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RESEARCH ARTICLE

Productive and Reproductive Performance Diversity of Indigenous Chicken in Eritrea

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Abstract

Background and Objective: Poultry production in Eritrea is predominantly traditional and relies largely on indigenous chickens (ICs). This study evaluated the productive and reproductive variability among IC ecotypes across 16 sub-regions, representing approximately 24% of the country's administrative areas.
Materials and Methods: Data were collected from 384 households across 105 villages using structured questionnaires. Egg weight and external egg quality traits were measured using digital balances and calipers. Non-parametric variables related to broodiness management were analyzed using chi-square (χ^2) tests in SPSS version 27 and visualized with DATAtab. Parametric traits, including inter-clutch period (ICP), hatchability, survivability and productivity parameters, were analyzed using analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) test in JMP Pro 17. The influence of traditional broodiness management practices on ICP was further evaluated using a generalized linear mixed model (GLMM) implemented in RStudio version 4.3.0 with the *glmmTMB* package. Farmers' trait preferences were quantified using the Relative Importance Index (RII), while effective population size (N_e) and inbreeding rate (ΔF) were estimated for mature flocks.
Results: Significant variation was observed in broodiness control practices ($\chi^2 = 475.36$, $p < 0.001$), with 72% of farmers employing leg-tying, which significantly influenced ICP ($F = 10.4058$, $p<0.001$). The longest ICPs were recorded in the BAR (5.92 weeks) and GOG (4.50 weeks) ecotypes. GLMM results indicated that only traditional management practices had a significant effect on ICP ($p<0.05$). Across ecotypes, mean brooding frequency was 2.54 times per hen per year, with an average of 10.94 eggs set per clutch. Mean hatchability was 81.27% (range: 73.78-87.90%), while chick survivability to eight weeks averaged 51.31% (range: 45.19-61.88%). Productivity parameters showed that cockerels reached mating age at 5.55±0.04 months, while pullets attained first egg laying at 6.29±0.03 months. Hens averaged 3.39±0.045 clutches per year, 12.08±0.14 eggs per clutch and 40.77±0.70 eggs per year, with significant variation among ecotypes ($p<0.0001$). Mean egg weight was 44.15±0.33 g (range: 35.19-50.89 g; $p<0.0001$) and the mean shape index was 74.91±0.24% ($p = 0.0308$). Farmers ranked egg production as the most important trait in hens (RII = 0.81) and plumage colour as the most important trait in cocks (RII = 0.88). The mean effective population size was 4.6, corresponding to an inbreeding rate of 11.4% per generation.
Conclusion: The findings demonstrate substantial productive and reproductive diversity among indigenous chicken ecotypes in Eritrea, highlighting opportunities for targeted genetic improvement and sustainable management strategies tailored to specific production objectives.

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INTRODUCTION

The Global South, which is home to nearly half of the world's population, remains heavily dependent on agriculture for subsistence livelihoods and is characterized by pronounced income and wealth inequalities[1,2]. In the context of intensifying climate change impacts-manifested through rising temperatures and the increasing emergence of zoonotic infectious diseases there is an urgent need to promote agricultural practices that are sustainable and adapted to the socio-economic and environmental realities of these regions[3]. Within this framework, targeted evaluation of Indigenous Chicken (IC) variants is particularly important. The global poultry population was estimated at approximately 34.4 billion birds in 2023, with Africa contributing about 2.07 billion, underscoring the continent's substantial role in the global poultry sector[5]. Chickens account for approximately 90% of the global poultry population[6]. In Africa, chickens constitute nearly 80% of total poultry numbers, the majority of which are indigenous ecotypes[7]. Indigenous chickens represent more than 70% of the total chicken population in sub-Saharan Africa[8]. Furthermore, in East Africa, including Eritrea, over 75% of rural households are engaged in indigenous chicken production, with approximately 80% of the population residing in rural areas[8,9].

Poultry production in Eritrea is predominantly traditional, commonly referred to as backyard or village-based production systems and is practiced in both rural and urban households[10]. This system relies almost exclusively on indigenous chicken ecotypes, which constitute approximately 95% of the national chicken population in Eritrea[5,12] Indigenous chickens play a critical role in the livelihoods of rural, resource-constrained households by contributing to income generation and poverty alleviation[13]. They possess valuable adaptive traits, including thermo-tolerance, disease resistance and desirable meat quality[14]. For marginalized rural women in particular, indigenous chickens serve as a reliable source of income due to their low capital requirements, scavenging ability, self-propagation and adaptability to harsh tropical environments[15,16].

Despite these advantages, indigenous chickens generally exhibit low production potential, which limits their contribution to meeting the growing demand for animal protein in developing countries . In Eritrea, empirical data on indigenous chicken productivity remain limited. A study by Habteslasie[10] in the Gash-Barka region reported that male indigenous chickens reached first mating at 5.46 months, while females laid their first egg at 6.08 months, with significant regional variation. On average, indigenous chickens produced approximately 4 clutches per year, with about 14 eggs per clutch, resulting in an annual egg production of about 56 eggs per hen under traditional management systems[17]. Low productivity, slow growth rate, late sexual maturity and limited egg output constrain the contribution of indigenous chickens to household food security and income generation[18,19]. Consequently, genetic improvement aimed at enhancing productivity, reproductive performance and adaptability-without compromising the inherent hardiness of indigenous chickens-represents a strategic and urgently needed intervention[19]. However, comprehensive evaluations of the performance characteristics of diverse indigenous chicken ecotypes in Eritrea are currently lacking. Therefore, this study assessed variability in productivity, reproductive performance and survivability of indigenous chicken ecotypes across 16 sub-regions, providing a critical foundation for the development of effective and sustainable genetic improvement programs.

MATERIALS AND METHODS

Nomenclature and classification of indigenous chicken ecotypes: This study adopted the nomenclature and classification system proposed by Tadelle *et al.*[20], in which indigenous chicken (IC) ecotypes are identified according to their geographical origin. Accordingly, each ecotype was designated by the name of its corresponding sub-region.

Study area description and data collection: The study was conducted in Eritrea, located in the Horn of Africa and encompassed 16 sub-regions representing approximately 24% of the country's administrative sub-regions across four major administrative regions. Figure 1 shows the study area in Eritrea. The selected sub-regions ranged in elevation from 21 to 2528 m above sea level and were chosen based on several criteria, including high indigenous chicken population density, limited introduction of exotic breeds, strategic relevance, accessibility and proximity to market centers[17]. A preliminary reconnaissance survey, conducted in collaboration with local administrative authorities, confirmed the distribution and dominance of indigenous chickens within the selected locations. The sub-regions included in the study, along with their corresponding abbreviations, are presented in Table 1.

Sampling framework: A multistage sampling design incorporating purposive, random and systematic techniques was employed to select administrative regions, sub-regions, villages and households at the national level. The number of households sampled from each village was allocated proportionally to village size, using Google Earth Pro

