Hasan Moftah Ahmed Ahmad et al./Animal Production. 27 (3): 217-233, 2025
Accredited by Kemenristek Dikti No 32a/E/KPT/2017. ISSN 1411-2027

Toward the Development of a New Libyan Local Chicken Breed

Hasan Moftah Ahmed Ahmad[1,2], Muhammad Rizwan Yousaf[1], Bilal Ahmed[1], Edy Kurnianto[1], Asep Setiaji[1], Fatmawati Mustofa[1], Dela Ayu Lestari[1], and Sutopo Sutopo[1*]

[1]Department of Animal Science, Faculty of Animal and Agricultural Sciences, Diponegoro University, Semarang, Indonesia
[2]Department of Animal Science, Faculty of Animal and Agricultural Sciences, Sirte University, Sirte, Libya
***Corresponding author: drsutopo36@gmail.com**

Abstract. This study aims to describe the Libyan chicken breed and its origin, and to evaluate its potential for the development of a new Libyan local chicken breed with high genetic quality and productivity. A qualitative research design has been implemented to carry out this research with a descriptive-analytical approach. Data collection was done by reviewing scholarly literature from scientific journals, academic books, and credible online databases. This research analyzed previous studies to determine patterns that outline the genetic potentials, challenges, and opportunities in breeding programs for enhancing the productivity and resilience of Libyan local chickens. The results showed that the indigenous chicken varieties of Libya, such as Gallus gallus, Baladi or El-Balad, and Hypeco, are essential to the nation's agricultural and culinary traditions. These varieties are hardy and ideal for rural and semi-urban locations with limited access to contemporary farming infrastructure. This study's findings highlight Hypeco's potential as a top contender for the creation of a new breed of locally grown chickens in Libya with superior genetic quality and productivity. In the face of issues with food security, their resilience to intense heat, limited feed supply, and limited water supplies makes them priceless assets. A lack of effective farming methods, contemporary breeding procedures, and the required infrastructure limits these local hens' production and economic viability. These local hens' production and economic viability are limited by a lack of effective farming methods, contemporary breeding procedures, and the required infrastructure. Building infrastructure to assist the regional poultry business should also be a priority. This entails expanding access to veterinary care, storage facilities, water, and high-quality feed.

Keywords: Local chicken, Genetic quality, Productivity, Libya.

Introduction

Indigenous poultry serves as a critical nutritional resource for local populations and serve as valuable models in genetic studies (Chomchuen et al., 2022). Compared to their broiler counterparts, local chickens possess better disease resistance, adaptability to a local environment, and the ability to act in unfavorable situations. Chickens have played an important role in research since they were one of the first animals used by Mendel in his classic experiments on inheritance, and they became the first domestic animal to be completely sequenced. More than 11 billion indigenous chickens exist worldwide and make important contributions to various traditional and commercial production systems. In developing nations, backyard chickens serve as a source of accessible protein, supplemental income, and cultural value (Nawaz et al., 2023).

Indigenous chickens originating from distinct geographical regions also retain a high level of genetic variation but are often not distinctly classified into breeds (Bukachi et al., 2022). In Libya, village chickens are raised for eggs, meat, and economic security, and represent a mix of egg-producing, meat-producing, dual-purpose, and ornamental types (Manyelo et al., 2020). Generally, they are well adapted to arid climates, with acceptable laying performance and broad genetic heterogeneity between regions. However, very limited research exists on Libyan local chickens, and there is currently no structured breeding program that evaluates or improves their genetic potential (Sithole et al., 2024).

The need for a new Libyan local chicken breed is founded on a number of pressing challenges that include the following: local production remains inefficient due to low productivity, irregular performance, and the

absence of systematic selection practices. Most of the breeding is done through household practices in an uncoordinated manner. Some of the disadvantages seen with this practice are minimal control over mating, loss of unique genetic traits, and inconsistent growth and egg-laying characteristics. The limited adoption of advanced biotechnological tools, such as genomic selection and performance recording, hinders Libyan farmers from identifying and propagating superior genetic lines. Other major factors contributing to the limitation of progress include infrastructural problems, lack of standards for appropriate breeding goals, and minimum government or institutional interest (Anand et al., 2023). This study aims to identify the existing types of Libyan chickens, tracing their genetic origins, and discussing their potential for structured genetic and agricultural improvement. A scientifically based breeding program is then vital as a means of conserving the local genetic resources to improve productivity, enhance food security, and ensure long-term sustainability of the sector in Libya.

Chicken Breed

Originally from Southeast Asia, traders and sailors introduced chickens to other parts of the world. Today's local village chickens are the result of centuries of cross-breeding with foreign breeds and haphazard breeding within the flock. This makes it hard to standardize the characteristics and productivity of conventional chickens (Bibi et al., 2020). There is no comprehensive list of the breeds and types of chickens used by smallholders in rural regions, despite the abundance of information available on some indigenous communities from various locales (Malapane et al., 2024).

Materials and Methods

This study employs a narrative review methodology to evaluate the prospects of developing a new Libyan local chicken breed through the enhancement of genetic quality and productivity. The review synthesizes existing scientific evidence rather than conducting laboratory or field experiments from past breeding, genetic, and production studies. More specifically, this analysis focuses on Libyan local chicken breeds, specifically Baladi/El-Balad, Hypeco, and Avian breeds, which are widely reared by rural and peri-urban farmers. The species Gallus gallus (domestic chicken) is only referred to as the general biological species and not as a Libyan breed, hence avoiding inconsistency in using terms.

A literature analysis was performed for data collection: scientific books, peer-reviewed articles, research reports, encyclopedias, and reliable digital sources. Information on genetic characteristics, production performance, challenges in breeding, and farmers' perceptions of local chickens was obtained from printed and electronic materials. A literature review, therefore, combines knowledge gaps and existing knowledge from disparate academic sources on the present breeding programs, as stated by Busetto et al. (2020). This research methodology will provide full insight into the opportunities and constraints related to the creation of a new breed variety of local chicken in Libya.

A systematic review that was done to assess local genetic chicken was also used in this study. The study design complied with PRISMA (Preferred Reporting Items for Systematic Reviews), which is a set of recognized principles for systematic reviews. A thorough search approach was developed and put into practice across electronic databases, such as Google Scholar and PubMed. Using a mix of keywords and controlled vocabulary phrases associated with "((local) OR (native)) AND (genetic)) AND (chicken)) AND (breed)) AND (quality)) AND (productivity) AND (Libya)", the search sought to find pertinent research published from 2020 up to 2025.

