

Chapter 1

General Introduction

1.1 Background of the Study

The global livestock sector plays a pivotal role in food security, employment and rural economic development. With the world population projected to surpass 9.7 billion by 2050, the demand for animal-derived protein is expected to increase dramatically (Food and Agriculture Organization (FAO, 2023). This trend is particularly significant in low- and middle-income countries, where rapid urbanization and income growth are transforming dietary preferences towards greater consumption of meat, milk and eggs. Consequently, pressure on traditional livestock systems-primarily dependent on cattle, goats, sheep and poultry is intensifying. These systems are often constrained by factors such as land degradation, limited feed resources, disease outbreaks and low productivity, making them insufficient to sustainably meet future protein needs (Thornton et al., 2022).

In response to these challenges, the diversification of livestock production has become increasingly vital. Diversification not only enhances productivity but also improves resilience to economic and climatic shocks and allows for more efficient use of available resources (Herrero et al., 2021). Within this context, non-traditional or exotic livestock species such as the ostrich (*Struthio camelus*) have attracted growing interest. Ostrich farming is gaining popularity due to the species' rapid growth rate, high feed efficiency, low-fat meat content and ability to thrive in harsh environments (Mushi et al., 2022). Moreover, ostriches yield valuable by-products such as high-quality leather, feathers and medicinal oil, thereby contributing to multiple income streams for farmers and entrepreneurs.

Ostriches are the largest extant birds, are indigenous to the savannas and semi-arid regions of Africa. Their unique physiological and behavioral traits make them particularly suited to hot and dry environments. Adult ostriches can weigh between 100 and 150 kilograms and grow up to 2.7 meters tall. Though they are flightless, they can run at speeds of up to 70 kilometers per hour, a trait that has evolved as a predator avoidance strategy (Deeming, 2021). Their natural resistance to many local pathogens and low water requirements make

them a potentially sustainable option for livestock farming in regions facing climatic and ecological stress.

Internationally, ostrich farming has evolved from a niche industry into a more commercially organized sector, particularly in countries like South Africa, which leads global ostrich meat and leather exports. Australia, China, Israel and the United States have also developed commercial ostrich farming industries through the integration of scientific breeding, nutrition and marketing strategies (Sales and Horbańczuk, 2018). The global demand for ostrich meat is being driven by health-conscious consumers who seek alternatives to traditional red meats, while the exotic leather market continues to thrive in the fashion and automobile industries.

In Bangladesh, the scope of ostrich farming is relatively new but expanding steadily. It was introduced by private entrepreneurs in the last decade, with the aim of exploring non-traditional animal farming as a means to boost income and reduce reliance on conventional livestock (Alam et al., 2023). Several farms have been established in districts such as Dhaka, Gazipur and Rajshahi. These ventures have demonstrated the viability of ostrich farming under Bangladeshi agro-climatic conditions, though they are still at a formative stage and face a variety of challenges ranging from lack of technical knowledge to insufficient regulatory support.

The rationale for introducing ostrich farming in Bangladesh is rooted in both economic and environmental factors. Given the limited arable land and growing feed competition among livestock, the introduction of high-efficiency animals like ostriches may provide a feasible alternative. Ostriches convert feed to body mass more efficiently than cattle or goats and require less land area for rearing. Additionally, the rising awareness about healthy eating habits among urban consumers is generating a niche market for lean, low-cholesterol meats such as ostrich meat (Hoffman et al., 2020).

From a development perspective, ostrich farming can offer substantial livelihood opportunities, particularly in rural and peri-urban areas. It has the potential to create jobs across various points of the value chain from hatcheries and breeding farms to slaughtering, processing, marketing and export. When supported with appropriate training, financial investment and veterinary care, ostrich farming could emerge as a viable avenue for inclusive economic growth and rural development in Bangladesh (Rahman et al., 2024).

In summary, the growing global demand for animal protein, coupled with the limitations of traditional livestock sectors in developing countries, underscores the urgent need for diversification. Ostrich farming represents an innovative and sustainable option with high commercial potential. While countries like South Africa and Australia have capitalized on this opportunity, Bangladesh is only beginning to explore its potential. Early evidence suggests that, with the right policy interventions and research support, ostrich production could significantly contribute to the country's food security, nutrition and rural livelihoods.

1.2 Rationale of the Study

The livestock sector is an essential pillar of Bangladesh's agricultural economy, contributing significantly to rural income, employment and national food security. It accounts for about 13% of the agricultural GDP and employs nearly 20% of the rural workforce directly or indirectly (DLS, 2023). Traditionally, this sector has centered around the rearing of cattle, goats, sheep and poultry. While these animals have historically fulfilled the protein and economic needs of rural populations, several pressing challenges have emerged in recent years. These include limited availability of grazing land, high feed costs, disease outbreaks and environmental degradation-all of which hamper productivity and pose serious risks to the sustainability of conventional livestock systems (Islam et al., 2022; Rahman et al., 2023).

With rising concerns over food security and nutritional adequacy, especially in densely populated nations like Bangladesh, there is a growing need to explore alternative livestock options that are both economically viable and ecologically sustainable. One such option is the ostrich, which has increasingly been recognized for its substantial contribution to meat, leather, feather and oil markets globally. Ostrich meat is high in protein, low in cholesterol and fat and contains essential micronutrients such as iron and zinc, making it a heart-friendly substitute for traditional red meats (Hoffman et al., 2020). These nutritional benefits align with the dietary shift among urban consumers in Bangladesh toward healthier and leaner animal proteins (Alam et al., 2023).

Furthermore, ostriches possess efficient feed conversion ratios and can thrive under intensive and semi-intensive rearing systems. They are well-suited to arid and semi-arid environments and exhibit natural resilience to many diseases that commonly affect other livestock species (Mushi et al., 2022). This makes ostrich farming a potential solution for addressing the twin challenges of productivity and sustainability in the livestock sector. The

diversification of animal farming through ostrich production can also offer new income-generating opportunities for smallholder farmers and entrepreneurs, especially in rural and peri-urban areas where land resources are scarce and conventional farming options are limited (Kabir et al., 2023).

Despite the considerable promise of ostrich farming, its development in Bangladesh remains in a nascent stage. Initial ventures by private entrepreneurs and a handful of pilot farms have demonstrated the feasibility of ostrich production under local conditions. However, these initiatives are often hampered by a host of structural and institutional barriers. Key challenges include the absence of technical knowledge among farmers, lack of trained personnel in ostrich management and veterinary care, inadequate market infrastructure and limited access to quality feed and breeding stock. Additionally, the lack of standardized husbandry practices and research-backed production protocols has restricted the replication and scalability of successful models (Moreki and Seabo, 2019).

Scientific literature on ostrich farming in Bangladesh is extremely limited, especially concerning the productive and reproductive performance of ostriches under the country's specific climatic, nutritional and managerial conditions. Understanding these parameters is crucial for the development of efficient breeding and rearing strategies tailored to the local context. Reproductive traits such as egg production, hatchability, chick survivability and age at sexual maturity are essential for establishing a sustainable ostrich population. Similarly, growth performance indicators, such as body weight gain, feed conversion efficiency and mortality rates can provide insights into optimal nutrition and management practices (Deeming, 2021).

In addition to the biological and managerial aspects, there is a pressing need for policy-level interventions to support the growth of the ostrich industry. This includes the formulation of regulatory frameworks for exotic animal farming, provision of subsidies or soft loans to interested farmers, investment in veterinary training programs and creation of a reliable value chain for ostrich products. Moreover, awareness-building campaigns are necessary to educate consumers about the nutritional benefits of ostrich meat and promote demand in both domestic and export markets (Rahman et al., 2024).

Therefore, this study is both timely and essential. It aims to fill critical knowledge gaps by assessing the productive and reproductive performances of ostriches under Bangladeshi conditions. By generating empirical data and practical insights, the study seeks to inform

stakeholders-including policymakers, researchers, extension workers and entrepreneurs-about the viability and requirements of ostrich farming. The findings of this research could pave the way for the scientific and commercial advancement of ostrich production in Bangladesh, ultimately contributing to agricultural diversification, rural development and national food security.

1.3 Global Trends in Ostrich Production

Over the past few decades, the global ostrich industry has undergone a significant transformation, transitioning from traditional hunting and subsistence use in native African regions to large-scale commercial farming systems across several continents. South Africa remains the epicenter of ostrich production and export, leading the world in the supply of ostrich meat, feathers and especially high-quality leather (Department of Agriculture, Forestry and Fisheries [DAFF], 2022). The industry in South Africa is well-integrated, with advanced breeding programs, regulated slaughterhouses and established export channels to Europe, Asia and North America. South African ostrich meat is particularly favored in health-conscious markets due to its leanness, high protein content and low levels of cholesterol and saturated fat (Hoffman et al., 2020).

Global interest in ostrich farming has surged, driven by growing demand for alternative protein sources, luxury leather and sustainable livestock options. As dietary preferences shift globally-fueled by increasing awareness of non-communicable diseases and the environmental impact of red meat-ostrich meat is being marketed as a healthy substitute to beef and lamb. According to the International Meat Secretariat (2023), the global ostrich meat market is projected to grow steadily, particularly in urban centers where consumers are more health-conscious and willing to explore novel meats. Markets such as the United States, Germany, the Netherlands, China and the United Arab Emirates have witnessed increasing imports of ostrich meat and by-products in recent years (Pogorzelska-Przybyłek et al., 2023).

Ostrich leather has similarly carved out a premium niche in the global fashion industry. Known for its distinct quill pattern and durability, ostrich leather is used by leading fashion houses for handbags, wallets, belts and footwear. The global luxury leather goods market has embraced ostrich leather not only for its aesthetic appeal but also for its rarity and exclusivity, which adds value to luxury products (Mutibvu et al., 2022). Additionally, the

feathers of ostriches are utilized in the manufacture of decorative items, dusters and costumes, especially in cultural and entertainment industries.

To meet the expanding global demand, countries outside Africa-such as Australia, the United States, China, Israel and several European nations-have developed sophisticated ostrich farming industries. These countries have invested in research and development aimed at improving breeding efficiency, disease management, feed optimization and overall productivity. Genetic selection programs are being used to enhance growth rates, reproductive success and meat yield in farmed ostriches (Sales and Horbańczuk, 2018). Moreover, the adoption of intensive production systems with precise control over environmental conditions and biosecurity measures has significantly improved ostrich farm performance in developed nations (Louw et al., 2021).

Biosecurity is a critical aspect of modern ostrich farming. The industry has learned from historical disease outbreaks-such as avian influenza in the early 2010s-which devastated ostrich populations in parts of South Africa and halted international exports temporarily (World Organization for Animal Health [WOAH], 2022). As a result, global producers now place a strong emphasis on vaccination, sanitary practices and disease surveillance. These measures are integrated into ostrich production protocols to ensure food safety and maintain market access in countries with stringent sanitary standards, such as those in the European Union (Zhou et al., 2023).

In parallel, advancements in ostrich nutrition have played a pivotal role in enhancing production efficiency. Recent research has explored the use of formulated feeds enriched with probiotics, enzymes and locally available feed resources to optimize nutrient absorption and reduce costs (Mushi et al., 2022). Nutritionists have also worked on balancing amino acid profiles and mineral supplementation to improve growth and egg production in breeding ostriches. The ability to fine-tune diets based on life stage, physiological needs and climate has led to better weight gain, reproductive success and reduced mortality.

Importantly, sustainability has become a key driver of innovation in the global ostrich industry. Compared to traditional livestock such as cattle, ostriches produce significantly less methane, require less water and have a lower environmental footprint per unit of meat produced (Smit et al., 2022). These characteristics position ostrich farming as an eco-

friendly alternative aligned with global efforts to reduce greenhouse gas emissions and transition to more sustainable agricultural systems.

Despite these promising global trends, the expansion of ostrich farming is not without challenges. In many countries, the industry still faces issues related to high startup costs, limited genetic stock, lack of trained personnel and unstable market prices. Additionally, consumer acceptance of ostrich meat remains low in certain regions due to cultural preferences, lack of awareness, or misconceptions about exotic meat products (Karunaratne et al., 2021). Therefore, strategic marketing, farmer education and public awareness campaigns are necessary to expand consumer bases and stimulate industry growth.

1.4 Ostrich Farming in Bangladesh: Current Scenario

Ostrich farming in Bangladesh is a relatively new venture that has gained gradual momentum since its inception in the early 2010s. The emergence of this non-traditional livestock practice was primarily driven by private entrepreneurs seeking to diversify animal agriculture and explore alternative sources of income and nutrition. The first commercial ostrich farms were established in districts such as Dhaka, Gazipur, Rajshahi, Mymensingh, Chattogram and Dinajpur with breeders importing foundational stock from countries like South Africa, Zimbabwe and Australia (Kabir et al., 2023). These pioneering farms introduced ostrich production to the local agribusiness landscape, creating curiosity among farmers and investors about the commercial feasibility of this giant bird.

Despite initial enthusiasm, ostrich farming in Bangladesh has experienced fluctuating fortunes. Some farms faced significant challenges including inadequate veterinary support, improper management, lack of specialized feed and insufficient knowledge of ostrich biology and husbandry practices. As a result, a number of ventures either scaled back their operations or ceased entirely due to financial unsustainability (Alam et al., 2023). In many cases, poor record-keeping, inexperience in exotic animal care and the absence of clear regulatory guidelines further complicated business continuity. A recurring issue has also been the lack of consumer awareness about ostrich meat, which resulted in limited market demand and delayed return on investment for many small-scale farmers.

The study conducted by Miah et al. (2020) confirmed that ostrich chicks could perform well under the agro-environmental conditions of Bangladesh when provided with proper management and feeding strategies.

Nevertheless, a handful of farms have managed to persist and evolve by adapting improved management strategies, seeking technical knowledge from foreign sources and forming informal networks for information sharing. Some success stories have highlighted the potential profitability of ostrich farming under improved feeding systems and proper health management (Hassan et al., 2023). These examples have helped maintain public interest and contributed to a cautious optimism about the future of ostrich production in the country.

DLS of Bangladesh has gradually acknowledged the potential of ostrich farming as a tool for livestock diversification and rural development. As the nation works toward achieving Sustainable Development Goals (SDGs), particularly those related to poverty reduction, nutrition improvement and climate resilience, non-conventional livestock such as ostriches are being recognized for their low resource requirements and high commercial value (DLS, 2023). The DLS has expressed a willingness to incorporate ostrich production into broader livestock development frameworks, albeit at a pilot or experimental scale.

Government initiatives, although nascent, include the provision of training workshops and seminars, the development of technical manuals and tentative support in regulatory aspects such as licensing and biosecurity (Begum et al., 2022). However, there is currently no comprehensive policy or dedicated research initiative focusing exclusively on ostrich farming. Most farms still rely heavily on trial-and-error approaches, often without access to reliable technical data on ostrich nutrition, health care, reproduction, or market behavior under Bangladeshi conditions.

Additionally, the academic and research community has only recently begun to explore ostrich production scientifically. Institutions such as Bangladesh Agricultural University (BAU) and the Livestock Research Institute (LRI) have started collecting preliminary data on ostrich physiology, feed intake and behavioral patterns. These initiatives are still in their infancy but signal growing institutional interest in expanding the research base required for a science-driven ostrich industry (Chowdhury et al., 2023). Without a well-established body of scientific knowledge tailored to the local agro-ecological and socioeconomic context, it remains difficult to formulate evidence-based guidelines for prospective ostrich farmers.

Another key limitation is the absence of formal supply chains and processing infrastructure. Although ostrich meat is nutritionally superior-being high in protein and low in cholesterol-its acceptance in Bangladeshi markets remains minimal due to lack of familiarity and high pricing relative to traditional meat sources (Ahmed et al., 2022). Furthermore, there are no

standardized abattoirs or cold chain logistics designed specifically for exotic meat products, which inhibits proper slaughtering, packaging and preservation of ostrich meat for commercial sale. Similarly, the utilization of ostrich by-products such as leather, feathers and oil is still underdeveloped, largely due to the absence of specialized tanning units, processing facilities, or branding channels for luxury items.

Moreover, access to capital and credit facilities for ostrich farming is severely limited. Most financial institutions do not recognize ostrich farming as an established or low-risk venture, which discourages investment. There is also a lack of insurance schemes for exotic livestock, exposing farmers to high levels of economic vulnerability in the event of disease outbreaks or mortality.

Despite these challenges, the long-term potential of ostrich farming in Bangladesh remains promising. Given the country's increasing population, growing demand for animal-based protein and shrinking per capita agricultural land, ostrich farming could serve as an innovative solution that meets food security needs while offering attractive economic returns. With proper planning, targeted research, supportive policy frameworks and stakeholder collaboration, the ostrich sector could evolve into a viable component of Bangladesh's diversified livestock industry.

1.5 Relevance to Sustainable Development Goals (SDGs)

Ostrich farming in Bangladesh has the potential to contribute significantly to the achievement of several Sustainable Development Goals (SDGs). These goals, established by the United Nations as part of the 2030 Agenda for Sustainable Development, address global challenges related to poverty, hunger, economic inequality, environmental degradation and peace and justice. By focusing on the expansion of ostrich farming, Bangladesh can advance sustainable agriculture, improve rural livelihoods and enhance food security while contributing to the broader global agenda of sustainable development.

1.5.1 SDG 1: No Poverty

One of the most direct impacts of ostrich farming in Bangladesh is its potential to alleviate poverty, particularly in rural areas. The establishment of ostrich farms can generate income for farmers and local communities by creating employment opportunities in various stages of production, including farm management, feed production, veterinary care and processing. Additionally, by diversifying income streams through the sale of ostrich meat, feathers,

leather and oil, farmers can mitigate the financial risks associated with over-reliance on traditional livestock such as cattle, goats and poultry (Kabir et al., 2023).

1.5.2 SDG 2: Zero Hunger

Ostrich farming offers a promising solution to diversify protein sources in Bangladesh, contributing to food security and nutrition. As the demand for animal protein rises globally, including in Bangladesh, traditional livestock farming struggles to meet the growing demand. Ostrich meat, being leaner and lower in cholesterol and fat than beef, poultry, or pork, is increasingly recognized for its health benefits (Hoffman et al., 2020). By promoting ostrich farming, Bangladesh can increase the availability of alternative protein sources, which is particularly crucial in urban areas where access to diverse food sources may be limited.

Furthermore, the nutritional profile of ostrich meat could play an important role in combating malnutrition, particularly for vulnerable populations. With increasing awareness of the benefits of healthy eating, there is a rising demand for low-fat, high-protein meats, making ostrich farming a viable solution to meet these dietary needs (Mushi et al., 2022). This aligns with SDG 2's goal of improving food systems and ensuring that nutritious food is accessible to all, while reducing reliance on conventional livestock that may place greater strain on the environment.

1.5.3 SDG 8: Decent Work and Economic Growth

Ostrich farming can significantly contribute to SDG 8 by promoting inclusive economic growth and decent employment opportunities in rural areas. As Bangladesh transitions towards a more diversified agricultural economy, ostrich farming offers potential for rural development and job creation, especially in underserved and marginalized regions. By establishing ostrich farms, local communities can be empowered through capacity building, training and the establishment of entrepreneurial ventures related to ostrich farming (Rahman et al., 2021).

In addition to direct employment in farming activities, the development of a related ostrich product processing industry (such as meat processing, leather goods and feather production) can create further job opportunities. As the sector grows, the demand for skilled labor, including veterinarians, farm managers and technicians, will also increase, leading to the creation of high-quality jobs in rural Bangladesh (Kabir et al., 2023). This aligns with SDG

8, which aims to promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

1.5.4 SDG 12: Responsible Consumption and Production

Ostrich farming has the potential to significantly contribute to SDG 12, which focuses on ensuring sustainable consumption and production patterns. Ostriches are well-adapted to arid climates and are more resource-efficient than many traditional livestock species. They require less water and space, making them suitable for resource-scarce environments and reducing the environmental footprint of livestock farming. Compared to cattle and other traditional livestock, ostriches produce fewer greenhouse gas emissions and use less land for grazing (Hassan et al., 2022a).

Furthermore, the by-products of ostrich farming, such as feathers, leather and oil, can be used in sustainable production processes. For example, ostrich feathers are used in high-end fashion and craft industries, while ostrich leather is prized for its strength and unique texture, contributing to the growing market for sustainable luxury goods (Sales and Horbańczuk, 2018). As such, the development of ostrich farming in Bangladesh can contribute to the global shift towards more responsible and sustainable production practices, reducing the environmental impact of the livestock sector.

1.6 Justification of the Study

The scientific investigation of ostrich farming in Bangladesh, particularly its productive and reproductive performance, is crucial for several reasons. Given the nascent stage of ostrich farming in the country, there is a significant gap in knowledge regarding optimal management practices, breeding techniques and health protocols specific to the Bangladeshi context. This study aims to fill this gap by providing empirical data on the performance of ostriches under local environmental and management conditions.

Understanding the productive and reproductive parameters of ostriches in Bangladesh is vital for the development of targeted strategies to improve production efficiency and economic viability. By examining key factors such as feed conversion efficiency, weight gain, fertility rate, hatchability and chick survivability, this study will help identify the best management practices and breeding methods that can enhance productivity and ensure the sustainability of ostrich farming in Bangladesh (Deeming, 2021).

Moreover, this research will support policy development by providing evidence-based recommendations to the government and relevant stakeholders. These recommendations could guide the formulation of policies that encourage the growth of the ostrich farming industry, such as subsidies for farmers, training programs and the establishment of veterinary support systems. The findings of this study will also contribute to the development of an efficient market infrastructure, addressing key issues such as product marketing and consumer awareness (Mushi et al., 2022).

In line with Bangladesh's national goals of poverty reduction, rural development and environmental sustainability, this study will highlight the opportunities for ostrich farming to contribute to sustainable economic development. By focusing on the potential benefits of ostrich farming, this research aims to promote a more diverse and sustainable agricultural sector that aligns with the global objectives of the United Nations' SDGs.

Objectives

The overall specific objectives of this study are :

- i) To investigate the major constraints and emerging opportunities in ostrich farming practices in Bangladesh to develop a sustainable model for future expansion.
- ii) To evaluate the effects of dietary methionine and lysine supplementation on the growth performance and survivability of ostrich chicks.
- iii) To analyze the behavioral patterns, social interactions and breeding behavior of captive ostriches under semi-intensive farming conditions.
- iv) To determine the carcass characteristics and assess the nutritional composition of ostrich meat produced under semi-intensive management systems.
- v) To examine the physical attributes and nutritional content of ostrich eggs collected from semi-intensive farming environments.
- vi) To assess reproductive performance and identify key factors influencing the hatching success of ostrich eggs under artificial incubation.

Chapter 2

Review of Literature

2.1 Introduction to Ostrich Farming

Ostrich (*Struthio camelus*), the largest living bird species, is native to the savannahs and arid regions of Africa. As the flightless birds with extraordinary speed and adaptability, ostriches have evolved to survive in harsh environments with minimal water and high temperatures (Deeming, 2013). In recent decades, their unique biological and economic traits have made them a target for domestication and commercial farming globally. The shift towards ostrich farming is driven not only by the growing demand for alternative meat sources but also by the bird's ability to efficiently utilize feed and produce multiple valuable by-products (Sales and Horbańczuk, 2018).

Ostrich meat is widely recognized for its superior nutritional qualities. It is rich in protein, iron and omega-3 fatty acids, while being low in cholesterol and saturated fats (Hoffman et al., 2020). These attributes have positioned ostrich meat as a health-conscious alternative to traditional red meats such as beef and mutton. The rising global incidence of lifestyle diseases, such as obesity and cardiovascular conditions, has further stimulated demand for lean and nutritious meat options, bolstering the ostrich industry (Mushi et al., 2022).

Besides meat, ostriches offer economic value through other products. Ostrich leather is highly durable and has a unique quill pattern, making it a luxury material in fashion and upholstery. The feathers are used in decorative items, traditional costumes and even industrial applications due to their static-resistant properties. Furthermore, ostrich oil-extracted from the fatty tissues-is utilized in the pharmaceutical and cosmetic industries for its anti-inflammatory and skin-nourishing qualities (Horbańczuk and Sales, 2019).

The environmental adaptability of ostriches also adds to their appeal as livestock. Unlike many conventional livestock species, ostriches can thrive in semi-arid and marginal lands, requiring relatively less water and feed inputs. They exhibit a high feed conversion ratio (FCR) and show resilience to certain environmental stressors, which is especially relevant in regions vulnerable to climate change (Aganga et al., 2021).

The global ostrich industry, although still developing in many regions, reflects a strategic shift in agricultural diversification. Countries like South Africa, the United States, China

and Australia have capitalized on ostrich farming through investments in genetics, feed formulations and biosecurity systems (DAFF, 2022). As global populations grow and land for traditional livestock becomes limited, alternative farming systems such as ostrich production offer sustainable solutions to food security and rural development (Rahman et al., 2021).

2.2 Global Expansion and Commercialization

South Africa remains the leading country in ostrich farming and the export of ostrich products (DAFF, 2022). It accounts for a major share of global ostrich meat, leather and feather exports, driven by its long-standing expertise and specialized infrastructure. The success of the South African ostrich industry is attributed to government support, private sector innovation and research institutions that continuously improve breeding, husbandry and disease management protocols. Countries such as Australia, the United States, Israel and China have also developed competitive ostrich industries. These nations have embraced modern technologies in hatchery management, artificial incubation, genetic selection and biosecurity systems to enhance productivity and maintain international quality standards (Mushi et al., 2022). In Australia, the ostrich industry has focused on value addition and market-oriented processing, including the development of gourmet ostrich meat products (Hoffman et al., 2020).

Israel has invested significantly in ostrich research and intensive production systems, utilizing precision agriculture to monitor health and feed efficiency. Meanwhile, China has ramped up ostrich farming in response to its growing demand for alternative proteins and luxury goods. The rapid expansion is further fueled by the country's consumer market size and support for agricultural diversification (Deeming, 2021).

In the United States, ostrich farming is driven by niche market demands and health-conscious consumers seeking alternatives to beef and pork. The regulatory environment and technological infrastructure in the U.S. have enabled efficient meat processing and leather production, creating added value for farmers. Globally, the commercialization of ostrich farming is marked by continuous research in nutrition, genetics and veterinary care. Advances in feed formulations aim to optimize feed conversion ratios while enhancing meat quality. Breeding programs have been developed to improve fertility, hatchability and chick survival rates. In terms of disease control, global producers have implemented biosecurity

protocols to prevent outbreaks and maintain flock health, contributing to a more resilient production system (Deeming, 2021).

The international ostrich market is driven not only by health trends but also by the demand for eco-conscious and ethical meat alternatives. Ostrich farming's low environmental footprint, combined with its high economic return, positions it as a model for sustainable livestock development in the 21st century.

2.3 Anatomy and Physiology of Ostriches

Understanding the anatomy and physiology of ostriches is essential for effective management and health care in commercial production systems. Ostriches are the largest extant birds and are anatomically adapted for running rather than flying. They possess long, muscular legs with two toes, aiding in high-speed locomotion up to 70 km/h, a key defense mechanism in the wild (Deeming, 2013). The lightweight body and strong skeletal frame enable endurance and speed, critical for their survival and domestication.

Physiologically, ostriches have a unique digestive system compared to other poultry. They are monogastric, with a large, muscular proventriculus and gizzard that aid in the mechanical breakdown of feed. Their long intestinal tract supports efficient nutrient absorption, enabling better feed conversion efficiency than many ruminants (Hassan et al., 2022a). The ability to digest high-fiber diets allows ostriches to thrive in environments with limited high-quality forage, making them suitable for arid and semi-arid climates.

The thermoregulatory system of ostriches is also distinct. They exhibit physiological adaptations such as panting, vasodilation and behavioral strategies like wing-flapping to cope with heat stress, which is vital in tropical and subtropical environments. These adaptations are essential for ensuring bird welfare in varying climatic conditions (Mushi et al., 2022).

Reproductively, ostriches display a unique system among ratites. Males possess a retractable phallus and females are induced ovulators, laying large eggs that can weigh up to 1.5 kg. The reproductive cycle is influenced by photoperiod, nutrition and social hierarchy. The nesting behavior involves communal nesting with one dominant hen laying in the same nest, increasing reproductive output (Deeming, 2013). Male ostriches are involved in incubation and chick rearing, highlighting the need for gender-specific management strategies.

Sexual maturity is reached around two to three years of age, with peak reproductive performance occurring between four and seven years. The reproductive season typically spans spring and summer, although this can be managed under artificial lighting and controlled environments to extend laying periods. Factors such as stress, poor nutrition and inadequate housing significantly affect fertility and hatchability (Hassan et al., 2022a).

A thorough understanding of ostrich anatomy and physiology aids in formulating balanced diets, designing housing systems and implementing health management protocols that enhance productivity and reproductive efficiency. This knowledge is crucial for regions like Bangladesh, where ostrich farming is emerging, to ensure informed decisions and sustainable development in the sector.

2.4 Nutritional Requirements

Ostrich nutrition plays a pivotal role in enhancing productive and reproductive efficiency. As herbivorous monogastric animals with a high capacity for digesting fibrous materials, ostriches require a diet rich in fiber and moderate in protein. Forage-based systems supplemented with grains, minerals and vitamins have been found to support optimal health and performance (Aganga et al., 2021). Key nutrients such as protein, calcium and phosphorus are particularly important during the growth and laying phases. Adequate protein intake supports muscle development and feather quality, while calcium and phosphorus are essential for skeletal health and eggshell formation. Studies have shown that imbalances in these nutrients can lead to leg deformities, poor growth rates and decreased reproductive performance (Mushi et al., 2022). Feed efficiency in ostriches also significantly influences meat quality and economic returns. High-quality diets have been linked to better carcass composition, with reduced fat deposition and improved lean meat yield (Hoffman et al., 2020). In regions with variable feed resources, locally available forages such as Napier grass, alfalfa and agricultural by-products may serve as viable alternatives when properly balanced (Horbańczuk and Sales, 2019).

Feeding strategies should also account for the different nutritional needs across life stages. Chicks require higher protein levels (20–24%) to support rapid growth, while adult birds can be maintained on lower-protein rations (12–16%). Mineral supplementation, particularly with calcium, phosphorus and trace elements such as zinc and manganese, becomes more critical during the laying season to maintain egg production and shell integrity (Aganga et al., 2021).