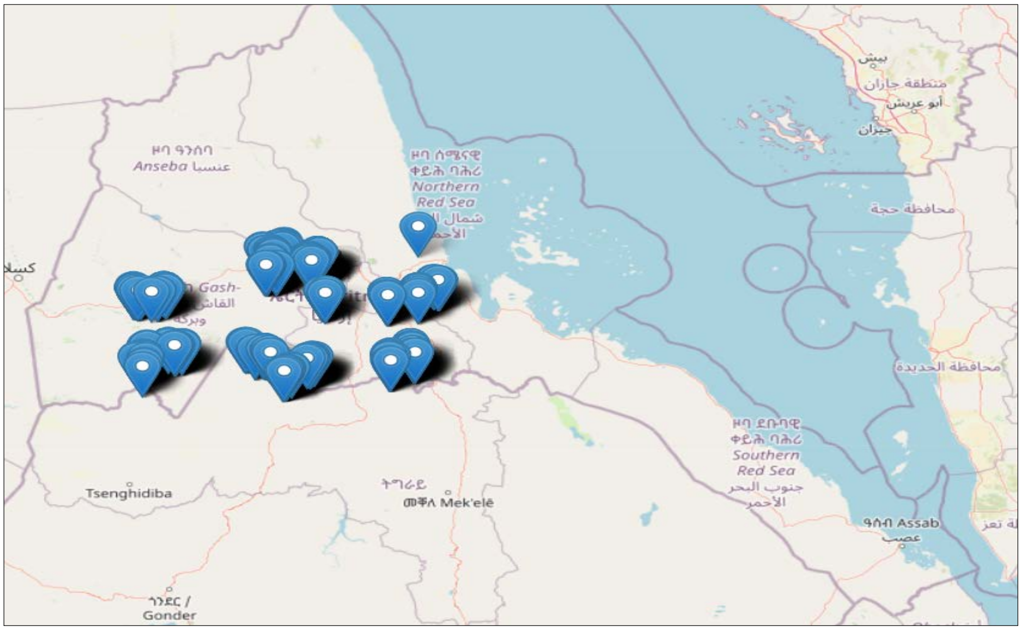

Fig. 1: Map of the study area in Eritrea

Table 1: Ecotypes/sub-regions and their respective abbreviations

Number	Ecotype/sub-region	Code
1	Adi-Tekeliezan	ADTEK
2	Keren	KER
3	Hagaz	HAGZ
4	Mensura	MEN
5	Barentu	BAR
6	Gogne	GOG
7	Tokonbia	TOK
8	Shambqo	SHAM
9	Molqi	MOLQ
10	Emni-Haili	HAYL
11	Mai-ayni	AYNI
12	Dekemhare	DEKE
13	Adikeyh	KEIH
14	Mai-mne	MNE
15	Foro	FORO
16	Fshe-Mrara	FM

satellite imagery[21], following methodologies described by Habteslassie[10] and Vougat *et al.*[22]. The overall household sample size was determined using Cochran's (1963) formula for infinite populations ($\geq$50,000), as applied in previous studies by Mahoro *et al.*[23]:

$$N = \frac{z^2 \times p \times q}{e^2}$$

Where:

N : Required sample size
Z : z-score for the desired level of confidence (1.96 for 95% confidence)
p : Estimated proportion of population with the characteristics of interest
q : 1-p
e : Desired margin of error

Based on the findings of Habteslassie[10], which indicated that approximately 70% of households rear ICs, a sample size of 384 households was calculated to estimate this proportion with precision. The calculation was conducted using a 95% confidence level and a 5% margin of error.

Data were systematically collected from 384 households across 105 villages distributed among 16 sub-regions. Data collection involved the use of a structured questionnaire, direct field observations and standardized measurements. Semi-structured interviews were conducted to document indigenous knowledge related to chicken production systems and their performance. Individual IC egg weights were measured using a digital balance with a precision of 0.01 g. Egg dimensions, including length and width, were measured using a caliper, following the methodologies described by Wang *et al.*[24] and Habteslassie[10].

Statistical analysis: The χ^2 test, together with descriptive statistics, was used to evaluate variation in categorical data for non-parametric variables, particularly those related to broodiness-breaking practices. These analyses were performed using IBM SPSS version 27[25], while graphical data visualization was conducted using DATAtab[26]. For parametric variables, including inter-clutch period, hatchability rate, survivability rate and productivity performance of IC, analysis of variance was followed by Tukey's Honestly Significant Difference (HSD) test for *post hoc* comparisons where significant mean differences were detected. These analyses were conducted using JMP Pro 17[27]. Hatchability rate was calculated according to the methods of Ahmed and Ahmed[28] and Damte *et al.*[29], defined as the ratio of hatched chicks to the total number of eggs set and expressed as a percentage. Similarly, survivability rate was calculated as the proportion of chicks surviving to eight weeks relative to the total number of chicks hatched, multiplied by 100, in accordance with the approaches of Damte *et al.*[29] and Desta and Wakeyo[17]. Egg shape index was calculated using the following formula, as described by Wijedasa *et al.*[30] and Wang *et al.*[24]:

$$\text{Shape Index (\%)} = \frac{\text{Egg width (mm)}}{\text{Egg lenght (mm)}} \times 100$$

A linear model was used to assess the impact of ecotype on broody hen performance such as hatchability, chick survival up to 8 weeks, broodiness frequency per hen per year, eggs set per broody hen and on production parameters includes age at first mating for cockerels, age at first egg for pullets, number of clutches per hen per year, clutch length in days, eggs per clutch, eggs per year, egg weight, egg length, egg width and egg shape index. The model was specified as:

$$Y_{ij} = \mu + \alpha_{ith} + \varepsilon_{ij}$$

Where:

Y_{ij} : Dependent variable for the ij-th ecotype
μ : Overall mean
α_i : Effect of the ith sub-region
ε_{ij} : Residual error term

To evaluate the effects of traditional management practices on inter-clutch period (ICP) across Eritrean sub-regions, a generalized linear mixed model (GLMM) was applied. This modelling framework accommodated categorical predictors (ecotypes) and binary predictors (management practices), with ICP duration specified as the continuous response variable. The model included one random effect (384 households) and multiple fixed effects, namely 16 sub-regions, three agroecological zones classified by elevation (highland, midland and lowland), feed supplementation frequency (0-3 times per day) and traditional interventions employed to interrupt broodiness. Statistical analyses were conducted in RStudio (version 4.3.0) using the *glmmTMB* package.

Normality assessment of ICP count data using Q-Q plots (Appendix) and the Shapiro-Wilk test (p-value $= 5.83 \times 10^{3}$) indicated a substantial deviation from normality; therefore, a negative binomial distribution was adopted. Evidence of overdispersion was observed, as the variance (3.08) exceeded the mean (2.81). Model simplification was performed using backward elimination, retaining only statistically significant predictors ($p<0.05$). The final model, specified with a negative binomial error distribution and incorporating the retained fixed effects, was expressed as follows:

$$\log(\mu_i) = \beta_0 + \sum_{k=1}^{k} \beta_k X_{ik} + \mu_{j[j]}$$

Where:

μ_i : Expected ICP for observation i
β_0 : Intercept
β_k : Coefficients for the kth predictors variable
X_{ik} : Predictor values (including ecotypes, agroecology, feed supplementation frequency and traditional practices)
$u_{j[i]}$: The random intercept for household j
K : The number of fixed effect predictors

Farmers' trait preferences were evaluated using the Relative Importance Index (RII) model, following the methodologies described by Kapella *et al.*[31] and Chen *et al.*[32]. The RII approach quantifies the relative importance of selected criteria through a transformation matrix scaled from 0 to 1, where higher values indicate greater importance and lower values represent reduced importance. This non-parametric method was applied to data obtained from structured questionnaires employing a five-point Likert scale (1 = not important, 2 = slightly important, 3 = neutral, 4 = very important, 5 = extremely important). Farmers evaluated a total of 14 traits-seven associated with hens and seven associated with cocks-based on the framework proposed by Habteslassie[10]. The RII was calculated as:

$$\text{Relative Importance Index (RII)} = \frac{\sum W}{A \times N}$$

where:

W : Weight given to each factor by respondents,
A : Highest possible weight (5)
N : Total number of respondents (N = 384)

The effective population size (N_e) and the rate of inbreeding (ΔF) were estimated for flocks maintained by households possessing mature breeding males, using the formula proposed by Falconer and Mackay (1996), consistent with the approaches described by Habteslassie[10], Mahoro *et al.*[23] and Yussif *et al.*[33]:

$$N_e = \frac{4N_m N_f}{N_m + N_f}$$

where, N_e denotes the effective population size, N_m represents the number of breeding males and N_f denotes the number of breeding females.

