crosses supports earlier reports that frizzle and naked neck genes may enhance thermoregulation and nutrient utilisation under hot conditions.

The superior performance of F × E suggests a favourable interaction between the frizzle gene and exotic genetic background, resulting in enhanced growth efficiency under humid tropical conditions.

Table 3: Feed Conversion Ratio (FCR) of F₁ Crossbred Normal feathered, Naked neck and Frizzle Chickens

Genetic groups	Main crosses			Reciprocal crosses		
Age (weeks)	E x NF	E x Na	E x F	NF x E	Na x E	F x E
2	3.22±0.04[a]	3.18±0.01[ab]	3.08±0.01[b]	2.11±0.01[c]	2.06±0.06[c]	2.03±0.01[d]
4	3.65±0.07[a]	3.45±0.04[b]	3.23±0.22[c]	2.87±0.09[d]	2.41±0.50[e]	2.13±0.04[e]
6	3.66±0.02[a]	3.58±1.07[a]	3.36±0.81[b]	2.61±1.87[c]	2.34±0.05[d]	2.20±0.01[d]
8	2.45±0.10	2.32±1.00	2.26±0.95	1.95±0.66	2.56±1.09	1.69±0.00
10	3.55±0.10[a]	3.48±0.02[b]	3.40±1.08[c]	3.12±1.07[d]	3.09±1.86[d]	3.01±1.08[e]
12	3.76±0.03[a]	3.69±0.02[a]	3.51±0.01[b]	2.46±0.04[c]	2.21±0.02[d]	2.17±2.08[d]
14	4.25±1.09[a]	3.98±1.08[a]	3.62±1.10[b]	2.76±0.99[d]	2.64±0.78[c]	2.71±1.84[d]
16	3.67±0.03[a]	3.51±1.03[a]	3.24±0.55[b]	2.98±0.04[c]	2.75±1.08[d]	2.53±1.21[e]
18	3.97±0.61[b]	3.86±0.66[a]	3.34±1.02[b]	2.67±0.02[c]	2.82±1.91[c]	2.49±0.92[d]

[a–e]Means±Standard Error of mean with different superscripts in the same row are significantly different (P<0.05)

Linear Body Measurements (LBM)

Body weight and linear body measurements (LBM) of cockerels and pullets at 18 weeks are presented in Tables 4 and 5. Genotype significantly affected (P < 0.05) most morphometric traits.

Reciprocal crosses exhibited greater body length, wing length, keel length, drumstick length, and breast width compared to the main crosses. However, shank length was generally higher in the main crosses.

Among reciprocal crosses, F × E birds showed superior morphometric development in both sexes, consistent with their higher body weights and improved growth performance. Larger breast width and keel length indicate enhanced musculoskeletal development and potential meat yield advantages.

The observed genotype differences confirm that morphometric traits are under strong genetic control and may serve as indirect selection criteria for meat-type improvement in indigenous chickens.

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Table 4: Body Weight and Linear Body Measurements (LBM) of Cockerels in Various Genetic Groups at 18 Weeks

Genetic groups	Main crosses →			Reciprocal crosses →		
Parameters	**E x NF**	**E x Na**	**E x F**	**NF x E**	**Na x E**	**F x E**
BW (g)	1250±30.55^{d}	1120±65.01^{d}	1110±10.87^{d}	2098.98±63.57^{b}	1650.02±20.97^{c}	2550.00±53.85^{a}
BL (cm)	34.89±0.87^{b}	32.44±0.56^{c}	33.21±0.32^{c}	39.25±1.08^{b}	36.09±0.56^{b}	42.19±1.19^{a}
WL (cm)	16.79±0.16^{b}	17.34±1.64^{b}	17.77±0.91^{b}	19.11±0.55^{ab}	23.34±0.13^{a}	21.98±0.30^{a}
KL (cm)	12.08±0.32^{c}	12.03±0.15^{c}	13.44±0.71^{b}	15.67±0.38^{a}	13.17±0.74^{b}	16.22±0.81^{a}
SL (cm)	9.53±0.23^{b}	10.91±0.44^{a}	9.64±0.34^{b}	10.23±0.39^{ab}	9.19±0.38^{b}	10.18±0.37^{ab}
BRWT	11.38±0.88^{d}	9.98±0.88^{e}	10.38±0.22^{e}	14.14±0.21^{b}	12.54±0.12^{c}	16.77±0.19^{a}
(cm)	10.00±0.71^{b}	10.66±0.79^{b}	9.53±0.80^{b}	12.21±0.78^{a}	11.70±0.81^{ab}	12.65±0.18^{a}
DS (cm)						