Water availability and hygiene also play a central role in ostrich nutrition. Clean, fresh water should be accessible at all times, as dehydration can adversely affect feed intake, digestion and thermoregulation. Feed management practices, including regular feed analysis and formulation adjustments, are essential to ensure nutrient adequacy and cost-effectiveness.

2.5 Productive Performance

Productive performance is a fundamental aspect of ostrich farming that directly influences economic viability. Key performance indicators include growth rate, feed conversion ratio (FCR), carcass yield and meat quality. These parameters are largely influenced by genetics, nutrition, environmental conditions and farm management practices (Deeming, 2021).

2.5.1 Growth Rate and Feed Conversion

Ostriches are widely recognized for their rapid growth, which positions them as a promising species for commercial meat production. Under optimal management systems, ostrich chicks can reach body weights ranging between 90 and 120 kg within 10 to 14 months of age (Horbańczuk and Sales, 2019). This accelerated growth is facilitated by their inherent physiological traits and ability to efficiently utilize dietary nutrients, making them economically attractive in diversified livestock farming.

One of the most important parameters influencing the commercial viability of ostrich farming is the feed conversion ratio (FCR), which refers to the amount of feed required to gain a unit of body mass. Ostriches typically exhibit FCRs ranging from 3.5 to 4.5, although this value is influenced by various factors including age, breed, feed quality, housing, environmental stress and management practices (Aganga et al., 2021). A lower FCR reflects better feed efficiency and cost-effectiveness, which is critical in high-input livestock operations.

Proper feed formulation is essential for optimizing both growth performance and FCR. Diets must be well-balanced in terms of energy, protein, fiber, vitamins and minerals. Particularly during the early growth phase, higher levels of dietary protein (approximately 20–24%) are required to support muscle development and skeletal integrity (Mushi et al., 2022). According to Miah et al. (2020), ostrich chicks fed with protein-enriched starter diets demonstrated significantly higher average daily gains and better feed efficiency compared to those on standard poultry rations. Their study also noted that chicks fed diets supplemented with amino acids such as methionine and lysine achieved greater weight gain and survivability, highlighting the importance of targeted nutrient supplementation.

Environmental conditions also have a notable impact on feed efficiency. In high-humidity regions such as Bangladesh, stress due to heat and poor ventilation can lead to reduced feed intake and impaired digestion, thereby affecting growth rates (Rahman et al., 2021). Studies in tropical climates have suggested that adjusting energy and fiber levels according to seasonal variations can help mitigate environmental stress and maintain growth momentum.

The growth trajectory of ostriches is not linear; rather, it follows distinct phases. During the first 3 months, chicks exhibit a rapid growth spurt with daily weight gains ranging between 400 and 600 g, especially under intensive rearing systems with proper feed and biosecurity measures. Empirical data from experimental trials conducted by Islam et al. (2023) at Hajee Mohammad Danesh Science and Technology University revealed that ostrich chicks achieved average live weights of 33.1 kg by the 12th week, with feed conversion ratios improving significantly when diets were fortified with methionine and lysine. These results reinforce the findings of Miah et al. (2020) and validate the nutritional and environmental compatibility of ostrich farming in subtropical settings.

Moreover, genetic potential also plays a critical role in determining growth performance. Ostriches from South African and Australian bloodlines have been observed to grow faster and attain higher slaughter weights compared to birds from indigenous or mixed lines (Hoffman et al., 2020). This underlines the importance of selective breeding and genetic improvement programs in enhancing feed utilization and meat yield.

2.5.2 Carcass Yield and Dressing Percentage

Carcass yield is one of the most significant economic indicators in evaluating the profitability of ostrich farming. It represents the proportion of the bird's live weight that results in marketable meat and by-products. Ostriches typically achieve a dressing percentage ranging from 55 to 60 percent, depending on factors such as diet, age at slaughter, breed and management practices (Sales, 2014). This relatively high dressing percentage, combined with the large body size of the ostrich, makes it an economically attractive alternative to conventional livestock such as cattle or goats.

The nutritional regime plays a crucial role in determining both carcass yield and meat quality. Birds provided with energy-rich, protein-balanced diets tend to exhibit improved muscle development, reduced fat deposition and superior meat texture (Hoffman et al., 2020). In particular, studies have shown that supplementation with key amino acids such as methionine and lysine enhances carcass traits by promoting lean tissue growth while

maintaining feed efficiency. Islam et al. (2023) reported that ostrich chicks fed with graded levels of methionine and lysine not only achieved higher live body weights but also yielded significantly better carcass weights and dressing percentages under local rearing conditions in Bangladesh.

Apart from meat, ostriches are also valuable for their by-products, including leather, feathers and oil, which contribute to the overall economic return per bird. Ostrich leather is considered one of the most luxurious and durable exotic leathers available, highly prized in the global fashion industry for its natural quill pattern, tensile strength and aesthetic value (Hassan et al., 2022a). It is commonly used in the manufacture of high-end boots, handbags, wallets and car interiors. The skin of ostriches slaughtered at around 10 to 14 months provides optimal leather quality, with proper tanning techniques further enhancing durability.

Ostrich feathers also have commercial uses, ranging from decorative arts and costume design to dusting equipment in electronics and automotive industries. Furthermore, ostrich oil, extracted primarily from adipose tissues, contains high levels of unsaturated fatty acids and has gained popularity in cosmetic and therapeutic applications due to its anti-inflammatory and skin-nourishing properties (Zhang et al., 2018).

In the context of Bangladesh, the potential to maximize carcass yield and dressing percentage lies in the adoption of scientific slaughtering techniques, cold chain infrastructure and standardized meat processing systems. At present, the absence of modern abattoirs tailored for large exotic birds limits the commercial exploitation of ostrich meat and by-products. Introducing value-added processing units, improving hygienic slaughtering practices and ensuring proper training for farm and abattoir personnel can significantly improve meat yield, quality and consumer acceptance.

2.5.3 Meat Characteristics

Ostrich meat is widely recognized for its exceptional nutritional profile, making it a healthier alternative to traditional red meats such as beef and mutton. It is low in total fat and cholesterol, yet rich in high-quality protein, iron and essential amino acids. The meat has a deep red coloration, closely resembling lean beef in appearance, but it contains significantly less saturated fat, making it more appealing to health-conscious consumers and those managing cardiovascular risks (Magwedere et al., 2020).

From a biochemical standpoint, ostrich meat typically contains 23–26% crude protein, 1–2% intramuscular fat and low cholesterol levels, often below 60 mg per 100 grams of meat. It also has a high iron content, making it suitable for individuals with iron-deficiency anemia (Hoffman et al., 2020). These favorable nutritional attributes, combined with its tenderness and palatability, have positioned ostrich meat as a premium product in upscale and specialty markets across Europe, Asia and the Middle East.

Recent experimental studies in Bangladesh by Islam et al. (2023) reported that ostrich meat produced under controlled feeding and management conditions exhibited high dressing percentages and favorable meat characteristics, including low lipid content, high unsaturated fatty acid levels and an ideal meat-to-bone ratio. These findings confirm that ostrich meat, when produced under suitable agro-climatic and nutritional conditions, can meet both domestic and international quality standards.

Furthermore, the absence of marbling in ostrich meat makes it suitable for a variety of culinary applications, from grilled steaks to gourmet sausages, without the health concerns associated with conventional red meats. As awareness grows, ostrich meat could be positioned as a functional food offering health benefits beyond basic nutrition.

2.5.4 Productive Efficiency under Various Systems

The productive efficiency of ostriches, defined by parameters such as growth rate, feed conversion, survivability and reproductive output which varies significantly across different farming systems. Globally, three primary production models are practiced: intensive, semi-intensive and extensive systems.

In intensive systems, such as those in South Africa and Israel, birds are reared in climate-controlled environments with access to scientifically formulated rations, automated feeding and strict biosecurity measures. These systems allow for maximum productivity, with faster growth rates, lower mortality and higher hatchability due to optimized incubation conditions (Deeming, 2021). However, such systems require high capital investment and skilled labor.

Semi-intensive systems, often used in developing countries, balance controlled feeding and housing with access to outdoor pens. While performance metrics are lower than in intensive systems, costs are reduced, making this model more feasible in low-resource settings. Extensive systems, which rely on natural grazing and minimal intervention, are the least productive but are sometimes employed in arid or semi-arid areas where land is abundant and feed costs are prohibitive (Alshamy et al., 2023).

In the context of Bangladesh, ostrich farming is still in its nascent phase. Most farms currently operate as semi-intensive units, combining locally available feed ingredients with commercial rations. According to Kabir et al. (2023), although detailed performance data remain limited, early results indicate that ostriches have the genetic and physiological potential to perform well under local conditions if given adequate nutrition, space and disease control. Future productivity improvements will depend on the adoption of structured breeding programs, nutritional optimization and the gradual introduction of intensive management principles.

2.5.5 Egg Production

Egg production is an important reproductive performance indicator in ostrich farming and directly affects the economic viability of breeding operations. Under optimal management conditions, a healthy and mature female ostrich can lay between 40 and 100 eggs during a breeding season, which typically lasts six to eight months (Hassan et al., 2022a). However, the number of eggs laid varies considerably based on several factors including age, genetics, nutrition, environmental stimuli and the social structure of the breeding flock.

Age plays a vital role in the reproductive output of female ostriches. First-year breeders generally lay fewer eggs, typically between 10 and 30, due to physiological immaturity and lower ovulation efficiency. Egg production usually increases during the second and third breeding seasons and tends to peak between four and seven years of age. After this peak period, productivity gradually declines (Aganga et al., 2021). Selecting breeder stock from high-producing hens and removing low-yielding birds from the breeding population are standard practices for maintaining egg production at optimal levels.

Genetic potential significantly influences egg-laying performance. Selective breeding programs in countries such as South Africa have improved reproductive efficiency by favoring females with larger clutch sizes and shorter intervals between egg-laying cycles. Introducing genetically superior bloodlines into ostrich flocks in Bangladesh may enhance reproductive efficiency and help build a more productive breeding base (Hoffman et al., 2020).

Environmental conditions, particularly temperature, humidity and photoperiod, strongly affect the reproductive cycle. Ostriches are seasonal layers and egg production is typically concentrated in the warmer months with longer daylight hours. Deeming and Bubier (2020) noted that light duration has a direct effect on reproductive hormone secretion, which

influences the start and length of the laying season. In the context of Bangladesh, the main laying period typically extends from March to October, although the use of artificial lighting and improved shelter conditions may extend this season or improve consistency in egg-laying performance.

The male-to-female ratio in breeding groups also affects fertility and egg production. A commonly recommended ratio is one male for every two or three females, which helps ensure successful mating while avoiding excessive competition among hens. Poor male fertility, overcrowding and lack of space for natural mating can reduce fertility rates and overall reproductive efficiency (Rahman et al., 2021).

2.5.6 Environmental Influence on Performance

Environmental conditions play a critical role in the productive performance of ostriches. As native desert-adapted birds, ostriches can tolerate a wide range of temperatures; however, high humidity, excessive rainfall and abrupt temperature changes, common in tropical and subtropical climates like Bangladesh, can lead to thermal stress, reduced feed intake and compromised immune function (Moreki and Seabo, 2019).

Heat stress in particular can suppress feed efficiency and growth, increase water intake and predispose birds to respiratory and gastrointestinal disorders. Therefore, appropriate housing designs that promote natural ventilation, shade and thermal insulation are essential to buffer environmental fluctuations. The use of ventilated shelters, mist-cooling systems and seasonally adjusted feeding schedules has been shown to improve performance under humid conditions (Rahman et al., 2021).

Additionally, photoperiod influences the reproductive cycle of ostriches, particularly egg-laying and fertility. Artificial light regimes may be necessary to simulate optimal breeding conditions during shorter daylight months, especially in controlled or semi-intensive production systems.

Another crucial factor is biosecurity, which directly impacts survivability and production. In the absence of vaccines and approved pharmaceuticals for ostriches in Bangladesh, the prevention of disease outbreaks depends heavily on hygiene, pest control, quarantine measures and regular health monitoring. As noted by Miah et al. (2020), farms that adopted stringent environmental and biosecurity protocols recorded significantly lower mortality rates and better overall flock performance.

2.6 Reproductive Performance

Reproductive performance is a cornerstone of successful ostrich farming, significantly affecting flock expansion, production planning and farm profitability. In ostrich production systems, reproductive traits such as age at sexual maturity, egg production, fertility rate, hatchability and chick survivability are considered vital indicators of reproductive efficiency (Deeming, 2021).

2.6.1 Age at Sexual Maturity

Age at sexual maturity is a critical determinant of reproductive efficiency and economic sustainability in ostrich farming systems. Ostriches are known for their relatively late onset of sexual maturity compared to commercial poultry, which inherently lengthens generation intervals and slows flock expansion (Deeming, 2021). Understanding the factors influencing the timing of sexual maturity is therefore central to optimizing production.

Female ostriches typically reach reproductive maturity between 24 and 30 months of age, while males can show spermatogenic development from around 18–24 months but often require additional time to establish consistent mating competence and fertile semen production (Moreki and Seabo, 2019; Malebana et al., 2022). The delay in male reproductive consistency is partly due to behavioral maturation and the physiological time needed for testicular development and stabilization of semen quality (Horbańczuk et al., 2023).

Recent research highlights a complex interplay of intrinsic and extrinsic factors that can either accelerate or delay the onset of sexual maturity:

- 1) **Nutritional status:** Adequate and balanced nutrition, particularly dietary protein (16–18%) and trace minerals such as zinc and selenium, is crucial for gonadal development. Deficiencies or imbalances can postpone puberty, reduce subsequent fertility and limit lifetime egg production (Ghebremariam et al., 2021; Abou El-Azm et al., 2023).
- 2) **Photoperiod and seasonality:** Ostriches, like many avian species, show some sensitivity to photoperiod. Studies conducted in subtropical and temperate regions indicate that controlled lighting programs can modestly influence sexual maturity by synchronizing reproductive hormone release (Horbańczuk et al., 2021).

- 3) **Social dynamics and flock structure:** Social factors such as flock density, sex ratio and hierarchy can impact behavioral and physiological readiness for breeding. Overcrowding or excessive male aggression has been reported to delay female maturation and reduce early laying performance (Malebana et al., 2022).
- 4) **Genetics:** Although ostrich breeding has not yet benefited from large-scale genetic selection programs, emerging evidence suggests variation in puberty onset between strains (Southern African Black vs. Zimbabwean Blue). Selective breeding for earlier sexual maturity could be a feasible long-term strategy (Li et al., 2022).

Under **intensive and semi-intensive systems** with optimized feeding, veterinary care and environment, some producers have reported females starting to lay as early as 20–22 months, though early maturity does not always translate into high fertility or hatchability initially (Deeming and Bubier, 2020). It is generally recommended that breeding be delayed until at least 24 months to allow full skeletal and reproductive tract development, thereby supporting better egg quality and reducing risks such as prolapse (Aganga et al., 2021).

2.6.2 Fertility Rate

Fertility in ostriches is recognized as a complex and multifactorial trait, shaped by genetic, physiological, environmental and managerial factors (Moreki et al., 2020). Semen quality, which includes sperm motility, concentration and morphology, plays a critical role in determining fertility outcomes. Female reproductive health, age and the timing and frequency of mating events are also central to reproductive success (Li et al., 2022).

In commercial ostrich production systems, fertility rates typically range between 50% and 80%. Controlled breeding programs and artificial insemination techniques have demonstrated the potential to raise these rates to above 85% (Abou El-Azm et al., 2023; Malebana et al., 2022). Controlled mating systems help minimize unpredictability by enabling the selection of males with superior semen quality, which directly contributes to higher fertility (Horbańczuk et al., 2021).

The management of male-to-female ratios is another critical consideration. Most farms achieve optimal results by maintaining approximately one male for every two or three females. This ratio supports adequate mating opportunities while helping to reduce male aggression and social stress within the flock, both of which can negatively affect fertility (Malebana et al., 2022). Seasonal manipulation of photoperiod has also been shown to

influence reproductive hormones and stimulate breeding behavior, particularly in subtropical and temperate farming systems (Horbańczuk et al., 2023).

Nutrition is closely linked to reproductive performance. Diets enriched with essential trace minerals such as zinc and selenium, along with vitamins A and E, support spermatogenesis and enhance semen quality (Aganga et al., 2021; Tshabalala et al., 2018). Conversely, nutritional deficiencies, abrupt changes in feed composition, or mycotoxin contamination can reduce fertility by affecting hormone regulation and gamete viability.

Stress management is equally important. Factors such as overcrowding, poor housing design, environmental temperature fluctuations and excessive handling can elevate stress hormone levels, which in turn suppress reproductive hormone secretion and reduce mating success (Hassan et al., 2022a).

Recent research has also explored assisted reproductive technologies, including artificial insemination and semen cryopreservation, although their widespread application in ostrich farming remains limited by practical and anatomical challenges (Li et al., 2022). Nevertheless, these methods show promise for enhancing genetic improvement programs and safeguarding genetic diversity in both commercial and conservation contexts (Horbańczuk et al., 2023).

2.6.3 Hatchability

Hatchability, defined as the proportion of fertile eggs that progress to successfully hatched, viable chicks, is a central indicator of reproductive success and farm profitability in commercial ostrich production (Horbańczuk et al., 2019). Typical hatchability rates in ostrich farms fluctuate between 40% and 70%; however, well-managed systems using advanced incubation technologies and rigorous egg management can occasionally achieve rates above 75% (Deeming and Bubier, 2020; Hassan et al., 2022).

Artificial incubation remains the standard practice in modern ostrich farming. Natural brooding is often avoided due to its unpredictability, lower capacity and higher risk of egg breakage and embryonic mortality resulting from parental aggression or trampling (Mushi et al., 2022). Artificial incubation systems, when properly optimized, provide consistent environmental conditions critical to embryonic development.

Several factors significantly influence hatchability:

- 1) **Egg turning:** Frequent turning (ideally every 2–3 hours) prevents the embryo from adhering to the inner shell membrane and promotes uniform heat distribution and gas exchange (Sales, 2014).
- 2) **Temperature:** Incubators should maintain a narrow temperature range between 36.0°C and 36.5°C; even small deviations can result in embryonic deformities or mortality (Deeming, 2021).
- 3) **Humidity:** Early incubation stages typically require 20–25% relative humidity to promote gradual moisture loss and optimal air cell development. In the final hatching phase, humidity should be increased to 35–40% to prevent excessive desiccation of membranes and assist chicks in pipping (Mushi et al., 2022).
- 4) **Egg handling and hygiene:** Regular removal of infertile, cracked, or contaminated eggs helps prevent bacterial growth and cross-contamination. Eggshell sanitation (using mild disinfectants or UV treatment) further reduces microbial load and improves hatchability outcomes (Aganga et al., 2021; Abou El-Azm et al., 2023).
- 5) **Egg storage:** Eggs stored for more than 7–10 days before incubation often show reduced hatchability due to decreased viability of the blastoderm and altered moisture content (Horbańczuk and Cooper, 2020).

Furthermore, breeder nutrition plays a pivotal role; deficiencies in vitamins A, D and E or minerals like calcium and selenium have been linked to increased embryonic mortality and poor shell quality (Tshabalala et al., 2018).

Despite technological advances, embryonic mortality remains highest during the first and last weeks of incubation. Early losses often relate to genetic defects or maternal nutrition, while late losses are frequently linked to temperature fluctuations, humidity mismanagement, or bacterial infections penetrating through micro-cracks in the shell (Hassan et al., 2022).

2.6.4 Chick Viability and Survival

Chick survival during the first few weeks after hatching remains one of the most critical challenges in commercial ostrich farming. Reported mortality rates in this early phase often range between 20% and 40%, mainly due to factors such as yolk sac infections, dehydration, poor brooder management, nutritional imbalances and environmental stressors (Mushi et al., 2022).

Effective brooder management is essential to reduce early chick losses. This includes maintaining stable brooder temperatures, typically around 28 to 30 degrees Celsius initially with gradual reduction, ensuring adequate ventilation to prevent harmful gas accumulation and following strict hygiene protocols to limit bacterial contamination. Together, these measures directly influence chick survival and growth (Magwedere et al., 2020).

A study conducted by Miah et al. (2020) at the Advanced Avian Research Farm of Hajee Mohammad Danesh Science and Technology University in Dinajpur, Bangladesh, illustrates the importance of proper management and feeding. In this study, fifteen unsexed ostrich chicks imported from South Africa were reared under controlled conditions and provided with commercial broiler starter feed up to twelve weeks of age. The study reported high survivability and consistent growth performance. The average live weight increased from approximately 998 grams at the end of the first week to over 33 kilograms by the twelfth week. The highest daily weight gains were observed during the ninth and tenth weeks, reaching around 614 and 590 grams per day, respectively. Feed intake increased steadily from about 114 grams per day in the first week to nearly 970 grams per day by the twelfth week, reflecting good adaptation to external feeding. The best feed conversion efficiency was recorded during the fifth week at approximately 1.01, indicating effective nutrient utilization under appropriate management conditions.

Early chick viability is also closely linked to the transition from yolk sac nutrient reserves to external feed. Efficient absorption and use of yolk nutrients support immune development and energy supply during the first days of life. Failure in this transition often leads to so-called starve-outs, where chicks fail to initiate or maintain external feeding, resulting in increased mortality (Horbańczuk et al., 2019; Magwedere et al., 2020).

Improving survival rates in ostrich chicks therefore requires an integrated approach. This includes providing well-designed brooders with stable heat and humidity, offering high-quality and easily digestible starter diets, maintaining strict hygiene and biosecurity measures and closely monitoring chick behavior and health indicators during the first few weeks. Findings from Miah et al. (2020) demonstrate that under suitable management and environmental conditions, ostrich chicks can achieve high survival rates and good growth performance, which supports the development of ostrich farming even in new regions like Bangladesh.

In Bangladesh, scientific research on ostrich reproductive performance remains sparse, largely because ostrich farming is a relatively new venture in the country and local research infrastructure is still developing. Despite this, anecdotal evidence and preliminary observations from several commercial farms suggest that ostriches can achieve reproductive performance comparable to those reported in more established ostrich-producing countries, provided that key management requirements are met (Kabir et al., 2023).

Initial reports from semi-intensive farming systems in districts such as Dinajpur and Dhaka indicate that fertility rates can reach between 60% and 75%, although variability remains high and consistent record-keeping is limited. Hatchability rates, based on on-farm observations rather than controlled scientific trials, have ranged from approximately 40% to 60%. These values are influenced by factors such as breeder age, flock structure, seasonal temperature fluctuations and access to balanced diets specifically formulated for ratites.

Management practices play a central role in shaping reproductive success. Farms that invest in proper breeder nutrition, balanced male-to-female ratios, shaded enclosures and scheduled health monitoring generally report better fertility and hatchability outcomes. Conversely, farms operating under more extensive or resource-limited conditions often encounter challenges, including higher embryonic mortality and reduced fertility, which can be linked to heat stress, nutritional deficiencies and limited veterinary support.

The absence of systematically collected data remains a critical barrier to improving reproductive performance at the national level. Well-designed local studies are urgently needed to document fertility rates, hatchability, age at sexual maturity and chick viability under Bangladeshi climatic conditions. Establishing these benchmarks would help farmers refine breeding strategies, improve production planning and contribute to the sustainable growth of ostrich farming in the country.

Overall, while early indications point to the feasibility of ostrich farming in Bangladesh, the sector's long-term success will depend on developing context-specific management guidelines and investing in scientific research to generate reliable baseline reproductive data.

2.7 Hatchery Management and Chick Rearing

Hatchery management and chick rearing are critical components of ostrich farming, significantly influencing chick viability, early growth and overall farm productivity. Efficient hatchery operations reduce embryonic losses and enhance hatchability, while post-

hatch management improves chick survivability during the vulnerable early stages of life (Horbańczuk et al., 2021).

2.7.1 Artificial Incubation Practices

Ostriches, unlike commercial poultry species, produce large eggs averaging 1.3 to 1.5 kg, which require specialized incubation protocols. Artificial incubation is widely practiced in commercial operations due to its ability to ensure consistent conditions, increase hatchability and accommodate more eggs than natural incubation by the female bird (Deeming and Bubier, 2020). Successful incubation depends on precise control of temperature, humidity, egg turning and ventilation.

The optimal temperature range for ostrich egg incubation lies between 36.0°C and 36.5°C, while humidity levels must be maintained around 20–25% during the early stages and increased to 35–40% in the final hatching phase (Mushi et al., 2022). Automated incubators equipped with temperature and humidity sensors are recommended to reduce human error and ensure uniform incubation conditions. Turning the eggs multiple times daily (ideally every 2 to 3 hours) helps prevent the embryo from adhering to the eggshell membrane and facilitates even nutrient distribution (Sales, 2014).

2.7.2 Factors Affecting Hatchability

Numerous intrinsic and extrinsic factors influence the hatchability of ostrich eggs. These include egg age, shell thickness, breeder nutrition, sanitation and incubation conditions. Studies have shown that eggs stored for more than 7 days before incubation exhibit reduced hatchability and thicker-shelled eggs may impede gas exchange during development (Aganga et al., 2021). Eggshell contamination is also a major concern; therefore, sanitization using mild disinfectants or ultraviolet (UV) light is often employed in commercial hatcheries (Abou El-Azm et al., 2023).

Embryonic mortality is most frequent during the first and last weeks of incubation, often linked to inadequate temperature control or bacterial infections (Horbańczuk and Cooper, 2020). Routine candling at 14 and 28 days of incubation helps monitor development and identify infertile or dead-in-shell eggs early, which can then be removed to prevent contamination.

2.7.3 Chick Hatching and Post-Hatch Management

Once chicks hatch, they require prompt attention to transition from a controlled incubation environment to brooding. Newly hatched ostrich chicks are extremely sensitive to environmental changes and poor management during this phase can result in high mortality rates (Magwedere et al., 2020). Critical parameters for post-hatch success include temperature regulation, space availability, cleanliness and nutrition.

Brooding temperature should start at approximately 30°C during the first week and be gradually reduced by 2–3°C per week until ambient temperatures are reached (Hassan et al., 2022b). The brooding area must be clean, well-ventilated and dry, with sufficient space to avoid overcrowding. Chicks also require exposure to natural light for proper circadian rhythm development and immune system stimulation.

2.7.4 Challenges and Research Gaps

Despite improvements in hatchery technologies, ostrich chick mortality remains a persistent challenge, with rates ranging from 20% to 40% in the first month post-hatch in many systems (Mushi et al., 2022). Common causes include yolk sac infections, dehydration, leg deformities and failure to adapt to feed. There is limited scientific data on chick-rearing practices in the context of tropical climates such as Bangladesh, where temperature and humidity variations may impact survival differently than in temperate regions.

Future research should focus on developing region-specific protocols for brooding, disease prevention and early nutrition. Enhancing hatchery infrastructure, capacity-building for farmers and establishing standard operating procedures (SOPs) tailored to local contexts will be instrumental in reducing early chick losses and promoting sustainable ostrich production.

2.8 Health and Disease Management

Health management is a cornerstone of successful ostrich farming, as the profitability and sustainability of production systems largely depend on minimizing disease-related mortality and maximizing productivity. Although ostriches are generally hardy animals, they are susceptible to various infectious and non-infectious diseases that can severely impact flock health, particularly in intensive rearing systems (Horbańczuk and Cooper, 2020).

2.8.1 Common Diseases Affecting Ostriches

Several viral, bacterial and parasitic diseases are known to affect ostriches. Among the most significant are Newcastle disease and avian influenza, which can cause widespread outbreaks with high morbidity and mortality. Though ostriches may exhibit less severe symptoms than chickens, they can act as carriers and amplify disease transmission within mixed-species farms (Mushi, et al., 2022; Abou El-Azm et al., 2023).

Bacterial infections, including salmonellosis, colibacillosis and bacterial enteritis, are also major concerns in ostrich chicks and juveniles. These infections typically result from poor sanitation, contaminated feed or water and overcrowded housing conditions (Aganga et al., 2021). Bacterial enteritis, in particular, is associated with diarrhea, dehydration and sudden death in young chicks, which contributes to high early mortality rates.

Parasitic infestations such as helminthiasis, coccidiosis and external parasites like mites and lice can impair growth and reproduction. Internal parasites may lead to anorexia, weight loss and reduced feed efficiency, especially under free-range or semi-intensive systems without proper deworming protocols (Magwedere et al., 2020).

2.8.2 Biosecurity and Preventive Measures

Effective disease control in ostrich farming relies on a comprehensive biosecurity program. Preventive measures include proper farm hygiene, controlled access to farm premises, disinfection protocols and regular veterinary inspections (Horbańczuk et al., 2021). Isolating new stock through quarantine practices for a minimum of 21–30 days before mixing with the main flock helps prevent disease transmission.

Vaccination is another critical aspect of health management. While ostriches are not routinely vaccinated in many countries due to limited vaccine licensing, some producers administer poultry vaccines for diseases like Newcastle disease, fowlpox and infectious bursal disease based on risk assessments (Deeming and Bubier, 2020). However, immunological responses in ostriches to poultry vaccines remain under-researched, highlighting the need for ostrich-specific vaccine trials and protocols.

2.8.3 Nutritional Health and Immunity

Proper nutrition plays a significant role in enhancing the immune response in ostriches. Diets enriched with essential vitamins (especially A, D and E), minerals (zinc and selenium) and probiotics can boost natural immunity and reduce susceptibility to diseases (Tshabalala

et al., 2018). Clean water and mycotoxin-free feed are also necessary to prevent diseases associated with feed contamination, such as aflatoxicosis.

Stress is a predisposing factor for disease outbreaks in ostrich flocks. Overcrowding, poor ventilation, transport stress and abrupt dietary changes can suppress the immune system and increase disease incidence (Hassan et al., 2022a). Therefore, maintaining optimal environmental and management conditions is essential for disease prevention.

2.8.4 Health Challenges in Bangladesh's Context

The emergence of ostrich farming in Bangladesh brings with it unique challenges in disease management due to the tropical climate, limited veterinary expertise and insufficient ostrich-specific health data. According to Kabir et al. (2023), ostrich farmers in Bangladesh often rely on trial-and-error methods or poultry protocols, which may be ineffective or even harmful. The lack of diagnostic laboratories capable of handling exotic avian species further complicates disease identification and control.

There is also a critical shortage of veterinarians trained specifically in exotic livestock medicine. As a result, minor health issues may escalate into serious outbreaks due to delayed or improper treatment. Moreover, the absence of standardized disease surveillance programs for ostriches hinders early detection and reporting, raising the risk of zoonotic disease transmission.