The effective population size (N_e) was subsequently employed to estimate the expected level of inbreeding within the population, as it provides a widely accepted metric for assessing inbreeding risk[33]. The inbreeding coefficient increment per generation (ΔF) was calculated for each study sub-region as well as for the overall population using N_e values, following the methodology outlined by Yussif *et al.*[33]. The rate of inbreeding was determined using the expression:

$$\Delta F = \frac{1}{2N_e}$$

Where:

ΔF : The expected increase in inbreeding per generation

N_e : Corresponds to the effective population size

RESULTS

Across the surveyed sub-regions, the majority of households employed a range of traditional practices to mitigate broodiness (Fig. 2), primarily to enhance egg production by inducing broody hens to resume laying. Overall, nine distinct broodiness-breaking methods were documented, with their adoption varying significantly among sub-regions ($\chi^2 = 475.36$, $p<0.001$). Tying the hen's leg was the most widely practiced method, reported by 72% of households. This practice was particularly prevalent in DEKE (95.83%), KEIH

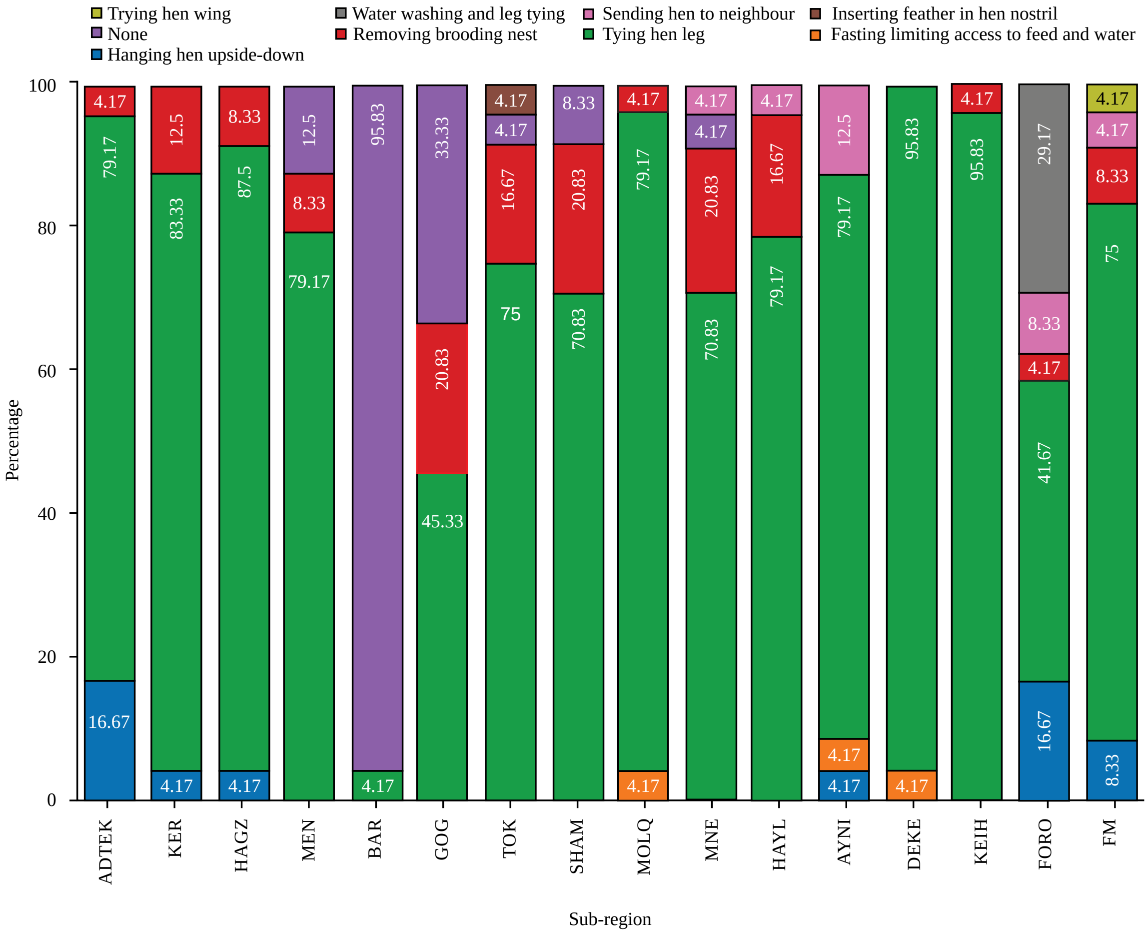

Fig. 2: Traditional methods of breaking broodiness

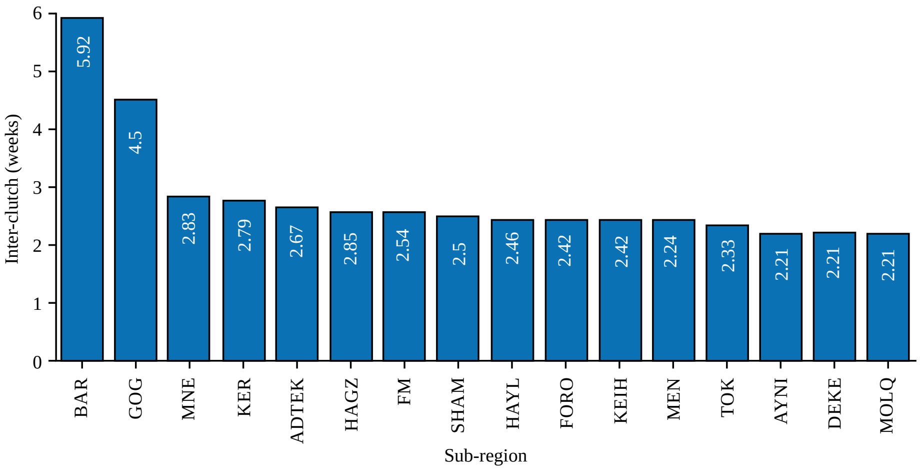

Fig. 3: Mean inter-clutch in weeks across studied sub-regions

(95.83%), ADTEK (79%), KER (83%), HAGZ (87.5%), MEN(79.17%), TOK (75%), SHAM (70.83%), MOLQ (91.67%), MNE (70.83%), HAYL (79.17%), AYNI (79.17%) and FM (75%).

Removal of the brooding nest was reported by 9% of farmers, notably in the GOG, SHAM and MNE sub-regions. Other practices were less frequently employed, including hanging the hen upside down (3%), relocating the broody hen to a different location (2%), combining leg-tying with washing the hen (2%), restricting access to feed and water (1%) and tying the wing or inserting a feather into the nostrils (1%). In contrast, a high proportion of farmers in BAR (95.83%), GOG (33.33%) and MEN (12.5%) reported the absence of any traditional management practices to control broodiness.

These findings are consistent with previous reports from Eritrea by Habteslassie[10] and from southern Ethiopia by Shanku and Amanuel[34], which documented similar broodiness-management practices within indigenous chicken production systems.

The effects of the nine broodiness-breaking practices on inter-clutch periods differed significantly among the studied sub-regions (F = 10.4058, $p<0.001$) (Fig. 3). The longest inter-clutch periods were recorded in the BAR and GOG sub-regions, with mean durations of 5.92 and 4.50 weeks, respectively. Notably, these sub-regions also exhibited the lowest levels of adoption of traditional broodiness-breaking practices (Fig. 2). In contrast, the remaining 14 sub-regions showed comparatively shorter and more uniform inter-clutch periods, ranging from 2.21 weeks in Molqi to 2.83 weeks in May-mne, with no statistically significant differences observed among them.

Impact of traditional management practices on inter-clutch interval: A Generalized Linear Mixed Model (GLMM) with a negative binomial distribution was employed to evaluate the relationship between the inter-clutch interval, expressed as the number of weeks until the subsequent laying cycle and ecological, management and supplementation-related factors across the studied sub-regions. Household identity was included as a random effect to account for within-household variation. Initial model evaluation using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and log-likelihood values (AIC = 1265.4, BIC = 1387.8, log-likelihood = −601.7) indicated that traditional management practices were the only factors exerting a statistically significant effect on the inter-clutch interval ($p<0.05$) (Table 2). In contrast, ecotype, agroecological zone and feed supplementation showed no significant associations with the inter-clutch period.

A stepwise backward elimination procedure was subsequently applied to remove non-significant predictors ($p>0.05$), thereby improving model parsimony and goodness of fit. Consistent with the stricter penalization of model complexity imposed by BIC relative to AIC[35], the final and most parsimonious model retained traditional management practices as the sole explanatory variable, providing an optimal balance between model simplicity and explanatory power (Table 2).