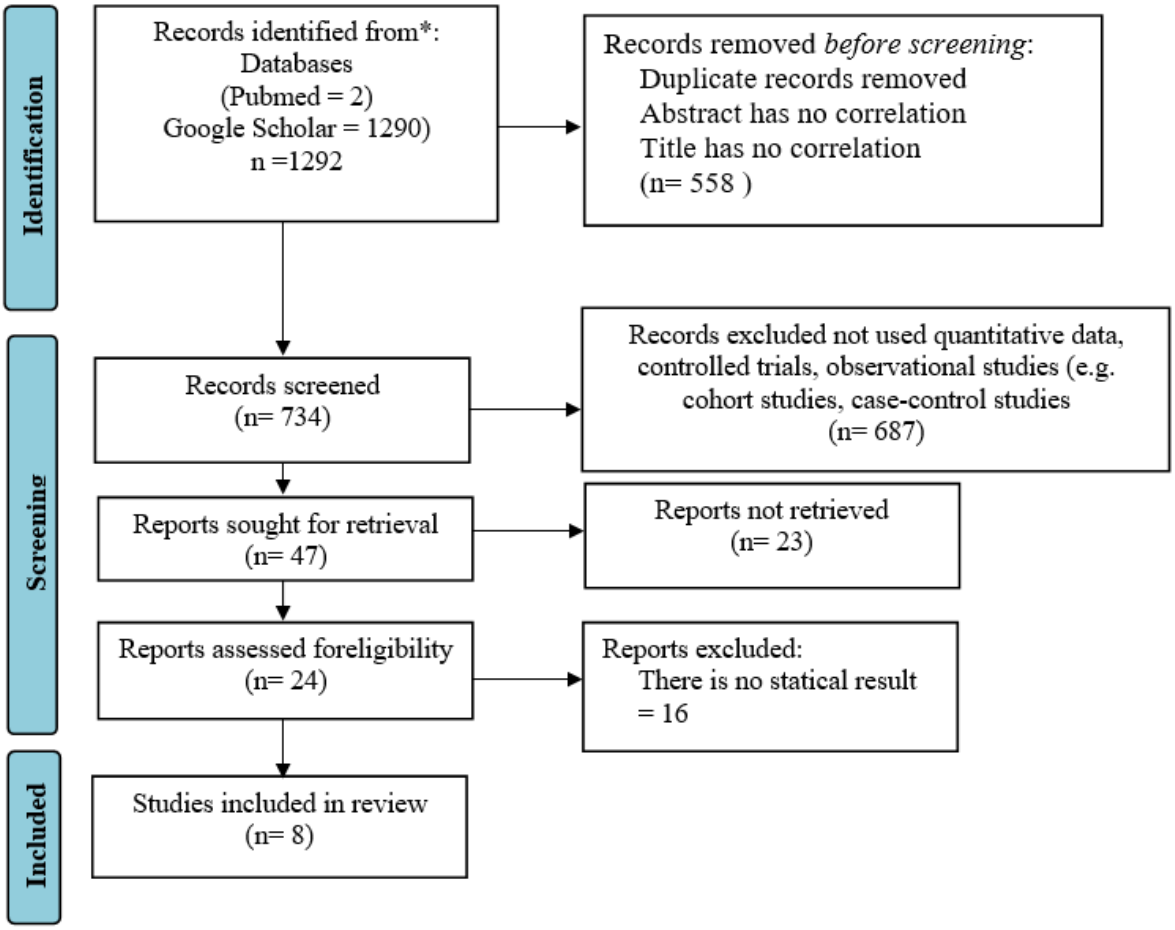

Figure 1. Literature Screening Results

The exclusion of irrelevant articles was done in successive steps to obtain only relevant and high-quality studies for this review. Identification through two databases yielded a total of 1,292 articles: PubMed, n = 2; and Google Scholar, n = 1,290. Records were automatically excluded as duplicates in the first elimination stage, followed by a manual screening of titles and abstracts for relevance to the research topic. Articles with titles and/or abstracts that did not discuss Libyan local chicken, genetic quality, or poultry productivity were excluded. A total of 558 articles were excluded at this stage. The methodological eligibility was further assessed in the remaining 734 articles of the second stage. Articles were excluded if the methods adopted were not quantitative, such as experimental, statistical modeling, or data-based comparison. Studies providing only narrative reviews, theoretical discussions, or descriptive observations that did not include numerical data were removed during this step; hence, 687 records were discarded.

Next, 47 studies were shortlisted for full-text retrieval. However, due to database restrictions or unavailable full texts, 23 could not be accessed in the full version. The remaining 24 studies then underwent a detailed eligibility assessment, focusing on the presence of statistical analysis, measurable outcomes, such as growth rate or feed conversion ratio, or egg production, with clear methodology related to genetic improvement or productivity of Libyan chickens. In this step, 16 studies were excluded for reasons including the absence of statistical

results or incomplete quantitative findings. Only eight studies met all the inclusion criteria: relevance, methodological rigor, data completeness, and statistical validity; these were included in the final synthesis and analysis.

Results and Discussion

Population of Libyan chicken

Over time, Libya's chicken population has experienced has changed dramatically in terms of quantity, geographic distribution, and production systems that demonstrate more advanced developments in the nation's agricultural processes and economic conditions (Alawamy et al., 2020). RT-PCR was used to detect AIV in 269 cloacal swabs of various live poultry species. The subtypes were not ascertained, but results showed 28 out of 269 (10.41%) were positive for AIV. Among the poultry species surveyed, only ducks (21.5%), local chickens (12.24%), and geese (7.14%) tested positive for Avian Influenza Virus (AIV) seropositivity (Kammon et al., 2022). A vital component of Libya's agricultural economy, poultry production offers the local populace a significant supply of protein and helps ensure food security. Chicken production is one of the primary components of Libya's agricultural economy. Approximately 25 million chickens, as compared to a mere 220,000 cows and 5–6 million sheep and goats, made up the majority of the livestock as of the early 2000s. Between 1998 and 2009, domestic poultry production satisfied only 50% of the national demand. During this period, small ruminants (sheep and goats) continued to dominate the livestock sector, accounting for 67–80% of total meat output. Livestock, in general, made a total contribution of almost 30% of Libya's agri-GDP, mirroring the sector's significant role toward ensuring food security and supporting livelihoods in rural areas (OEC, 2025).With about 5% of the workforce employed and nearly 9% of the GDP coming from agricultural operations, agriculture plays a significant role in the Libyan economy. The majority of agricultural goods are produced on privately held farms, demonstrating how reliant agriculture is on the private sector. In order to produce grain and fodder, the government has set up a few irrigation projects in the desert (Fig. 1) (Zurqani et al., 2019). Due to its mostly desert environment, Libya is a North African nation that faces significant constraints related to water scarcity and limited arable land, the demand for poultry products especially chicken meat and eggs has steadily grown over time despite these challenges (Vlaicu et al., 2024).

In Libya's poultry industry, the population's health and well-being are also crucial concerns. Periodic outbreaks of bird illnesses have resulted from the nation's difficulties implementing efficient veterinary care and disease control methods (Liebhart et al., 2023). Particularly in big commercial farms where the danger of disease transmission is increased owing to the dense number of chickens, these outbreaks can have catastrophic impacts on chicken populations. The Libyan government has responded by working with international groups to enhance disease detection, veterinary care, and biosecurity protocols on chicken farms (Amalraj et al., 2023).