2.8.5 Research Gaps and Recommendations

Research on ostrich health in Bangladesh remains in its infancy. There is an urgent need for studies focusing on disease epidemiology, immunology and the development of ostrich-specific vaccines and drugs. Establishing collaborative research centers and integrating ostrich health modules into veterinary curricula would help bridge this knowledge gap.

Policymakers must also prioritize ostrich health in national livestock frameworks to provide farmers with training, vaccination access and disease monitoring systems. Future studies should also explore the adaptability of ostriches to the local pathogens and climatic stressors in Bangladesh, enabling region-specific health protocols and management practices.

2.9 Ostrich Farming in Bangladesh: Status and Potential

Ostrich farming in Bangladesh is a relatively recent endeavor, emerging in the early 2010s through entrepreneurial ventures that sought to diversify the country's livestock industry. Initially, private farms were established in various districts including Dhaka, Rajshahi,

Gazipur, Mymensingh, Dinajpur and Chattogram, importing breeding stock primarily from South Africa and Australia (Kabir et al., 2023). These pioneering initiatives were driven by the promise of high returns from meat, leather, feathers and oil products and were aligned with the growing global trend toward exotic livestock production.

Despite the initial enthusiasm, many of these early ventures encountered significant obstacles, leading to the closure of several farms. The primary challenges included a lack of technical knowledge on ostrich husbandry, absence of trained veterinary personnel familiar with ratite physiology, inadequate incubation and brooding infrastructure and poor chick survivability due to nutritional and environmental mismanagement (Alam et al., 2022). Additionally, consumer unfamiliarity with ostrich meat and limited domestic marketing channels hindered consistent demand, thereby impacting financial sustainability (Rahman and Sultana, 2023).

Nonetheless, DLS has recognized the potential of ostrich farming and has included it in its broader livestock diversification strategies. Recent policy efforts aim to provide technical support, facilitate veterinary capacity building and promote public awareness regarding the nutritional and economic benefits of ostrich products (DLS, 2023). National livestock fairs and training programs have increasingly featured ostrich farming as a viable alternative to traditional poultry and ruminant farming (Hasan et al., 2023).

Moreover, Bangladesh's subtropical climate, characterized by long summers and mild winters, closely resembles the arid and semi-arid conditions of southern Africa where ostriches naturally thrive (Chowdhury et al., 2024). This climatic compatibility offers an ecological advantage for adapting ostrich farming to local environmental conditions, provided that appropriate management practices are adopted. Research also indicates that ostriches demonstrate considerable resilience to local weather extremes, with proper shelter and biosecurity measures in place (Begum et al., 2022).

Economically, ostrich farming holds immense promise in the context of rural development and poverty alleviation. With appropriate investment, training and infrastructure, ostrich farms can generate significant employment and income in peri-urban and rural areas. The high-value nature of ostrich products, particularly meat and leather, presents potential for export-oriented growth, aligning with Bangladesh's ambitions for agricultural diversification and sustainable economic development (Miah et al., 2023). Additionally, ostrich meat is increasingly gaining popularity among health-conscious consumers due to

its low fat and cholesterol content, which could open niche markets in urban centers and among affluent populations (Sarker et al., 2023).

Despite these prospects, scientific literature specific to ostrich production under Bangladeshi conditions remains sparse. Limited empirical data on productivity, reproductive performance, nutritional needs and disease prevalence hampers evidence-based policymaking and farm-level decision-making. Research institutions, such as the Bangladesh Livestock Research Institute (BLRI), have only recently begun to explore the biological and economic feasibility of ostrich farming in the country (BLRI, 2023). Collaboration with international research bodies and knowledge-sharing with countries experienced in ostrich husbandry may accelerate the learning curve.

2.10 Climatic and Environmental Suitability

The climatic and environmental conditions of Bangladesh present both challenges and opportunities for ostrich farming. Bangladesh has a tropical monsoon climate characterized by high temperatures and humidity, with distinct wet and dry seasons. While ostriches are naturally adapted to arid and semi-arid environments, their ability to thrive in tropical conditions depends significantly on the management of environmental factors, particularly temperature, humidity and ventilation (Rahman et al., 2021).

Ostriches, native to the savannas and deserts of Africa, are well-suited to hot, dry climates and can withstand extreme temperatures ranging from 40°C during the day to cooler nights. Their thick skin, long legs and ability to conserve water make them resilient to harsh conditions. However, Bangladesh's high humidity, particularly during the monsoon season, can lead to heat stress, reduced productivity and an increased risk of disease (Hassan et al., 2022a). Excessive moisture in the environment can also affect the health of the birds, leading to respiratory problems and increased susceptibility to fungal infections (Akter and Islam, 2023).

To mitigate the impact of high humidity, it is crucial to implement appropriate housing systems that provide adequate ventilation and air circulation. Research by Chowdhury et al. (2024) indicates that proper housing structures, such as well-ventilated sheds with shade and cool environments, are essential for maintaining optimal growth and reproductive performance. These shelters help protect ostriches from direct sunlight and reduce the effects of heat stress, which can be particularly detrimental during Bangladesh's summer

months. Furthermore, the birds' need for clean, dry bedding is critical, as damp bedding can lead to the proliferation of parasites and other pathogens, adversely affecting their health.

During the monsoon season, when rainfall is frequent, managing water drainage in ostrich pens becomes crucial. Flooding can be detrimental to both the birds' health and the quality of their feed and water supply. The construction of raised pens and the use of proper drainage systems are important practices to avoid waterlogging and maintain hygienic conditions for the birds (Hossain and Mia, 2022). Additionally, avoiding overcrowding and providing adequate space for foraging and movement can reduce the stress caused by high humidity and poor air quality (Deeming, 2021).

In contrast to the challenges posed by the wet season, the dry season in Bangladesh can be more favorable for ostrich farming, with lower humidity and moderate temperatures. However, during the peak summer months, temperatures can soar, which requires the implementation of cooling systems such as misting, fans, or shaded areas for the birds to reduce the impact of heat stress (Ahmed and Hossain, 2023). Water availability also becomes critical in these months, as ostriches consume large amounts of water to regulate body temperature, especially when exposed to high heat.

In terms of grazing and diet, Bangladesh's tropical vegetation offers potential for foraging, but it must be supplemented with a nutritionally balanced diet, including high-fiber roughage and grains to meet the birds' energy needs (Aganga et al., 2021). The availability of diverse plant species can provide nutritional variety, but it is essential to ensure that the plants are free from toxins and that the pasture is not overgrazed.

Overall, the climatic suitability of Bangladesh for ostrich farming is not without its challenges. However, with proper environmental management, including climate-controlled housing, effective water management and attention to seasonal variations, ostriches can adapt to the local climate and achieve high productivity and reproductive success. Moreover, with increasing research on climate-resilient ostrich farming practices, particularly in tropical regions, the knowledge base for managing ostrich farms in Bangladesh is growing, offering hope for the expansion of the industry in the future (Begum et al., 2022).

2.11 Socioeconomic Impact and Employment Generation

Ostrich farming, with its high economic potential, offers a valuable opportunity for socioeconomic development, particularly in rural areas. This form of livestock farming not

only provides direct employment opportunities but also stimulates growth in several allied sectors. As a relatively new and exotic form of livestock production, ostrich farming presents a unique pathway for rural economic diversification, offering farmers the opportunity to transition from traditional livestock production to a more lucrative and diversified model of agriculture (Kabir et al., 2023).

2.11.1 Employment Generation in Rural Areas

One of the key advantages of ostrich farming is its potential for job creation, particularly in rural regions where employment opportunities are limited. Ostrich farming requires skilled labor for day-to-day operations, including feeding, breeding management and health care. As the demand for ostrich products increases, it can create direct employment opportunities for individuals in various roles, such as farm workers, farm managers and technical experts (Alam et al., 2023). Additionally, the establishment of large-scale ostrich farms or processing units can lead to the creation of support jobs in areas such as administration, transportation, marketing and distribution.

Beyond direct farm-based employment, ostrich farming can stimulate local economies by creating jobs in ancillary industries, such as feed production, hatchery management and veterinary services (Hossain and Mia, 2022). As ostrich farms expand, the demand for high-quality feed and specialized equipment increases, thereby providing employment opportunities for individuals involved in the manufacture and distribution of animal feed. Hatchery management is another crucial sector for the growth of ostrich farming, as efficient egg incubation and chick rearing are essential for maintaining a productive farm. This requires trained personnel, thus opening additional job prospects.

Veterinary services also play a critical role in the development of the ostrich farming sector. As ostrich farming grows, there will be a greater need for veterinary professionals with expertise in exotic livestock. Veterinarians who specialize in avian species can provide vital services related to disease prevention, treatment and health monitoring. This not only benefits the health and productivity of ostriches but also creates sustainable employment within the veterinary sector (Rahman et al., 2021).

2.11.2 Increased Livelihood Opportunities

Ostrich farming can significantly enhance the livelihoods of rural families by providing a sustainable source of income. As an alternative to traditional livestock farming, ostriches offer farmers a higher return on investment due to the valuable products derived from the

birds, including meat, leather, feathers and oil (Deeming, 2021). Ostrich meat is recognized for its health benefits, being lean, low in cholesterol and a source of high-quality protein. The leather produced from ostriches is highly valued in the luxury goods market, particularly in the fashion industry and has a high price per unit, making it an attractive income source for farmers (Sales and Horbańczuk, 2018).

Moreover, ostrich feathers, which are used in decorative arts and fashion, provide an additional income stream for farmers (Mushi et al., 2022). These products, when marketed effectively, can generate significant revenue, particularly if targeted toward international markets. This can increase the income levels of rural communities, helping to reduce poverty and improve overall economic conditions in these areas.

2.11.3 Contributions to National Economic Development

The potential for ostrich farming to contribute to the national economy extends beyond job creation. The export of ostrich products, especially meat and leather, presents an opportunity for Bangladesh to diversify its agricultural exports. The international demand for ostrich products is growing, particularly in regions such as the Middle East and Europe, where there is an increasing interest in high-quality, exotic meats and luxury goods (Hoffman et al., 2020). The export potential of ostrich products can help Bangladesh tap into new markets, contributing to the country's foreign exchange earnings.

The expansion of ostrich farming also aligns with broader agricultural diversification efforts in Bangladesh, which seek to reduce dependence on traditional livestock sectors such as cattle and poultry. This diversification can help stabilize the agricultural economy, providing resilience against market fluctuations, disease outbreaks and environmental challenges that affect traditional livestock farming (Kabir et al., 2023).

2.11.4 Women's Empowerment and Social Development

In addition to its economic benefits, ostrich farming can have a positive impact on gender equality and social development. Women in rural Bangladesh often face limited employment opportunities, but ostrich farming offers potential for women's involvement in both direct and indirect roles. Women can participate in farm management, egg collection, hatchery operations and value-added product development, such as processing ostrich leather or feathers. As women gain employment in these areas, their social status and economic independence may improve, contributing to overall social development in rural communities (Ali et al., 2023).

Furthermore, the ability of ostrich farming to empower women and promote gender equality is enhanced by the fact that it is less physically demanding than traditional livestock farming, making it more accessible to women and marginalized groups. By providing women with the tools and resources to engage in entrepreneurial activities, ostrich farming can help break the cycle of poverty and increase women's participation in rural economic development (Hassan et al., 2022a).

2.12 Constraints in Ostrich Farming

Despite the promising potential of ostrich farming in many parts of the world, including Bangladesh, several barriers hinder its widespread adoption and growth. These constraints are multifaceted and affect various aspects of the ostrich farming value chain, including financial investments, human capital, consumer awareness, research and policy support. Addressing these barriers is essential for unlocking the full potential of ostrich farming in Bangladesh and other developing countries.

2.12.1 High Startup Costs for Infrastructure and Breeding Stock

One of the most significant challenges faced by potential ostrich farmers is the high initial investment required to establish a viable farming operation. The cost of acquiring breeding stock, building appropriate infrastructure and purchasing specialized equipment can be prohibitive, especially for small-scale farmers (Hassan et al., 2022a). Ostriches are not only expensive to acquire, but they also require specialized enclosures, feed systems and housing that are different from traditional livestock. For example, the birds need large, secure enclosures to prevent escapes, as well as controlled environments that protect them from extreme weather conditions. These initial investments in infrastructure and breeding stock are substantial compared to more conventional livestock farming operations, which can discourage potential entrants, particularly in a developing country like Bangladesh.

Additionally, importing breeding stock from countries like South Africa or Australia adds to the cost, particularly given the logistical challenges and quarantine requirements involved. The limited availability of high-quality local breeding stock further exacerbates this issue (Kabir et al., 2023). While the cost of production may decrease as farmers gain experience and scale up operations, the initial financial burden remains a significant hurdle for new entrants.

2.12.2 Lack of Trained Personnel and Veterinary Expertise

The lack of trained personnel and specialized veterinary expertise is another major constraint in the development of ostrich farming in Bangladesh (Mushi et al., 2022). Ostrich farming requires specific knowledge and skills in areas such as feeding, breeding, disease management and hatching. However, there is a shortage of professionals with the expertise required to manage ostrich farms effectively. Most veterinarians in Bangladesh are trained to work with traditional livestock and the specialized care required for ostriches is often not part of the standard veterinary curriculum (Hassan et al., 2022a).

In addition to veterinary services, ostrich farming also requires skilled farm workers who understand the unique needs of the birds, including their nutritional requirements, breeding patterns and health management protocols. This shortage of trained labor further limits the ability of farmers to manage ostrich farms efficiently and sustainably. To address this issue, there is a need for specialized training programs and capacity-building initiatives targeted at both veterinarians and farm workers to ensure they have the skills required to successfully manage ostrich farming operations.

2.12.3 Poor Awareness Among Consumers

Another significant constraint facing ostrich farming in Bangladesh is the lack of consumer awareness regarding ostrich meat and other ostrich products (Hassan et al., 2022b). Despite the health benefits of ostrich meat, such as its low cholesterol and fat content, many consumers in Bangladesh are unfamiliar with the nutritional value of ostrich products. This lack of awareness limits consumer demand and, consequently, the profitability of ostrich farming. As a result, farmers face challenges in finding reliable markets for their products, which can make the sector less attractive to potential investors.

Additionally, the lack of awareness extends to the general population's understanding of ostrich leather, feathers and oil, all of which have high economic value. Without an established consumer base, farmers find it difficult to generate sufficient revenue from all the products derived from ostriches, further discouraging investment in the sector.

To overcome this constraint, it is essential to increase consumer awareness through targeted marketing campaigns that highlight the health benefits and environmental sustainability of ostrich products. Efforts to educate consumers about the value of ostrich meat, leather and feathers, as well as the cultural and economic significance of ostrich farming, can help build demand and foster a market for these products.

2.12.4 Inadequate Research and Extension Services

The lack of adequate research and extension services in Bangladesh also hampers the growth of ostrich farming. While countries like South Africa and Australia have invested heavily in research to improve ostrich farming techniques, the situation in Bangladesh is quite different. There is a limited amount of local research focused on the specific challenges and opportunities of ostrich farming under Bangladeshi conditions (Kabir et al., 2023). This lack of research prevents the development of localized best practices for ostrich management, feeding, breeding and disease control, which could optimize productivity and reduce operational risks.

Furthermore, extension services that provide farmers with technical advice and support are underdeveloped in the context of ostrich farming. Most extension programs in Bangladesh are centered around traditional livestock farming and ostrich farming is often overlooked. Without proper guidance from agricultural extension services, farmers may struggle to implement the best practices necessary for successful ostrich farming.

Research institutions and agricultural extension services must prioritize ostrich farming as a key area for development. Establishing dedicated research programs focused on the biology, management and economics of ostrich farming can provide essential insights that help improve productivity and sustainability. Extension services should also be adapted to include ostrich farming and should offer technical support to farmers on a regular basis.

2.12.5 Absence of Government Subsidies or Policy Support

Government policies and subsidies play a crucial role in supporting the development of new agricultural industries. However, in Bangladesh, there is a lack of government support for ostrich farming, which further limits its growth potential (Kabir et al., 2023). Unlike other sectors, such as poultry or cattle farming, ostrich farming has not received significant policy backing, subsidies, or incentives that could encourage investment and mitigate risks for farmers. Government intervention is needed to promote ostrich farming as a viable business venture and to provide financial and technical support to new and existing farmers.

The absence of a clear policy framework also complicates the establishment of effective regulations for the industry, including health and safety standards, market development and export regulations. Policymakers must recognize the potential of ostrich farming to contribute to economic development and food security and create supportive policies that

facilitate industry growth. These policies could include subsidies for infrastructure development, tax incentives for farmers and funding for research and training programs.

2.13 Opportunities for Sustainable Development

Ostrich farming has emerged as a promising avenue for sustainable agricultural development, particularly in regions like Bangladesh, where traditional livestock farming faces numerous challenges related to resource scarcity and environmental degradation. As a relatively low-resource-intensive alternative to conventional livestock such as cattle and goats, ostrich farming offers several opportunities for enhancing agricultural sustainability, promoting rural development and contributing to economic growth. This section outlines the key opportunities that ostrich farming presents for sustainable development, focusing on resource efficiency, environmental sustainability, rural livelihood enhancement and export potential.

2.13.1 Efficient Resource Utilization

One of the most significant advantages of ostrich farming is the bird's ability to thrive in resource-constrained environments. Unlike traditional livestock, which often require large amounts of land, water and feed, ostriches are relatively more efficient in their resource use. According to Mushi et al. (2022), ostriches require less water and feed compared to cattle, making them an ideal option for countries like Bangladesh, where water scarcity and land degradation are pressing concerns. Ostriches are also resilient to extreme weather conditions and can tolerate high temperatures and arid climates, reducing the need for expensive climate-control infrastructure. These traits make ostriches a more sustainable option for integrated farming systems, where they can be raised alongside other crops and livestock with minimal resource competition.

Furthermore, ostriches have a relatively low environmental footprint when compared to other livestock species. For instance, they produce less methane, a potent greenhouse gas, than cattle (Hassan et al., 2022a). This characteristic aligns with global goals for reducing the environmental impact of agriculture, especially in the context of climate change. Ostriches' ability to thrive on grassland and forage-based diets without the need for intensive grain-based feeding systems further enhances their sustainability. By reducing the pressure on land and feed resources, ostrich farming contributes to a more sustainable food production system.

2.13.2 Integration into Agricultural Systems

Ostrich farming can be integrated into existing agricultural systems, offering additional revenue streams and diversifying farm income. In Bangladesh, where smallholder farming is prevalent, ostrich farming provides a valuable opportunity to diversify income sources and reduce dependency on a single crop or livestock species (Kabir et al., 2023). Ostriches can be raised on pasturelands, which reduces the need for additional arable land and allows farmers to benefit from a multi-tiered farming approach.

Integrated farming systems that combine ostrich farming with crop production can also improve soil health and contribute to more sustainable land management practices. For example, ostriches can help control pests and weeds in crop fields, reducing the need for chemical pesticides and herbicides. In turn, the manure from ostriches can be used as organic fertilizer, enhancing soil fertility and reducing the reliance on chemical fertilizers. This integration of ostrich farming into broader agricultural systems enhances resource use efficiency and promotes sustainable farming practices.

2.13.3 Rural Development and Livelihood Enhancement

Ostrich farming offers significant opportunities for rural development, particularly in regions with limited access to other economic opportunities. The establishment and expansion of ostrich farms can create employment opportunities in both primary and ancillary sectors. These include jobs in farm management, veterinary services, feed production, hatchery operations and transportation. As Mushi et al. (2022) suggest, ostrich farming has the potential to create new employment opportunities, especially in rural areas, where job opportunities are often limited.

Additionally, ostrich farming can serve as a source of income for rural households, offering a viable alternative to traditional livelihoods. In many rural areas of Bangladesh, where agriculture is the primary source of income, ostrich farming provides a new avenue for economic diversification. Smallholder farmers can benefit from the sale of ostrich meat, eggs, leather, feathers and oil, with each by-product contributing to a diverse revenue stream. Moreover, the income generated from ostrich farming can help improve the quality of life for rural families, providing access to better education, healthcare and infrastructure (Kabir et al., 2023).

Furthermore, the establishment of ostrich farms in rural areas can foster local entrepreneurship. Local entrepreneurs can engage in ostrich farming as well as the

development of value-added products such as ostrich leather goods, feathers for fashion and decor and meat for export or local consumption. The expansion of ostrich farming also has the potential to stimulate rural economies through increased demand for support services, including transportation, packaging and marketing, which can further promote economic growth in these areas.

2.13.4 Export Potential and Foreign Exchange Earnings

Ostrich farming in Bangladesh also presents significant opportunities for boosting the country's foreign exchange earnings. As global demand for ostrich meat, leather and other by-products increases, Bangladesh can capitalize on this trend by developing a robust export sector. According to Mushi et al. (2022), countries such as South Africa, Australia and the United States have successfully tapped into international markets for ostrich products, generating substantial revenue. Bangladesh, with its strategic location and growing agricultural sector, has the potential to become a significant exporter of ostrich products, especially to markets in the Middle East, Europe and Asia.

Ostrich meat, known for its low fat and cholesterol content, is in high demand in health-conscious markets, particularly in countries where red meat consumption is high but health concerns are driving shifts towards leaner alternatives (Hassan et al., 2022b). The leather, feathers and oil derived from ostriches also have high market value, with uses in luxury fashion, upholstery and cosmetics industries. By focusing on the production of high-quality ostrich products, Bangladesh can position itself as a key player in the global market, enhancing its export potential and contributing to national economic growth.

To capitalize on this export potential, it is crucial for the government and private sector to invest in market research, quality assurance and compliance with international standards. Establishing clear trade policies and building relationships with international buyers will be key to ensuring the successful export of ostrich products from Bangladesh.

2.13.5 Contribution to National and Global Sustainability Goals

Ostrich farming aligns with several global sustainability initiatives, including the United Nations Sustainable Development Goals (SDGs). As a resource-efficient and environmentally friendly livestock option, ostrich farming contributes to SDG 12 (Responsible Consumption and Production) by promoting sustainable agricultural practices (Mushi et al., 2022). The efficient use of resources in ostrich farming, combined with the

reduced environmental impact compared to conventional livestock, positions it as a key contributor to sustainable food production systems.

Additionally, ostrich farming supports SDG 1 (No Poverty) by providing income generation opportunities for smallholder farmers and rural communities. The diversification of income sources through ostrich farming can help lift rural households out of poverty, contributing to overall economic development. Furthermore, the development of the ostrich farming sector supports SDG 8 (Decent Work and Economic Growth), as it creates employment opportunities in both the agricultural and non-agricultural sectors, driving inclusive economic growth.

2.14 Research Gaps and Future Directions

Ostrich farming in Bangladesh, while still in its nascent stages, holds immense potential for economic and agricultural development. However, several research gaps exist that need to be addressed to unlock the full potential of ostrich farming in the region. These research gaps span across various domains, including local adaptation, disease resistance, reproductive technologies and economic viability under Bangladeshi conditions. Collaborative research between academic institutions, government agencies and industry stakeholders is crucial to accelerating the growth of the ostrich farming sector and ensuring its sustainability.

2.14.1 Local Adaptation and Climate Suitability

One of the most critical research gaps in ostrich farming in Bangladesh pertains to the local adaptation of ostriches to the tropical and monsoon climate. While ostriches are well-suited to arid and semi-arid environments, there is limited research on their ability to adapt to the high humidity and heavy rainfall characteristic of Bangladesh's tropical climate (Rahman et al., 2021). Studies are needed to evaluate the physiological and behavioral responses of ostriches to the local climate, including their heat tolerance, stress levels and overall health under different environmental conditions. Research could also focus on identifying optimal housing and management strategies that mitigate the effects of environmental stressors such as high humidity and seasonal monsoons.

Understanding the specific environmental conditions that influence the growth, reproduction and overall health of ostriches in Bangladesh will enable farmers to better manage their farms and improve productivity. Developing guidelines for climate-adapted

housing, ventilation systems and pasture management will be essential to making ostrich farming more sustainable in the country.

2.14.2 Disease Resistance and Health Management

Another significant research gap in ostrich farming is the lack of comprehensive studies on ostrich-specific diseases and health management practices in tropical climates like Bangladesh. While ostriches are susceptible to common poultry diseases such as Newcastle disease, avian influenza and bacterial enteritis, little is known about the prevalence and management of these diseases in the context of Bangladesh's unique climate and farming systems (Mushi et al., 2022). Research is needed to identify the specific pathogens and diseases affecting ostriches in Bangladesh, as well as effective diagnostic methods and treatments.

In addition to understanding disease dynamics, there is a need for research on improving disease resistance in ostriches through selective breeding or vaccination programs. For example, studies on genetic resistance to specific diseases and the development of vaccines tailored to the local environment would be valuable in reducing disease outbreaks and improving flock health. Furthermore, establishing more robust biosecurity practices and health monitoring systems for ostrich farms will be essential for preventing disease transmission and ensuring long-term sustainability.

2.14.3 Reproductive Technologies and Efficiency

Reproductive efficiency is a key determinant of the profitability and sustainability of ostrich farming. While some studies have focused on the general reproductive performance of ostriches, there is limited research on improving reproductive technologies and techniques specific to Bangladesh's farming conditions. For example, research into artificial insemination (AI), embryo transfer and genetic selection could help enhance fertility rates, hatchability and chick survival, which are critical for the success of ostrich farming (Deeming, 2021; Hassan et al., 2022b).

There is also a need to explore the impact of local genetic variability on reproductive performance. Understanding how different genetic lines perform under Bangladeshi environmental conditions will help in selecting the best breeding stock for local farms. Moreover, studies on the effect of nutrition, management and seasonality on egg production and fertility would provide valuable insights into optimizing reproductive outcomes.

2.14.4 Economic Viability and Market Development

The economic viability of ostrich farming in Bangladesh remains a major research gap. Although ostrich farming has potential for high returns, there is limited data on the profitability of ostrich farming under local conditions, including the costs associated with infrastructure, feed, labor and veterinary care. Research is needed to conduct cost-benefit analyses and economic feasibility studies to determine the financial sustainability of ostrich farming in Bangladesh. These studies should also consider market dynamics, such as consumer demand for ostrich meat and by-products, as well as the potential for export markets.

Moreover, a comprehensive understanding of the marketing and distribution challenges faced by ostrich farmers is essential. Research into consumer awareness, product acceptance and market development strategies will be necessary to expand the domestic market for ostrich products. This could include developing marketing campaigns to educate consumers on the health benefits of ostrich meat and the versatility of ostrich by-products, as well as identifying potential export markets for ostrich products.

2.14.5 Collaborative Research and Policy Development

To address these research gaps, collaboration between academic institutions, government agencies and private sector stakeholders will be essential. Government agencies, particularly the Department of Livestock Services (DLS), should play an active role in facilitating research and providing support for the development of ostrich farming in Bangladesh. This could include funding research initiatives, offering technical support to farmers and developing policies that encourage investment in the ostrich farming sector.

Academic institutions can contribute by conducting applied research that focuses on the practical aspects of ostrich farming, such as nutrition, genetics, disease management and economic viability. Collaborative research programs between universities and international organizations could also help bring in expertise from established ostrich farming countries, facilitating knowledge transfer and capacity building.

Furthermore, the development of policies that address the challenges of ostrich farming, such as providing subsidies for infrastructure development, offering financial support for research and creating a regulatory framework for the industry, will be essential to the long-term success of ostrich farming in Bangladesh.

Chapter 3

Exploring the Future of Ostrich Farming in Bangladesh: Key Problems and Promising Prospects

3.1 Introduction

Livestock and poultry play a vital role in the socio-economic development of Bangladesh. In recent years, the growing demand for animal protein, coupled with rising awareness of health and nutrition, has spurred interest in alternative sources of meat and by-products. Among the emerging options, ostrich farming presents a unique and largely untapped opportunity in the country's livestock sector. Ostriches, native to Africa, are the largest living bird species and are farmed commercially in many countries for their meat, leather, feathers and oil. Ostrich meat is low in fat and cholesterol and high in protein and iron, making it a healthy alternative to red meats such as beef or lamb (Sales and Horbańczuk, 2018).

In regions like South Africa, Australia, Israel and parts of Europe, ostrich farming has evolved into a highly profitable agribusiness. The diversification of animal farming with exotic species like ostriches offers potential benefits in developing countries like Bangladesh, where the economy relies heavily on agriculture and livestock. The adaptability of ostriches to various climates and their low feed-to-meat conversion ratio add to their appeal as an alternative livestock option. Furthermore, ostriches are hardy birds that can be raised on marginal lands unsuitable for traditional livestock, offering an additional incentive for promoting their production (Moreki and Seabo, 2012).

Despite the promising prospects, the ostrich industry in Bangladesh is still in its infancy. The country's experience with ostrich farming is limited, with only a few small-scale farms currently in operation. These pioneering farms have encountered numerous obstacles, including lack of knowledge, insufficient veterinary support, unregulated hatchery practices, inadequate policy frameworks and absence of institutional backing. Farmers often face challenges in sourcing quality breeding stock, accessing affordable feed, managing diseases and marketing ostrich products domestically and internationally. As a result, the sustainability of ostrich production in Bangladesh remains uncertain without strategic intervention and policy reform (Islam et al., 2020).

Bangladesh is facing significant challenges in meeting the growing demand for safe, nutritious and affordable animal protein. Traditional livestock resources such as cattle, goats and poultry are under pressure due to rapid urbanization, limited grazing land, high feed costs and disease outbreaks. Against this backdrop, ostrich farming has emerged as a potential solution to diversify the animal protein base and boost rural income. However, very limited scientific studies have been conducted to investigate the viability and sustainability of ostrich production in the country.

Understanding both the challenges and the potential of this sector is critical to shaping appropriate policy interventions, developing suitable technologies and encouraging investment. This study seeks to explore the problems and prospects of ostrich farming in Bangladesh, with the aim of supporting future planning, scientific research and commercial adoption. By analyzing the current status, constraints and future outlook of the ostrich industry, the research intends to provide a comprehensive baseline that can inform policymakers, entrepreneurs and livestock stakeholders.

Globally, ostrich farming has experienced both growth and fluctuations. South Africa has historically dominated the ostrich industry, accounting for approximately 70% of the world's production of ostrich meat and leather (Van Schalkwyk et al., 2005). However, outbreaks of avian influenza and changing global trade policies have impacted production trends. Countries like China, India and Malaysia have begun exploring ostrich farming due to its economic potential and adaptability to different agro-climatic conditions. The global ostrich industry is now valued not only for meat but also for its high-quality leather, feathers and cosmetic-grade oil derived from ostrich fat.