Trait preference: Table 3 summarizes farmers' preferences for selected hen traits. Overall, breeding hens were predominantly selected based on productivity-related characteristics (Table 3). Egg production emerged as the most important trait, with a relative importance index (RII) of 0.81, followed by hatchability (RII = 0.75) and maternal ability, which recorded an RII of 0.44. Preferences for these traits were largely consistent across the studied sub-regions, with egg production consistently ranked as the most important trait (rank 1) in several locations, including KER, HAGZ, MEN and

Table 2: Refined model examining the impact of traditional management practices on inter-Clutch Intervals

Variable/parameter	classification	Coefficient of estimate	Standard error	z-value	Pr(>|z|)
Intercept		0.9614	0.1715	5.61	2.1e-08***
Traditional practices	Feed restriction	-0.1141	0.4151	-0.27	0.78
Traditional practices	Tying leg	-0.0767	0.1758	-0.44	0.66
Traditional practices	Taking away nest	-0.1382	0.2040	-0.68	0.50
Traditional practices	None	0.8982	0.1831	4.91	9.3e-07 ***
Traditional practices	Feather on nostril	-0.2683	0.7276	-0.37	0.71
Traditional practices	transfer to neighbour	-0.0451	0.2818	-0.16	0.87
Traditional practices	Dipping in water with leg tying	-0.0741	0.2970	-0.25	0.80
Traditional practices	Tying wing	0.1372	0.6023	0.23	0.82

Percentages with asterisks (***) within the same column for a specific parameter are highly significantly different ($p<0.001$), AIC (1241.3), BIC (1284.8), loglik (-609.7)

Table 3: Household preference on hen traits

Hen trait	UNIM	SLIM	MO	IM	VRIM	Total weight	N	A*N	RII	Rank
Egg production	3	66	219	432	835	1555	384	1920	0.8099	1
Egg size	95	146	144	180	90	655	384	1920	0.3411	4
Hatchability	11	60	264	608	500	1443	384	1920	0.7516	2
Plumage colour	88	138	72	32	245	575	384	1920	0.2995	6
Hen mothering behaviour	79	174	399	176	25	853	384	1920	0.4443	3
Body weight	97	180	45	88	175	585	384	1920	0.3047	5
Feather pattern	10	8	9	16	50	93	384	1920	0.0484	7

Unimportant (UNIM), Slight-Important (SLIM), Moderate (MO), Important (IM), Very-important (VRIM)

Table 4: Household preference on cock traits

Cock trait	UNIM	SLIM	MO	IM	VRIM	Total weight	N	A*N	RII	Rank
body weight	16	148	591	152	290	1197	384	1920	0.6234	3
plumage colour	1	4	114	572	1000	1691	384	1920	0.8807	1
comb type	11	78	186	648	530	1453	384	1920	0.7568	2
mating frequency	10	6	3	0	0	19	384	1920	0.0099	7
shank type/colour	254	114	45	40	15	468	384	1920	0.2438	5
body size	63	404	210	120	75	872	384	1920	0.4542	4
feather pattern	29	14	3	4	10	60	384	1920	0.0313	6

Unimportant (UNIM), Slight-Important (SLIM), Moderate (MO), Important (IM), Very-important (VRIM)

BAR. In contrast, hatchability (rank 2) was identified as the most critical trait in sub-regions such as Adi-tekelezan, Tokombia and Shambqo.

In the context of cock selection (Table 4), the majority of farmers exhibited a strong preference for plumage colour, as indicated by the highest relative importance index (RII) value of 0.88. This trait was followed in importance by comb type (RII = 0.76) and body weight (RII = 0.62). Consistent with these findings, Habteslassie[10] reported that the cock breed most commonly preferred in Eritrea is characterized by red or reddish-brown plumage and a rose comb.

Effective population size and rate of inbreeding: Effective population size (N) at both the household (HH) and sub-regional (SR) levels was estimated based on the recorded numbers of breeding males and females within each tier, as summarized in Table 5. At the household level, the highest N values were observed in the TOK, FM and DEKE sub-regions, with corresponding values of 6.80, 6.07 and 5.94, respectively. In contrast, effective population sizes at the sub-regional level were substantially larger for the same sub-regions, reaching 163.15, 145.69 and 142.65, respectively. The lowest N estimates were recorded in MNE, ADTEK and KEIH, with household-level values of 2.88, 3.45 and 3.60 and sub-regional-level values of 69.00, 82.71 and 86.36, respectively.

With respect to inbreeding, higher rates of inbreeding per generation (ΔF) were observed in MNE, ADTEK and KEIH at the household level, with coefficients of 17.39, 14.51 and 13.90% per generation, respectively. At the sub-regional level, the corresponding inbreeding rates were markedly lower, at 0.72, 0.60 and 0.58% per generation. Conversely, the lowest household-level inbreeding rates were recorded in TOK (7.36%), FM (8.24%) and DEKE (8.41%), which is consistent with their relatively larger effective population sizes at the household level.

Hatchability and survivability of chicks: Parameters related to hatchability performance and chick survivability within the production system are summarized in Table 6. Analysis of brooding practices across the studied sub-regions revealed significant variation in the annual brooding frequency per hen. The BAR sub-region exhibited the highest mean brooding

Table 5: Effective population size and rate of inbreeding at household and sub-region level

		Sub-Region/Ecotype															
Level	Parameter	ADTEK	KER	HAGZ	MEN	BAR	GOG	TOK	SHAM	MOLQ	MNE	HAYL	AYNI	DEKE	KEIH	FORO	FM
HH	Nm	1.08	1.21	1.58	1.58	2.00	1.63	2.21	1.46	1.54	0.96	1.21	1.29	1.79	1.25	1.63	2.00
	Nf	4.21	5.38	5.67	4.38	4.08	4.54	7.38	4.00	4.67	2.88	3.92	4.13	8.71	3.21	4.13	6.29
	Ne	3.45	3.95	4.95	4.65	5.37	4.79	6.80	4.27	4.64	2.88	3.69	3.93	5.94	3.60	4.66	6.07
	ΔF(%)	14.51	12.67	10.10	10.75	9.31	10.44	7.36	11.70	10.79	17.39	13.54	12.71	8.41	13.90	10.72	8.24
SR	NM	26.00	29.00	38.00	38.00	48.00	39.00	53.00	35.00	37.00	23.00	29.00	31.00	43.00	30.00	39.00	48.00
	Nf	101.00	129.00	136.00	105.00	98.00	109.00	177.00	96.00	112.00	69.00	94.00	99.00	209.00	77.00	99.00	151.00
	Ne	82.71	94.71	118.80	111.61	128.88	114.89	163.15	102.60	111.25	69.00	88.65	94.43	142.65	86.36	111.91	145.69
	ΔF(%)	0.6	0.53	0.42	0.45	0.39	0.44	0.31	0.49	0.45	0.72	0.56	0.53	0.35	0.58	0.45	0.34

HH: Households, SR: Sub-region, Nm: Number of males, Nf: Number of females, Ne: Effective population size and F: Inbreeding rate