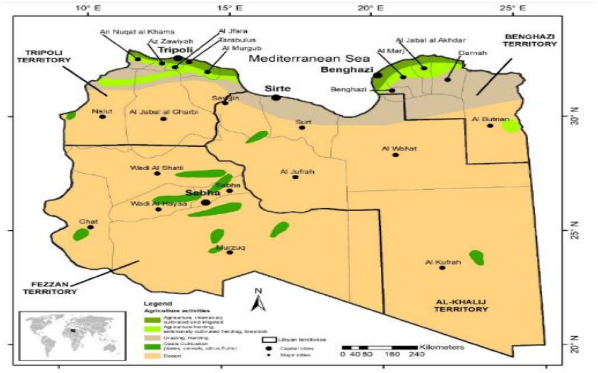

Figure 2. Locations of agricultural activities in Libya (Zurqani et al., 2019)

Notwithstanding the difficulties, Libya's chicken population is still increasing, albeit more slowly than in some other areas (Riber Wurtz, 2023). The poultry industry continues to be a vital part of the nation's food production system as it attempts to reconstruct its agricultural

sector. Libya's chicken population has the potential to grow further with sustained assistance for both commercial and small-scale poultry producers, as well as investments in feed production, veterinary care, and biosecurity, which would increase future food security and economic stability (Fathelrahman et al., 2020)

Breed of Libyan chicken

Local chicken breeds in Libya, all derived from the domestic chicken species (*Gallus gallus domesticus*), include Baladi (or El-Balad), Hypeco, and Avian. A significant population of domestic chickens (*Gallus gallus*) is reared in Libya, particularly in rural regions. Over time, these hens have adapted to Libya's severe climate, which includes intense heat, little water, and a lack of food sources. Local chicken breeds are hence renowned for their toughness and tenacity (Ka et al., 2024).

Figure 3. Libyan Native Chicken

The Baladi, also known as El-Balad, chicken has adapted to the harsh desert climate of Libya, which is characterized by high temperatures, few water supplies, and difficult feed conditions. A dual-purpose breed, the Baladi chicken is often kept for both meat and eggs. Its ability to adapt to free-range systems, where it forages for food, is one of its noteworthy characteristics, which makes it the perfect breed for conventional, small-scale agricultural methods (Youssef et al., 2024).

The Hypeco chicken, which has gained popularity in commercial poultry production, is another significant breed in Libya. The Hypeco breed is known for its exceptional egg production ability, making it a significant asset in commercial operations, in contrast to the Baladi, which is primarily raised in rural settings. A chicken production study revealed that the Hypeco breed exhibits an average laying rate exceeding 0.5 eggs per day. Libyans consume less than 30.51 grams of eggs per day when they should consume a minimum of 35 grams (Balal, 2023). The poultry sector incurred annual losses ranging from $128 to $165 million due to heat stress (Wasti et al., 2020). Due to a large decrease in the H/L ratio, local Libyan chickens experienced less stress than broiler chickens (El-Safty, 2012). Despite not being native to Libya, the Hypeco chicken has been included into the local poultry business because, like the native breeds, it can thrive in hot environments (Bozrayda Hubara, 2020). The Avian breed, though not native, has also successfully adapted to Libya's climate. The Avian breed is suited for both free-range and semi-intensive farming systems due to its reputation for resilience and capacity to tolerate high temperatures (Bozrayda and Hubara, 2020).

Libyan chicken History

As with most of the other regional chicken varieties, Libyan chicken history is strongly linked to the general history of chicken domestication and dispersal. Approximately 10,000 years ago, the wild red junglefowl (Gallus gallus), native to Southeast Asia, is thought to have been domesticated (Al-Jumaili et al., 2020). Domestic chickens moved west slowly, as far as the Middle East and North Africa, on a combination of overland Silk Road routes and marine trade. In North Africa, chickens would have reached Libya along Phoenician, Carthaginian, and later Roman trade routes that cut across the Mediterranean Basin. In ancient times, ancient ports such as Leptis Magna and Sabratha large commercial and urban centers in contemporary Libya were major points of

importation for agricultural products and livestock. These ports connected Libya to Sicily, Crete, Egypt, and the Levant, and therefore it was feasible for chickens to be introduced together with cereals, olives, and other essentials (Al-Jumaili et al., 2020).

Archaeological evidence from Nubia during the reign of Taharqa and Roman North Africa reveals chicken bones in settlement middens, suggesting that poultry was already an integral part of local diets in the 1st millennium BCE (Gifford-Gonzalez and Hanotte, 2011). Even in Libya alone, zooarchaeological evidence from excavations in the marketplace of Leptis Magna consists of chicken bones of the Roman Imperial age, suggesting their presence in urban diets. Genetic analysis of African village chickens mirrors an admixed origin with maternal haplogroups back to Indian subcontinental and East Asian, and to Mediterranean, introductions. This suggests that Libyan chicken flocks, as well as those of neighboring Tunisia and Egypt, are the result of repeated introductions over history, subsequent to adaptation to local environments of arid, hot climate (Gifford-Gonzalez Hanotte, 2011).

Natural selection and centuries-old agricultural practices have developed Libyan chickens over thousands of years, the country's arid climate with its hot temperatures and sparse rain supporting strength and heat tolerance (Ariza et al., 2021). The genetic pool of Libya's poultry has been enriched by multiple introductions from various geographic regions and time frames. The earliest introductions were most likely via Mediterranean trade during the Phoenician, Carthaginian, and Roman eras (circa 2nd century BC–1st century AD) from southern Europe and the Levant, bringing chickens. Subsequent introductions followed with the Arab conquest of North Africa in the 7th century, reported to have brought North African poultry breeds of the Arabian Peninsula and possibly the Indian subcontinent via Red Sea trade routes (Essid, 2024). As was the case in other parts of Africa, the Ottoman period may also have introduced extra genetic influence from Anatolia and the southeastern Mediterranean, and commercial birds from Europe and North America such as Leghorns and Rhode Island Reds were also introduced in the 20th century. These earlier introductions are still the foundation of contemporary Libyan fowl populations since gene research indicates that local chickens bear a combination of ancient Asian and Mediterranean lineages (Essid, 2024).

Local chickens have managed to maintain unique features in spite of these external effects because they have a lengthy history of adapting to the Libyan environment. Libyan native chickens retained a number of typical features through centuries of exposure to external genetic influence, primarily due to their long history of adaptation to the harsh environment of the nation. They have high tolerance to heat, being capable of maintaining productivity under summer temperatures of up to 40 °C; high feed efficiency, being able to survive and develop on inferior-quality or limited feed resources; and acceptable resistance to dominant poultry diseases, particularly those from the arid and semi-arid zones. Their adaptability and role in sustainable poultry farming have renewed interest in conserving regional breed. In a nation where food production is sometimes hampered by harsh weather and little resources, efforts to preserve native chicken breeds are motivated by the understanding that these chickens are not only significant culturally but also essential for improving agricultural sustainability (Kpomasse et al., 2023).