In this context, Bangladesh can draw lessons from international practices while adapting strategies to fit local environmental, economic and cultural realities. Research from other developing countries shows that ostrich farming can be an important tool for job creation, rural development and foreign exchange earnings when supported with appropriate infrastructure and training (Moreki and Tshireletso, 2013). However, adopting exotic species also carries risks, such as disease introduction, ecological imbalance and economic failure if not managed properly.

This study focuses on both qualitative and quantitative aspects of ostrich farming in Bangladesh. The key focus areas include: farmer awareness, farm management practices, breeding systems, feed and nutrition, disease control, market access, economic feasibility

and policy gaps. Although ostrich farming is still limited in scale within the country, the findings will offer valuable insights into the foundational problems and the potential trajectory of the sector. Due to the lack of widespread adoption, data availability may pose a limitation; however, interviews, case studies and stakeholder consultations will complement secondary data.

Objectives:

To guide the investigation, the following specific objectives have been formulated:

- i) To identify and analyze the major problems faced by ostrich farmers in Bangladesh, production, health management, market access and institutional support.
- ii) To explore the prospects and economic potential of commercial ostrich farming in Bangladesh.

3.2 Materials and Methods

3.2.1 Study Area and Duration

This research was conducted across selected districts from all seven administrative divisions of Bangladesh, chosen for their known or emerging ostrich farming activities. The study covered the districts of Dhaka, Gazipur, Tangail, Jamalpur, Narsingdi, Narayanganj and Manikganj from the Dhaka division; Mymensingh from Mymensingh division; Sylhet and Habiganj from Sylhet division; Rangpur and Dinajpur from Rangpur division; Rajshahi and Pabna from Rajshahi division; Khulna and Satkhira from Khulna division; and Chattogram from Chattogram division.

These districts were selected due to their accessibility, variation in agro-ecological conditions and the presence of early adopters in ostrich farming. The study was conducted over a seven-month period from October 2020 to April 2021, which covered both dry and transitional seasons, allowing a more comprehensive understanding of seasonal challenges and management dynamics in ostrich production.



Figure 3.1 Black circles indicating the study districts across Bangladesh

(Source: Local Government Engineering Department, www.lged.gov.bd)

3.2.2 Research Design

An exploratory, cross-sectional research design was adopted to investigate the multidimensional challenges and opportunities of ostrich production. This design was appropriate given the nascent state of ostrich farming in Bangladesh and the lack of prior structured data on the subject.

The research relied on a mixed-methods approach to capture both the numerical trends and qualitative insights. The study tools included a semi-structured questionnaire, direct observations, key informant interviews (KIIs), farm record analysis and Focus Group Discussions (FGDs). This multi-method triangulation helped to ensure validity and reliability of the data (Creswell and Plano Clark, 2017).

The questionnaire was developed in both Bengali and English and included a combination of dichotomous, multiple-choice, Likert-scale and open-ended questions. It was designed around major themes such as housing, feeding, breeding, disease management, economics, marketing practices, constraints and farmers' outlook on future prospects.

A pilot test was conducted with three ostrich farmers and the questionnaire was refined based on their feedback regarding content clarity, cultural sensitivity and logistical feasibility. The final version was verified by an academic panel before implementation.

3.2.3 Sampling Method and Sample Size

Given the limited penetration of ostrich farming in Bangladesh, purposive sampling was used to identify relevant districts. From these districts, a multistage sampling procedure was applied to locate active ostrich farms. Due to the absence of a centralized database or farmer registry for ostrich production, the initial identification relied on informal networks, including social media platforms such as Facebook groups, YouTube farming channels, e-commerce listings (e.g., Bikroy.com) and direct contacts with early adopters and agribusiness networks.

From an identified pool of 30 ostrich farmers, simple random sampling was used to finalize a sample that was representative yet logistically feasible. The appropriate sample size was calculated using Slovin's formula (Adanza, 2006):

$$n = \frac{N}{1 + N(e)^2}$$

$$n = \frac{30}{1 + 30(0.05)^2} = 27.91 \approx 28$$

Where,

n is the sample size sought;

N is the research population,

e is the level of confidence (taken as 95%).

For inclusivity, 30 farmers were ultimately selected, covering a wide geographical and operational diversity.

3.2.4 Data Collection

Data collection was executed through direct on-farm visits, semi-structured interviews **and** document review. Key categories of data included:

- 1) **Demographic characteristics:** Age, education, previous farming experience and training.
- 2) **Production variables:** Number of birds, sex ratio, egg production, fertility rate, hatchability and mortality.
- 3) **Management practices:** Feeding regimes, housing design, breeding strategies, biosecurity and disease management.
- 4) **Economic indicators:** Cost of inputs (chicks, feed, labor), sources of finance, marketing channels, sale prices and profitability.
- 5) **Perceptions and challenges:** Farmers' insights into constraints and potential improvements.

To ensure accuracy, on-site observation was used to verify claims regarding housing, feed and bird condition. In cases where records were not available, Participatory Rural Appraisal (PRA) tools such as seasonal calendars, problem ranking and SWOT analysis were employed, especially during FGDs.

Both primary data (from field visits and interviews) and secondary data (from journals, reports and websites) were used to triangulate findings and build a holistic view of ostrich farming.

3.2.5 Statistical Analysis

All collected data were coded and entered into SPSS version 27.0 for statistical analysis (IBM, 2022). Descriptive statistics, including frequencies, percentages, mean values and standard error of means (SEM), were calculated to summarize the data. Where applicable, cross-tabulations and correlation analysis were employed to identify associations among variables such as education level and adoption of scientific feeding practices.

Open-ended responses were thematically analyzed and, where possible, quantified for integration into the overall results. Local measurement units were converted into international units (e.g., kilograms, liters, square meters) to ensure standardization.

3.2.6 Challenges Encountered During the Study

Conducting this study during the COVID-19 pandemic introduced a variety of fieldwork constraints:

- 1) Travel restrictions and health safety protocols made it difficult to access some remote farms.
- 2) Farmer unavailability due to illness, quarantine, or social obligations disrupted scheduled interviews.
- 3) Reluctance to disclose sensitive information, particularly on capital investment, chick sourcing and mortality rates, affected data comprehensiveness.
- 4) Lack of farm records meant much of the data had to be collected through recall, which could impact accuracy.
- 5) Communication barriers, including differing levels of technical literacy, required simplification and repeated explanations of scientific terms during interviews.

Despite these obstacles, consistent rapport-building, community liaison support and methodological flexibility helped ensure the quality of data collected.

3.3 Results

3.3.1 General Farming Management Status and Practices

3.3.1.1 Demographics of Farmers

The demographic and socioeconomic profile of the ostrich farmers in Bangladesh is presented in Table 3.1. The average age of the respondent farmers was 45.75 ± 1.98 years. A majority (88%) of the farms were owned by male farmers. The average duration of experience in ostrich farming was 4.38 ± 0.94 years. Regarding educational background, 12.5% of the farmers had less than SSC education, 25.0% had HSC, 25.0% had a Bachelor's degree and 37.5% had a Master's degree (Figure 3.2).

3.3.1.2 Purpose of Ostrich Rearing

Ostrich rearing in Bangladesh is a relatively new farming activity. The study revealed that 37.5% of the respondents raised ostriches for ornamental purposes, 37.5% for commercial purposes and 25.0% for research purposes.

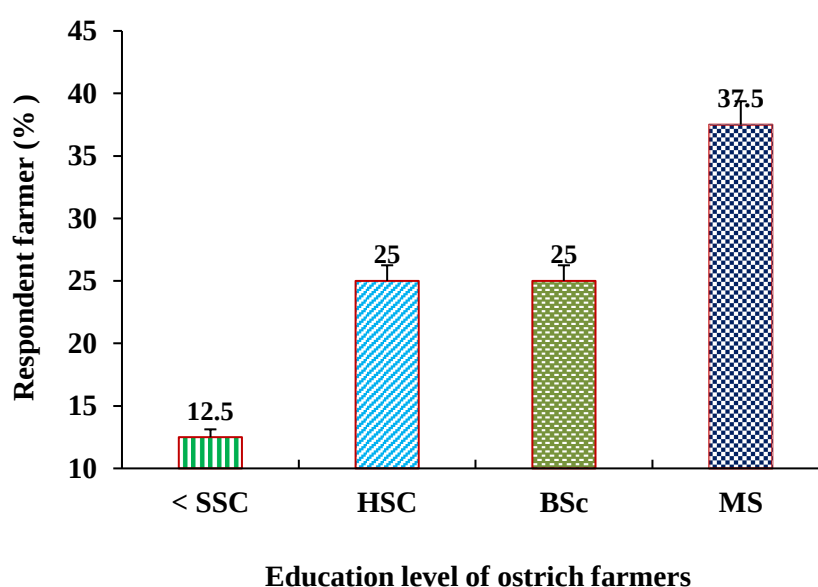


Figure 3.2 Education level of ostrich farmers in Bangladesh

3.3.1.3 Sources of Technical Support

Farmers in the study area seek technical support from a variety of sources. The results showed that 50.0% of farmers received technical support from Hajee Mohammad Danesh Science and Technology University, 87.5% utilized the internet, 25.0% consulted with chick suppliers and 37.5% sought help from zoo experts.

3.3.1.4 Flock Structure

The average flock size was 18.29 ± 5.07 birds, with the average live body weights of male and female ostriches recorded as 116.67 ± 8.82 kg and 92.50 ± 7.50 kg, respectively (Table 3.1). The majority (75%) of the farmers kept both male and female ostriches, while 25% raised only females due to the unavailability of males.

Table 3.1 General farming management of ostrich in Bangladesh

Parameters	Mean $\pm$SEM
Age of farmers (year)	45.75 $\pm$ 1.98
Experience of ostrich farming (Year)	4.38 $\pm$ 0.94
Flock size (number)	18.29 $\pm$ 5.07
Weight of adult cock (kg)	116.67 $\pm$ 8.82
Weight of adult hen (kg)	92.50 $\pm$ 7.50
Weight of egg (g)	1467 $\pm$ 88
Egg laid in each farm till date (No.)	37.33 $\pm$ 3.93
Price of ostrich chick (BDT, thousand)	13.29 $\pm$ 1.04
Price of adult ostrich (BDT, thousand)	137.50 $\pm$ 12.50

3.3.1.5 Housing and Management

Regarding housing systems, 37.5% of farmers used free-range systems, while 62.5% employed semi-intensive systems. In terms of seasonal care, 50% of the farmers took extra precautions during the hot season to ensure the comfort of the ostriches, whereas 50% did not. In contrast, 62.5% of farmers provided additional care during the winter season, while 37.5% did not. During winter, 75% of farmers offered brooding to chicks for an average period of 18.33 ± 2.59 days, while 25% did not provide additional heating. In the summer, 62.5% of farmers provided brooding for an average of 12.00 ± 2.53 days, while 37.5% did not (Table 3.1). Notably, 100% of the farmers did not follow any lighting procedures for breeder ostriches. Interestingly, only three farmers reported having ostriches that laid eggs and these eggs were laid in sandy nests about 2 meters in diameter and 0.5 meters deep, with male ostriches assisting in nest construction and brooding.

3.3.1.6 Feeding Practices

All the farmers (100%) used commercial poultry feed and roughage as the primary feedstuff for ostriches. Specific feed types included broiler starter (87.5%), layer starter (12.5%), a mixed feed of broiler starter and layer starter (12.5%), broiler pre-starter (12.5%), broiler grower (25.0%) and vegetable and fodder (100%) (Figure 3.3). Additionally, 87.5% of

farmers provided pieces of stone as feed, 25.0% fed fruits, eggs and bakery food and 62.5% supplemented their ostrich's feed with commercial vitamin or vitamin-mineral premixes. Interestingly, none of the farmer calculated feed efficiency (FE) and many farms wastage feed due to a lack of proper feeding knowledge (Figure 3.4).

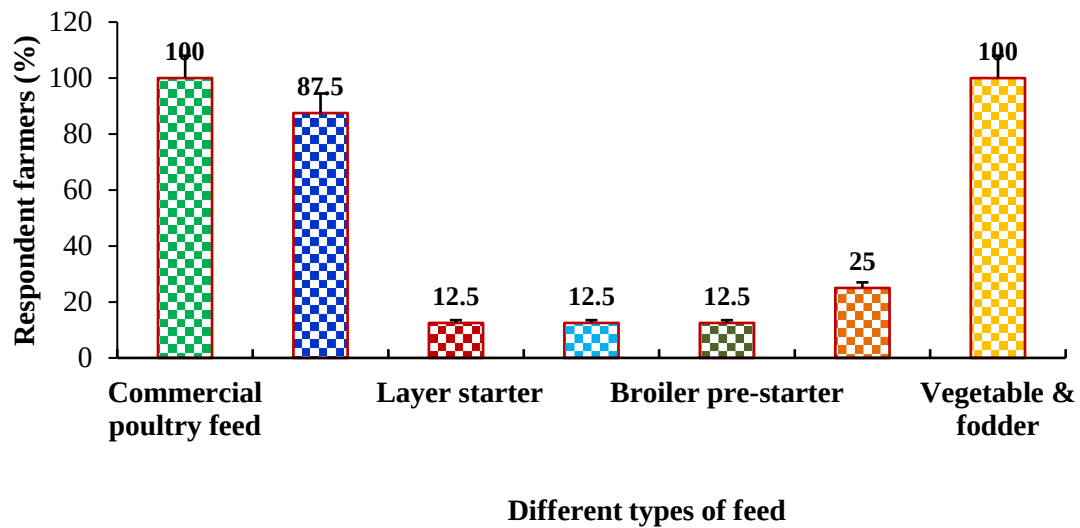


Figure 3.3 Types of feed used by ostrich farmers

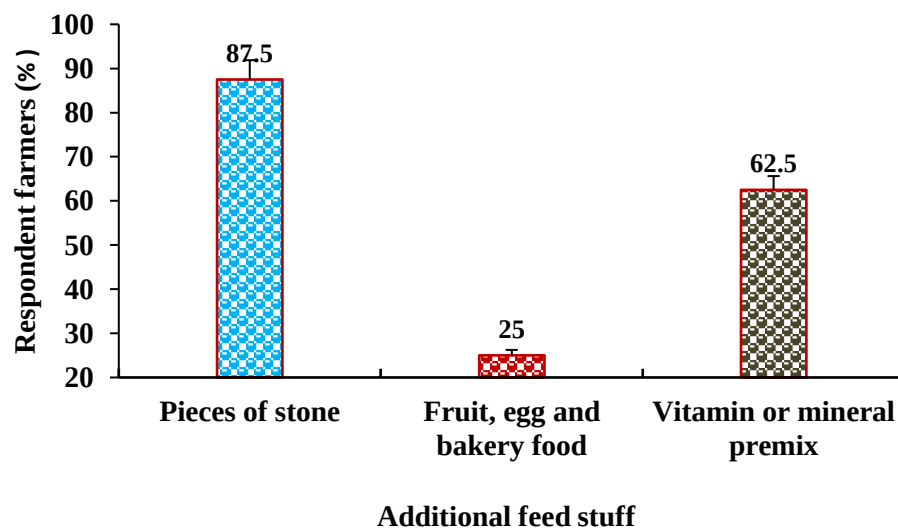


Figure 3.4 Additional feedstuffs used by ostrich farmers

3.3.1.7 Health Management

The study found that 100% of the farmers experienced health issues, including paralysis and slip tendon/leg, which caused high mortality within the first 16 weeks of age. A majority

(62.5%) of farmers reported that their ostriches did not suffer from major diseases. However, 37.5% of the farmers experienced diseases such as Salmonella, coccidiosis, chronic respiratory disease (CRD), E-coli, eye infections, mouth lesions and malnutrition. Some farmers (25%) also reported parasitic infestations, pox and Newcastle disease. As a result, 37.5% of farmers used vaccines for avian influenza, Newcastle disease and pox, while 62.5% did not vaccinate their ostriches (Figure 3.5). Notably, farmers with more years of experience in ostrich farming had lower mortality rates in their flocks. The mortality rate ranged from 35% to 80%, with experienced farmers reporting lower mortality compared to new farmers (Figure 3.6).

3.3.1.8 Marketing

Ostrich products such as meat, eggs, skin, eggshells, bones and feathers have not been commercially introduced in Bangladesh. The study revealed that 25% of farmers sold ostrich meat at a price of 2,000 BDT per kilogram. However, many potential buyers inquired about whether the meat was halal or haram. Furthermore, 100% of the farmers expressed uncertainty regarding where to sell ostrich products or whether there was a consumer base for ostrich meat. They reported that neither government nor non-government agencies had taken any initiatives to overcome these challenges, hindering the growth of ostrich farming in Bangladesh.

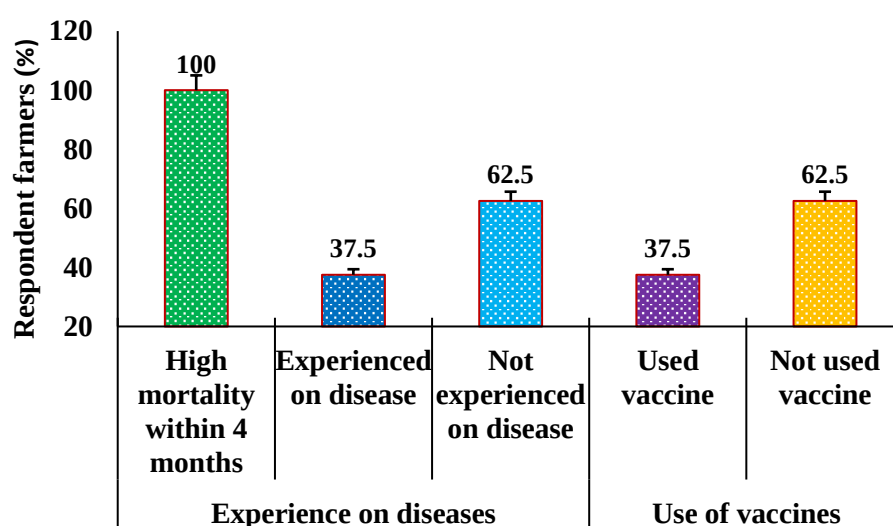


Figure 3.5 Farmers' experiences with diseases and vaccination in ostriches

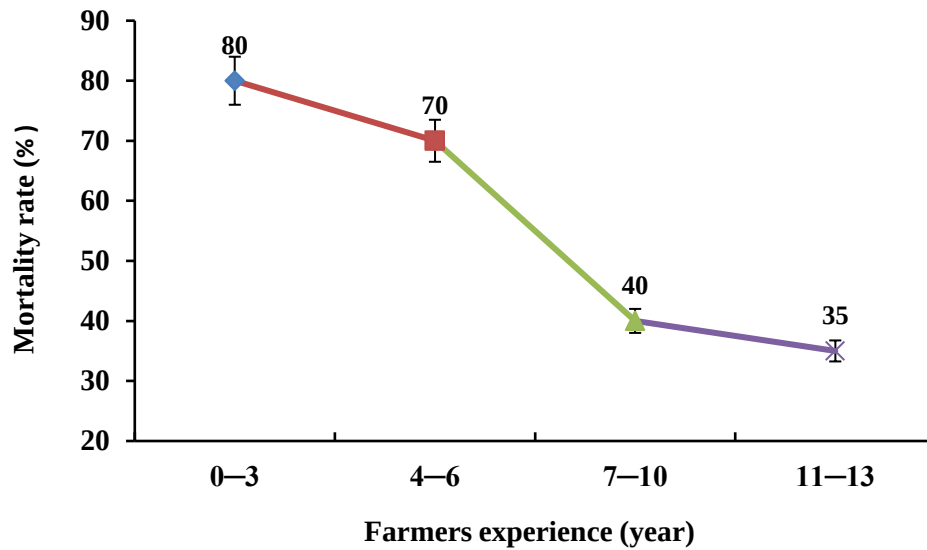


Figure 3.6 Farmers' experience on ostrich mortality rate

3.3.2 Productive and Reproductive Performance

3.3.2.1 Male-Female Ratio, Mating, Fertility and Hatchability

All farmers in the study adhered to natural breeding methods for ostrich reproduction. None of the farmers used artificial insemination (AI) as a reproductive technique. The male-to-female ratio was $1:1.75 \pm 0.25$. The fertility rate for ostrich eggs has not yet been identified in the context of Bangladesh. Farmers attributed the infertility to irregular mating, disturbances during mating and improper nutrition.

3.3.2.2 Farmers' Perceptions on Problems in Ostrich Farming

The study identified several challenges faced by farmers in ostrich farming. These included high chick mortality (87.5%), difficulty marketing ostrich meat (75%), unfamiliarity with ostriches as poultry (75%), unavailability of ostrich chicks (87.5%) and lack of standardized feeding practices (75%) (Figure 3.7).

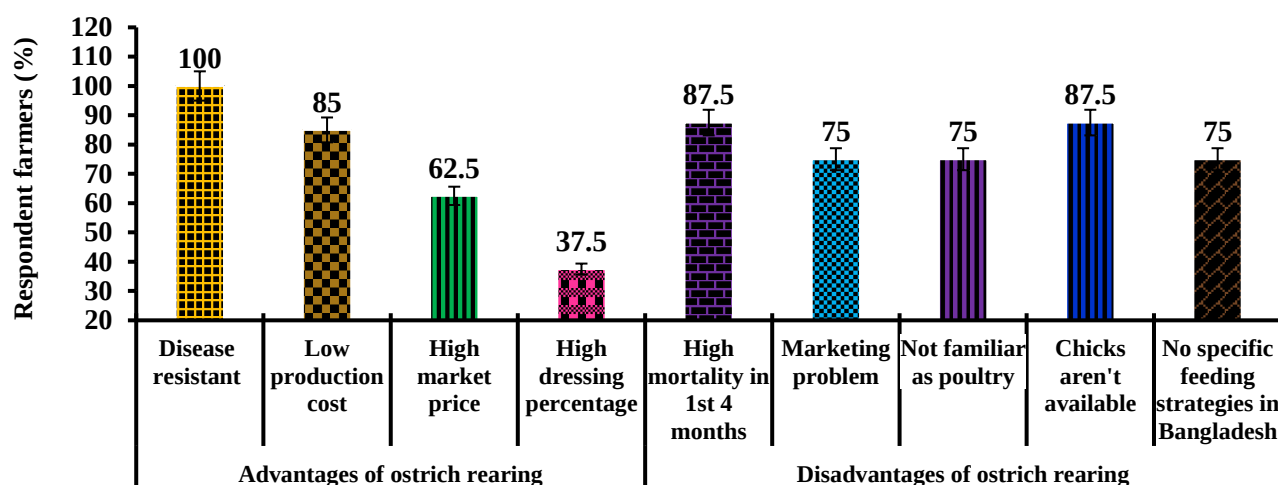


Figure 3.7 Farmers' perceptions of the advantages and disadvantages of ostrich farming

3.4 Discussion

The results of this study provide significant insights into the current state of ostrich farming in Bangladesh, highlighting the demography of farmers, farming practices, technical support, flock management, health and reproductive performance. Despite ostrich farming being a relatively new venture in the country, the study underscores both the challenges faced by farmers and the potential for growth in this sector.

3.4.1 Demographic Profile and Farming Practices

The average age of ostrich farmers (45.75 ± 1.98 years) suggests that ostrich farming is primarily managed by middle-aged individuals who are likely to possess considerable experience in agriculture or animal husbandry (Table 3.1). This finding aligns with studies in other countries, where ostrich farming has been predominantly adopted by middle-aged individuals with previous livestock farming experience (Fakoya et al., 2015). The predominance of male farmers (88%) is consistent with the broader trend in agricultural industries across South Asia, where male participation tends to be higher due to cultural and economic factors (Hossain et al., 2021).

The educational background of farmers, with 12.5% having less than an SSC qualification and 37.5% holding a Master's degree, indicates that there is a fair mix of educational levels among ostrich farmers. This distribution suggests that while some farmers may lack formal training in modern farming techniques, a significant portion possesses higher education,

potentially facilitating their ability to adopt more advanced farming practices (Rajendran et al., 2022).

The purpose of ostrich farming, with 37.5% of farmers indicating ornamental rearing and 37.5% engaged in commercial farming, reflects the diverse objectives behind ostrich farming in Bangladesh. While ornamental purposes may limit production output, commercial and research-driven rearing have more potential for sustainability and profitability. According to a study by McCrindle and Verwoerd (2019), commercial ostrich farming is often driven by the demand for meat, leather and feathers, which may not yet be fully realized in Bangladesh due to underdeveloped markets.

3.4.2 Technical Support and Knowledge Transfer

The sources of technical support for ostrich farmers are diverse, with farmers relying heavily on institutions like Hajee Mohammad Danesh Science and Technology University (50%) and the internet (87.5%) (Figure 3.1). This suggests that there is a growing interest in knowledge-sharing through both traditional academic institutions and online platforms. However, the relatively low involvement of local agricultural extension services and non-government organizations highlights a gap in formal support for the sector. According to Mehmood et al. (2021), successful agricultural industries are often supported by strong extension services, which provide farmers with the necessary knowledge and guidance to improve productivity and overcome challenges. In Bangladesh, increasing collaboration between research institutions and farmers could enhance productivity and ensure the sustainability of ostrich farming.

3.4.3 Flock Structure and Management Systems

The flock size of 18.29 ± 5.07 birds (Table 3.1) indicates that most farms are relatively small-scale. Small-scale farms are typical in the early stages of commercial farming systems and as the industry grows, larger commercial farms may emerge. The average weights of male (116.67 ± 8.82 kg) and female (92.50 ± 7.50 kg) ostriches observed in this study are consistent with international standards for mature ostriches, where males typically weigh between 120-140 kg and females around 100-110 kg (Fakoya et al., 2015). The findings suggest that farmers are achieving relatively good growth performance, although nutritional strategies may need refinement, particularly considering the wide variation in body weight within farms.

The mixed housing systems, with 37.5% of farmers adopting free-range and 62.5% using semi-intensive systems, reflect the flexibility required to adapt to the varied climatic and geographical conditions across the country. The free-range system, although offering better welfare for ostriches, may not be ideal in terms of maximizing productivity due to higher predation risks and environmental stressors. The semi-intensive systems, which are more controlled, might offer better productivity, particularly in terms of egg production and chick survival (Ahmed et al., 2021). The farmers' awareness and adoption of climate-specific care practices, such as extra care during the hot season (50%) and winter brooding (62.5%), demonstrate an understanding of the environmental stress that can negatively affect ostrich health and productivity.

3.4.4 Feeding Practices

The widespread use of commercial poultry feed and roughage (100%) is a common practice in newly established ostrich farming systems. However, the specific use of broiler starter, layer starter and other specialized feeds suggests that farmers may not be fully aware of the specific nutritional needs of ostriches at various life stages (Figure 3.3). The lack of a standardized feeding regime and reliance on a mix of feeds indicate a need for more tailored feeding strategies to improve feed conversion efficiency and reduce feed wastage. Recent research suggests that feeding programs tailored to the nutritional needs of ostriches at different stages of growth can significantly improve production outcomes (Hussein et al., 2020). Educating farmers on feed formulation and efficient feeding practices will be crucial for enhancing the productivity of ostrich farming in Bangladesh.

3.4.5 Health and Disease Management

The study revealed that 100% of farmers encountered diseases such as paralysis and slip tendon, which were particularly prevalent in chicks less than 16 weeks old. High chick mortality rates within the first 3 months, reported by 87.5% of farmers, are indicative of underlying health management issues. The lack of vaccination programs (62.5%) and poor disease management practices are major concerns that need to be addressed. Studies from similar emerging ostrich farming sectors in Africa and South America highlight that effective vaccination programs and early disease detection are key to reducing mortality and improving productivity (Grobler et al., 2020). Furthermore, the identification of diseases like salmonella and *E. coli* suggests that biosecurity and hygiene practices may be insufficient, contributing to disease outbreaks.

The lower mortality rates in more experienced farmers suggest that practical experience plays a significant role in reducing health-related challenges. Experienced farmers may be better equipped to manage diseases, recognize symptoms early and implement corrective measures more effectively than newcomers.

3.4.6 Reproductive Performance

The reproductive performance of ostriches in Bangladesh is still in its infancy, with fertility rates and hatchability largely undefined. The male-to-female ratio of $1:1.75 \pm 0.25$ is in line with recommended practices for natural breeding in ostriches (Wilson et al., 2018). However, the inability to successfully incubate ostrich eggs and the lack of artificial insemination (AI) use suggest a critical gap in reproductive management. The failure to hatch eggs artificially, despite efforts by the Department of Genetics and Animal Breeding, could be attributed to infertile eggs, which may stem from irregular mating, poor nutrition, or suboptimal management practices. These challenges are not unique to Bangladesh, as similar difficulties have been reported in other countries where ostrich farming is still developing (Chigavazira et al., 2021).

3.4.7 Marketing and Market Development

The lack of a well-established market for ostrich products, particularly meat, eggs and leather, represents one of the biggest challenges facing ostrich farming in Bangladesh. While 25% of farmers managed to sell ostrich meat at a rate of 2,000 BDT per kilogram, there was a general lack of knowledge about the potential consumers and outlets for ostrich products. The absence of government or non-governmental initiatives to promote ostrich products further exacerbates the problem. The development of a market for ostrich products, supported by both governmental and private sector initiatives, could greatly enhance the sustainability of ostrich farming in Bangladesh. Studies from countries with successful ostrich industries, such as South Africa, highlight the importance of establishing a strong marketing and consumer education strategy to ensure the success of new agricultural ventures (Birkett et al., 2019).

3.5 Conclusion

Ostrich farming in Bangladesh shows promising potential for economic growth but remains constrained by limited technical support, inadequate health management and weak market infrastructure. This study reveals that most farms are operated by middle-aged, educated male farmers who possess basic husbandry knowledge yet face challenges in feeding, disease control and reproduction. While universities and online sources provide some guidance, formal extension services are lacking. Small flock sizes and varied systems reflect an industry in its early stages. Strengthening farmer capacity, improving infrastructure and developing markets for ostrich meat, eggs and leather are essential for advancing this emerging sector.