Table 6. Hatchability and survivability parameters

	Parameter (Mean±SE)					
Ecotype	Average frequency of brooding/hen/year	Egg set to broody hen	Rate of hatching egg	Hatchability (%)	Survival rate 8 weeks	Survival to 8 weeks (%)
ADTEK	2.42±0.13^{bcdef}	11.21±0.22^{abcd}	9.17±0.29^{abc}	81.83±2.09^{ab}	5.42±0.37^{ab}	58.93±3.13^{abc}
AYNI	2.63±0.13^{bcde}	10.21±0.29^{bcd}	8.21±0.34^{bc}	80.45±2.33^{ab}	4.58±0.28^{abc}	55.78±2.43^{abc}
BAR	4.08±0.19^{a}	12.17±0.47^{a}	10.38±0.49^{a}	85.33±2.36^{ab}	5.29±0.46^{ab}	50.31±3.26^{abc}
DEKE	2.08±0.10^{ef}	11.13±0.19^{abcd}	9.25±0.31ab^{c}	83.35±2.53^{ab}	5.75±0.33^{a}	61.88±2.55^{a}
FM	2.21±0.16^{cdef}	11.79±0.31^{ab}	10.17±0.36^{ab}	86.09±1.67^{a}	4.88±0.35^{abc}	48.75±3.98^{abc}
FORO	2.58±0.15^{bcde}	9.92±0.44^{cd}	7.50±0.37^{c}	76.16±2.40^{ab}	3.42±0.32^{c}	45.19±3.01^{c}
GOG	2.83±0.18^{bcd}	11.29±0.37^{abc}	8.96±0.46^{abc}	79.04±2.74^{ab}	4.25±0.37^{abc}	46.53±2.74^{bc}
HAGZ	1.71±0.14^{f}	12.13±0.33^{a}	9.58±0.43^{ab}	78.62±2.28^{ab}	4.88±0.37^{abc}	50.54±2.69^{abc}
HAYL	2.33±0.14^{bcdef}	11.21±0.22^{abcd}	8.25±0.31^{bc}	73.78±2.57^{b}	5.00±0.32^{abc}	60.57±2.94^{ab}
KEIH	2.29±0.09^{cdef}	10.58±0.26^{abcd}	8.25±0.39^{bc}	77.48±2.67^{ab}	4.92±0.40^{abc}	59.53±3.62^{abc}
KER	2.17±0.13d^{ef}	11.63±0.33^{abc}	9.21±0.45^{abc}	78.46±2.77^{ab}	4.58±0.34^{abc}	49.00±2.76^{abc}
MEN	1.92±0.13^{ef}	10.58±0.54^{abcd}	8.29±0.66^{bc}	76.53±3.65^{ab}	3.88±0.43^{bc}	45.16±2.78^{c}
MNE	2.88±0.13^{bcd}	10.04±0.34^{cd}	8.54±0.39^{abc}	84.56±2.32^{ab}	4.21±0.37^{abc}	48.20±3.45^{abc}
MOLQ	3.04±0.15^{b}	9.54±0.29^{d}	8.17±0.31^{bc}	85.68±2.09^{ab}	3.75±0.24^{bc}	45.80±2.31^{c}
SHAM	2.92±0.22^{bc}	10.29±0.34^{bcd}	8.83±0.46^{abc}	85.10±2.58^{ab}	4.13±0.25^{abc}	46.95±2.31^{bc}
TOK	2.58±0.16^{bcde}	11.38±0.49^{abc}	10.00±0.52^{ab}	87.90±2.38^{a}	4.83±0.37^{abc}	47.85±2.77^{abc}
Over-all	2.54±0.89	10.94±0.095	8.92±0.11	81.27±0.65	4.61±0.09	51.31±0.78
F-value	13.952	5.1183	3.8087	2.9158	3.2876	4.0086
p-value	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001

Mean with asterisks (^{abc}) within the same column for a specific parameter are highly significantly different at respected p-value and SE: Standard error

frequency, at 4.08±0.19 times per year, followed by MOLQ (3.04±0.15) and SHAM (2.92±0.22). In contrast, the HAGZ sub-region recorded the lowest annual brooding frequency, at 1.71±0.14, indicating a pronounced disparity among sub-regions ($p<0.0001$).

The mean number of eggs set per broody hen across the investigated sub-regions was 10.94, with significant variation observed among ecotypes ($p<0.0001$). The highest averages were recorded in BAR and HAGZ, with 12.17 and 12.13 eggs per hen, respectively, whereas the lowest values were observed in MOLQ and FORO, at 9.54 and 9.92 eggs per hen, respectively. Sub-regions such as HAGZ and BAR, which exhibited larger clutch sizes (Table 7), correspondingly recorded a greater number of eggs set per broody hen (Table 6). Hatchability rates differed significantly among sub-regions ($p<0.0001$), with the highest value reported in TOK (87.9%) and the lowest in HAYL (73.78%). Chick survivability at 8 weeks of age also varied significantly across ecotypes, with the highest survival rates observed in DEKE (61.88%) and HAYL (60.57%). Overall, the mean chick survivability across the 16 sub-regions was 51.31%, with the lowest rates recorded in FORO (45.19%) and MOLQ (45.80%).

Productive performance of indigenous chicken: The reproductive and productive performance parameters of indigenous chickens (ICs), presented in Table 7, included age at sexual maturity, annual clutch frequency, clutch duration, number of eggs per clutch and annual egg production. In the present study, the mean age at first mating of cockerels was 5.55±0.04 months, while pullets reached first egg-laying at 6.29±0.03 months. No significant variation was observed in the age at onset of mating among cockerels across ecotypes ($p = 0.7934$), indicating a relatively uniform attainment of sexual maturity. In contrast, the age at first egg-laying varied

Table 7: Productive and reproductive performance of IC

	Parameter (Mean±SE)					
Ecotype	Age cockerel 1st mating	Age pullet 1st egg	Number/clutch/hen/year	Clutch length in days	Egg per clutch	Egg/year
ADTEK	5.21±0.22	6.17±0.14^{b}	3.18±0.16^{bcd}	17.13±1.16	11.42±0.47^{b}	35.73±1.94^{cd}
AYNI	5.67±0.14	6.25±0.09^{b}	3.19±0.13b^{cd}	16.17±0.97	12.21±0.48^{ab}	38.34±1.67^{bcd}
BAR	5.63±0.20	6.21±0.15^{b}	4.22±0.20^{a}	17.88±1.00	12.63±0.44^{ab}	53.07±2.93^{a}
DEKE	5.75±0.22	6.96±0.18^{a}	3.14±0.14^{bcd}	15.33±0.74	11.13±0.66^{b}	34.98±2.60^{cd}
FM	5.79±0.16	6.42±0.17^{ab}	3.48±0.22^{abcd}	19.00±1.25	14.25±0.81^{a}	48.52±3.37^{ab}
FORO	5.42±0.18	6.25±0.12^{b}	3.60±0.14^{abcd}	17.71±1.32	12.08±0.70^{ab}	42.61±2.39^{abcd}
GOG	5.63±0.16	6.29±0.09^{b}	3.610.21^{abcd}	14.96±0.81	11.29±0.35^{b}	40.98±2.90^{abcd}
HAGZ	5.54±0.22	6.25±0.09^{b}	2.91±0.18^{d}	18.08±1.20	12.29±0.65^{ab}	34.99±2.17^{cd}
HAYL	5.63±0.20	6.38±0.15^{ab}	2.99±0.13^{cd}	18.46±1.20	13.21±0.72^{ab}	39.62±2.74^{bcd}
KEIH	5.54±0.13	6.21±0.1^{b}	2.88±0.12^{d}	18.29±0.95	11.17±0.39^{b}	32.09±1.67^{d}
KER	5.42±0.18	6.42±0.15^{ab}	3.24±0.16^{bcd}	19.00±1.09	11.63±0.46^{ab}	38.17±2.85^{bcd}
MEN	5.63±0.13	6.17±0.12^{b}	3.09±0.16^{bcd}	18.04±1.17	11.38±0.53^{b}	34.60±2.15^{cd}
MNE	5.54±0.16	6.13±0.13^{b}	3.39±0.18^{bcd}	16.25±0.63	11.96±0.55^{ab}	40.54±2.69^{abcd}
MOLQ	5.42±0.17	6.25±0.14^{b}	3.79±0.18^{abc}	16.13±0.74	12.17±0.53^{ab}	46.16±3.26^{abc}
SHAM	5.46±0.16	6.04±0.04^{b}	3.81±0.14^{ab}	17.13±0.78	12.21±0.45^{ab}	46.14±2.23^{abc}
TOK	5.63±0.15	6.21±0.08^{b}	3.74±0.17^{abc}	17.42±0.77	12.21±0.59^{ab}	45.81±3.17^{abc}
Over-all	5.55±0.04	6.29±0.03	3.39±0.045	17.31±0.25	12.08±0.14	40.77±0.70
F-value	0.6914	2.6687	5.1493	1.5045	2.0825	5.1111
p-value	0.7934	0.0007	<0.0001	0.1005	0.0102	<0.0001

Mean with asterisks (abc) within the same column for a specific parameter are highly significantly different at respected p-value; SE= Standard error

significantly among ecotypes (p<0.0001), with DEKE exhibiting the highest mean age (6.96±0.18 months), while SHAM and MNE recorded the lowest ages, at 6.04±0.04 and 6.13±0.13 months, respectively.