Genetic Improvement and Performance Across Generations

One of the most important areas for the poultry sector in Libya to improve is the genetic potential of its chicks. The majority of chickens in Libya are native varieties that have developed

Table 1. Growth Rate (g/day) Across Generations

Author (Year)	Breed	Generation	Growth Rate (g/day)
Hanlon et al. (2021)	Gallus gallus	F1	12
Ahmed (2023)	Baladi (El-Balad)	F1	10
Ahmad (2025)	Hypeco	F1	14
Ibrahim et al. (2020)	Avian	F1	13
Hanlon et al. (2021)	Gallus gallus	F2	13
Ahmed (2023)	Baladi (El-Balad)	F2	11
Ahmad (2025)	Hypeco	F2	15
Ibrahim et al. (2020)	Avian	F2	14
Hanlon et al. (2021)	Gallus gallus	F3	14
Ahmed (2023)	Baladi (El-Balad)	F3	12
Ahmad (2025)	Hypeco	F3	16
Ibrahim et al. (2020)	Avian	F3	15

over generations in the region and show a high level of tolerance to the resource scarcity and dry climate of the nation. In contrast to commercial varieties, these indigenous breeds typically struggle with poor productivity, slower growth rates, and lower meat outputs. Therefore, in order to fulfill the growing demand for poultry products, improve food security, and increase the sustainability of the poultry business, it is imperative that the genetic potential of Libya chickens be explored and improved (Banach Żywica, 2023). Libyan chickens' genetic potential analyzed based on growth rate, egg production disease resistance and meat yield, environmental adaptability, genomic selection and marker-assisted breeding.

Growth Rate

The growth rate of Libya chickens is one of the primary areas for genetic improvement. Although native breeds, like the Baladi or El-Balad, have adapted to live in dry environments, their development rates are often slower than those of commercial types. Breeding programs greatly increase growth rates by including higher-performing breeds, like Hypeco. Growth rates have been seen to rise over the course of subsequent generations; in the third generation, Hypeco reached up to 16 g/day (Martyniuk, 2020).

The growth rate data analyzed across studies by Hanlon et al. (2021), Ahmed (2023), Ahmad (2025), and Ibrahim et al. (2020) indicated a similar trend of genetic progress and performance through generations, which signifies the appropriateness of the selective breeding programs. The consistent enhancement in growth rates from the F1 to F3 generations suggests the successful inheritance and stabilization of traits related to feed efficiency, muscle deposition, and adaptability are being transmitted and reinforced successfully. Baladi (El-Balad), though it showed the minimum growth performance, its increase was consistent and indicated a latent potential which can be exploited by crossbreeding with faster-growing strains. The Hypeco breed, on the other hand, had the highest growth rates continuously within the range of 14–16 g/day, reflecting its better genetic potential for rapid weight gain and efficiency of feed conversion-characteristics that are definitely required in modern poultry production systems.

The comparative data further present that Avian and Gallus gallus lines also benefited from generational selection, though at a moderate rate, showing that not only is the breed a determinant of growth improvement but also management, nutrition, and environmental conditions. Synthesized, these findings point to a broader conclusion: combining the robust adaptability of local breeds like Baladi with the

high growth potential of improved lines such as Hypeco could yield a genetically superior Libyan chicken breed optimized for both productivity and resilience. This supports a strategic breeding model that focuses on enhancing genetics through selection while maintaining the local traits of adaptability across studies.

Egg Production

Another important element for the Libyan poultry industry's development is the genetic potential for increased egg production. Productivity may be limited because local breeds usually produce fewer eggs than commercial layers. Breeds like Hypeco, have demonstrated notable advancements in egg production; by the third generation, output had increased to 260 eggs annually (Nolte et al., 2020).

Table 2 shows consistency with an upward trend in egg production through successive generations among all chicken breeds, indicating a successful outcome of selection and better genetic potential achieved thus far. On average, egg production has increased by about 5-10% per generation, reflecting the cumulative benefits accruing from genetic selection and refinement in management. Across breeds, Hypeco showed the most consistent productivity and, in generational sequence, averaged 250-260 eggs per year by the F3 generation, well above the traditional breeds represented by Gallus gallus and Baladi. This trend would thus indicate that hybrid or selectively bred strains, as represented by Hypeco, possess a superior laying performance based on enhanced reproductive efficiency and possibly improved feed conversion.

In contrast, one of the least productive birds across generations was Baladi (El-Balad), attaining only 180-200 eggs/year, reflecting its considerably lower genetic selection intensity and its orientation toward dual-purpose rather than specialized egg-laying functions. Selective breeding interventions resulted in a significant improvement in the reproductive performance over generations; this improvement was most marked in hybrid and improved lines. The result clearly points to the possibility of sustained genetic progress through systematic breeding programs integrating indigenous adaptability and commercial productivity traits.

Disease Resistance and Meat Yield

For chicken farming to be sustainable, disease resistance is an essential quality, especially in areas where avian illnesses are common. Although Libya chickens adapt well to their environment, they may be more disease-resistant. Libya chickens' genetic resilience can be increased by crossbreeding them with disease - resistant breeds like Hypeco.

Table 2. Egg Production (Eggs/year) Across Generations

Author (Year)	Breed	Generation	Egg Production (eggs/year)
Hanlon et al. (2021)	Gallus gallus	F1	220
Ahmed (2023)	Baladi (El-Balad)	F1	180
Ahmad (2025)	Hypeco	F1	240
Ibrahim et al. (2020)	Avian	F1	210
Hanlon et al. (2021)	Gallus gallus	F2	225
Ahmed (2023)	Baladi (El-Balad)	F2	190
Ahmad (2025)	Hypeco	F2	250
Ibrahim et al. (2020)	Avian	F2	220
Hanlon et al. (2021)	Gallus gallus	F3	230
Ahmed (2023)	Baladi (El-Balad)	F3	200
Ahmad (2025)	Hypeco	F3	260
Ibrahim et al. (2020)	Avian	F3	230

Table 3. Disease Resistance (%) and Meat Yield (kg) Across Generations

Author (Year)	Breed	Generation	Disease Resistance (%)	Meat Yield (kg)
Hanlon et al. (2021)	Gallus gallus	F1	85	1.8
Ahmed (2023)	Baladi (El-Balad)	F1	80	1.5
Ahmad (2025)	Hypeco	F1	90	2.0
Ibrahim et al. (2020)	Avian	F1	88	1.9
Hanlon et al. (2021)	Gallus gallus	F2	86	1.9
Ahmed (2023)	Baladi (El-Balad)	F2	83	1.7
Ahmad (2025)	Hypeco	F2	92	2.2
Ibrahim et al. (2020)	Avian	F2	89	2.0
Hanlon et al. (2021)	Gallus gallus	F3	88	2.0
Ahmed (2023)	Baladi (El-Balad)	F3	85	1.8
Ahmad (2025)	Hypeco	F3	94	2.3
Ibrahim et al. (2020)	Avian	F3	91	2.1

For instance, Hypeco's disease resistance increased dramatically, reaching 94% by the third generation (Ferraz, 2024). In chicken farming, meat output is a crucial economic factor. Compared to commercial varieties, native Libya chickens often have smaller bodies and produce less meat. However, meat productivity might be increased by crossbreeding with higher-yielding breeds like Hypeco and Avian. These commercial varieties showed notable increases in meat production in experiments; by the third generation, Hypeco was producing 2.3 kg per bird (Obremski et al., 2023).