3.6 Limitations

While this study provides useful insights into the current status and potential of ostrich farming in Bangladesh, several limitations should be recognized:

- 1) **Limited sample size and geographic scope:** The study covered only a small number of farms concentrated in certain regions, which may not reflect the full diversity of farming practices across the country.
- 2) **Dependence on self-reported data:** Information gathered through interviews and questionnaires could be influenced by recall errors or the desire to give socially acceptable answers.
- 3) **Cross-sectional design:** As the research captured data at a single point in time, it could not track longer-term trends in productivity, profitability, or market growth.
- 4) **Incomplete farm records:** Many farms lacked detailed data on feed use, health, or breeding performance, which limited the depth of statistical analysis.
- 5) **Lack of national studies and local benchmarks:** The scarcity of published Bangladeshi research meant relying on international references that may not fully apply to local conditions.
- 6) **Emerging market and policy gaps:** The absence of a structured market system and formal policies made it difficult to fully assess market integration and institutional support.

- 7) **Focus limited to socio-economic aspects:** Due to resource constraints, the study did not include laboratory analysis of meat quality, genetics, or disease diagnostics.
- 8) **Rapidly evolving industry:** As ostrich farming is still developing, the findings may quickly become outdated; ongoing studies are needed to keep pace with sector changes.

3.7 Recommendations

- 1) **Farmer Training and Education:** Develop targeted training programs focusing on nutrition, disease control, breeding and sustainability. Collaborations with universities and experts can help bridge knowledge gaps.
- 2) **Health Management Improvement:** Reduce chick mortality and disease through regular veterinary care, vaccination programs and improved biosecurity. Educating farmers on preventive health practices is essential.
- 3) **Boosting Reproductive Efficiency:** Address infertility and the absence of artificial insemination by improving natural breeding techniques, enhancing nutrition and supporting research on AI viability.
- 4) **Market Development for Ostrich Products:** Promote ostrich meat, eggs and leather through strategic marketing and public awareness campaigns. Government support is needed to build market infrastructure and expand consumer access.
- 5) **Strengthening Extension Services:** Engage agricultural extension officers and institutions like HSTU to provide field-based support, technical training and research-backed farming solutions.
- 6) **Public and Private Sector Collaboration:** Formulate supportive policies, offer subsidies and encourage joint initiatives involving government, NGOs and private enterprises to scale up ostrich farming.
- 7) **Promotion of Sustainable Farming:** Encourage environmentally friendly and resource-efficient farming practices to increase productivity while preserving ecological balance.

Chapter 4

Optimizing Growth Performance in Ostrich Chicks: The Role of Dietary Supplementation of Methionine and Lysine

4.1 Introduction

The ostrich is the largest extant flightless bird species, has emerged as a valuable alternative to traditional poultry and livestock production due to its high-quality meat, rapid growth rate and by-products such as feathers, leather and oil. Originally native to Africa, ostriches have been domesticated and farmed worldwide, including regions such as the Middle East, Europe, Australia and Asia. In recent years, Bangladesh has seen a growing interest in ostrich farming, driven by increasing demand for lean meat and diversification in animal protein sources (Hassan et al., 2022a).

Ostrich meat is gaining global recognition as a health-conscious red meat alternative because of its low fat, low cholesterol and high protein content (Sales and Horbańczuk, 2018). Compared to beef or lamb, ostrich meat contains significantly less intramuscular fat and saturated fatty acids while providing comparable iron levels (Magwedere et al., 2020). These attributes make it suitable for consumers with cardiovascular risks or those seeking healthy dietary options. Additionally, the economic value of ostrich-derived by-products, such as high-grade leather and cosmetic-grade oil, adds further incentive to promote ostrich farming commercially (Hoffman et al., 2020).

Despite its potential, ostrich farming in Bangladesh remains in its nascent stages, constrained by limited technical knowledge, unstandardized feeding practices and insufficient scientific literature on nutrition under tropical conditions. Unlike commercial poultry, the dietary needs of ostriches-especially regarding amino acid supplementation-are less understood. Among the ten essential amino acids that birds cannot synthesize endogenously, methionine and lysine are the most limiting in typical cereal-based diets. These amino acids are vital for feather development, muscle growth and overall metabolic efficiency (Corzo et al., 2007; Rehman et al., 2019).

Methionine plays a pivotal role in methyl group donation required for biochemical processes such as DNA methylation and polyamine synthesis. It also contributes to the synthesis of cysteine, taurine and glutathione, thus supporting antioxidant defense mechanisms (Shini et

al., 2015). Lysine, on the other hand, is primarily responsible for the formation of collagen, elastin and muscle tissue and also modulates calcium absorption and immune responses (Hernandez et al., 2018). Deficiencies in either methionine or lysine can lead to impaired growth, poor feed conversion, feather anomalies and reduced reproductive efficiency in birds.

Studies on commercial poultry have demonstrated that optimizing levels of methionine and lysine improves feed conversion ratio (FCR), live weight gain and carcass yield (Bunchasak, 2009). However, extrapolating these findings to ostriches is not straightforward due to their unique digestive physiology and longer growth cycle. Ostriches have a voluminous hindgut and function as hindgut fermenters, a system distinct from chickens or turkeys. Therefore, nutrient requirements, digestion efficiency and amino acid utilization may differ considerably (Deeming, 2013).

Globally, limited data are available on the specific amino acid requirements of ostriches, particularly in their early growth stages. Preez (1991) and Ullrey and Allen (1996) provided initial insights into amino acid guidelines, but these were based on experimental observations under South African or North American climates. According to Iowa State University's Nutrition Guidelines (1997), starter diets for ostrich chicks recommend lysine levels of 0.90% and methionine at 0.37%. However, the applicability of these guidelines under the hot and humid conditions of South Asia remains uncertain.

Bangladesh's subtropical climate, characterized by high humidity and fluctuating temperatures, poses unique challenges to ostrich rearing. Heat stress can significantly impair feed intake, metabolic rate and immune function, thereby altering nutrient requirements (Ahmed and Hossain, 2023). Hence, determining optimal amino acid supplementation under local conditions is crucial for maximizing production efficiency.

To further elaborate, it is important to understand the metabolic pathways and physiological mechanisms through which methionine and lysine influence avian growth and development. Methionine is not only a building block for protein but also serves as a precursor for important metabolic compounds such as S-adenosylmethionine (SAM), which plays a central role in methylation reactions, polyamine synthesis and cellular homeostasis (Wu, 2013). SAM is known to regulate gene expression and impact various cellular processes including antioxidant defense, immune modulation and tissue repair. In ostrich chicks,

where fast growth requires high metabolic turnover, methionine becomes critical for maintaining physiological integrity.

Lysine also plays a crucial role in nutrient metabolism. It is actively involved in carnitine synthesis, which is essential for fatty acid oxidation in mitochondria (Wang et al., 2016). This is particularly relevant in ostriches, which deposit relatively low amounts of fat but require efficient lipid metabolism for thermoregulation and muscle energy supply. Additionally, lysine has been shown to support intestinal health by stimulating mucin production, thus protecting against enteric pathogens and improving nutrient absorption efficiency (Kidd et al., 2021).

From a broader livestock nutrition perspective, precision feeding of amino acids has emerged as a sustainable strategy to optimize productivity while minimizing nitrogen excretion and environmental pollution. Over- or under-supplementation of amino acids can lead to economic losses and ecological concerns (Selle and Liu, 2019). For ostrich farmers in Bangladesh, who often lack standardized feed formulations and rely on mixed cereal-legume rations, identifying the ideal balance of amino acids is both a technical and economic priority.

Furthermore, ostrich farming holds socio-economic implications in Bangladesh. It presents an opportunity for rural entrepreneurship, women's empowerment and protein diversification in the national diet. However, poor growth performance and high chick mortality have been reported due to unbalanced rations and inadequate husbandry practices (Kabir et al., 2023). In this context, scientific studies that evaluate the functional impact of dietary components like methionine and lysine can substantially contribute to improving farm productivity and profitability.

Research in similar species has provided encouraging evidence. For instance, in emus and rheas-two ratite relatives-dietary manipulation of amino acids significantly affected growth curves, immune responses and reproductive performance (Horbańczuk et al., 2021). Although extrapolation must be cautious, such findings underline the importance of targeted amino acid nutrition in large flightless birds.

Objectives

The specific objectives of this study were:

- 1) To evaluate the effects of varying levels of dietary methionine and lysine on the growth performance of ostrich chicks.
- 2) To provide practical recommendations for ostrich farmers in Bangladesh aiming to optimize chick growth.

4.2 Materials and Methods

4.2.1 Study Site and Experimental Duration

The experimental study was conducted at the Poultry Research Center of the Bangladesh Livestock Research Institute (BLRI), located in Savar, Dhaka. The facility offers controlled conditions for climate and housing, ideal for conducting precision-based animal trials. The duration of the study was eight weeks, covering the critical growth phase from the 1st to the 9th week of life in ostrich chicks. This early developmental stage is crucial, as nutritional deficiencies or imbalances during this period can have long-term effects on growth and survivability (Sales, 2014).

4.2.2 Experimental Birds and Design

A total of twenty-four healthy, one-week-old ostrich chicks, imported from South Africa, were used. The chicks were randomly allocated to four dietary treatment groups in a completely randomized design (CRD), with three replicates per group and two birds per replicate, ensuring minimal bias and uniformity in distribution. The four treatment groups included:

T₀ (Control): Basal diet without amino acid supplementation.

T₁: Basal diet supplemented with 0.3% methionine and 0.8% lysine.

T₂: Basal diet supplemented with 0.4% methionine and 1.0% lysine.

T₃: Basal diet supplemented with 0.5% methionine and 1.2% lysine.

This experimental framework allowed the researchers to compare the influence of incremental levels of methionine and lysine on growth parameters. The levels of methionine and lysine supplementation in the treatment groups were selected based on previous literature and nutritional guidelines (Alagawany et al., 2020).

4.2.3 Diet Formulation and Nutritional Strategy

The feed was formulated based on previous nutritional guidelines for ratites and poultry (du Preez, 1991; NRC, 1994). Ingredients included maize, wheat bran, soybean meal, full-fat soybeans, distillers dried grains with soluble (DDGS), poultry by-product meal, rice bran oil, vitamins and minerals. The diets were balanced for energy (approximately 2915 kcal/kg), crude protein (around 23%) and adjusted lysine and methionine contents as per treatment specifications (Table 4.1).

Table 4.1 Ingredients and nutrient composition of the formulated basal diet

Ingredients	Amount (kg)	Nutrient composition	Amount
Maize	405	ME (kcal/kg)	2912.35
Wheat Bran	115	Crude Protein (%)	22.0819
Soya DOC 45%	235	Fat (%)	7.15
DDGS (Rice) 40%	15	Lysine (%)	1.3083
Soybean (Full Fat)	150	Methionine (%)	0.5962
Poultry Byproduct Meal	10	Threonine (%)	0.8848
MCP-Monocalcium phosphate	6	Av. Phosphorus (%)	0.4638
LSP-Lime Stone Powder	35	Calcium (%)	1.7361
Oil - Rice Bran	10	Sodium (%)	0.2738
Salt	5	Crude Fiber (%)	4.8575
Soda-Sodium	1.8	Moisture (%)	9.5476
DL-Methionine	2.8	T.D.N (%)	78.125
L-Lysine HCL	1.5		
L-Threonine	0.5		
Choline Chloride, 60%	1.5		
Vitamin Premix	0.5		
Mineral Mixture	1		
TM-Trace Mineral	0.5		
Phytase-5000	0.1		
Lipidin - Poultry	0.5		
Acidifier	1		
Probiotic	0.15		
Antioxidant	0.15		
Toxin Binder	2		
Total:	1000		

Forage supplementation included green leafy vegetables such as water spinach (*Ipomoea aquatica*), cabbage (*Brassica oleracea*) and spinach (*Spinacia oleracea*) to simulate a semi-natural feeding environment and encourage foraging behavior, which is crucial for the gut health of ostriches (More, 1996).

The chemical composition of the experimental diets was confirmed through proximate analysis following the methods described by AOAC (2019).

4.2.4 General Management Practices

4.2.4.1 Brooding and Environmental Control

Ostrich chicks, due to their poikilothermic nature in early life, require external thermal support to regulate body temperature. Brooding was initiated at 35°C during the first week of life and reduced by 2-3°C weekly until ambient temperatures (around 25°C) were achieved. Infrared heat lamps were used alongside chick guards to provide consistent heat and restrict unnecessary movement during early brooding. Bedding consisted of rice husk, changed regularly to maintain hygiene and minimize the risk of microbial infections. The brooding area was monitored using digital thermometers and hygrometers to ensure environmental consistency.



Photo 4.1 Rearing of experimental ostrich chicks

4.2.4.2 Housing System

Each treatment group was allocated to specially designed pens measuring 2.0 m × 2.5 m with an adjoining outdoor free-range area of 24.5 m × 10 m. The pen design adhered to animal welfare protocols, ensuring adequate space for locomotion, comfort behaviors (dust bathing, wing flapping) and reduction of stress-induced anomalies. Pen walls were constructed using a combination of galvanized mesh and solid barriers to prevent injuries and ensure proper ventilation. Sand flooring was used to mimic the natural habitat and facilitate normal gait development (Bertram and Burger, 1981).

4.2.4.3 Lighting Program

Continuous lighting (24 hours) was provided during the first two weeks to stimulate feeding behavior and support thermoregulation. From the third week onward, the lighting schedule was gradually adjusted to follow the natural day–night cycle. Proper photoperiod management is known to influence metabolic rhythms and hormonal development in ratites (Lambrechts, 2017).



Photo 4.2 Condition of the experimental ostrich chicks at night

4.2.4.4 Biosecurity and Sanitation Measures

Comprehensive biosecurity measures were enforced throughout the study. All personnel entering the ostrich units were required to wear disinfected boots and coats, pass through footbaths containing Timsen solution (1 g/L) and maintain strict entry protocols. Housing facilities were cleaned bi-weekly with disinfectants including Halamid and sodium hypochlorite to limit microbial proliferation. Feed and water containers were sanitized daily to prevent contamination. Rodent traps and insect control measures were also deployed around the facility perimeter (Tully and Shane, 1996).

4.2.4.5 Immunization and Veterinary Care

A prophylactic vaccination program was implemented, beginning with Baby Chick Ranikhet Disease Vaccine (BCRDV) administered via the ocular route at 10 and 25 days of age, followed by Ranikhet Disease Vaccine (RDV) given intramuscularly at 9 weeks of age (Table 4.2). The cold chain was strictly maintained during vaccine storage and administration. Supportive care included periodic administration of vitamin-mineral premixes (Vitamin AD3E, B-complex and selenium supplements), calcium gluconate and electrolytes to bolster immunity and physiological functions (Ullrey and Allen, 1996).

Table 4.2 Vaccination during experimental period

Age of the birds	Name of vaccine	Route of administration	Dose
10 days	*BCRDV	Eye drop	One drop in one eye
25 th days	*BCRDV	Eye drop	One drop in one eye
9 th week	**RDV	***I/M	1.5 ml/bird

BCRDV means Baby Chicks Ranikhet Disease Vaccine, **RDV means Ranikhet Disease Vaccine, *I/M means Intramuscular*

4.2.4.6 Medication and Preventive Health Monitoring

Medicines used for the experimental birds are shown in Table 4.3. Deworming was carried out biweekly using broad-spectrum anthelmintics to prevent gastrointestinal parasitism. Preventive antibiotics such as tylosin were administered at minimal dosages under veterinary advice to counteract early-stage bacterial infections, especially during sudden weather changes. Health monitoring included daily observations for signs of lethargy,

reduced feed intake, abnormal posture and lesions. Suspected birds were isolated and treated immediately. Mortality and morbidity rates were recorded for each group.

Table 4.3 Medicines used for the experimental birds

Trade name of medicines	Dose	Duration of administration	Route of application	Time of application
Lysovit	1g/1litre	3 days	With drinking water	Two times in every month
EL plex (B ₁ , B ₂ and B ₆)	1ml/1litre	3 days	With drinking water	Two times in every month
ESel (E and Selenium)	1ml/1litre	3 days	With drinking water	One time in every month
Vitamin AD ₃ E	1ml/1litre	3 days	With drinking water	Two times in every month
Renalytes	1g/1litre	During hot season	With drinking water	During hot season
Renaflox	1g/1litre	3 days	With drinking water	As per physician's suggestion
Renamox	1g/1litre	3 days	With drinking water	As per physician's suggestion
Neuro-B	1.5 ml	2 times /week	I/M	As per physician's suggestion
Zimax	1tab/day	5 days	Oral administration	As per physician's suggestion

4.2.4.7 Enrichment and Behavioral Management

To mitigate boredom and behavioral disorders such as feather pecking or toe-pulling, environmental enrichment strategies were adopted. These included provision of hanging ropes, pebbles for pecking and natural foraging materials. Rotational access to the free-range paddocks was scheduled to reduce environmental monotony and promote exercise. Behavioral patterns such as preening, running and social interactions were observed and recorded weekly to assess welfare status (Sales, 2014).

These extensive general management strategies ensured the overall well-being, health and optimal growth of the ostrich chicks, thereby contributing to the reliability and applicability of the research outcomes.

4.2.5 Data Collection Procedures

Accurate and consistent data collection was a critical component of this study to assess the effects of dietary methionine and lysine supplementation on ostrich chick performance. The following parameters were systematically recorded:

1. Growth Performance Parameters:

- 1) **Initial and Final Body Weight:** Each chick's body weight was measured weekly using an electronic digital scale with a sensitivity of ± 1 gram. Measurements were taken before feeding to avoid variability caused by gut fill.
- 2) **Average Daily Gain (ADG):** Calculated as the difference in body weight over successive weeks divided by the number of days between weightings.
- 3) **Total Feed Intake:** Daily feed offered and refusals were measured to compute the total feed intake per bird.
- 4) **Feed Conversion Ratio (FCR):** Determined as the amount of feed consumed per unit of body weight gained ($\text{FCR} = \text{Feed intake} / \text{Body weight gain}$).

2. Water Consumption: Clean, cool water was provided ad libitum and recorded daily using graduated containers. The amount consumed per bird was estimated by subtracting refusals from total water offered.

3. Morphometric Measurements: Body dimensions were recorded using a non-stretchable measuring tape and Vernier calipers where necessary. Parameters measured included:

- 1) Shank diameter and length
- 2) Toe diameter and length
- 3) Neck diameter and length
- 4) Wing and feather length
- 5) Heart girth
- 6) Body length
- 7) Body height (from claw base to crown)

Measurements were taken every week and each measurement was performed by the same trained individual to minimize observer bias.

4. Health and Welfare Indicators: Observations on chick behavior, gait, feather condition and any clinical signs of illness or discomfort were documented. Mortality and morbidity rates were logged, along with the probable causes when identifiable.

4.2.6 Statistical Analysis

All collected data were coded and entered into SPSS version 27.0 for statistical analysis (IBM, 2022). Descriptive statistics (means and standard errors) summarized the data. One-way ANOVA tested for significant differences among treatment groups (T_0 – T_3) at $P < 0.05$, followed by Tukey's HSD for post hoc comparisons. Pearson's correlation coefficients were calculated to explore relationships between body weight and morphometric traits such as shank length, neck diameter and wing length, with correlation strength interpreted as weak ($r < 0.3$), moderate ($0.3 \leq r < 0.7$), or strong ($r \geq 0.7$). Multiple linear regression models were developed to predict body weight from these traits.

4.3 Results

This section presents the comprehensive outcomes of the dietary experiment evaluating the effects of methionine and lysine supplementation on growth performance, feed efficiency, body morphometry and predictive biometric relationships in ostrich chicks. These findings are substantiated through detailed tabular data (Tables 4.4, 4.5 and 4.6).

4.3.1 Growth Performance Metrics

Table 4.4 presents a comprehensive overview of the growth performance of ostrich chicks from 5 to 12 weeks of age under four different dietary treatments. The initial body weights were comparable among groups, indicating uniform starting conditions. The control group (T_0), which received a basal diet without additional amino acid supplementation, had an average initial weight of 6350 ± 149 g. Groups T_1 , T_2 and T_3 also began at similar weights, ranging from 6320 ± 134 g to 6480 ± 151 g, confirming that any subsequent differences in growth outcomes can be attributed to dietary effects.

Final body weight showed significant improvement in the supplemented groups. The T_3 group, which received the highest level of supplementation (0.5% methionine and 1.2% lysine), achieved the greatest final weight of 28868 ± 2021 g, followed by T_2 (27839 ± 1847

g), T₁ (26872 ± 1699 g) and T₀ (25407 ± 1411 g). The differences between T₃ and T₀ were statistically significant (P < 0.05), indicating a substantial impact of amino acid supplementation on growth. The improved weight gain in T₂ and T₃ suggests a positive dose-response effect.

Feed intake also varied notably across the groups. While the control group (T₀) consumed the highest amount of feed (59847 ± 2929 g per bird), T₃ consumed the lowest (45897 ± 1633 g per bird). Despite lower feed intake, birds in the T₃ group achieved the highest weight gain, resulting in a significantly improved feed conversion ratio (FCR) of 2.05 ± 0.053, compared to the poorest FCR of 3.14 ± 0.216 in the control group. This outcome clearly demonstrates the enhanced nutrient utilization and metabolic efficiency achieved through amino acid supplementation.

Table 4.4 Different parameters associated with growth of ostrich chicks (age 5-12 weeks)

Parameter	T ₀	T ₁	T ₂	T ₃
Initial Body weight (g/b)	6350±149	6320±134	6430±154	6480±151
Final Body weight (kg/b)	25.41±1.41 ^a	26.87±1.70 ^{ab}	30.84±1.85 ^b	32.21±2.02 ^b
Live weight gain (kg/b)	19.06±1.37	20.55±1.37	24.37±1.60	25.73±1.51
Total Feed intake (g/b)	59.85±2.93	59.58±1.91	57.99±1.75	58.90±1.63
Average Live weight gain (g/day)	390±0.031 ^a	420±0.048 ^{ab}	440±0.054 ^b	460±0.05 ^b
FCR	3.14±0.216 ^b	2.90±0.094 ^{ab}	2.38±0.072 ^b	2.29±0.053 ^a
Water intake (ml/b)	104480±827 ^b	94270±591 ^a	96460±882 ^a	105190±1040 ^b
Shank diameter (cm)	13.60±0.43 ^a	14.27±0.31 ^{ab}	14.83±0.56 ^{ab}	15.91±0.75 ^b
Shank length (cm)	34.52±0.83 ^{ab}	33.22±1.52 ^a	35.37±1.51 ^{ab}	35.41±1.89 ^b
Toe diameter (cm)	15.07±0.62	14.94±0.83	16.04±0.62	15.32±0.98
Toe length (cm)	12.12±0.49	13.82±0.68	13.48±0.71	13.73±0.88
Neck diameter (cm)	15.93±0.43	15.76±0.33	15.53±0.48	15.37±0.58
Neck length (cm)	57.47±1.89 ^a	63.33±1.92 ^{ab}	62.07±2.42 ^{ab}	66.92±2.79 ^b
Wing length (cm)	42.72±1.58 ^a	44.58±1.95 ^{ab}	45.69±2.06 ^{ab}	46.41±2.43 ^b
Feather length (cm)	26.83±2.35 ^a	28.17±2.11 ^{ab}	29.47±2.18 ^b	31.64±12.11 ^b
Body length (cm)	69.10±2.56	72.77±2.58	74.33±2.84	76.86±2.99
Heart girth (cm)	74.92±1.98 ^a	77.43±2.08 ^{ab}	78.74±2.28 ^{ab}	83.50±2.44 ^b
Body height (cm)	85.48±3.03 ^a	88.97±2.95 ^{ab}	91.28±3.43 ^{ab}	96.27±3.41 ^{ab}

Values are Mean±Standard error (SE), Significant values are marked with superscripts (a,b).

Water intake was also recorded as a supporting physiological parameter. Interestingly, T₃ birds consumed slightly more water (105190 ± 1040 ml) than the control group, which may reflect increased metabolic activity and growth processes. However, T₀ and T₃ did not differ significantly in water intake, suggesting that water consumption alone was not a major contributing factor to weight differences.

Body morphometric traits provide valuable insight into skeletal development, musculoskeletal robustness and overall physiological growth. As shown in Table 4.4, birds in the amino acid-supplemented groups exhibited consistent and statistically significant improvements in nearly all body measurement parameters compared to the control group.

Shank measurements serve as strong indicators of leg development. The T₃ group recorded the highest mean shank diameter (15.91 ± 0.75 cm) and shank length (35.41 ± 1.89 cm), both significantly greater than the control (T₀), which measured 13.60 ± 0.43 cm and 34.52 ± 0.83 cm respectively. These enhancements reflect the positive role of dietary methionine and lysine in supporting bone growth and skeletal integrity.

Toe length and diameter, although not statistically significant across all treatments, were highest in T₃ and T₂. T₂ recorded the longest toe diameter (16.04 ± 0.62 cm) and T₁ had the highest toe length (13.82 ± 0.68 cm), suggesting potential individual variation rather than consistent treatment effects in these specific traits.

Neck length showed a clear upward trend, increasing from 57.47 ± 1.89 cm in T₀ to 66.92 ± 2.79 cm in T₃. This progressive improvement in cervical extension may relate to better muscular development and improved access to feed, contributing indirectly to superior growth rates. Although neck diameter showed no statistically significant differences, a mild decrease from T₀ to T₃ was observed, possibly due to variation in fat deposition or individual conformation.

Wing length also followed a positive trend, with the T₃ group exhibiting the longest wings (46.41 ± 2.43 cm) compared to T₀ (42.72 ± 1.58 cm), indicating enhanced musculoskeletal development and feather support. Feather length was similarly highest in T₃ (31.64 ± 12.11 cm), suggesting improved protein utilization for integumentary growth, particularly in keratin-rich tissues.

Heart girth, another important indicator of thoracic volume and internal organ development, increased significantly from 74.92 ± 1.98 cm in T_0 to 83.50 ± 2.44 cm in T_3 . This implies not only increased cardiac and pulmonary capacity but also better overall physiological condition. Similarly, body height and length improved across treatments, with T_3 recording the tallest birds (96.27 ± 3.41 cm) and longest bodies (76.86 ± 2.99 cm), further supporting the conclusion that nutritional intervention promoted proportional and efficient growth.

4.3.2 Statistical Correlations and Regression Analysis

To better understand the relationships between body weight and morphometric traits in ostrich chicks, Pearson correlation and multiple regression analyses were conducted, with results summarized in Table 4.5.

The correlation matrix revealed strong and mostly significant positive associations between body weight and all recorded body measurements, indicating that as birds gained weight, they also exhibited proportional increases in skeletal and muscular dimensions. Among these, body length ($r = 0.984$), neck length ($r = 0.971$) and wing length ($r = 0.974$) showed the strongest correlations with body weight, all statistically significant at the 0.05 level. These findings suggest that these traits are reliable field indicators of growth performance.

Table 4.5 Correlation coefficient of body weight and body measurements of ostrich chicks

Parameter	Body weight	Shank diameter	Neck length	Wing Length	Feather Length	Body Length	Heart girth	Body height
Body weight	1.000							
Shank diameter	0.949	1.000						
Neck length	0.971*	.996**	1.000					
Wing Length	0.974*	0.873	0.904	1.000				
Feather Length	0.924	0.899	0.905	0.948	1.000			
Body Length	0.984*	0.926	0.946	.990*	.974*	1.000		
Heart girth	0.917	0.932	0.928	0.917	.992**	.960*	1.000	
Body height	0.940	0.923	0.928	.951*	.998**	.981*	.995**	1.000

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Similarly, high correlation values were found between body weight and heart girth ($r = 0.917$), body height ($r = 0.940$), shank diameter ($r = 0.949$) and feather length ($r = 0.924$).

These measurements reflect both internal capacity and external structure, providing a holistic view of growth status. The relationships between predictor variables themselves (e.g., between feather length and body height, $r = 0.998$) were also notably high, which reinforces the interconnectedness of skeletal and tissue development in growing ostrich chicks.

To further explore the predictive value of these measurements, multiple regression analyses were performed using various combinations of traits are shown in Table 4.6. The results confirmed that certain body measurements can accurately predict live body weight with high statistical reliability. Among the tested models, the combination of feed conversion ratio (FCR) and body height showed the highest predictive power, explaining 99.5% of the variance in body weight ($R^2 = 0.995$). This indicates that growth efficiency and skeletal stature are key contributors to overall weight gain.

Table 4.6 Regression statistics of body weight and body measurements of Ostrich chicks

Predictors: (Constant)	R Square	Adjusted R Square	Estimate %	Collinearity Statistics			Residuals Statistics
				Correlations	Tolerance	VIF	Mahalanob is Distance
Shank length and shank diameter	0.914	0.742	74.2	0.308	0.905	1.105	2.172
Toe length and toe diameter	0.86	0.58	58	0.199	0.916	1.041	2.249
Neck length and neck diameter	0.974	0.923	92.3	-0.863	0.97	3.908	1.686
Feather length and wing length	0.949	0.847	84.7	0.948	0.102	9.83	2.189
Heart girth and body length	0.977	0.931	93.1	0.96	0.12	12.71	2.244
FCR and body height	0.998	0.995	99.5	-0.929	0.9	7.32	2.245
Weekly feed and water Intake	0.98	0.94	94	-0.54	0.709	1.411	2.239

R Square: The coefficient of determination (Proportion of variation in the dependable and predictable independent variable), VIF: Variance Inflation Factor

Another highly predictive model included heart girth and body length, which together explained 93.1% of the variance in body weight ($R^2 = 0.977$). This model is particularly useful for field application, as both measurements are easy to obtain and reflect core structural and physiological growth.

Other notable models included:

- 1) Neck length and diameter, accounting for 92.3% of the variation in weight.
- 2) Weekly feed and water intake, predicting 94% of weight variation.
- 3) Feather and wing length, explaining 84.7%.
- 4) Shank length and diameter, explaining 74.2%.
- 5) Toe length and diameter, with the lowest but still considerable predictive power at 58%.

The inclusion of FCR as a predictive variable is particularly valuable, as it integrates internal metabolic efficiency with external morphometry. This allows for more accurate growth modeling and assists in designing efficient feeding regimes and selection strategies for commercial ostrich production.

Collinearity diagnostics indicated acceptable tolerance levels (>0.1) and Variance Inflation Factors ($VIF < 10$) across all models, confirming the absence of harmful multicollinearity. Furthermore, residual statistics and diagnostic plots supported the assumptions of normality, linearity and homoscedasticity, validating the suitability of the models for practical use.