Significant differences were also observed in annual clutch frequency per hen among ecotypes (p<0.0001). The highest clutch frequency was recorded in BAR (4.22±0.20), followed by SHAM (3.81±0.14), yielding an overall mean of 3.39±0.045 clutches per year. In contrast, KEIH (2.88±0.12) and HAGZ (2.91±0.18) exhibited the lowest annual clutch frequencies. Clutch duration did not differ significantly among ecotypes (p = 0.1005) and averaged 17.31±0.25 days. However, the number of eggs per clutch varied significantly across the 16 sub-regions (p = 0.0102). The highest mean number of eggs per clutch was observed in FM (14.25±0.81), followed by HAYL (13.21±0.72) and BAR (12.63±0.44), resulting in an overall mean of 12.08±0.14 eggs. The lowest clutch sizes were recorded in ADTEK (11.42±0.47), DEKE (11.13±0.66), GOG (11.29±0.35), KEIH (11.17±0.39) and MEN (11.38±0.53), as detailed in Table 7.

A highly significant variation in estimated annual egg production was observed among the surveyed sub-regions (p<0.0001), with an overall mean of 40.77±0.70 eggs per hen per year. The highest annual egg production was recorded in BAR (53.07±2.93 eggs) and FM (48.52±3.37 eggs). These were followed by TOK, SHAM and MOLQ, which exhibited statistically comparable levels of production, with mean values of 45.81±3.17, 46.14±2.23 and 46.16±3.26 eggs per hen per year, respectively. In contrast, the lowest annual egg production was observed in KEIH (32.09±1.67 eggs per hen per year), a value that did not differ significantly from those recorded in ADTEK (35.73±1.94), DEKE (34.98±2.60), HAGZ (34.99±2.17) and MEN (34.60±2.15).

Table 8 summarizes the external egg quality traits of the 16 indigenous chicken (IC) ecotypes. Statistically significant differences (p<0.05) were observed among ecotypes for egg weight (g), egg width (mm), egg length (mm) and egg shape index (%), reflecting the combined influence of genetic (ecotype-related) and environmental factors on egg morphology in IC populations. Overall, the mean egg weight was 44.15±0.33 g and the relatively high F-value (24.35) together with the low p<0.0001) indicate pronounced differentiation among ecotypes. The FM ecotype produced the heaviest eggs (50.89±0.85 g), whereas the GOG and BAR ecotypes recorded the lowest egg weights, at 35.19 ± 0.93 g and 35.85±1.08 g, respectively.

The egg shape index is a key parameter for characterizing avian species and serves as an important indicator of egg quality and subsequent chick survival[36]. In the present study, egg shape index values ranged from 71.96% in SHAM to 76.61% in TOK, with most ecotypes clustering around the overall mean value of 74.91% (Table 8).

DISCUSSION

Traditional methods for breaking broodiness and their impact on inter-clutch intervals: Broodiness in indigenous chickens (ICs) is a critical trait, serving as the primary natural mechanism for egg incubation. However, extended broody periods can substantially reduce lifetime egg production[37].

As noted by Zalal *et al.*[38], traditional practices aimed at terminating broodiness are designed to shorten the reproductive cycle by targeting the brooding, setting and rest phases, thereby minimizing inter-clutch periods (ICPs) between successive egg-laying cycles.

The predominant methods identified in the present study, including tying the hen's legs and removing the brooding nest, are consistent with previous reports from Eritrea[10] and southern Ethiopia[34]. Interventions such as disturbing the laying nest or restricting a broody hen's mobility can effectively terminate broodiness within 3-4 days, depending on the intensity of the broody behavior[39]. In regions like Eritrea, where extension services supporting village-level IC production remain limited[10], farmers rely heavily on indigenous knowledge transmitted across generations. Practices such as leg-tying have gained widespread acceptance due to their demonstrated effectiveness based on communal experience. Nevertheless, some farmers avoid these interventions due to concerns regarding potential hen mortality or uncertainty about their ability to enhance egg production.

The primary objective of these traditional interventions is to accelerate reproductive cycles and reduce ICPs[40]. However, many of these practices carry inherent drawbacks, including increased risk of disease transmission when broody hens are relocated to neighboring households and inhumane procedures-such as inserting feathers into the nostrils or restricting access to food and water-which may elevate mortality. Therefore, rigorous evaluation of their effects on ICP duration is essential.

In the present study, households that did not employ traditional broodiness-breaking practices exhibited significantly prolonged ICPs (estimate = 0.8982, $p < 9.3 \times 10$) compared to those that applied these methods. Other examined practices showed no significant impact on ICPs, with p-values ranging from 0.5 to 0.87, indicating negligible deviation from the baseline. Furthermore, the minimal random effect of household identity (variance = 8.19×10) suggests that the impact of these practices is consistent across households. The selection of a negative binomial model over a Poisson model, due to overdispersion (2.14×10), further validates the robustness of the analytical approach.

Ecological, management and supplemental factors were found to have limited influence on ICPs in ICs, reflecting their high adaptability to diverse environmental conditions[19]. As Kpomasse *et al.*[19] reported, ICs have evolved to reproduce efficiently across varied habitats, relying minimally on external management interventions. Physiologically, broodiness is initiated by a surge of prolactin from the pituitary gland, which suppresses reproductive hormones, induces ovarian regression and halts egg production[41]. Traditional practices, such as nest removal and leg-tying, disrupt the stimuli maintaining this broody state, thereby facilitating the resumption of the egg-laying cycle[40].

Trait preference: Consistent with the observations of Habteslassie[10], most households in the studied sub-regions lack access to improved chicken breeds and breeding control within existing systems remains limited. Nevertheless, farmers' selection of traits is influenced by multiple factors, including market objectives, household consumption needs, cultural practices and environmental conditions[42]. The pronounced preference for hen traits associated with productive and reproductive performance in this study aligns with findings from Kapella *et al.*[31] in Tanzania and Adan[43] in Ethiopia. As reported by Kapella *et al.*[31], rural households depend on egg production both as a source of high-quality protein and as a means of income generation and flock expansion. Selecting hens that produce more eggs per clutch directly contributes to food security and improves household livelihoods. Additionally, prioritizing hatchability ensures effective flock replenishment, particularly under conditions of high mortality, where restocking through purchase is often expensive or logistically challenging[10,44].

For cocks, the strong preference for plumage colour (RII = 0.88) observed in this study is consistent with reports from Eritrea[10] and several Ethiopian regions, including Amhara[45], Dire Dawa[43], Oromia[46] and Tigray[47]. As noted by Kapella *et al.*[31], farmers generally prioritize traits associated with egg and chick production in hens, whereas physical attributes are more highly valued in cocks, particularly under free-range management where cocks are more likely to be sold or consumed. Aklilu *et al.*[48] reported a preference for double-combed birds over single-combed birds, although black-coloured chickens were culturally perceived as bringing misfortune. Habteslassie[10] explains that the term "DIRB," used by local Tigrigna speaking communities, collectively refers to both pea and rose comb types and reflects the belief that roosters with double combs are more suitable for breeding than those with single combs. However, concerns regarding reduced fertility in males carrying the Rose-comb allele have been documented in several studies, including Dahloum *et al.*[49]. Supporting evidence from Egahi *et al.*[50] and further corroborated by Eiki[51] in Namibia suggests that the preference for pea and rose combs is particularl strong among traditional worshippers in Nigeria and Namibia, likely influencing these selection practices.

Effective population size and inbreeding rate: The effective population size (N_e) and inbreeding rate (ΔF) across sub-regions such as FORO, MOLQ, SHAM, GOG, MEN and HAGZ (Table 5) are consistent with previous reports[10,43]. Both Birara *et al.*[45] and Habteslassie[10] noted that the presence of free-roaming indigenous chickens (ICs) and the absence of breeding males in some households can compromise the accuracy of N_e and ΔF estimates due to reliance on uncontrolled natural mating. Similarly, Chebo *et al.*[52] emphasized that maintaining multiple cocks in such production systems is inefficient, as frequent dominance interactions among males reduce reproductive success.

The N_e of a flock is determined by the number of breeding males and females at a given time and is therefore sensitive to fluctuations in flock size and management practices, which consequently influence the rate of inbreeding per generation[53]. Vucetich *et al.*[54] further demonstrated that skewed sex ratios substantially reduce N_e, thereby increasing ΔF, since the inbreeding rate is inversely proportional to N_e. Population bottlenecks, arising from disease outbreaks or seasonal culling, further exacerbate reductions in N_e and elevate ΔF. Given that N_e is calculated as the harmonic mean of population sizes across generations, even transient bottlenecks can exert a pronounced impact on N_e[55].