Table 3 clearly and consistently presents that through generations, an improvement in the traits of resistance to disease and yield of meat is noted, which indicates selection and better management contributed to increased genetic robustness and efficiency of production in all chicken breeds under consideration. In general, disease resistance improved in all studies by some 3-5% per generation, reflecting increased adaptive immunity and resilience against common poultry pathogens. This trend probably reflects positive effects from the integration of resistant parent stocks, as well as possibly improved vaccination and biosecurity strategies within breeding programs. Hybrid Hypeco was superior in most instances, with a resistance level of up to 94% in F3 and the largest meat yield, with an average of 2.3 kg, indicating high genetic adaptability and production potential. However, the breed also showed some inconsistencies, which had considerable negative consequences for production performance under various challenge conditions.

At the opposite extreme, Baladi (El-Balad) expressed the lowest resistance, 80–85%, and meat yield, 1.5–1.8 kg, probably because of its local genetic makeup, which emphasizes hardness and adaptability to environmental conditions rather than fast growth. Gallus gallus and Avian demonstrated stable and moderate progress; this may indicate that both commercial and native breeds are responsive to generational selection, though at different rates. Selective breeding has contributed not only to productivity gains but also to enhanced disease resilience, pointing toward a synergistic enhancement of both performance and health traits. These findings support the potential of hybridization and generational selection as sustainable strategies for developing high-performing, disease-tolerant poultry lines suited for diverse production systems.

The results of this study demonstrate how well the mating and selection experiment improved the growth rate, egg output, illness resistance, and meat yield of native Libyan chicken breeds. Significant gains were seen in

subsequent generations across all evaluated variables, indicating that the selection process improved the genetic quality and productivity of the chicken breeds. The findings show that all breeds have clearly improved in terms of growth rate over the course of several generations, with Hypeco showing the quickest development, reaching 16 g/day by the third generation. This rise in growth rate indicates that the selection experiment was successful in accelerating the hens' pace of development, which is an important aspect in raising poultry (Mottet Tempio, 2017).

Generation after generation also showed steady gains in egg output. In contrast to other breeds like Gallus gallus and Avian, which produced fewer eggs, the results indicate that Hypeco produced the most eggs in each generation, reaching a peak of 260 eggs annually by F3. The need of choosing high-productivity breeds for upcoming breeding projects was highlighted by the Baladi or El-Balad breed's constant lower egg output. The success of the selection procedure is supported by the growth in egg production throughout generations, which also implies that more genetic refinement may improve reproductive output. This is crucial for enhancing the sustainability of Libyan poultry farming (Bello et al., 2022).

Hypeco had the highest disease resistance of any generation, reaching 94% in F3, making the increases in disease resistance more noticeable. For poultry, disease resistance is an essential characteristic as it lessens the need for antibiotics and other medical interventions, resulting in healthier flocks and more environmentally friendly farming methods (Abdel-Wareth et al., 2024). Positive trends were seen in meat yield, with all breeds showing increases in meat production over time. Once again, Hypeco performed better than the others; F3 produced 2.3 kg of meat, followed by Avian and Gallus gallus. The higher meat output indicates that growth factors that lead to increased meat production were successfully addressed throughout the selection phase (Maharjan et al., 2021).

Environmental Adaptability

The capacity of Libyan hens to adapt to the local environment is one of their biggest benefits. These hens have adapted to live in dry, desert-like environments where food and water are scarce. The goal of proposed genetic modification for Libyan hens would be to increase their output while maintaining their capacity to withstand the hostile climate (Van et al., 2020). Given their importance in local agriculture and their ability to adapt to the difficult climatic conditions of the region, there is a great deal of opportunity for establishing Libya chicken breeds. Even though Libya's poultry sector confronts obstacles including scarce resources and severe weather, the country's food security and agricultural sustainability might be enhanced by utilizing the distinctive qualities of the local chicken breeds. Local chickens in Libya have the potential to become more widely used for both household consumption and commercial poultry production with the right investment in breeding, farming practices, and infrastructure (Neeteson et al., 2022).

The ability of Libya chickens to withstand intense heat and dry circumstances is one of the main reasons they are a valued commodity. For small-scale farmers who do not have access to the infrastructure needed for large-scale commercial chicken farming, this makes them a great option. Local chickens in Libya are renowned for their durability in terms of reproduction in addition to their versatility. Due to their ability to breed and lay eggs under rather challenging circumstances, these chickens offer local populations a reliable supply of protein (Alagawany et al., 2020).

Poultry farming is still carried out in many areas using antiquated techniques, which could not optimize the genetic potential of regional chicken. Farmers can increase their output of

meat and eggs and become more competitive in the market by investing in selective breeding and raising the general genetic quality of these chicken (Yusuf and Popoola, 2021). Additionally, in order to prevent illnesses that have the potential to wipe out entire populations of poultry, access to veterinary care and immunizations is essential. Farmers would also be able to increase output and lower losses with improved infrastructure, such as easier access to feed, water, and storage facilities. Libya can boost general economic growth by establishing a chicken sector based on regional breeds and generating new job possibilities in rural regions (Zhang et al., 2022).

Applying a planned breeding program to Libya chickens is essential to improving their genetic quality, productivity, and adaptability, as well as their distinctive resistance to the harsh environment of the country. A well-designed program can enhance gross growth rate, egg production, disease resistance, quality of meat, and environmental adaptability, without diminishing the desirable traits that enable these chickens to perform under challenging situations such as heat stress and resource limitation (Oke et al., 2024). This scheme would bring the local farming methods and modern scientific methods into harmony with each other, capitalizing on both the benefit of native breeds and the potential for safe crossbreeding based on highly yielding commercial lines with high growth and production rates (Ouédraogo et al., 2020).

The primary targets of the breeding program must be enhancing productivity and environmental adaptability at the same time. Genetic selection specifically should be focused on minimizing the age at which market weight can be achieved through growth rate acceleration, making it more efficient. Egg production enhancement is also an important element because enhanced annual egg-laying ability enhances the viability of small-scale poultry farming in Libya. Additionally, breeding schemes should emphasize enhanced disease resistance to reduce flock mortality and reduce antibiotic reliance, while enhancing meat production to challenge commercial broilers for Libya chickens. Significantly, sustaining flexibility to Libya's arid climate and low resources is important in order to guarantee that productivity gains do not penalize survival across local farming systems (Karaman et al., 2022).

There must be well-defined selection criteria for these goals so as to guide the selection of breeding material. Growth rate, egg production, meat percentage, and resistance to disease are key performance traits that need to be measured and ranked in selection. At the same time, behavioral traits such as docility and heat tolerance have to be considered since they influence ease of management and long-term survivability. Good monitoring and successive selection across generations can progressively build these traits without decreasing the width of the genetic base (Aseged et al., 2021).

To apply these objectives, there is a need for a mix of breeding methods. Crossbreeding commercial breeds with local Libya chickens can transfer valuable production characteristics, while selection of purebreds serves to maintain distinctive genetic characteristics that confer local adaptability. Line breeding might also serve to focus desirable traits, but it should be carried out cautiously to prevent potential risk of over-inbreeding and genetic bottlenecks (Liu et al., 2025). Such technologies of the present age such as marker-assisted selection (MAS) also have powerful tools to identify genes linked with growth, egg laying, or disease resistance and thus breed more accurately and efficiently (De Mori and Cipriani, 2022).