4.4 Discussion

The present study examined the effects of dietary supplementation of methionine and lysine on ostrich chick growth performance, nutrient utilization, morphometric development and predictive trait relationships. The findings clearly demonstrate that increasing levels of these amino acids significantly improved body weight gain, feed efficiency, skeletal structure and overall chick vitality. These outcomes align with established amino acid functionality in avian species and emphasize their indispensable roles in commercial ratite nutrition. This

reinforces the view that precision amino acid supplementation is essential to maximize productivity, economic returns and sustainability in exotic poultry production systems.

4.4.1 Growth Performance and Nutrient Efficiency

Chicks receiving enhanced amino acid diets, especially in group T₃, exhibited the highest body weight and average daily gain (ADG), supporting existing literature on the anabolic effects of methionine and lysine in poultry and ratites (Zhao et al., 2021; Ullrey and Allen, 1996). Methionine contributes to methylation and antioxidant processes, while lysine supports muscle accretion, enzymatic activities and calcium retention essential for metabolic and skeletal development (Corzo et al., 2007).

The improvement in feed conversion ratio (FCR) from 3.14 in T₀ to 2.05 in T₃ highlights metabolic optimization achieved through nutrient balance. Enhanced amino acid availability likely reduced deamination losses and supported more efficient protein synthesis, resulting in better growth at lower feed intake (Rehman et al., 2019). Such metabolic efficiency also reduces nitrogen excretion and environmental pollution, aligning with sustainable livestock production principles. In a broader context, this aligns with global demands for more efficient meat production systems that are both cost-effective and ecologically sound.

4.4.2 Structural and Morphometric Advancements

Morphometric traits such as shank length, heart girth and feather development were significantly enhanced in supplemented groups. These traits are critical indicators of musculoskeletal health, organ development, thermoregulation efficiency and carcass yield potential in large flightless birds (Mushi et al., 2022). Feather growth, notably superior in T₃, is directly linked to keratin formation which is a process reliant on methionine and other sulfur-containing amino acids (Babiker and Mohamed, 1988).

Not only do these physical traits reflect external development, but they also imply internal organ and metabolic health. Improved heart girth, for example, may correspond to cardiovascular development necessary to support increased body mass. Additionally, these measurements are significant for welfare assessment, as structurally sound birds are less prone to injury and mobility-related stress. Thus, these improvements not only contribute to productivity but also enhance welfare standards which is a growing concern among consumers and regulators.

4.4.3 Predictive Relationships and Practical Application

The study also established strong positive correlations between body weight and morphometric traits such as body length ($r = 0.984$), neck length ($r = 0.971$) and shank diameter ($r = 0.949$), confirming the predictive potential of these measurements. Multiple regression analysis revealed that body weight could be accurately estimated using simple traits like heart girth and body length ($R^2 = 0.977$), or FCR and body height ($R^2 = 0.998$).

These models provide cost-effective tools for farm-level performance monitoring, especially in smallholder systems where digital weighing devices are unavailable or impractical. This approach could form the basis of future mobile-app based decision support systems that enable real-time flock assessment and selection. Furthermore, such correlations enable breeders to refine selection strategies by identifying birds with higher growth potential through non-invasive measurements early in the production cycle (Sales, 2014).

4.4.4 Implications for Ostrich Farming in Bangladesh

Given the limited but growing interest in ostrich farming in Bangladesh, these results serve as a foundational reference for formulating nutritionally optimized diets using locally available resources. The use of methionine at 0.5% and lysine at 1.2% not only promotes superior growth but also improves feed economy and bird welfare. These improvements also foster consumer confidence in meat safety and quality that factors vital for market development.

Implementing these dietary practices may lead to increased productivity, reduced mortality and enhanced market readiness, thereby transforming ostrich farming from an experimental endeavor into a sustainable industry. In regions with fluctuating feed ingredient availability, the findings also highlight the potential of amino acid supplementation to standardize production outcomes across variable environmental and nutritional conditions.

The observed improvements in survival rate in T_3 further reinforce the critical role of nutritional adequacy in early-life development and immune competence. Methionine and lysine have been implicated in improving antioxidant status and gut barrier integrity, which are crucial for disease resistance and resilience against environmental stressors (Zhao et al., 2021). These benefits also align with global movements toward more ethical and economically viable animal production systems.

4.5 Conclusion

These findings suggest that dietary supplementation of methionine and lysine significantly enhances growth performance and survivability in ostrich chicks. This nutritional approach provides a practical and cost-effective strategy for improving early-stage development in semi-intensive farming systems in Bangladesh. The observed increase in weight gain and feed efficiency highlights the importance of balanced amino acid intake during critical growth phases. Implementing such dietary practices can help reduce chick mortality, optimize resource use and improve profitability for ostrich producers. These results support the advancement of efficient feeding systems tailored to the needs of Bangladesh's emerging ostrich farming industry.

4.6 Limitations

While this study offers valuable insights into the effects of methionine and lysine supplementation on ostrich chick growth, several limitations should be noted:

- 1) **Limited sample size:** The small number of chicks may reduce statistical power and limit generalizability to larger farming systems.
- 2) **Short experimental period:** Focused only on the starter phase (1–9 weeks), so long-term effects on reproduction, sexual maturity and carcass traits remain unknown.
- 3) **Single controlled environment:** Conducted under uniform farm conditions, which may not reflect the diverse climates and housing systems found in practice.
- 4) **Restricted genetic diversity:** Studied only one ostrich strain, limiting applicability to other breeds or crosses with potentially different nutrient responses.
- 5) **No biochemical or immune data:** Relied on growth and morphometric traits without measuring blood biochemistry, hormones, or immune markers that could reveal underlying physiological effects.
- 6) **Lack of economic analysis:** Did not assess feed cost per kg gain, ROI, or overall profitability of amino acid supplementation.

4.7 Recommendations

- 1) **Supplement Starter Diets:** Include 0.5% methionine and 1.2% lysine in diets for chicks aged 1–9 weeks.
- 2) **Farmer Training on Amino Acids:** Educate farmers on the importance of amino acids for bird health and performance.
- 3) **Standardize Measurement Protocols:** Develop practical morphometric standards for consistent field assessment.
- 4) **Public–Private Partnerships:** Support collaborations to produce and market amino acid-fortified feeds.
- 5) **Research Nutrient–Gene Interactions:** Promote studies on how genetics and nutrition interact for precision feeding.
- 6) **Explore Amino Acid Effects:** Investigate the role of amino acids in reproduction, gut health and bird longevity.
- 7) **Promote Standardized Nutrition:** Encourage unified nutritional and welfare standards to support export-focused farming.

Chapter 5

A Comprehensive Study on the Ethology of Captive Ostriches: Patterns, Social Dynamics and Breeding Behavior

5.1 Introduction

The ostrich, belonging to the order Struthioniformes, is the largest extant species of bird and represents a significant avian evolutionary lineage with a unique set of morphological, physiological and behavioral adaptations suited for survival in arid and semi-arid environments (Deeming, 2022). Native primarily to the savannas and open woodlands of sub-Saharan Africa, ostriches are flightless, cursorial birds equipped with long legs for rapid locomotion and strong defensive capabilities. Their remarkable endurance, efficient water use and thermoregulatory adaptations have enabled them to thrive in harsh conditions, making them well suited for commercial farming in diverse climatic zones, including parts of South Asia such as Bangladesh (Bertram, 1992).

In recent decades, there has been increasing global interest in ostrich farming due to its potential as a sustainable alternative to conventional poultry. Ostriches are valued for their lean red meat, high-quality leather and feathers and have demonstrated promising productivity in controlled environments (Deeming and Bubier, 2001). However, successful ostrich farming hinges not only on nutritional and environmental management but also on a deep understanding of their behavioral ecology. Unlike chickens or turkeys, ostriches exhibit a complex behavioral repertoire influenced by their natural instincts, which may not fully manifest in confined or unfamiliar captive environments (Menon et al., 2014).

Understanding the behavioral characteristics of ostriches is vital for multiple reasons. Firstly, behavior serves as an early indicator of health and welfare. Deviations from normal behavioral patterns, such as excessive pacing, aggression, or feather plucking that can indicate environmental stress, poor nutrition, or social disharmony (Sambraus, 1994). Secondly, reproductive success in ostriches is tightly linked to their behavioral expression. Mating rituals, courtship displays and nesting behaviors are all behaviorally mediated and are susceptible to disruption under artificial farming conditions (Deeming, 2021). Hence, ethological studies offer insights not only into animal welfare but also into enhancing productivity and sustainability of ostrich farming systems.

The behavioral profile of ostriches includes a variety of activities such as feeding, drinking, walking, running, resting, standing, preening, social interactions and reproductive behaviors. Daily time budgets of these behaviors have been documented in various studies, mostly conducted in African or Western farming contexts (Berendsen, 1995). These time budgets offer insights into the species' natural rhythms and help in optimizing feeding schedules, enclosure designs and social groupings. However, regional variations in climate, management practices and enclosure design significantly influence these behavioral patterns. As such, direct observations under local conditions, such as in Bangladesh, are critical for developing context-specific management strategies.

Ostriches are highly social animals that typically form groups ranging from small familial units to larger communal aggregations in the wild. Social hierarchy is established through displays of dominance and submissive behaviors, particularly among males during the breeding season. Aggression, especially in males, is common when competing for access to females or defending territories. Males are known for their spectacular courtship rituals involving booming calls, wing flapping and "kantling" displays, which play a central role in mate selection (Sauer and Sauer, 1966). In captivity, where space is limited and natural mate selection may be restricted, these behaviors can be suppressed or expressed abnormally, often resulting in reduced fertility or reproductive success (Ross and Deeming, 1998).

Furthermore, ostriches exhibit behavioral plasticity in response to environmental stimuli. They have evolved efficient thermoregulatory strategies such as panting, wing spreading and sand-bathing to maintain homeostasis in high ambient temperatures (Louw, 2021). These behaviors are particularly important in subtropical regions like Northern Bangladesh, where temperatures can fluctuate significantly between seasons. Inadequate opportunities to express such behaviors due to poor enclosure design or lack of environmental enrichment may result in heat stress, behavioral frustration and diminished welfare. The study of these behavioral responses provides valuable guidelines for designing ostrich-friendly housing systems and microclimate management practices.

Reproductive behaviors in ostriches are notably complex. The species follows a primarily polygynous mating system, wherein a dominant male may mate with multiple females. The mating process involves elaborate courtship displays by males, which, if successful, are followed by copulation and communal nesting. In natural settings, the major hen and the territorial male take the lead in incubating eggs, with incubation lasting approximately 42–

44 days (Bertram, 1992). In captivity, however, these natural processes may be altered or suppressed due to human intervention, artificial incubation and changes in social dynamics. Moreover, environmental variables such as photoperiod, temperature and humidity have been shown to significantly affect mating success, egg laying and hatchability.

Parental care is also an important behavioral trait in ostriches. In the wild, both males and females participate in nest defense and chick rearing, with adults displaying distraction behaviors to protect chicks from predators. In captivity, while predator threats are minimized, parental behaviors can still be critical, especially in natural incubation setups. Observing such behaviors can help determine the feasibility of natural brooding systems in controlled environments and inform decisions about whether artificial brooding is necessary or desirable under specific conditions.

The literature on ostrich behavior, while rich in general descriptions, often lacks detailed ethograms under subtropical captive conditions. Most existing studies are based in South Africa, Australia, or temperate regions of Europe and North America (Deeming and Bubier, 2001; Menon et al., 2014). These regions differ significantly in temperature regimes, daylight duration and farming infrastructure compared to Bangladesh. As a result, extrapolating findings from these studies may not provide accurate or effective guidelines for local farming practices. There is, therefore, a pressing need to document ostrich behavior in the specific environmental context of Bangladesh, particularly to support the nascent but growing ostrich farming industry in the region.

This study was undertaken to address this research gap by systematically observing and documenting the behavioral characteristics of African Black ostriches (*Struthio camelus domesticus*) under captive conditions in a semi-intensive farming system in Northern Bangladesh. The study employed both qualitative observations and quantitative time-budget analyses to identify patterns in daily activity, social behavior, reproductive rituals and parental care. Specific attention was given to how these behaviors vary across different times of day, seasons and social configurations. The study also explored how factors such as temperature fluctuations, feed delivery schedules and human presence affect the natural behavioral rhythms of the birds.

By developing a comprehensive understanding of these behavioral patterns, this research aims to inform evidence-based recommendations for improved management practices, welfare enhancement and reproductive efficiency in ostrich farms operating in similar

climatic and ecological settings. The results will not only be valuable for farm owners and veterinary professionals but also contribute to the academic literature on avian ethology and the practical domain of exotic livestock management. Furthermore, this research may serve as a foundation for policy development and training programs aimed at promoting sustainable ostrich farming in Bangladesh and beyond.

Objectives

The primary aim of this study is to gain a comprehensive understanding of the behavioral characteristics of ostriches under captive conditions in Bangladesh. Specific objectives of the research are:

- 1) To investigate the daily time-activity budgets of captive ostriches, including feeding, locomotion, resting, grooming and other behavioral patterns.
- 2) To examine the social interactions, dominance hierarchy and adaptive behavioral responses of ostriches in relation to environmental and management factors.
- 3) To evaluate reproductive behaviors such as courtship, mating, egg-laying, incubation and parental care in order to enhance breeding efficiency and welfare in ostrich farming systems.

5.2 Materials and Methods

5.2.1 Study Area and Environmental Conditions

This study was conducted at the Advanced Animal Research Center, located within the premises of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur-5200, Bangladesh. The research site is situated in a subtropical agro-climatic zone characterized by hot summers, moderate winters, high humidity and seasonal rainfall. The annual average temperature in the region ranges between 16°C and 32°C, with relative humidity levels fluctuating between 60% and 85%, depending on the season. The photoperiod varies from 10.5 to 13.5 hours throughout the year.

The choice of location was ideal for investigating ostrich behavior under a semi-intensive farming model in a subtropical climate, where temperature and humidity variations could significantly influence both general and reproductive behaviors. Weather data, including ambient temperature, humidity and rainfall, were collected from the Bangladesh Meteorological Department and were considered during behavioral interpretation.

5.2.2 Experimental Animals and Management Protocol

A total of 14 healthy, mature African Black ostriches (*Struthio camelus domesticus*), aged seven years, were included in the study. The experimental group comprised 11 males and 3 females, all of which were imported from South Africa and acclimatized to local conditions for over one year prior to the commencement of the study. All birds were maintained under controlled captive conditions at the research facility.

During the breeding season (January–August), the birds were separated into three breeding pairs (one male and one female per enclosure) to observe natural courtship, mating and nesting behavior. Each breeding pair was housed in an individual enclosure measuring 15 meters × 12 meters (180 m²), ensuring a 90 m² area per bird, consistent with international standards for captive ostrich management. The enclosures were surrounded by 2.4-meter-high chain-link fences and included shaded areas, sandy nesting patches and open foraging zones to allow for natural movement and behavior.

Remaining unmated males were kept in group housing in adjacent enclosures, allowing for indirect visual and vocal interaction with paired birds, which helped simulate a more natural social environment.

5.2.3 Feeding and Nutritional Management

All ostriches were fed a standardized breeder ration formulated to meet the nutritional requirements of adult birds during the reproductive season. The daily ration consisted of 1.5 kg of pelleted concentrate feed per bird, with the following average composition: Crude Protein (CP): 18%, Metabolizable Energy (ME): 10.26 MJ/kg, Calcium and Phosphorus: 2.5% and 0.8% respectively.

To satisfy the birds' fiber and foraging needs, fresh Napier grass (*Pennisetum purpureum*) was provided twice daily. Clean drinking water was available ad libitum and vitamin-mineral supplements were administered biweekly to prevent deficiencies and support reproductive health.

The feeding schedule was fixed, with rations delivered at 08:00 h and 16:00 h daily. Feed intake and foraging behavior were monitored as part of the behavioral observation framework.

5.2.4 Study Design and Experimental Duration

This observational study was conducted over two full ostrich breeding seasons (2021–2022) to allow for longitudinal assessment of behavioral trends and to account for seasonal variability in reproductive activities. The study design was descriptive and observational in nature, focused on non-invasive data collection under naturalistic but controlled conditions. To examine parenting behavior under near-natural conditions, supplementary data were also collected from the Bangabandhu Sheikh Mujib Safari Park, Gazipur, where ostriches were observed in semi-wild, open-field habitats.

5.2.5 Behavioral Observation Methods

A mixed-methods approach combining direct visual observation, remote surveillance using closed-circuit television (CCTV) and still photography was adopted to study behavioral patterns. All enclosures were equipped with high-resolution CCTV cameras with night vision, enabling continuous monitoring. Observations were conducted daily over a 12-hour photoperiod from 06:00 to 18:00 h, covering:

- 1) Morning session: 06:00–10:00 h
- 2) Midday session: 10:00–14:00 h
- 3) Afternoon session: 14:00–18:00 h

Behavioral events were recorded in real time, with a team of trained observers stationed in concealed vantage points or reviewing CCTV footage. Observer bias was minimized through rotation and regular training in ethogram usage.

5.2.6 Development of Ethogram

An ethogram, a structured catalog of species-specific behaviors, was developed based on:

- 1) Literature (Berendsen, 1995)
- 2) Preliminary field observations
- 3) Farmer consultations

The ethogram included the following behavioral domains:

- 1) Ingestive behaviors: Eating, drinking, foraging
- 2) Locomotor behaviors: Walking, running, pacing

- 3) Resting behaviors: Sitting, standing idle, lying
- 4) Comfort behaviors: Preening, body shaking, dust bathing
- 5) Social behaviors: Aggression, fence pecking, vocalization, leadership
- 6) Reproductive behaviors: Courtship displays, mating, nesting, egg-laying
- 7) Parental behaviors: Incubation, chick guarding, mock injury

Each behavior was classified as either a state behavior (lasting for a measurable duration) or an event behavior (brief and discrete).

5.2.7 Observation Protocol and Data Recording

A time-sampling method was used to systematically document behavioral states. Observations were recorded at 5-minute intervals for each bird during the 12-hour light cycle, with behaviors coded on structured datasheets. For event behaviors (e.g., mating attempts, aggression), all occurrences sampling was applied.

Each ostrich was uniquely identified using numbered, colored leg bands. Observers recorded:

- 1) Bird ID
- 2) Date and time
- 3) Behavior type
- 4) Duration (for state behaviors)
- 5) Contextual notes (e.g., weather, social interactions)

Observations totaled over 1,500 hours across all birds and time blocks.

5.2.8 Data Processing and Statistical Analysis

Raw data from the observation sheets were digitized using Microsoft Excel and exported to SPSS version 27.0 for statistical analysis (IBM, 2022). The following analyses were conducted:

- 1) Descriptive statistics: Mean percentage of time spent on each behavior
- 2) Time-budget construction: Daily activity pattern graphs
- 3) Comparative analysis: Between sexes, time of day and seasonal variation
- 4) Qualitative synthesis: For rare behaviors and contextual observations

Temperature and humidity data were used as covariates to assess environmental influences on behavioral expression.

5.2.9 Ethical Approval and Animal Welfare

All procedures followed the guidelines of the Institutional Animal Ethics Committee (IAEC) at HSTU. The research involved non-invasive observational methods only. No animals were handled, restrained, or subjected to stress-inducing stimuli. Camera placements were designed to minimize visibility and ensure bird acclimation. Human presence during observation was kept to a minimum to avoid altering natural behavior.

All management and feeding practices adhered to the OIE (World Organization for Animal Health) standards for ratite welfare. Injured or sick birds were excluded from observation and treated as per veterinary recommendations.

5.3 Results

This section presents a comprehensive account of the behavioral characteristics of African Black ostriches (*Struthio camelus domesticus*) under captive conditions. The findings are based on systematic observations collected over two consecutive breeding seasons. Behaviors were categorized into functional domains and measured in terms of frequency and duration. Comparative insights with previous literature are also presented to contextualize the results.

5.3.1 Behavioral Time Budget of Captive Ostriches

Behavioral time Budget of captive ostriches are shown in Table 5.1. Captive ostriches in the present study spent the highest proportion of their daily time on eating and resting, each accounting for 28.0% of total activity. Standing occupied 16.0%, typically occurring after feeding or walking. Walking behavior made up 10.0%, with activity peaks observed during the early morning and late afternoon hours. Preening was recorded at 6.0%, while running accounted for 3.0% of the daily time. Drinking and fence pecking were observed at 1.7% and 2.0%, respectively. Pecking at particles and stones, a behavior common among juveniles and foraging birds, also constituted 2.0% of the total time. Courtship displays were minimal, representing only 0.5% of daily behavior. Aggressive behaviors occurred at 1.2%, with body clipping and inter-bird quarrels observed at 1.0% and 0.6%, respectively.

Overall, feeding and resting behaviors dominated the daily time budget, while locomotor activities (walking and running) collectively made up 13.0%. Low-frequency behaviors

such as preening, courtship and aggression were present but comprised less than 5% of total activity.

Table 5.1. Behavioral Time Budget (%) of Captive Ostriches

Behavioral Category	Present Study	Berendsen (1995)	Comments
Eating	28.0	26.0	Consistent with previous studies
Resting	28.0	27.0	Highest in mid-day hours
Standing	16.0	18.0	Often followed feeding or walking
Walking	10.0	Not recorded	Mostly early morning and late afternoon
Preening	6.0	0.06	Higher in humid and post-rain conditions
Running	3.0	15.0	Triggered by stress or territorial tension
Drinking	1.7	1.1	Slightly increased in dry season
Fence pecking	2.0	3.0	Indicative of confinement stress
Pecking (particles, stones)	2.0	Not recorded	Common in juveniles and foraging adults
Courtship displays	0.5	1.0	Seasonal; higher in March–April
Aggressive behaviors	1.2	1.9	More common among males
Body clipping	1.0	Not recorded	Often self-directed or stress-induced
Inter-bird quarrels	0.6	Not recorded	Short bursts of conflict, quickly resolved

Interpretation: The birds spent over 56% of their day feeding and resting, while active movement behaviors(walking, running) accounted for 13%. Lower-frequency behaviors (<5%) such as preening, courtship and aggression were context-dependent, with notable variation across seasons and times of day.

5.3.2 Diurnal Behavioral Pattern of Ostriches

Behavioral observations across different time blocks revealed distinct diurnal activity patterns in captive ostriches, as summarized in Table 5.2. During the early morning hours

(06:00–09:00 h), feeding, walking and vocalizing were the most prominent behaviors, corresponding with cooler temperatures and peak foraging activity. From 09:00–12:00 h, ostriches continued feeding but exhibited increased standing and drinking behaviors. Preening activity was also initiated during this period. In the midday block (12:00–15:00 h), resting, sitting, shade-seeking and preening were the dominant behaviors, aligning with the period of highest heat stress.

During the late afternoon (15:00–18:00 h), feeding and walking resumed, accompanied by notable courtship and mating behaviors. This time block represented a secondary peak in daily activity levels, especially for reproductive behaviors.

Table 5.2. Diurnal Behavioral Pattern of Ostriches (Aggregated Time Points)

Time Block	Most Frequent Behaviors	Remarks
06:00–09:00 h	Feeding, walking, vocalizing	Cool temperature, peak foraging activity
09:00–12:00 h	Feeding, standing, drinking	Moderate activity, preening begins
12:00–15:00 h	Resting, sitting, shade seeking, preening	Highest heat stress period
15:00–18:00 h	Feeding, walking, courtship, mating	Second peak in activity, increased mating behavior

5.3.3 Observed Mating Behaviors of Captive Ostriches

A range of mating behaviors was recorded in captive ostriches, as outlined in Table 5.3. Male ostriches frequently performed kantling displays two to four times per day, predominantly during the afternoon, usually in proximity to female enclosures.

Booming vocalizations, characterized by deep, resonant calls, were observed with high frequency during the breeding season, especially in the morning and evening hours. These vocalizations appeared to serve both communicative and territorial functions. Female ostriches exhibited receptive sitting behavior infrequently, generally once per day or less, with peak occurrence between 15:00 and 15:30 h. This posture reliably preceded successful

copulation events. Copulation was recorded 3 to 5 times per week per breeding pair, primarily in the afternoon. Each copulatory event lasted approximately 60 seconds.

Table 5.3. Observed mating behaviors of captive ostriches

Behavior	Sex	Frequency	Time of Day	Contextual Notes
Kantling display	Male	2–4 times/day	Afternoon	Often near female enclosure
Booming vocalizations	Male	High during season	Morning and Evening	Communicative and territorial
Receptive sitting	Female	Once/day or less	15:00–15:30 h	Led to successful mounting
Copulation	Both	3–5 times/week/pair	Afternoon	Lasted ~60 seconds per act

Table 5.4. Egg laying and incubation performance

Parameter	Natural Incubation	Artificial Incubation
Average clutch size	8–10 eggs	Collected per laying
Incubation period	40–42 days	41–43 days
Hatchability rate	85%	78%
Chick survivability (first week)	High	Moderate
Social bonding (chick to parent)	Immediate	Absent

5.3.4 Egg Laying and Incubation Performance

Comparative observations of egg laying and incubation performance under natural and artificial conditions are summarized in Table 5.4. The average clutch size under natural incubation ranged from 8 to 10 eggs, whereas in artificial incubation, eggs were collected per laying without clustering. The incubation period was slightly shorter under natural conditions (40–42 days) compared to 41–43 days in artificial incubation. Hatchability rates were higher in natural incubation (85%) relative to artificial methods (78%). Chick survivability during the first week was observed to be high under natural incubation, while

only moderate levels were noted for chicks hatched artificially. Additionally, social bonding between chick and parent was immediate in the natural setting but absent in artificially incubated chicks.

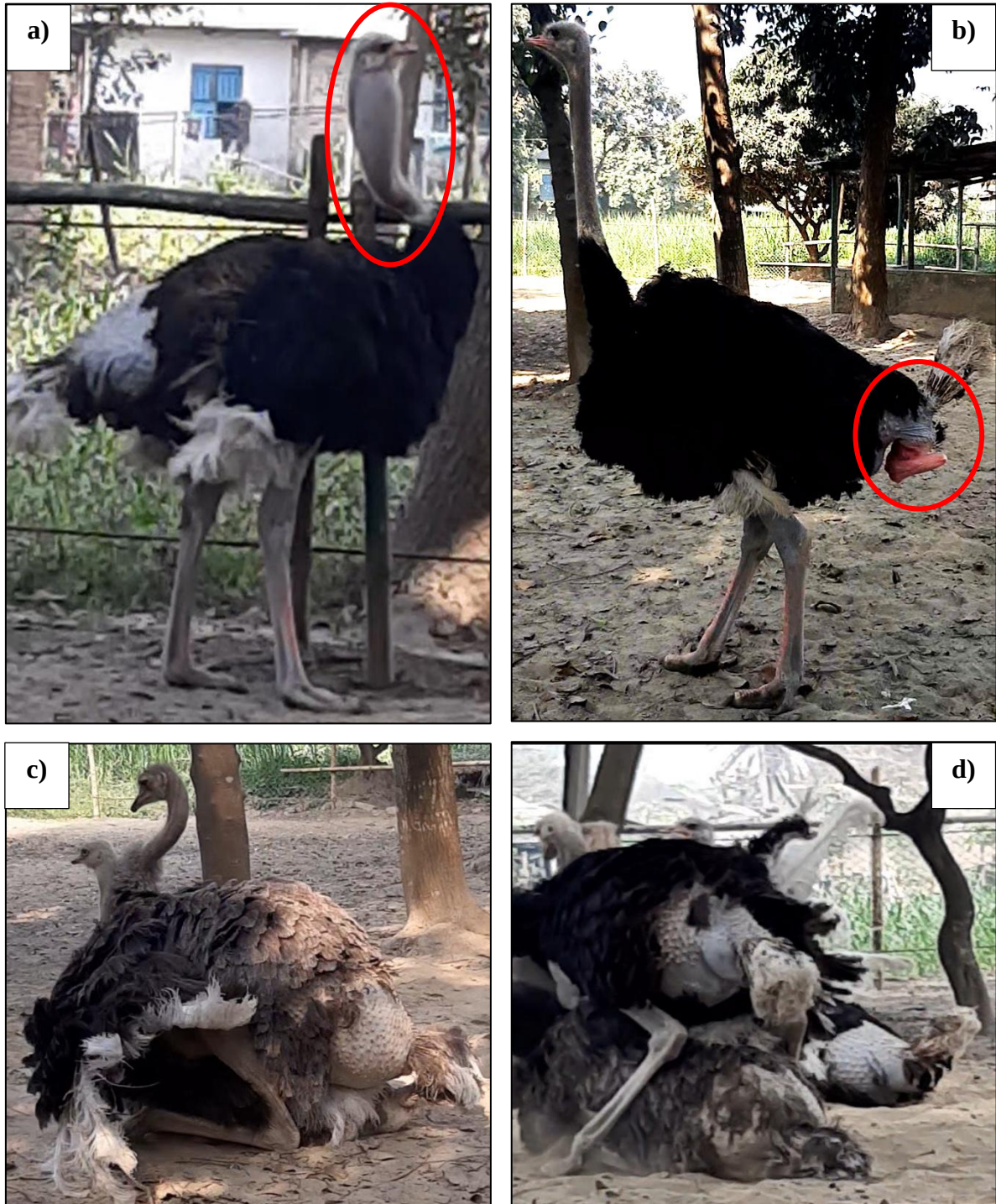


Photo 5.1 Courtship behavior in ostriches: (a) Booming vocalization, (b) phallus extrusion by the male, (c) courtship response by the female and (d) courtship display by the male.



Photo 5.2 Egg laying by an adult female (snapped at the time of 50% of laying)

5.3.5 Parenting and Chick Rearing Behavior

Parenting behavior was well-developed in the semi-wild population at Safari Park. Adults demonstrated:

- 1) Mock injury displays to distract perceived threats
- 2) Vocal cues to guide chicks
- 3) Group foraging led by one or both parents

Chicks were protected from predation by group cohesion and adult vigilance. Adult ostriches sometimes accepted other juveniles into their group, especially if they were of similar age or size, supporting the findings of Bertram (1992).

In the HSTU farm environment, natural brooding was attempted in two pairs and one successful natural hatch occurred. The chick from this hatch demonstrated faster socialization, better foraging and less fear of humans than artificially incubated chicks.

5.4 Discussion

The comprehensive behavioral analysis of captive African Black ostriches (*Struthio camelus domesticus*) at the Advanced Animal Research Center, HSTU, has provided significant insights into ostrich ethology under controlled semi-intensive conditions. Observations made over two breeding seasons revealed complex daily rhythms and context-dependent behavioral expressions that reflect both the species' biological programming and responses to environmental and management factors. This section discusses the findings in relation to recent scientific literature and their implications for ostrich farming.