$^{a-e}$Means±Standard Error of mean with different superscripts in the same row are significantly different (P<0.05). BW = Body weight, BL = Body length, WL = Wing length, KL = Keel length, SL = Shank length, BRWT = Breast width, DS = Drumstick

The results also showed that among the reciprocal crossbreds, the F x E hybrids in both cockerels and pullets had superior body weight and better LBM, hence had growth potential in the tropical environment

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Table 5: Body Weight and Linear Body Measurements (LBM) of Pullets in Various Genetic Groups at 18 Weeks

Genetic groups	Main crosses →			Reciprocal crosses →		
Parameters	**E x NF**	**E x Na**	**E x F**	**NF x E**	**Na x E**	**F x E**
BW (g)	775.00±52.02^{c}	826.29±52.97^{c}	751.92±60.35^{c}	1670.89±71.01^{ab}	1240.83±65.63^{b}	1850.19±69.62
BL (cm)	30.52±3.51^{b}	23.54±1.29^{c}	28.66±1.61^{b}	33.78±1.62^{ab}	34.99±1.60^{a}	^{a}
WL (cm)	13.12±3.87^{c}	15.76±0.83^{bc}	12.98±0.29^{c}	16.12±1.44^{b}	19.54±1.48^{a}	35.03±1.76^{a}
KL (cm)	9.44±0.70	8.75±0.53	9.41±0.69	11.07±0.72	10.48±0.72	19.14±0.86^{a}
SL (cm)	8.25±0.40^{b}	10.28±0.38^{a}	8.18±0.38^{b}	9.83±2.72^{ab}	7.63±0.57^{b}	12.66±0.79
BRWT (cm)	10.07±0.72^{c}	8.15±0.11^{c}	9.04±0.66^{c}	13.04±0.40^{ab}	11.11±0.55^{b}	8.47±0.72^{ab}
DS (cm)	7.71±0.59^{d}	9.11±0.61^{c}	8.19±0.80^{c}	11.15±0.27^{ab}	10.02±0.90^{b}	14.71±1.19^{a}
						12.00±0.57^{a}

$^{a-e}$Means±Standard Error of mean with different superscripts in the same row are significantly different (P<0.05). BW = Body weight, BL = Body length, WL = Wing length, KL = Keel length, SL = Shank length, BRWT = Breast width, DS = Drumstick

Mortality Rates

Mortality rates during brooding, rearing, and laying phases are presented in Table 6. Significant genotype effects (P < 0.05) were observed across all phases.

Brooding mortality was highest in crosses involving the naked neck genotype (E × Na and Na × E). Similarly, rearing mortality remained higher in these groups compared to others. Laying mortality was also elevated in E × Na.

The increased mortality associated with naked neck genotypes agrees with earlier reports suggesting reduced embryonic viability and early post-hatch survivability, particularly when the gene occurs in homozygous form. Increased embryonic malposition and metabolic disturbances have been suggested as contributing factors.

Conversely, frizzle-bearing crosses recorded lower laying mortality, supporting previous reports that the frizzle gene may confer adaptive advantages under high ambient temperatures through improved heat dissipation.

Overall, the findings indicate that while frizzle crosses demonstrated favourable growth and survivability under humid tropical conditions, naked neck crosses exhibited reduced early-life viability.

Table 6: Brooding, Rearing and Laying Mortality in F_1 Crossbred Normal feathered, Naked Neck, and Frizzle Chickens

Genetic groups	Main crosses →			Reciprocal crosses →		
Parameters	**E x NF**	**E x Na**	**E x F**	**NF x E**	**Na x E**	**F x E**
Brooding mortality (%)	0.54±0.01^{c}	36.67±7.40^{a}	23.90±0.81^{b}	22.10±0.78^{b}	34.44±0.80^{a}	25.42±0.32^{b}
Rearing mortality (%)	13.87±0.35^{c}	24.89±1.87^{b}	18.65±0.30^{cd}	16.90±0.98^{d}	25.43±0.64^{a}	20.18±0.32^{c}
Laying	0.57±0.00^{c}	26.67±2.72^{a}	0.57±0.00^{c}	0.57±0.00^{c}	4.90±0.30^{b}	0.57±0.00^{c}

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mortality (%)

[a–c]Means±Standard Error of mean with different superscripts in the same row are significantly different (P<0.05)

Conclusion

The results demonstrate that:

i. Genotype and cross direction significantly influence growth performance, feed efficiency, morphometric development, and survivability.
ii. Reciprocal crosses consistently outperformed main crosses.
iii. The F × E reciprocal cross showed the most favourable combination of growth rate, feed efficiency, and body conformation.
iv. Naked neck genotypes were associated with higher early-life mortality.

These findings underscore the importance of cross-direction and gene interactions in poultry breeding programmes aimed at improving meat-type performance under humid tropical environments.

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