A well-planned breeding program is needed to achieve sustainable progress. This involves initial selection of superior performers, planned crossbreeding and mating, continuous testing of progeny, and continued selection for subsequent generations. Accurate recording and handling of data are critical to the process

so that the breeders can track genetic lines, performance record, and health history so that they can make good decisions for subsequent generations (Han et al., 2020). Table 4 summarize of selection criteria and breeding strategy for developing a new Libya local chicken breed.

New methods for improving the genetic potential of Libyan hens are provided by developments in genomic selection and marker-assisted breeding. These methods make it possible to pinpoint certain genetic markers connected to desired characteristics including growth rate, resistance to illness, and egg output.

These contemporary technologies may be used into breeding programs to speed up the process of genetic improvement and provide more focused and effective breeding plans. This would support Libya's food security and sustainability objectives in addition to making chicken farming there more economically viable (Mansour et al., 2021).

Table 4. Summary of Selection Criteria and Breeding Strategy for Developing a New Libyan Local Chicken Breed

Trait / Criterion	Rationale (Why It Matters)	Breeding Strategy / Method Applied
Growth Rate	Faster growth reduces production time and raises profitability.	Select for high performers; cross with fast-growing lines, such as Hypeco; practice multi-generation selection.
Egg Production (Laying Rate)	Higher production of eggs optimizes food supply and increases economic returns among small-scale farmers.	Select for those hens which give maximum annual egg production; utilize hybrid vigor by crossing with improved commercial strains; progeny test.
Disease Resistance	Essential for survival when veterinary infrastructure is limited, reduces mortality and the use of antibiotics.	Incorporate genetically resistant lines. Apply marker-assisted selection, MAS, for immunity-related genes. Maintain strict biosecurity.
Meat Yield (Body Weight / Carcass Quality)	Higher meat yield increases market value and supports dual-purpose production systems.	Cross with high-yielding breeds, study carcass parameters, and select lines showing better feed conversion and muscle deposition.
Environmental Adaptability (Heat & Drought Tolerance)	A vital source for survival in Libya, considering its aridity and lack of resources.	Retain key characteristics of local Baladi and other similar indigenous breeds; monitor physiological tolerance; avoid excessive dilution of local adaptability.
Reproductive Efficiency	Ensures consistent replacement stock and supports long-term flock productivity.	Select breeders based on high fertility and hatchability rates and assess mating success over generations.
Behavioral Traits (Docility, Foraging Ability)	Influences ease of management and suitability for smallholder systems.	Selection should include behavioral scoring; retain desirable local behavioral traits through controlled backcrossing.
Genetic Diversity Preservation	Prevents inbreeding depression and maintains long-term adaptability.	Apply line breeding judiciously; establish multiple lines of breeding; monitor pedigree and genetic variation.
Use of Genomic Tools	Increase genetic improvement with higher accuracy and speed.	Apply MAS and genomic selection to identify markers linked to key traits. Integrate genomic data into selection decisions.

Table 5. Prevalence of the Local Genetic Chicken

No	Author & Year	State	Method of detection	n	Animal Type	Animal Prevalence	Egg Prod	Result
1	Miao et al. (2024)	China	Quantitative	47	Chickens	2,2 x 10-16	6%	Puan Panjiang black-bone chicken genetic diversity and its importance as a genetic resource for poultry breeding, improving knowledge of the biological processes underlying egg production, and aiding in the creation of breeding plans to boost sustainability and productivity in the poultry sector
2	Cappone et al. (2025)	Italy	linear mixed model	1488	Poultry	0.003	91.94%	Perceptions and preferences of Italian consumers toward domestic chicken products, with a focus on sustainability and nutritional qualities.
3	Begna et al. (2024)	Libya	Correspondence Analysis (CA)	192	Chickens	0.007	15.23%	Strong preferences for characteristics like hatchability and egg number emphasize how important these features are for production and how crucial it is to choose breeds that are resistant to regional illnesses.
4	Lordelo et al. (2020)	Portuguese	Quantitative	286	Chickens	0.001	58.08%	In many aspects, eggs from these natural genotypes are comparable to the quality of a commercial product. Customers are investing in local farmers and supporting the growth of local genetic resources while also acquiring a high-quality product in areas where eggs from local breeds are accessible.
5	Sumantri et al. (2020)	Indonesia	Quantitative	10	Chickens	N.A	45.2%	Future efforts will continue to focus on maintaining genetic variety as it is crucial for genetic development in breeding programs, particularly selection efforts that result in superior strains of certain agroecosystems or breeds.
6	Schreiter and Freick (2023)	Germany	Quantitative	66	Chickens	0.001	308.2%	According to this study, local breeds' laying performance was noticeably worse than that of a high-performing hybrid strain, although there were discernible benefits in terms of egg content and animal welfare metrics.
7	Yaman et al. (2020)	Indonesia	Quantitative	400	Chickens	N.A	1380%	Local chicken crossbreeding improved the quality and quantity of eggs produced by local chicken variants. Additionally, it was reported that local chicken variants

No	Author & Year	State	Method of detection	n	Animal Type	Animal Prevalence	Egg Prod	Result
								produced by crossbreeding had superior immunity to endemic illnesses compared to indigenous breed chicken.
8	Rizzi et al. (2022)	Italy	Quantitative	60	Chickens	< 0.05	77.9%	The findings showed that the eight local chicken breeds produced different types of eggs based on their laying rates and a variety of physical external and internal traits. These traits enable consumers to identify the genetic origin of the eggs by their shape and color of the eggshell and use them for various purposes to value the biodiversity of poultry.

Particularly for native breeds like the Libyan chicken, conservation genetics is essential to maintaining genetic diversity within livestock populations (Sponenberg, 2020). These chickens have important genetic features that make them easily adaptable to existing problems, such as climate problems. Conservation genetics has a significant function in the conservation of native breeds like the Libyan chicken, which possesses unique genetic traits that allow them to survive under the specific environmental and management conditions of Libya. These adaptations, which have been built up over decades, allow them to adapt to local difficulties like extreme climatic conditions and limited feed resources (Torres et al., 2022). Genetic diversity is the foundation for resilience in chicken populations. Genetic diversity serves as the foundation for adaptation, disease resistance, and fertility fitness. In addition to direct subsistence, the conservation of genetic diversity in Libyan chickens ensures their sustainability over the long term, reduces the negative impact of inbreeding, and keeps the risk of genetic erosion through replacement by high-performing commercial breeds low (Tian et al., 2024).