Observed variation in ΔF among households and sub-regions is consistent with the findings of Tadele *et al.*[56], primarily attributable to differences in N_e, which is strongly influenced by the number of breeding males and females. Higher N_e and lower ΔF values in the TOK and FM sub-regions correspond to larger numbers of breeding males and females, reflecting greater flock sizes per household. These sub-regions benefit from favorable environmental conditions, including superior scavenging feed availability, fertile soils and higher rainfall, which likely support larger flock sizes.

The overall mean N_e of 4.6 observed in this study is lower than that reported in Kenya (6.03)[57], Uganda (2200)[33] and Indonesia's Kokok Balenggek chickens (ranging from 38-279)[58] but higher than the 0.76-1.14 reported for the Amhara Region of Ethiopia[45]. Similarly, the mean inbreeding coefficient of 11.41% in this study exceeds those reported in Uganda (0.023%)[33], Indonesia (0.18-1.33%)[58] and Kenya (8.25%)[57], yet remains lower than the 44-65% observed in Ethiopia's Amhara Region[45].

Hatchability and chick survivability: Habteslassie[10] reported that in Eritrea, local farmers in different sub-regions select specific months for egg incubation and brooding of day-old chicks under broody hens, depending on factors such as household feed availability, ambient temperature for the broody hen, seasonal conditions affecting the chicks (e.g., rain, mud and other wet-season challenges that reduce survivability) and the presence of predators. In the present study, the annual average brooding frequency per hen (2.54 times) was comparable to Habteslassie[10], who reported 2.81 times in the Gash-Barka region of Eritrea and Assefa *et al.*[59], who reported 2.02 times in the Oromia region of Ethiopia. Variations in annual brooding frequency across sub-regions and ecotypes are largely attributed to environmental factors, particularly climate, ambient temperature and feed availability[60]. Increased feed availability can enhance the number of clutches per year, thereby raising brooding frequency[60]. Moreover, ecological and climatic stressors, such as heat load and disease pressure, influence the expression of broodiness[61]. Management and selection practices by farmers also play a significant role: broodiness may be suppressed to sustain egg production through traditional broodiness-breaking methods, or alternatively, encouraged to ensure flock replacement[10,62]. Since broodiness is a heritable, polygenic trait, genetic differences among ecotypes likely contribute to the observed regional variation in brooding frequency[63,64].

The mean number of eggs set per broody hen across the investigated sub-regions (10.94) was consistent with reports from Tanzania[65] (10.88 eggs) and Rwanda[23] (10.3 eggs). However, these values were lower than those reported by Habteslassie[10] in Eritrea (11.02 eggs), Assefa *et al.*[59] in Oromia (15.24 eggs), Birara *et al.*[45] in Amhara (12.4 eggs) and Dassidi *et al.*[66,67] in Chad (11.48 and 12.43 eggs, respectively). The number of eggs set under a broody hen directly influences hatchability; exceeding the hen's incubation capacity by a single egg can reduce hatchability by approximately 0.23%[41]. Habte *et al.*[39] indicated that the number of eggs set per hen is determined by factors including egg availability, egg size, broody hen size and maternal instinct. In the present study, sub-regions such as HAGZ and BAR, which exhibited higher egg clutch sizes (Table 7), correspondingly had a greater number of eggs set per broody hen (Table 6).

Hatchability and chick survivability: Hatchability rates varied significantly among the ecotypes ($p<0.0001$), with an overall hatchability across the study area of 81.27%, closely aligning with reports from northern Rwanda (81.37%)[68] and Ethiopia (81.72%)[69]. This value, however, is lower than the rates reported in Tanzania (83.71%)[65], western Rwanda (85.03%)[68] and Bangladesh (87.9%)[38] but higher than those documented in Eritrea (76.87%)[10], Fiji (78%)[70] and the Amhara region of Ethiopia (79.90%)[71]. According to Sonaiya and Swan (2004), as cited in Habteslassie[10], a hatchability rate of approximately 80% under broody hen incubation is considered normal, with a satisfactory range of 75-80%. Consequently, the observed hatchability of 81.27% in this study falls within the expected range.

Mekonnen *et al.*[72] highlight that hatchability performance in IC ecotypes fluctuates seasonally, as incubation outcomes under broody hens are strongly influenced by the timing of egg setting within the year. Similarly, Okeno *et al.*[57] reported that Ics with unrestricted access to vitamin-rich green pastures during scavenging exhibit improved fertility, emphasizing the critical role of vitamins in reproductive performance. Alemu and Terfa[40] further indicate that hatchability is affected by multiple factors, including the nutritional and health status of hens, genetic traits and the physical, storage and incubation conditions of the eggs. Seasonal variations and the number of eggs set per broody hen also contribute to differences in hatchability rates.

Habteslassie[10] observed that local communities in Eritrea employ diverse traditional materials to create suitable environmental conditions for broody hens, including locally made mud containers. Bedding materials vary according to ambient temperature and resource availability, ranging from donkey and goat dung to soil and ash[10]. Additionally, egg storage practices and selection criteria for incubation differ among communities, contributing to regional disparities in hatchability due to variations in management and environmental conditions.

Chick survivability at eight weeks of age also varied significantly, with an average survivability rate across the 16 sub-regions of 51.31%, consistent with previous reports such as 48.6% in the Gash-Barka region of Eritrea[10], 53.4% in the wet region of Fiji[70] and 55.64% in two districts of Tanzania[65]. The relatively low chick survival rates observed in this study, corroborated by Habteslassie[10], are largely attributed to high mortality caused by accidents, disease, predation, feed scarcity and suboptimal management practices. Alders and Pym[73] suggest that regional variations in chick survival are influenced by context-specific interventions adapted to local constraints. Furthermore, Habteslassie[10] reported that communities in different sub-regions of Eritrea employ localized strategies to mitigate chick mortality, including ethno-veterinary practices and innovative predator protection methods, such as the use of mosquito nets and other locally available materials, contributing to sub-regional differences in survivability.

Productive performance of indigenous chickens: The age at first mating for cockerels observed in this study is comparable to previous reports, including 5.46 months across three sub-regions of Gash-Barka in Eritrea[10], 5.1 months[45] and 5.76 months[71] in the Amhara Region of Ethiopia and 5.75 months in the Eastern Province of Rwanda[68]. These results indicate relatively earlier sexual maturation compared to the 6.93 months reported in Tanzania[67] and 7.00 months recorded in Kigali Province, Rwanda[68]. The non-significant variation observed ($p = 0.7934$) suggests uniformity in maturity, likely attributable to consistent photoperiods[74,75] and the retention of unselected, locally adapted genetics, without intensive selection for early maturity[76,77].

Similarly, the mean age at first egg-laying for pullets in the present study aligns with previous findings, including 6.4 months in Abeche, Chad[67], 6.25 months in the Amhara Region of Ethiopia[71] and 6.02 months in Gash-Barka, Eritrea[10]. These results suggest that the studied indigenous ecotypes attain sexual maturity earlier than their counterparts in Tanzania (7.24 months)[65], Rwanda (7.1 months)[78] and Kigali Province, Rwanda (9.0 months)[68]. Conversely, the observed age at first egg-laying is higher than the values reported in Chad (5.5 months)[66], Ethiopia (5.92 months)[45] and Uganda (5.20 months)[33].

According to Yihun *et al.*[79], variability in sexual maturity among indigenous hen ecotypes may arise from differences in management practices, including feeding strategies (supplementation versus scavenging), housing conditions and veterinary care. Additionally, Ngogo *et al.*[65] indicate that genetic factors may further contribute to the heterogeneity in maturity ages observed among these ecotypes.