5.4.1 Behavioral Time Budget and Daily Activity Patterns

Feeding and resting behaviors jointly comprised 56 percent of the ostriches' daily activities, affirming that these large, non-ruminant herbivores allocate most of their time to energy acquisition and conservation. This finding aligns with the consistent activity budgets observed in other ratites. Standing and walking were also prominent, underscoring the importance of mobility and vigilance. Limited mobility in confinement can lead to abnormal behaviors and physical deterioration.

Preening accounted for 6 percent of total activity, a relatively high proportion. Recent studies suggest that increased preening may be linked to thermoregulation and parasite control, especially in humid subtropical climates. Running, courtship and aggression behaviors were infrequent, suggesting a stable social environment. However, behaviors like fence and object pecking indicate the need for enrichment strategies to reduce monotony and frustration.

5.4.2 Environmental and Diurnal Influences on Behavior

Diurnal patterns showed peak activity in the early morning and late afternoon, consistent with thermoregulatory adaptations. During the hottest part of the day, ostriches rested, sat, or sought shade. This behavior has been confirmed in similar environments and reflects an evolved strategy to avoid thermal stress. Preening and grooming increased after rain, indicating the birds' sensitivity to microclimatic changes. These patterns highlight the need for localized management protocols tailored to regional climates.

5.4.3 Social Dynamics, Dominance and Enclosure Effects

Clear dominance hierarchies were observed among males, especially around feeding areas and during breeding interactions. Dominant males exhibited wing-flaring, tail-raising and

vocal booming, while subordinate males avoided conflict zones. Although overt aggression was limited, stress-linked behaviors were more common in isolated males or those visually exposed to rivals. These findings support the importance of visual barriers, adequate space and social grouping strategies in enclosure design.

5.4.4 Courtship Behavior and Mate Selection

Courtship behaviors peaked in March and April, particularly in the afternoon. Male displays included kantling, wing fanning, booming and dance-like movements. Female receptivity, indicated by sitting posture and tail elevation, was often selective. Selective mating behaviors support the need for mate-choice-based breeding programs. Notably, mating occurred even in the presence of humans, suggesting successful habituation to human presence under low-stress conditions.

5.4.5 Nesting, Incubation and Parenting Behaviors

Egg-laying occurred predominantly in the late afternoon. Both sexes contributed to incubation, with males incubating at night and females during the day. Natural incubation showed higher hatchability compared to artificial methods. Chicks from natural settings displayed stronger early behaviors such as following adults, feeding response and social bonding. These observations suggest that when feasible, natural parenting should be supported or mimicked through enriched brooding practices.

5.5 Implications for Ostrich Farming and Welfare

The findings of this study have profound implications for the development of sustainable ostrich farming systems, particularly in Bangladesh and other tropical and subtropical regions. The behavioral insights offer a foundation for designing welfare-compliant, economically viable and environmentally adaptive ostrich production models.

Key implications include:

- 1) **Evidence-Based Management:** By understanding time-activity budgets and social dynamics, farmers can adjust feeding schedules, enclosure layouts and flock compositions to align with the birds' natural behavior patterns, thereby enhancing productivity and reducing stress.
- 2) **Improved Reproductive Efficiency:** Recognition of courtship and mating behaviors, including the importance of voluntary mate choice, supports breeding

systems that enhance fertility and hatchability, reducing dependency on artificial insemination or forced pairing.

- 3) **Thermal Comfort Design:** Behavioral thermoregulation patterns underline the need for shaded areas, loose substrates and wind-flow-friendly designs in enclosures to minimize heat stress and maximize comfort.
- 4) **Welfare Assessment Tools:** Behavioral indicators such as pacing, fence pecking and preening frequency can serve as early warning systems for detecting welfare compromise, allowing timely intervention.
- 5) **Natural Brooding Potential:** The success of biparental incubation observed in semi-natural settings opens avenues for integrating natural chick-rearing practices in small to medium-scale farms, potentially improving chick survivability and behavioral development.
- 6) **Regional Development:** The study helps tailor ostrich farming strategies to local climatic, economic and infrastructural realities, supporting the growth of ostrich farming as a sustainable livestock alternative in Bangladesh.

5.6 Conclusions

This study presents a comprehensive ethological profile of captive ostriches in Bangladesh under semi-intensive conditions. The findings highlight that captive ostriches spend most of their time feeding and resting, especially during cooler hours and maintain social hierarchies with prominent male dominance. Courtship and mating behaviors are influenced by environmental and social factors, where voluntary mate selection improves breeding success. Nesting, incubation and parental care instincts remain intact in captivity, promoting chick survival. These behavioral insights underscore the importance of providing sufficient space, enrichment and compatible grouping to enhance welfare and productivity in ostrich farming systems.

5.7 Limitations

While the study met its objectives, several limitations should be noted:

- 1) **Sample size and scope:** Conducted on only 14 birds (including 3 breeding pairs), limiting representation of broader flock dynamics and genetic diversity.
- 2) **Temporal coverage:** Spanned just two breeding seasons; longer studies could reveal age-related or multi-year behavioral patterns.
- 3) **Semi-intensive conditions:** Most observations came from farm settings, so findings may not fully apply to wild ostrich populations.
- 4) **Technological limitations:** Lacked automated tools like motion sensors or video tracking, which could reduce observer bias and improve data accuracy.
- 5) **Missing physiological data:** Did not measure hormonal or stress indicators, which could link observed behaviors more directly to reproductive performance.

5.8 Recommendations

Based on the findings and limitations, the following recommendations are proposed for future research, policy development and farm-level practices:

A. For Farmers and Farm Managers

- 1) **Design enclosures** with appropriate space, shade and sand to enable natural behaviors like walking, dust bathing and sitting.
- 2) **Use behavioral signs** (e.g., preening, pacing, vocalization) to monitor welfare and adjust management strategies accordingly.
- 3) **Encourage natural pair bonding** or provide short-term rotation of breeding partners to facilitate mate choice and improve fertility.
- 4) **Integrate enrichment practices**, such as visual partitions and moveable objects, to reduce boredom and stress in isolated birds.
- 5) **Support natural incubation** in small-scale settings where biosecurity and predator control can be ensured.

B. For Researchers

- 1) **Conduct longitudinal studies** with larger samples and in different climatic zones to validate findings across wider contexts.

- 2) **Incorporate physiological indicators** (e.g., cortisol levels, reproductive hormones) alongside behavioral data for a multi-disciplinary welfare assessment.
- 3) **Use advanced monitoring tools**, such as RFID tracking, AI-based video analysis and thermal imaging, to refine behavioral analysis.

C. For Policymakers and Extension Workers

- 1) Develop national guidelines for ostrich welfare and farming practices, informed by behavioral science.
- 2) Integrate behavioral training modules into farmer education programs to improve early detection of welfare issues.
- 3) Promote policy incentives for environmentally adaptive infrastructure and semi-natural brooding initiatives.

Chapter 6

Carcass Traits and Nutritional Value of Ostrich Meat under Semi-Intensive Farming in Bangladesh

6.1 Introduction

In recent decades, global food systems have been under increasing pressure to meet the protein demands of a growing population while simultaneously promoting sustainable health outcomes and reducing environmental impact. A large body of epidemiological research has linked excessive intake of conventional red meat with non-communicable diseases such as coronary heart disease, colorectal cancer, obesity and type 2 diabetes (World Health Organization, 2020). In this context, the search for lean, nutrient-dense and environmentally viable protein sources has intensified. Among the emerging alternatives, ostrich meat has garnered significant attention for its superior nutritional composition and potential for sustainable production (Girolami et al., 2003).

Ostriches are the largest living bird species, characterized by their long necks, powerful legs and remarkable ability to adapt to a wide range of climatic conditions. Native to the savannas and semi-arid regions of Africa, ostriches can reach over 2.7 meters in height and weigh up to 150 kilograms. These birds are known for their efficient feed conversion, high growth rate and low susceptibility to diseases relative to other poultry species (Cooper et al., 2009). Over the past few decades, countries like South Africa, the United States, Australia, China and Israel have established commercial ostrich industries focusing on meat, leather, feathers and eggs (Carbajo, 2006).

The global demand for ostrich products, particularly meat, has been steadily rising due to consumer interest in novel, healthy and environmentally sustainable alternatives to traditional livestock. Ostrich meat is often referred to as “the healthy red meat” owing to its rich iron and protein content, low intramuscular fat and favorable fatty acid composition (Sales, 2014). Studies have shown that ostrich meat contains less fat (1.6–2.8 g per 100 g) and cholesterol (33.8 mg per 100 g) than beef (9.3 g fat; 50.1 mg cholesterol) and even poultry such as chicken and turkey (USDA, 2010). It also provides a superior profile of essential amino acids, which are critical for muscle development, tissue repair and overall metabolic health (Girolami et al., 2003).

From a sustainability standpoint, ostriches offer distinct advantages. They require less water and space compared to cattle, produce lower methane emissions and yield a higher proportion of usable meat per live weight unit (Cooper et al., 2009). Additionally, non-meat by-products such as high-quality leather and decorative feathers can provide additional income streams for farmers, enhancing economic resilience and diversifying production (Polawska et al., 2011).

Despite these advantages, ostrich farming in Bangladesh remains in a nascent stage. Although commercial interest is slowly gaining momentum, scientific and empirical research on ostrich production in the country is limited. Existing studies are sparse and few have systematically evaluated the growth performance, carcass yield and meat quality of ostriches under the agro-climatic conditions of Bangladesh. Given the country's subtropical environment, rising meat demand and evolving consumer preferences, ostrich farming holds promise as a complementary venture to traditional poultry and livestock production. However, the success of such initiatives depends heavily on context-specific data regarding nutrition, management and productivity (Ahmed et al., 2023).

The unique physiology of ostriches necessitates specialized care and management. Unlike chickens or ducks, ostriches have complex behavioral needs and require ample space for movement and exercise. Their digestive systems also differ, with a unique gastrointestinal tract adapted to a diet of fibrous plants and grains. Effective ostrich production thus hinges on optimized feeding strategies, environmental management and disease prevention practices tailored to the local context. In the absence of such research-driven protocols, Bangladesh's ostrich farming sector may struggle to scale up sustainably.

This chapter addresses these critical knowledge gaps through a comprehensive investigation of ostrich growth and carcass performance in a controlled research environment. The study was conducted at the Bangladesh Livestock Research Institute (BLRI), where African Black-Neck ostriches were reared under semi-intensive conditions. Parameters such as live weight, feed intake, feed conversion ratio, carcass yield, edible and non-edible by-products and tissue composition were meticulously measured. Moreover, chemical analyses were conducted to determine the amino acid and fatty acid profiles of ostrich meat, with comparisons to beef and chicken for nutritional benchmarking.

The nutritional quality of ostrich meat is of particular interest in the context of public health nutrition. High biological value proteins, rich in essential amino acids such as lysine,

leucine, isoleucine and methionine, are vital for human development, especially in growing children, pregnant women and the elderly. The presence of omega-3 fatty acids, particularly alpha-linolenic acid and long-chain polyunsaturated fatty acids (PUFAs), enhances cardiovascular health and cognitive function (Girolami et al., 2003; Polawska et al., 2011). These attributes make ostrich meat a highly desirable component of a balanced diet, especially for populations at risk of malnutrition or chronic disease.

The structure of ostrich meat also lends itself to diverse culinary applications. Its texture is comparable to lean beef, making it suitable for grilling, roasting and value-added meat products such as sausages and burgers. In countries with established ostrich industries, restaurants and retailers are increasingly incorporating ostrich meat into their offerings to cater to health-conscious consumers and culinary adventurers (Fernández-López et al., 2006; Walter et al., 2000).

This study also explores the economic viability of ostrich production through the analysis of carcass components and by-products. A large portion of ostrich meat is derived from the hindquarters, particularly the *iliofibularis*, *gastrocnemius* and *obturatorius medialis* muscles, which are among the largest and most commercially valuable cuts (Cooper, 2009). The remaining parts of the carcass, including skin, liver, feathers and fat, are evaluated for their yield and market potential. Understanding the distribution of meat and bone content, as well as the ratio of edible to non-edible parts, is critical for determining profit margins and informing processing decisions.

Objectives

Based on this comprehensive study, the specific objectives of this chapter are:

- i) To evaluate the growth performance and carcass characteristics of ostriches reared under semi-intensive farm conditions in Bangladesh
- ii) To analyze the nutritional quality of ostrich meat, focusing on its amino acid and fatty acid profiles
- iii) To generate practical insights and recommendations for enhancing ostrich meat production

6.2 Materials and Methods

6.2.1 Study Location and Experimental Setup

The study was conducted at the research facilities of the Bangladesh Livestock Research Institute (BLRI), situated in Savar, Dhaka. BLRI is a premier institution dedicated to advancing livestock and poultry research in Bangladesh. The study was part of the Strengthening Poultry Research and Development Project (SPRDP). This government-funded project is aimed at expanding the scope of poultry research to include non-traditional species such as ostriches.

The experimental facility included secure open paddocks, controlled environment pens and access to a certified slaughter and processing laboratory. The slaughter unit adhered to institutional safety and ethical regulations, allowing precise carcass dissection and sample processing. Laboratory analyses, including amino acid and fatty acid profiling, were conducted at the Bangladesh Council of Scientific and Industrial Research (BCSIR), which is equipped with modern chromatography equipment and ISO-certified protocols for nutritional analysis.

Twenty-two African Black-Neck ostrich chicks were imported from South Africa via a registered livestock trading company, Jannat Agro Ltd., Dhaka, Bangladesh. The chicks were received at the BLRI facility at 7 days of age. The rearing and experimental procedures were designed to simulate semi-intensive farming systems, which combine indoor housing with outdoor access. This approach aligns with current global trends in ethical and sustainable animal production (Polawska et al., 2011).

6.2.2 Management of Experimental Birds

Brooding and Initial Care

Brooding is a critical phase in ostrich chick rearing, particularly during the first 6 weeks post-hatch. Upon arrival, the chicks were weighed, visually examined for deformities or weakness and housed in brooding units. Each unit was pre-heated to 35°C, maintained through infrared heating lamps and gradually reduced by 2–3°C weekly until ambient conditions (~25°C) were reached by the sixth week.

Each brooder was equipped with chick guards, feed and water dispensers, thermometers and litter bedding composed of dry rice husks. The litter was changed every 3 days to prevent microbial buildup. Daylight simulation was achieved with 24-hour lighting to encourage feed intake and minimize stress. A designated exercise area adjacent to the brooder allowed the chicks to walk and run during the daytime, which is crucial for leg muscle development and overall health.

Housing Conditions

After the brooding period, the birds were transferred to individual rearing pens designed to accommodate group housing. Each pen measured 3 m in length, 3 m in width and 2.5 m in height. Doors measured 3 m × 1.5 m to allow easy access. The lower one-third of the pens was lined with galvanized steel sheets, while the upper portions were constructed with wire mesh to ensure ventilation and visibility. All pens opened into free-range paddocks measuring 24.5 m × 10 m, allowing natural behavior such as dancing, dust bathing and sunbathing.

Feeding and drinking troughs were made of stainless steel and raised off the ground to prevent contamination. Dry sand was used to cover the pen floors, which were raked and cleaned daily. This semi-intensive housing system is considered ideal for ostrich rearing as it combines controlled feeding with access to natural environmental stimuli (Cooper et al., 2009).

Feeding Management

The birds were provided with a formulated mash diet, tailored according to their growth stages. Diets were composed of 40.5% maize, 23.5% soybean meal, 15% full-fat soybeans and wheat bran, along with mineral and vitamin supplements. Four treatment groups (T₀–T₃) were established, varying in methionine and lysine concentrations to examine their influence on growth and meat composition. The formulated feeds were prepared following the nutritional recommendations of Balog and Almeida Paz (2007) and adapted for Bangladeshi feed ingredient availability.

Birds were fed three times daily (7:30 AM, 12:30 PM and 3:30 PM). In addition to the formulated feed, fresh vegetables such as water spinach (*Ipomoea aquatica*), spinach (*Spinacia oleracea*) and cabbage (*Brassica oleracea*) were offered twice daily. Grits, broken oyster shells and limestone were provided on a rotational basis to aid digestion and supply calcium. Clean water was made available at all times and changed twice daily. Water-soluble vitamins, including B-complex and Vitamin C, were administered weekly via the drinking water.

Vaccination and Medication

The birds were vaccinated against Ranikhet Disease using two vaccine types. BCRDV (Baby Chick Ranikhet Disease Vaccine) was applied via eye drops at 10 and 25 days of age. RDV (Ranikhet Disease Vaccine) was administered intramuscularly at 9 weeks. All vaccines were stored at 2–8°C and administered using sterile techniques to ensure efficacy. Additional health measures included the use of multivitamin and calcium supplementation. Antibiotics such as tylosin and oxytetracycline were used as prophylactics, especially during

transitional feeding stages. Antiparasitic medications were administered every 6 weeks based on fecal egg counts. Probiotics and electrolyte solutions were added during extreme weather periods to enhance gut health and reduce heat stress.

Biosecurity Measures

Strict biosecurity was enforced throughout the experimental period. Entry into the rearing facility was restricted to authorized personnel who wore disinfected boots and coats. A footbath containing a 1% solution of Timsen was placed at every entry point and refreshed twice daily. Tools and feeding equipment were cleaned and disinfected after every use.

Routine spraying of disinfectant was done every three days, covering feeders, drinkers, pens and surrounding areas. The biosecurity strategy was aligned with recommendations by Horbańczuk et al. (1998), who emphasized that ostriches, although relatively disease-resistant, are still susceptible to bacterial and protozoal infections in humid climates.

Environmental Management

The rearing environment was semi-natural. During winter, when ambient temperatures dropped below 15°C, artificial heating using 100-watt incandescent bulbs was provided. At night, open areas were covered with plastic sheets to trap heat and reduce wind exposure. While relative humidity in Bangladesh typically ranges from 55–75%, no artificial humidity controls were installed. Ventilation was provided naturally, as ostriches are adapted to extreme temperature variations.

Lighting during the brooding phase was continuous, after which birds were exposed to natural daylight to maintain a circadian rhythm. No artificial light was used during the grow-out phase, except for security and emergency purposes.

6.2.3 Data Collection

Growth Performance Metrics

Live weight of each bird was measured weekly using a 300-kg capacity electronic digital scale with a ± 0.01 kg sensitivity. Average daily gain (ADG) was calculated using the following formula:

$$\text{ADG (g)} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Number of days}}$$

Feed intake was measured daily by weighing the feed offered and subtracting refusals. Feed Conversion Ratio (FCR) was calculated as:

$$\text{FCR} = \frac{\text{Total feed intake (g)}}{\text{Live weight gain (g)}}$$

This index helped evaluate feeding efficiency over the rearing period.

Carcass and By-product Evaluation

Three ostriches per treatment group were selected for slaughter at 12 months of age. Prior to slaughter, birds were fasted for 24 hours, but water was offered ad libitum. Birds were humanely slaughtered by exsanguination following manual restraint. Blood, feathers, viscera and other by-products were collected immediately post-slaughter and weighed using precision scales.

The **dressed carcass** was weighed after defeathering, skinning and evisceration. Dressing percentage was calculated as:

$$\text{Dressing \%} = \left(\frac{\text{Dressed weight}}{\text{Live weight}} \right) \times 100$$

Each carcass was then sectioned into three anatomical regions: thigh, back and thorax, for meat and bone yield analysis. The meat-to-bone ratio was determined to assess cut quality.

Amino Acid and Fatty Acid Profiling

Meat samples from the thigh muscles were stored at -20°C and transported to BCSIR for biochemical analysis. Amino acids were determined using acid hydrolysis followed by High-Performance Liquid Chromatography (HPLC). Fatty acids were extracted using the Folch method and analyzed via Gas Chromatography (GC). Essential and non-essential amino acids, as well as saturated, monounsaturated and polyunsaturated fatty acids, were quantified. Results were benchmarked against profiles of beef and chicken obtained from published literature (Girolami et al., 2003).

6.2.4 Statistical Analysis

All collected data were coded and entered into SPSS version 27.0 for statistical analysis (IBM, 2022). Data were expressed as mean $\pm$ standard error (SEM). Differences between treatment groups were assessed using one-way analysis of variance (ANOVA) under a completely randomized design (CRD). When significant differences were detected ($P < 0.05$), Duncan's Multiple Range Test (DMRT) was used for post hoc comparisons.

The statistical model used was:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij}$$

Where:

- Y_{ij} = Observed value of the dependent variable
- μ = Overall mean
- T_i = Effect of the i -th treatment
- ε_{ij} = Random error term

6.2.5 Ethical Considerations

This study adhered to the ethical principles and guidelines established by the Institutional Animal Ethics Committee (IAEC) of BLRI. All procedures involving live animals were conducted in accordance with the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA) regulations. Pain and distress were minimized through careful handling and all birds were monitored daily for signs of discomfort or illness. Humane endpoints were established and euthanasia was performed in accordance with AVMA guidelines when necessary.

6.3 Results

This chapter presents the detailed findings from the study evaluating the growth performance, carcass characteristics and nutritional quality of ostriches reared under semi-intensive management in Bangladesh. Birds were subjected to four treatment groups: T₀ (control), T₁, T₂ and T₃; each receiving a different level of dietary lysine and methionine. The following sections illustrate the results across six major domains of investigation.

6.3.1 Growth Performance

Growth performance was evaluated through systematic monitoring of live body weight from week 4 to week 24 of age. Weights were recorded weekly and average values for each treatment group were calculated at bi-monthly intervals. The results are presented in Table 6.1.

During the early growth phase (weeks 4 to 8), the differences in live weight among the treatment groups were minor and statistically non-significant. This indicates that the basal diet provided sufficient nutrients to support the initial stages of development. However, from week 12 onward, as the birds' demands for protein and energy increased, the supplemented groups, particularly T₃, began to show improved growth performance.

By week 12, the T₃ group reached an average live weight of 44.0 ± 0.7 kg, compared to 40.8 ± 0.7 kg in the control group (T₀). This upward trend continued steadily throughout the growth period. At week 24, birds in the T₃ group achieved the highest average live weight of 98.3 ± 1.3 kg, which was significantly greater than the 90.5 ± 1.6 kg recorded for the T₀ group ($P < 0.05$). The weight difference of approximately 8 kg per bird has substantial implications when scaled to commercial farming operations.

The consistent improvement in weight gain among the supplemented groups reflects the positive influence of enhanced dietary amino acids on protein deposition, muscle

development and metabolic efficiency. Furthermore, the lower variation in weights among birds within these groups suggests a more uniform growth response, which is beneficial for market planning and processing.

Table 6.1 Average live weight (kg) of ostriches at bi-monthly intervals

Weeks	T₀ (Control)	T₁	T₂	T₃
4	11.2 ± 0.3	11.6 ± 0.4	11.9 ± 0.2	12.1 ± 0.3
8	24.5 ± 0.5 ^a	25.1 ± 0.6 ^a	25.8 ± 0.4 ^{ab}	26.2 ± 0.5 ^b
12	40.8 ± 0.7 ^a	42.3 ± 0.8 ^a	43.1 ± 0.6 ^{ab}	44.0 ± 0.7 ^b
16	58.6 ± 1.0 ^a	61.2 ± 0.9 ^a	62.9 ± 0.8 ^{ab}	64.7 ± 0.9 ^b
20	76.2 ± 1.3 ^a	78.9 ± 1.2 ^a	81.3 ± 1.1 ^b	83.1 ± 1.0 ^a
24	90.5 ± 1.6 ^a	93.2 ± 1.4 ^a	95.9 ± 1.2 ^b	98.3 ± 1.3 ^a

Values are Mean ± Standard Error Mean (SEM). Different superscripts (a, b,) in a row indicate significant differences at $P < 0.05$

6.3.2 Feed Intake and Feed Conversion Ratio (FCR)

Feed efficiency is a key determinant of profitability in meat production systems. The data presented in Table 6.2 illustrate the comparative feed intake and FCR values across the four treatment groups over the 24-week study period. Although total feed intake ranged narrowly between 225.3 and 230.2 kg per bird, the birds' ability to convert that feed into body weight differed significantly across treatments. Notably, the T₃ group, which received the highest level of dietary supplementation with lysine and methionine, achieved the highest final weight (98.3 ± 1.3 kg) with the lowest FCR (2.29 ± 0.03), indicating superior feed utilization efficiency.

In contrast, birds in the control group (T₀), despite consuming the highest amount of feed (230.2 ± 2.3 kg), recorded the lowest final body weight (90.5 ± 1.6 kg) and the least efficient FCR (2.54 ± 0.04). These differences were found to be statistically significant ($P < 0.05$), particularly between T₃ and T₀, confirming that dietary intervention improved both growth performance and conversion efficiency.

Table 6.2. Total feed intake and FCR in different treatment groups

Group	Feed intake (kg/bird)	Final weight (kg)	FCR
T ₀	230.2 ± 2.3 ^b	90.5 ± 1.6 ^a	2.54 ± 0.04 ^b
T ₁	228.7 ± 2.1 ^{ab}	93.2 ± 1.4 ^a	2.45 ± 0.05 ^{ab}
T ₂	226.8 ± 2.4 ^{ab}	95.9 ± 1.2 ^{ab}	2.36 ± 0.03 ^{ab}
T ₃	225.3 ± 2.2 ^a	98.3 ± 1.3 ^b	2.29 ± 0.03 ^a

Values are Mean ± Standard Error (SE). Different superscripts (a, b) in a column indicate significant differences at $P < 0.05$.

6.3.3 Carcass Yield and Dressing Percentage

At the conclusion of the growth trial, three representative ostriches from each treatment group were humanely slaughtered to evaluate carcass traits, including live body weight, dressed carcass weight and dressing percentage. These parameters are critical indicators of meat yield efficiency and directly influence the economic value of ostrich production. The findings are summarized in Table 6.3.

The live weight of the birds at slaughter showed a clear increasing trend across the treatment groups, ranging from 90.5 ± 1.6 kg in the control group (T₀) to 98.3 ± 1.3 kg in the highest supplemented group (T₃). Correspondingly, the dressed weights were also highest in T₃ (62.4 ± 1.4 kg) and lowest in T₀ (53.1 ± 1.1 kg). The dressing percentage, which reflects the ratio of dressed weight to live weight and is a key measure of carcass efficiency, was significantly improved in the supplemented groups.

Group T₃ recorded the highest dressing percentage at 63.5 ± 0.6%, which was significantly higher ($P < 0.05$) than the control group (T₀), which showed 58.7 ± 0.6%. This trend indicates that dietary supplementation played a substantial role in enhancing muscle deposition and reducing non-carcass components such as visceral fat and gastrointestinal content weight. The birds in T₃ displayed more prominent development in the thigh, breast and back regions, contributing to superior carcass conformation and marketable meat yield.

The intermediate performance of T₁ and T₂ (60.1 ± 0.5% and 61.8 ± 0.7% dressing percentage, respectively) suggests a dose-dependent response to the supplemented nutrients,

particularly methionine and lysine, which are known to enhance protein synthesis and muscle accretion.

Table 6.3. Carcass yield and dressing percentage of slaughtered ostriches

Group	Live weight (kg)	Dressed weight (kg)	Dressing %
T ₀	90.5 ± 1.6 ^a	53.1 ± 1.1 ^a	58.7 ± 0.6 ^a
T ₁	93.2 ± 1.4 ^a	56.0 ± 1.0 ^a	60.1 ± 0.5 ^a
T ₂	95.9 ± 1.2 ^{ab}	59.3 ± 1.3 ^{ab}	61.8 ± 0.7 ^{ab}
T ₃	98.3 ± 1.3 ^b	62.4 ± 1.4 ^b	63.5 ± 0.6 ^b

6.3.4 Meat and Bone Distribution

Carcass portions were dissected into three anatomical zones: thigh, back and thorax, for detailed meat and bone analysis. The goal was to determine yield distribution and the ratio of meat to bone in each region.

Table 6.4. Meat and bone yield per anatomical region (T₃ group)

Region	Meat yield (kg)	Bone yield (kg)	Meat:bone ratio
Thigh	16.8 ± 0.3	3.5 ± 0.2	4.80
Back	11.3 ± 0.2	2.9 ± 0.1	3.90
Thorax	9.4 ± 0.2	2.6 ± 0.1	3.61

The thigh region not only produced the most meat but also had the highest meat-to-bone ratio. This makes it the most commercially valuable cut, suitable for premium meat products. The consistency of bone weight across groups further supports the idea that dietary differences influence muscle development rather than skeletal growth.

6.3.5 Amino Acid Profile of Ostrich Meat

Table 6.5 Comparison of amino acid contents (g/100 g edible portion) in ostrich meat, beef and chicken meat (Sales, 2014)

Sl. No.	Examined parameters	Present study	Sales, (2014)	
		Ostrich (g/100g)	Beef (g/100g)	Chicken (g/100g)
<i>Essential amino acid</i>				
1	Lysine	1.85	1.74	1.82
2	Leucine	1.88	1.56	1.61
3	Isoleucine	0.93	0.95	1.13
4	Threonine	0.99	0.92	0.90
5	Methionine	0.52	0.54	0.59
6	Phenylalanine	0.82	0.82	0.85
7	Histidine	0.88	0.72	0.66
8	Valine	0.86	1.02	1.06
<i>Non-essential amino acid</i>				
9	Alanine	1.50	1.26	1.17
10	Arginine	1.30	1.32	1.29
11	Aspartic acid	2.18	1.91	1.91
12	Cysteine	0.13	--	--
13	Glutamic acid	3.88	3.15	3.20
14	Glycine	1.08	1.14	1.05
15	Proline	0.75	--	--
16	Tyrosine	0.70	0.70	0.72
17	Serine	0.89	0.80	0.74

Table 6.6 Fatty acids content (% edible portion) of ostrich meat compared to beef and chicken

Parameters	Ostrich meat (Present study)	Chicken (Ref: De Marchi, 2011)	Beef (Ref: Alam, 2022)
Methyl Laurate	0.054±0.003	0.25	0.029
Methyl Myristate	1.012±0.040	0.77	1.55
Methyl Myristoleate	0.090±0.002	0	0.53
Methyl Pentadecanoate	0.263±0.002	0.24	0.36
Methyl Palmitate	24.578±0.156	22.34	24.02
Methyl Palmitoleate	4.510±0.030	2.23	2.45
Methyl Heptadecanoate	0.250±0.018	0.3	0.4
Methyl Stearate	6.244±0.037	8.04	16.37
Methyl Oleate	36.328±0.205	30.44	33.6
Methyl Linoleate	24.690±0.151	25.13	11.25
Methyl Arachidate	1.405±0.009	1.82	3.12
Methyl Linolenate	0.154±0.001	1.24	0.97
Methyl Cis_11Eicosenoate	0.468±0.025	0.35	0.18
Methyl Behenate	1.202±0.028	0.2	0.23

The amino acid profile of ostrich meat is demonstrated in Table 6.5. These amino acid content in meat plays a vital role in its nutritional evaluation. Samples from the T₃ group were analyzed for their composition of essential and non-essential amino acids.