Despite being crucial to the country, Libyan chickens face important genetic risks. Inbreeding among small isolated flocks is likely the most concerning as it reduces genetic diversity and increases the risk of inbreeding depression (Hidalgo et al., 2021). The entry of commercial breeds such as high-performing broilers and layers also poses a risk through genetic dilution or replacement, where the breeds become favored for short intervals of productivity improvement. Broader concerns such as global warming, shifting to poultry farming systems, urbanization, and the expansion of commercial chicken production also risk undermining the traditional production systems, adding to the pressure on the gene pool of Libyan chickens (Lee, 2021). These growing risks, strategic conservation measures will be imperative to preserve genetic diversity and safeguard the long survival of native breeds.

To respond to these issues, conservation genetics offers useful techniques and methods of conserving Libyan chickens. These include genetic monitoring to determine population health, cryopreservation to conserve DNA, embryos, or semen for future use, and the creation of gene banks to protect endangered genetic material. In addition, methods such as genetic rescue, inserting genetic material from sibling but distinct populations effective in mitigating the risk of inbreeding depression and

promoting the Libyan chicken population's adaptability (Xue et al., 2020). Table 5 summarizes the prevalence of different local genetic chicken populations in Libya.

Conclusions

The main chicken breeds in Libya are Gallus gallus, Baladi or El-Balad, Hypeco, and Avian. These breeds exhibit significant thermotolerance and resilience to suboptimal nutritional and hydric conditions. These breed resources are of utmost importance to maintain a sustainable development of poultry in their country. Clear genetic improvement is evident for growth rate, egg production, disease resistance, and meat yield across generations; this testifies to the efficiency of a well-structured selection program. Of the different breeds studied here, Hypeco always performed better for all the characteristics evaluated and, therefore, holds great promise as the base for developing a new Libyan line of high productivity.

These advantages notwithstanding, the productivity of local breeds has not been fully realized because of constraints in traditional production systems, lack of access to relevant modern breeding technologies, or incomplete infrastructure. However, the present generation trends within all breeds confirm that deliberate selection with improved methods of breeding can realize considerably higher genetic progress. Further strengthening of growth efficiency, reproductive performance, and disease resilience remains key for their future improvement.

These results confirm the need to combine modern genetic approaches with the adaptive characteristics of indigenous Libyan breeds in order to enhance their productivity without losing the peculiar resilience. This would indeed constitute a sustainable way to enhance national poultry production and contribute to improving food security. Further research should be directed to the advancement of breeding strategy and conservation measures that guarantee the availability of such valuable genetic resources for long-term agricultural development in Libya.

Acknowledgments

The authors express their gratitude to Universitas Diponegoro Institutional Research Funding for funding this study and its publication, as well as to all contributors, scholars, and practitioners for their insightful contributions on native chickens from Libya

References

Abdel-Wareth AAA, AN Williams, M Salahuddin, S Gadekar and J Lohakare. 2024. Algae as an alternative source of protein in poultry diets for sustainable production and disease resistance: Present status and future considerations. Frontiers in Veterinary Science. 11:1382163. DOI: https://doi.org/10.3389/fvets.2024.1382163

Ahmad H. 2025. Physiological adaptation of poultry to tropical climates. International Science and Technology Journal. 37:1–15. DOI: https://doi.org/10.62341/hapc0227

Ahmed O. 2023. Evaluation of some productive and reproductive traits of three pigeon strains. PhD Thesis. Matrouh University, Egypt.

Alawamy JS, SK Balasundram, A Husni and CT Boon Sung. 2020. Detecting and analyzing land use and land cover changes in Al-Jabal Al-Akhdar, Libya using time-series Landsat data (1985–2017). Sustainability. 12(11):4490. DOI: https://doi.org/10.3390/su12114490

Al-Jumaili AS, SF Boudali, A Kebede et al. 2020. The maternal origin of indigenous domestic chicken from the Middle East, North and Horn of Africa. BMC Genetics. 21:30. DOI: https://doi.org/10.1186/s12863-020-0830-0

Anand A, M Subramanian and D Kar. 2023. Breeding techniques to dispense higher genetic gains. Frontiers in Plant Science. 13:1076094. DOI: https://doi.org/10.3389/fpls.2022.1076094

Aseged T, T Getachew and S Banerjee. 2021. Participatory identification of breeding objectives and selection criteria for Begaria cattle breed. Sustainability. 14(19):12766. DOI: https://doi.org/10.3390/su141912766

Assad AK. 2017. Considerable numbers of poultry die of disease in eastern Libya. The Libya Observer. Retrieved from: https://libyaobserver.ly/health/considerable-

numbers-poultry-die-disease-eastern-libya (accessed : December 01, 2025).

Balal I. 2023. An economic study of the production and consumption capacity of poultry production in Libya (2000–2020). DOI: https://doi.org/10.13140/RG.2.2.31357.74727

Bello SF, AC Adeola and Q Nie. 2022. Candidate genes in the improvement of egg production in ducks – a review. Poultry Science. 101(7):101850. DOI: https://doi.org/10.1016/j.psj.2022.101850

Besbes B. 2009. Genotype evaluation and breeding of poultry for performance under sub-optimal village conditions. World's Poultry Science Journal. 65:260–271. DOI: 10.1017/S0043933909000221.

Bibi S, S Noreen, A Rehman, S Mehmood and M Shah. 2020. Morphological characteristics of native chicken of village Chhajjian, Haripur Pakistan. Poultry Science. 100(3):100843. DOI: https://doi.org/10.1016/j.psj.2020.11.022

Bukachi SA, M Ngutu, D Omia, MM Musyoka, J Chemuliti and IK Nyamongo. 2022. Gender-linked dynamics and sustainable smallholder poultry value chains in Makueni County, Kenya. Sustainability. 15(14):10907. DOI: https://doi.org/10.3390/su151410907

Busetto L, W Wick and C Gumbinger. 2020. How to use and assess qualitative research methods. Neurological Research and Practice. 2:14. DOI: https://doi.org/10.1186/s42466-020-00059-z

Chomchuen K, V Tuntiyasawasdikul, V Chankitisakul and W Boonkum. 2022. Comparative study of phenotypes and genetics related to growth performance of crossbred Thai indigenous chickens (KKU1 vs. KKU2) under hot and humid conditions. Veterinary Sciences. 9(6):263. DOI: https://doi.org/10.3390/vetsci9060263

De Mori G and G Cipriani. 2022. Marker-assisted selection in breeding for fruit trait improvement: A review. International Journal of Molecular Sciences. 24(10):8984. DOI: https://doi.org/10.3390/ijms24108984

Ferraz MP. 2024. Antimicrobial resistance: The impact from and on society according to the One Health approach. Societies. 14(9):187. DOI: https://doi.org/10.3390/soc14090187

Han Y, K Wang, Z Liu, S Pan, X Zhao, Q Zhang and S Wang. 2020. Hybrid crop breeding information management system based on combining ability analysis. Sustainability. 12(12):4938. DOI: https://doi.org/10.3390/su12124938

Hanlon C, K Takeshima and GY Bédécarrats. 2021. Changes in control of the hypothalamic–pituitary–gonadal axis across strains of laying hens. Frontiers in Physiology. 12:651491. DOI: https://doi.org/10.3389/fphys.2021.651491

Hidalgo J, A Cesarani, A Garcia, P Sumreddee, N Larios, E Mancin, JG García, R Núñez and R Ramírez. 2021. Genetic background and inbreeding depression in Romosinuano cattle breed in Mexico. Animals. 11(2):321. DOI: https://doi.org/10.3390/ani11020321

Ibrahim Z, B Ali, RK Ali, A Jarad, W Farhan and M Hasan. 2020. Avian candidiasis: A review. Veterinary Research Journal. 12:1088–1091. DOI: https://doi.org/10.31838/ijpr/2020.12.01.199

Ka E, L Elmajdoub, A FM, A MM and A RS. 2024. Occurrence of nematodes in intestine of local chicken (Gallus gallus) and Pigeon (Columba livia domestica) in Misurata, Libya. Journal of Veterinary Research Advances 6: 53-58.