Clutch frequency, egg production and egg weight: The clutch frequency observed in this study closely aligns with Habteslassie[10], who reported 3.38 clutches per hen per year in Eritrea's Gash-Barka region. These results are also comparable to observations in Chad's Koundoul region (3.05±0.8 clutches)[66], the urban area of Abeche (3.56 clutches)[67], Ethiopia's Amhara Region (3.44 clutches)[71] and Fiji's semi-arid zone (3.5 clutches)[70]. However, the present findings are lower than the 5.7 clutches reported in Ethiopia's East Gojjam Zone[45] and 4.0 clutches documented in Cambodia[15] but exceed the 2.6 clutches recorded in Rwanda[78].

Regarding the average number of eggs per clutch, the current study's value of 12.08 is consistent with findings from Bangladesh (12.6 eggs)[37] and Chad's Koundoul region (12.4 eggs)[66]. This value is higher than those reported in Cambodia (11.6 eggs)[15], Tanzania (10.88 eggs)[67] and Eritrea's Gash-Barka region (11.53 eggs)[10], yet lower than the 13 eggs documented in Ethiopia's West Guji area[80] and the 13.41 eggs reported in

Uganda[33]. Annual egg production estimates for the indigenous ecotypes in the present study are comparable with previous reports: 40.22 eggs in Uganda[33], 40.91 eggs in urban Abeche, Chad[67], 30-60 eggs in Ethiopia[81], 48.8 eggs in Cambodia[15] and 46.6 eggs in Tanzania[65]. The present results, however, are lower than the 50.39 eggs recorded in West Guji, Ethiopia[80] and 51.55 eggs reported in Chad's Koundoul area[66] but exceed the 38.88 eggs per year previously documented in Eritrea's Gash-Barka region[10].

According to Habteslassie[10] and Yihun *et al.*[79], variation in egg production among IC ecotypes likely arises from differences in genetic background, management practices and disease incidence. Enhanced egg production is generally associated with increased feed supplementation, particularly during sowing and post-harvest seasons when scavenging feed resources are more abundant[45]. Yussif *et al.*[33] further highlight that broodiness substantially reduces egg production in ICs. This behavioral phase, involving egg incubation and chick rearing, is characterized by frequent nesting, reduced feed and water intake, elevated body temperature and temporary cessation of egg-laying[82].

Egg weight is a critical phenotypic trait influencing egg quality and reproductive fitness[83]. The mean egg weight observed in this study (44.15±0.33 g) aligns with reports from ICs in Indonesia (43.24 g)[84], three sub-regions of Eritrea (44.22 g)[10], Cameroon (44.89 g)[85], Madagascar (44.96 g)[86] and Fayoumi chickens (44.3 g)[87]. However, this value remains below the commercial egg weight of 63.5 g reported by Wambui *et al.*[88]. Liswaniso *et al.*[89] note that egg weight is strongly affected by environmental conditions, feed restriction and the average weight of the parent stock. Genotype, including breed or strain, also significantly influences egg weight[90], as it is directly proportional to the amount of albumen, yolk and eggshell[91]. Additional factors such as hen age, body size, diet, water intake, temperature, humidity and management practices further contribute to the observed variability in egg weight[35].

Despite their smaller egg sizes, the BAR and GOG ecotypes may offer advantages in low-input production systems due to their relatively higher annual egg output (Table 7). Smaller Ics often exhibit notable egg-laying efficiency, higher fertility rates[92,93] and potentially enhanced disease resistance[94]. When combined with effective predator avoidance and strong foraging ability, these characteristics position small-sized ecotypes, such as BAR and GOG, as valuable genetic resources[23]. Miyumo *et al.*[95] further reported that lower mature body weight in layers reduces maintenance costs, thereby allowing greater resource allocation to egg production. Consequently, BAR and GOG could serve as foundational stocks for developing egg-laying strains adapted to the feed-scarce and disease-prone conditions typical of Eritrea.

According to the classification by Kostaman et al.[90], eggs with a shape index below 72% are considered sharply pointed, those between 72 and 76% are classified as standard and eggs above 76% are regarded as round. Most indigenous chicken eggs in Eritrea exhibited a "normal standard" shape (72-76%), reflecting favourable egg quality. Furthermore, Saili *et al.*[84] observed that eggs with a shape index around 75% often achieve hatchability rates of 70-75%, whereas elongated eggs may experience reduced hatchability. These findings suggest that the majority of Eritrean ecotypes possess egg shape indices conducive to optimal hatchability outcomes.

CONCLUSION

The observed diversity in productive and reproductive traits among indigenous chicken (IC) ecotypes in Eritrea underscores the substantial yet underutilized genetic potential of these populations. This variation reflects long-term adaptation to heterogeneous agroecological conditions, management practices and farmers' selection preferences, highlighting the resilience of ICs as a cornerstone of sustainable poultry production in resource-limited settings. Farmers' trait preferences further indicate that village chicken production systems are not solely oriented toward egg and meat production but also toward the maintenance of birds with culturally significant morphological attributes, such as plumage colour and comb type, which play important roles in traditional and religious festivities within rural communities. Despite these strengths, the alarmingly high rates of chick mortality observed in this study have contributed to reduced effective population sizes (N_e) and elevated inbreeding rates (ΔF) at the household level, posing a serious risk to the long-term genetic viability of IC populations. These findings emphasize the need for targeted interventions, particularly community-based breeding and management programs aimed at reducing inbreeding while maintaining adaptive diversity. To optimally exploit the existing genetic variation, ecotype selection should be aligned with clearly defined production objectives. For egg-oriented lines intended to maximize laying efficiency under low-input systems, the BAR ecotype is recommended due to its superior annual egg production. Conversely, for meat-oriented lines, where growth potential and carcass yield may be inferred from egg weight as a proxy for body size, the FM ecotype appears most suitable. Finally, improvement strategies should integrate empirical research findings with effective extension services to promote humane and biosecure broodiness-breaking practices that shorten inter-clutch periods without compromising animal welfare or increasing mortality. Policymakers and development agencies are therefore encouraged to incorporate these insights into rural development programs, thereby strengthening indigenous chicken production as a vital component of sustainable agricultural systems in Eritrea and comparable environments worldwide.

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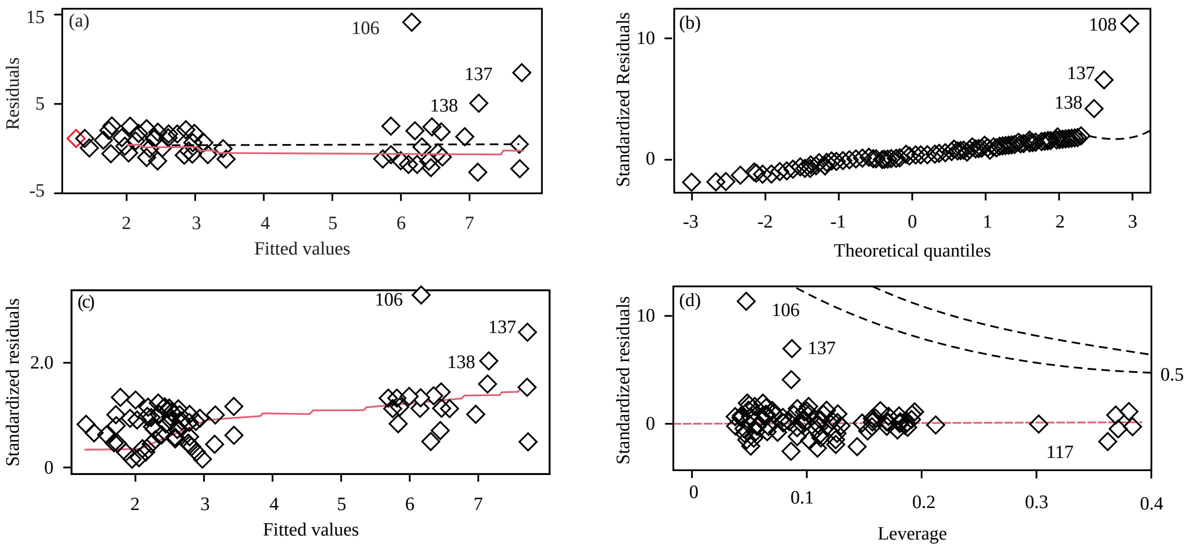
APPENDIX



Appendix (a-d): Diagnostic plot evaluating GLMM model assumption (a) residuals vs fitted, (b) Q-Q residuals, (c) Scale-location and (d) Residuals vs leverage

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