Kammon A, M Doghman and I Eldaghayes. 2022. Surveillance of the spread of avian influenza virus type A in live bird markets in Tripoli, Libya, and determination of the associated risk factors. Vet World. 15:1684–1690. DOI:10.14202/vetworld.2022.

Karaman S, Y Taşcıoğlu and O D Bulut. 2022. Profitability and cost analysis for contract broiler production in Turkey. Animals. 13(13):2072. DOI:10.3390/ani13132072.

Kozielec A, J Piecuch, K Daniek and L Luty. 2023. Challenges to food security in the Middle East and North Africa in the context of the Russia–Ukraine conflict. Agriculture. 14(1):155. DOI:10.3390/agriculture14010155.

Kpomasse CC, YAE Kouame, O N'nanle, FM Houndonougbo, K Tona and OE Oke. 2023. The productivity and resilience of indigenous chickens in tropical environments: improvement and future perspectives. J Appl Anim Res. 51(1):456–469. DOI:10.1080/09712119.2023.2228374.

Lee JH. 2021. Special issue: poultry genetics, breeding and biotechnology. Genes. 12(11):1744. DOI:10.3390/genes12111744.

Liu J, M Wei, J Lu, S Liu, X Li, X Wang, J Wang, D Zhang, T Lu and W Shi. 2025. Ammopiptanthus nanus population dynamics: bridging the gap between genetic variation and ecological distribution patterns. Biology. 14(2):105. DOI:10.3390/biology14020105.

Maharjan P, D Martinez, J Weil, N Suesuttajit, C Umberson, G Mullenix, K Hilton, A Beitia and C Coon. 2021. Physiological growth trend of current meat broilers and dietary protein and energy management approaches for sustainable broiler production. Animal. 15:100284. DOI:10.1016/j.animal.2021.100284.

Malapane OL, W Musakwa and N Chanza. 2024. Indigenous agricultural practices employed by the Vhavenda community in the Musina local municipality to promote sustainable environmental management. Heliyon.

10(13):e33713. DOI:10.1016/j.heliyon.2024.e33713.

Mansour R, P Liamputtong and A Arora. 2021. Food security among Libyan migrants living in Australia: a qualitative study. Sustainability. 13(24):13853. DOI:10.3390/su132413853.

Manyelo TG, L Selaledi, ZM Hassan and M Mabelebele. 2020. Local chicken breeds of Africa: their description, uses and conservation methods. Animals. 10(12):2257. DOI:10.3390/ani10122257.

Martyniuk E. 2020. Policy effects on the sustainability of animal breeding. Sustainability. 13(14):7787. DOI:10.3390/su13147787.

Mottet A and G Tempio. 2017. Global poultry production: current state and future outlook and challenges. World's Poult Sci J. 73:1–12. DOI:10.1017/S0043933917000071.

Nawaz AH, P Setthaya and C Feng. 2023. Exploring evolutionary adaptations and genomic advancements to improve heat tolerance in chickens. Animals. 14(15):2215. DOI:10.3390/ani14152215.

Obremski K, J Tyburski, P Wojtacha, I Skomorucha, J Pomianowski and P Parowicz. 2023. Assessment of the economic profitability of fattening selected chicken genotypes in an organic farm. Agriculture. 14(1):10. DOI:10.3390/agriculture14010010.

OEC. 2025. Poultry Meat in Libya. https://oec.world/en/profile/bilateral-product/poultry-meat/reporter/lby. (Accessed 30 June 2025).

Oke OE, OA Akosile, VA Uyanga, FO Oke, AI Oni, K Tona and OM Onagbesan. 2024. Climate change and broiler production. Vet Med Sci. 10(3):e1416. DOI:10.1002/vms3.1416.

Ouédraogo D, A Soudré, B Yougbaré, N Khayatzadeh, A Traoré, M Sanou, G Mészáros, PA Burger, OA Mwai, M Wurzinger and J Sölkner. 2020. Genetic improvement of local cattle breeds in West Africa: a review of breeding programs. Sustainability. 13(4):2125. DOI:10.3390/su13042125.

Riber AB and KE Wurtz. 2023. Impact of growth rate on the welfare of broilers. Animals. 14(22):3330. DOI:10.3390/ani14223330.

Sithole SM, KA Nephawe, TJ Mpofu, B Mtileni, ML Mphaphathi and JN Ngcobo. 2024. Extinction status, challenges, and conservation approaches of South African indigenous and village chickens: a systematic review. Agriculture. 15(2):216. DOI:10.3390/agriculture15020216.

Tian Y, Y Lin, Y Ma, J Li, SK Sahu, J Fan, C Lin, Z Li, M Shi, F He, L Bai, Y Fu, Z Deng, H Guo, H Li, Q Li, Y Xu, T Lan, Z Hou and S Yang. 2024. Population genomics reveals elevated inbreeding and accumulation of deleterious mutations in white raccoon dogs. Biology. 14(1):30. DOI:10.3390/biology14010030.

Torres E, D Iñigo, ML Rubio Teso and JM Iriondo. 2022. Facilitated adaptation as a conservation tool in the present climate change context: a methodological guide. Plants. 12(6):1258. DOI:10.3390/plants12061258.

Vlaicu PA, AE Untea and AG Oancea. 2024. Sustainable poultry feeding strategies for achieving zero hunger and enhancing food quality. Agriculture. 14(10):1811. DOI:10.3390/agriculture14101811.

Wasti S, N Sah and B Mishra. 2020. Impact of heat stress on poultry health and performances, and potential mitigation strategies. Animals. 10(8):1266. DOI:10.3390/ani10081266.

Xue Q, G Li, Y Cao, J Yin, Y Zhu, H Zhang, C Zhou, H Shen, X Dou, Y Su, K Wang, J Zou and W Han. 2020. Identification of genes involved in inbreeding depression of reproduction in Langshan chickens. Anim Biosci. 34(6):975. DOI:10.5713/ajas.20.0248.

Zhang L, J Ren and W Bai. 2022. Poultry waste-to-wealth: technological progress, modeling and simulation studies, and economic, environmental and social sustainability. Sustainability. 15(7):5620. DOI:10.3390/su15075620.

Zurqani HA, EA Mikhailova, CJ Post, C Lancelotti and S Biagetti. 2021. Mapping food production in hyper-arid and arid Saharan Africa in the Holocene—a view from the present. Quaternary. 4(2):13. DOI:10.3390/quat4020013.