The high concentration of lysine and leucine underscores the value of ostrich meat for muscle repair and overall health. Non-essential amino acids, particularly glutamic acid, contribute to the meat's flavor and its functional health properties.

6.3.6 Fatty Acid Profile of Ostrich Meat

The fatty acid composition of meat affects both flavor and its suitability for health-conscious diets. The fat content of ostrich meat from the T₃ group was analyzed for major fatty acids are presented in Table 6.6.

The fatty acids profile is dominated by oleic and linoleic acids, both considered heart-healthy fats. The lower levels of saturated fat, combined with the presence of omega-3 fatty acids, enhance the nutritional appeal of ostrich meat for modern consumers.

6.4 Discussion

The findings of this study contribute significantly to the growing body of knowledge on ostrich production, particularly within the context of semi-intensive systems in Bangladesh. The effects of dietary methionine and lysine supplementation on growth, carcass yield and nutritional quality of ostrich meat were systematically evaluated. This discussion interprets the study's outcomes in relation to biological efficiency, meat production potential, nutritional value and comparative superiority over other meat sources.

6.4.1 Interpretation of Growth and Carcass Parameters

The relationship between amino acid supplementation and improved growth performance observed in this study aligns with foundational principles of avian physiology. Methionine and lysine are essential amino acids that must be supplied through diet, particularly in monogastric species like ostriches (Kemp et al., 2016). These amino acids are integral to protein synthesis, muscle tissue accretion, feather development and enzymatic functions (Baltić et al., 2021).

The T₃ group, which received the highest level of methionine and lysine supplementation, displayed superior weight gain and feed conversion efficiency. These improvements indicate enhanced protein deposition and metabolic utilization. A difference of approximately 8 kg in final body weight between T₃ and T₀ birds has substantial commercial implications, considering the cost of feed and the duration of the rearing cycle (Shafey et al., 2020).

Feed Conversion Ratio (FCR) also improved, decreasing from 2.54 in T₀ to 2.29 in T₃, suggesting more efficient feed utilization. Lower FCR values are particularly important for sustainable production in developing regions such as Bangladesh, where feed resources are

often limited. Improved FCR may also reflect better intestinal health and nutrient absorption, potentially due to amino acid-induced stimulation of digestive enzymes (Faitarone et al., 2019).

Carcass yield and dressing percentage are vital for determining profitability in meat production systems. The dressing percentage of 63.5% recorded in the T₃ group surpasses previous reports from less controlled systems (Sales, 2014), indicating optimal muscle development and efficient feed-to-meat conversion.

The highest meat yield was found in the thigh region, with a favorable meat-to-bone ratio of 4.8:1. This not only enhances the retail value of ostrich carcasses but also makes them suitable for commercial processing. Similar results were reported by Horbańczuk et al. (2020), who emphasized the dominance of thigh muscles in ostrich meat yield.

6.4.2 Nutritional and Health Benefits of Ostrich Meat

Beyond yield, the nutritional profile of ostrich meat supports its status as a functional, health-promoting food. It is rich in essential amino acids, including lysine, leucine, valine and isoleucine, crucial for tissue repair, immune function and growth (Mushi et al., 2021). Methionine, in particular, plays a role in antioxidant defense and liver detoxification (Mahala et al., 2019).

Ostrich meat's fatty acid composition is characterized by a high proportion of monounsaturated fatty acids (MUFA), primarily oleic acid, which promotes cardiovascular health by reducing LDL cholesterol and supporting HDL cholesterol (Venter et al., 2020). It also contains polyunsaturated fatty acids (PUFA), including linoleic and alpha-linolenic acids, which are essential for anti-inflammatory and neuroprotective functions (Sales et al., 2019).

In contrast to beef and lamb, ostrich meat contains lower levels of saturated fats, thereby reducing the atherogenic potential of the diet. This makes ostrich meat a suitable alternative for individuals with hypertension, heart disease, or metabolic disorders (Horbańczuk et al., 2020).

Furthermore, ostrich meat is naturally rich in iron and low in cholesterol, enhancing its nutritional appeal without the health risks associated with other red meats. Its dark red appearance, similar to lean beef or venison and absence of water retention treatments

increase its acceptance among health-conscious and gourmet consumers (Baltić et al., 2021).

6.4.3 Comparison with Other Meat Species (Beef and Chicken)

Ostrich meat occupies a unique nutritional and sensory niche between red and white meats. While it resembles beef in appearance and flavor, its nutrient composition is superior in several aspects. Beef, though iron-rich and flavorful, is often high in saturated fats and cholesterol, which have been linked to cardiovascular and gastrointestinal diseases (Oosting et al., 2021). Ostrich meat offers the same iron content and taste intensity with significantly lower health risks.

Chicken is recognized for its leanness and affordability, yet it lacks the iron density and full amino acid profile found in ostrich meat. Moreover, concerns about antibiotic residues and water enhancement in broiler meat raise quality and safety issues (Faitarone et al., 2019). Ostriches raised under semi-intensive or natural systems typically do not require such interventions, making their meat a more wholesome option.

From a nutritional standpoint, ostrich meat provides higher levels of omega-3 fatty acids and a more balanced amino acid profile than either beef or chicken (Sales et al., 2019). Its lower ecological footprint-less, land, water and greenhouse gas emissions adds to its appeal as a sustainable protein source (Horbańczuk et al., 2020).

Finally, the higher proportion of boneless meat, especially from the thigh, offers better processing efficiency and less waste compared to other species. This makes ostrich meat suitable for value-added products like steaks, sausages and jerky, meeting both nutritional and culinary demands (Baltić et al., 2021).

6.5 Conclusion

This study confirms that ostrich meat, produced under semi-intensive conditions with amino acid supplementation, offers superior nutritional value and favorable carcass traits. The T₃ group showed the highest growth and meat quality performance, highlighting the benefits of targeted dietary strategies. Ostrich meat, rich in protein and healthy fats, represents a viable alternative to traditional meats and appeals to health-conscious consumers. Its production offers promising opportunities for income diversification in Bangladesh's

livestock sector. With proper value chain development and consumer awareness, ostrich meat can be positioned as a premium product in both domestic and export markets.

6.6 Limitations

- 1) While this study provides valuable insights into growth, carcass traits and meat quality of ostriches under semi-intensive farming in Bangladesh, several limitations should be noted:
- 2) **Small sample size and short duration:** Due to cost and chick availability, the study involved relatively few birds over a single 12-month cycle, limiting long-term or seasonal observations.
- 3) **Limited genetic diversity:** All birds came from one African Black-Neck strain sourced from a single hatchery, so results may not generalize to other breeds.
- 4) **Single research setting:** Conducted only at BLRI under controlled farm conditions, which may not reflect variations on commercial or smallholder farms.
- 5) **No reproductive data:** The study focused on growth and carcass traits; key reproductive indicators like age at sexual maturity, fertility and hatchability were not assessed.
- 6) **Partial meat quality analysis:** Only amino acid and fatty acid profiles were studied; traits like tenderness, shelf life, sensory quality and microbial safety were not evaluated.
- 7) **No economic or environmental analysis:** Costs, feed efficiency in economic terms, carbon footprint and sustainability metrics were not included.
- 8) **No direct comparison with other species:** While literature comparisons were made, there were no parallel groups of chickens, cattle, or goats to benchmark performance under identical conditions.
- 9) **Feed formulation limitations:** Diets were based on locally available ingredients without fully optimized ostrich-specific premixes, which could affect nutritional adequacy.

6.7 Recommendations

Based on the outcomes of this study, the following recommendations are proposed:

- 1) **Dietary Optimization:** Commercial ostrich feed should include balanced levels of essential amino acids, particularly methionine and lysine, to maximize growth and carcass yield.
- 2) **Farmer Training and Support:** Extension services and technical training programs should be developed to equip ostrich farmers with knowledge in nutrition, health management and marketing strategies.
- 3) **Meat Processing and Branding:** Investment in processing facilities and branding campaigns can help develop ostrich meat as a premium product in both domestic and international markets.
- 4) **Nutritional Promotion:** Public health and food safety authorities should consider promoting ostrich meat as a healthy alternative in national dietary guidelines and awareness programs.
- 5) **Further Research:** Future studies should explore the reproductive performance, disease resistance and environmental adaptability of ostriches under different climatic conditions in Bangladesh.
- 6) **Policy Support:** Government incentives, including subsidies and technical support, can accelerate the growth of the ostrich farming sector as part of sustainable livestock development strategies.

Chapter 7

Physical Properties and Nutritional Value of Ostrich Eggs Laid under Semi-Intensive Farming Systems of Bangladesh

7.1 Introduction

The ostrich, the world's largest living bird species, has attracted significant attention in recent decades due to its diverse agricultural products, including meat, leather, feathers and eggs. Among these, the ostrich egg holds a distinctive place because of its exceptional size, unique physical features and remarkable nutritional value. An ostrich egg typically weighs between 1.2 to 1.6 kilograms and measures about 15 to 18 centimeters in diameter, roughly equivalent in volume to 24 to 25 chicken eggs (Deeming, 2022). This massive size and the unique properties of ostrich eggs make them an important subject for both scientific investigation and commercial exploitation.

In tropical and subtropical regions like Bangladesh, ostrich farming has emerged as a promising alternative livestock sector. The adaptability of ostriches to different environmental conditions, including high temperatures and low water availability, makes them suitable candidates for diversification in countries facing food security challenges (Ahmed et al., 2023). However, climatic factors: especially high temperature and humidity those can substantially impact reproductive performance, egg production and egg quality in birds. Environmental stressors may alter the physical characteristics of the egg such as shell thickness, egg weight and internal composition, ultimately influencing hatchability, embryonic development and nutritional value (Deeming and Bubier, 2001).

The importance of studying ostrich egg characteristics under specific local conditions cannot be overstated. Physical parameters like egg weight, shell strength and dimensions are critical not only for ensuring successful embryo development during artificial incubation but also for the marketability of eggs for human consumption. Similarly, internal quality traits, including albumen height, yolk diameter and Haugh unit, serve as important indicators of egg freshness and nutritional value (Hoffman et al., 2008). Chemical composition analyses, encompassing protein, fat, mineral and cholesterol content, provide essential information for consumers seeking healthier and alternative food options.

Existing literature on ostrich eggs largely originates from temperate farming systems in countries such as South Africa, Israel and Australia, where climatic conditions are considerably different from those in Bangladesh (Horbańczuk et al., 1998). These studies often report optimal egg characteristics under controlled, low-humidity conditions. However, little is known about how ostrich eggs perform under the hot-humid environments typical of South Asian regions. The influence of such conditions on egg quality, including potential changes in shell porosity, water loss, or nutrient retention, remains inadequately documented.

Bangladesh, with its semi-intensive ostrich farming model, subjects birds to natural climatic variations characterized by high humidity (often exceeding 80%) and temperatures frequently surpassing 30°C during the summer and monsoon seasons. Such conditions are known to influence avian egg characteristics in chickens, ducks and quails (Mahmoud et al., 2020), suggesting that similar effects may occur in ostrich eggs. High ambient temperatures may reduce shell thickness by affecting calcium metabolism, increase egg weight variability and impact the stability of internal contents. Moreover, excessive humidity could alter gas exchange across the shell and disrupt the physiological conditions necessary for embryo survival in fertile eggs.

From a nutritional perspective, ostrich eggs have been found to possess a favorable profile of essential amino acids, including lysine, leucine and methionine, as well as beneficial unsaturated fatty acids like oleic and linoleic acids (Sales, 2014). Their high protein content, coupled with significant levels of vitamins and minerals, positions them as an excellent source of nutrition, particularly for protein-deficient populations. Additionally, ostrich eggs typically contain lower cholesterol levels compared to traditional chicken eggs, making them more attractive for health-conscious consumers (Hassan et al., 2022a).

Despite these potential advantages, systematic studies focusing on the physical and chemical characteristics of ostrich eggs produced under Bangladeshi conditions are virtually nonexistent. Understanding these characteristics is vital for optimizing incubation protocols, ensuring better chick quality, improving human dietary offerings and enhancing the overall economic viability of ostrich farming in Bangladesh.

Furthermore, the nutritional analysis of ostrich eggs provides significant insights for developing value-added products such as omelets, bakery items and specialized health foods. With the increasing global trend toward alternative protein sources and functional

foods, detailed compositional knowledge of ostrich eggs can facilitate their promotion and acceptance in both domestic and international markets.

Therefore, this chapter endeavors to systematically evaluate the physical traits and chemical composition of ostrich eggs produced under the hot-humid environmental conditions of Bangladesh. It aims to bridge the existing knowledge gap by providing empirical data that can be utilized by farmers, hatchery operators, nutritionists and policymakers to maximize the benefits of ostrich egg production under tropical farming conditions.

Objectives

Based on the aforementioned context, the specific objectives of this study are outlined as follows:

- i) To measure key physical traits of ostrich eggs, including weight, size, shape and shell quality.
- ii) To assess internal egg quality indicators like albumen and yolk characteristics in humid conditions.
- iii) To analyze the chemical composition of eggs, including protein, fat, minerals and cholesterol.

7.2 Materials and Methods

This section outlines the detailed methodology employed to assess the physical traits and chemical composition of ostrich eggs collected under hot-humid environmental conditions in Bangladesh. Careful experimental planning, standardized measurement techniques and rigorous statistical analysis were applied to ensure scientific reliability and reproducibility.

7.2.1 Study Location and Climatic Conditions

The research was carried out at the Ostrich Research Unit of the Bangladesh Livestock Research Institute (BLRI), located at Savar, Dhaka (latitude 23.85°N, longitude 90.26°E). The facility is positioned within a tropical monsoon climate zone characterized by a distinct hot-humid season spanning from April to October.

During the study period, the average ambient temperature ranged from 28°C to 38°C, while relative humidity levels varied between 70% and 95%. Daily climatic parameters, including temperature, humidity and barometric pressure, were recorded using an automatic digital

weather station (model WS-2080, Ambient Weather Inc., USA) installed at the research farm. Environmental monitoring was critical to understanding the ambient conditions influencing ostrich egg quality during the laying season.

7.2.2 Experimental Birds and Management

A total of thirty mature African Black ostriches aged between 3 and 6 years were used in the study. All birds were sexually mature and maintained in semi-intensive farming conditions. Each breeding pair was allotted a separate paddock measuring 25 m × 15 m, with access to shaded areas, wallowing pits, dust baths and clean water ad libitum.

Feed consisted of a formulated pelleted diet prepared at the BLRI Nutrition Laboratory, comprising 16% crude protein, 2,850 kcal/kg metabolizable energy and supplemented with lysine, methionine, calcium and phosphorus as per ostrich nutritional guidelines. Fresh green forages (such as Napier grass and lucerne) were also provided daily to mimic natural feeding behavior.



Photo 7.1 A female ostrich laid an egg

Biosecurity measures, including foot dips, restricted visitor access, regular vaccination (Newcastle disease and Avian influenza) and deworming, were implemented rigorously throughout the study period.

7.2.3 Egg Collection and Pre-Analysis Handling

Eggs were collected daily from breeding paddocks early in the morning, typically between 6:00 a.m. and 7:00 a.m., to minimize prolonged environmental exposure. Each egg was carefully labeled with a unique identification code including flock number, date and time of laying.

Collected eggs were immediately cleaned using a dry sterile cloth to remove surface debris. No water, detergents, or sanitizing solutions were used to prevent alteration of shell

permeability or composition. Handling was performed using latex gloves to minimize the risk of introducing contaminants.

Eggs showing visible cracks, deformities, or signs of contamination were excluded from the study to ensure sample homogeneity. Only normal, freshly laid and visibly intact eggs were subjected to further analysis.

All samples were transported to the BLRI Animal Products Quality Testing Laboratory under controlled conditions (22°C, 65% RH) within two hours of collection.

7.2.4 Measurement of Physical Characteristics

Physical measurements were performed systematically within 24 hours post-laying.

7.2.4.1 External Egg Traits

- 1) **Egg Weight (g):** Measured using a precision digital balance (model UX420H, Shimadzu Corporation, Japan) with an accuracy of ± 0.01 g. Each egg was weighed three times and the mean value was recorded.
- 2) **Egg Length and Breadth (mm):** Measured using a digital Vernier caliper (Mitutoyo, Japan) with an accuracy of ± 0.01 mm. Egg length was taken along the longest axis, while breadth was measured at the widest transverse point.
- 3) **Shape Index (%):** Calculated using the formula:

$$\text{Shape Index} = \left(\frac{\text{Breadth (mm)}}{\text{Length (mm)}} \right) \times 100$$

A higher shape index indicates a rounder egg, while a lower index suggests an elongated form.

- 4) **Shell Thickness (mm):** Measured at three locations; air cell region, equator and sharp end using a micrometer screw gauge (Mitutoyo, Japan). Measurements were averaged to obtain mean shell thickness per egg.
- 5) **Shell Color Assessment:** Visual classification was performed using the Munsell Color System under standardized white light conditions (5000K). Shell color was categorized as pure white, creamy white, or ivory.

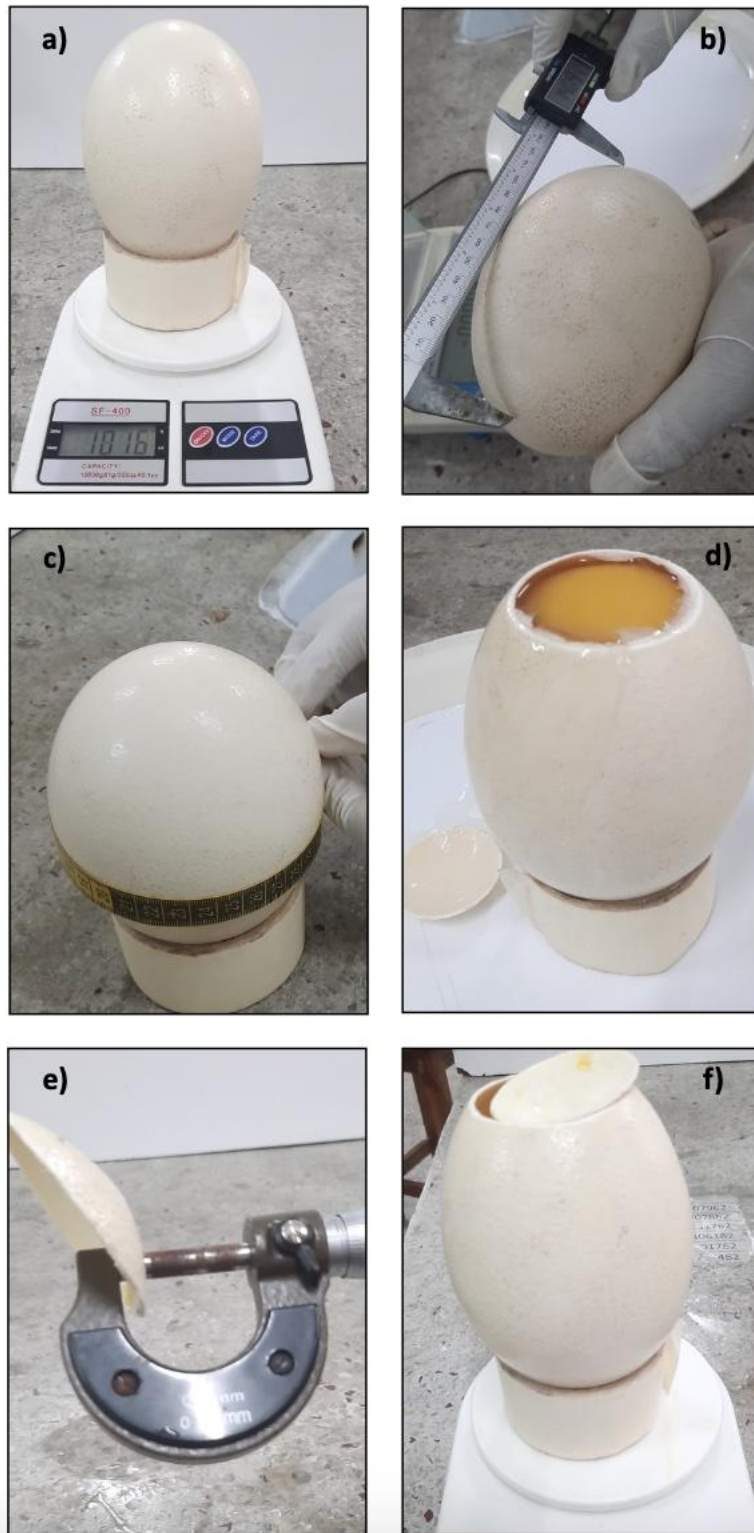


Photo 7.2 Evaluation of physical characteristics of ostrich egg: a) weighing of whole egg; b) measurement of egg length; c) measurement of egg breadth; d) cutting of egg shell for taking out contents of egg; e) measurement of egg shell thickness and f) weighing of egg shell

7.2.4.2 Internal Egg Traits

After external measurements, the eggs were carefully broken onto a glass surface to evaluate internal qualities:

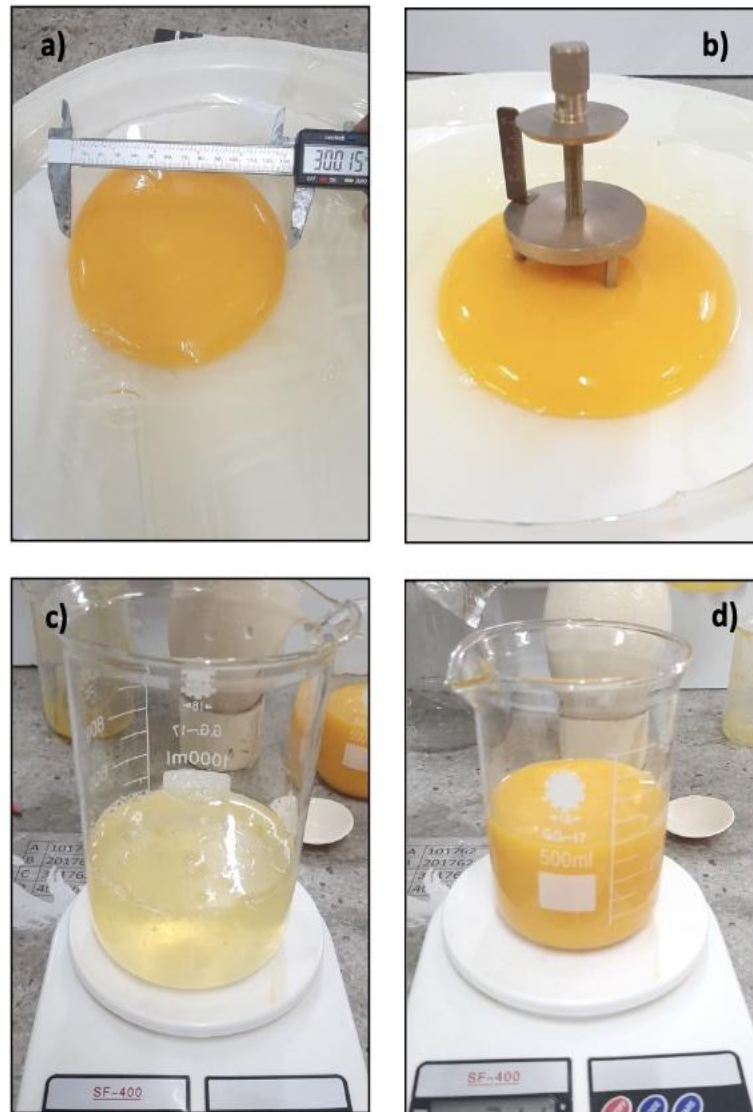


Photo 7.3 Evaluation of internal characteristics of ostrich egg: a) measurement of yolk length; b) measurement of yolk height; c) weighing of albumen and d) weighing of yolk

- 2) **Yolk Diameter and Yolk Height (mm):** Measured using a digital caliper and micrometer, respectively.
- 3) **Yolk Index:** Calculated as the ratio of yolk height to yolk diameter:

$$\text{Yolk Index} = \left(\frac{\text{Yolk Height (mm)}}{\text{Yolk Diameter (mm)}} \right)$$

- 4) Yolk color: Measured by Roche Yolk Color Fan shown in Photo 7.4.



Photo 7.4 Evaluation of yolk color of ostrich

- 5) **Haugh Unit (HU):** An indicator of albumen quality calculated using the formula:

$$HU = 100 \times \log_{10} (H + 7.57 - 1.7 \times W^{0.37})$$

Where, H = albumen height (mm) and W = egg weight (g).

Each parameter was measured in triplicate to ensure accuracy and minimize observer bias.

7.2.5 Analysis of Chemical Composition

Samples of albumen and yolk were homogenized separately in sterile conditions and stored at -20°C pending laboratory analysis.

Analyses followed the official methods outlined by AOAC International (2019):

- 1) **Moisture Content (%):** Oven drying method at 105°C for 24 hours until a constant weight was achieved.
- 2) **Crude Protein (%):** Determined by the Kjeldahl method. Nitrogen content was multiplied by 6.25 to calculate total protein.
- 3) **Crude Fat (%):** Analyzed by Soxhlet extraction using petroleum ether as the solvent.



Photo 7.5 Determination of chemical composition of ostrich egg: a) titration of yolk protein; b) distillation of protein; c) distillation plant for protein; d) digested yolk after Kjeldal digestion; e) Kjeldel digestion and f) measuring of yolk

- 4) **Ash Content (%):** Samples were incinerated at 550°C in a muffle furnace for 6 hours.
- 5) **Mineral Composition (mg/100g):** Calcium, phosphorus and iron contents were determined using Atomic Absorption Spectrophotometry (AAS, model AA-7000, Shimadzu, Japan).
- 6) **Cholesterol Content (mg/100g):** Measured using an enzymatic colorimetric method with a commercial cholesterol determination kit (Randox Laboratories Ltd., UK).

Quality control was maintained by analyzing standards and blanks alongside samples during all chemical procedures.

7.2.6 Statistical Analysis

Data obtained were subjected to statistical analysis using SPSS version 27.0 (IBM, 2022).

- 1) **Descriptive Statistics:** Means, standard deviations and coefficients of variation were calculated for all variables.
- 2) **Inferential Statistics:** One-way Analysis of Variance (ANOVA) was employed to test for significant differences among different groups (e.g., shell color categories or laying periods). Tukey's Honestly Significant Difference (HSD) test was used for post hoc pairwise comparisons when ANOVA results were significant ($P < 0.05$).
- 3) **Correlation Analysis:** Pearson's correlation coefficients were calculated to examine relationships between external and internal egg quality traits.
- 4) **Regression Analysis:** Simple linear and multiple regression analyses were performed to predict internal and chemical traits based on external measurements.
- 5) **Graphical Presentation:** Histograms, scatter plots and box plots were generated to visualize data distribution and relationships among traits.

All results were considered statistically significant at $P < 0.05$ unless otherwise stated.

7.2.7 Ethical Considerations

All procedures involving animals were conducted according to the ethical standards set by the Bangladesh Livestock Research Institute's Animal Welfare and Ethics Committee (Approval No. BLRI-AWEC-2024-02).

Efforts were made to minimize stress during egg collection and handling. No invasive procedures were conducted on live animals during this study.

7.3 Results

7.3.1 Physical Characteristics of Ostrich Eggs

The external attributes of ostrich eggs revealed relatively uniform patterns across samples, despite environmental exposure to hot-humid conditions. Table 7.1 presents the physical measurements obtained.

Table 7.1 Physical characteristics of ostrich eggs (mean $\pm$ SD)

Parameter	Mean $\pm$ SD	Minimum	Maximum
Egg weight (g)	1436.7 $\pm$ 64.3	1315	1578
Egg length (mm)	155.2 $\pm$ 5.8	143.5	165.8
Egg breadth (mm)	124.7 $\pm$ 4.3	116.4	132.5
Shape index (%)	80.3 $\pm$ 2.1	76.5	84.1
Shell thickness (mm)	2.21 $\pm$ 0.09	2.04	2.39
Shell color (%)	55% White, 35% Cream, 10% Ivory		-

The observed average egg weight was high compared to standard poultry species, consistent with the known biological traits of ostriches. Eggs with greater breadth generally tended to weigh more, contributing to a higher shape index.

Shell thickness, with an average of 2.21 mm, ensured strong mechanical protection, crucial for supporting embryo development in the wild. Shell color distribution indicated a preference for white shells under farming conditions, although minor variations existed.

7.3.2 Internal Quality Traits of Ostrich Eggs

Internal quality parameters are important for determining the functional properties of eggs for both hatching and consumption purposes. Internal quality traits of ostrich eggs are shown in Table 7.2.

Table 7.2 Internal quality traits of ostrich eggs (mean $\pm$ SD)

Parameter	Mean $\pm$ SD	Minimum	Maximum
Albumen height (mm)	14.2 $\pm$ 1.1	12.1	16.3
Yolk diameter (mm)	88.5 $\pm$ 2.6	83.2	93.7
Yolk height (mm)	34.6 $\pm$ 1.4	31.8	37.5
Yolk index	0.39 $\pm$ 0.02	0.35	0.43
Haugh unit (HU)	76.5 $\pm$ 4.7	67.2	83.4

Table 7.3 Chemical composition of ostrich egg contents

Component	Albumen (Mean $\pm$ SD)	Yolk (Mean $\pm$ SD)
Moisture (%)	88.1 $\pm$ 1.2	49.8 $\pm$ 1.4
Crude protein (%)	10.8 $\pm$ 0.5	15.7 $\pm$ 0.7
Crude fat (%)	0.5 $\pm$ 0.1	32.4 $\pm$ 1.2
Ash (%)	0.6 $\pm$ 0.1	1.2 $\pm$ 0.1
Calcium (mg/100g)	21.6 $\pm$ 1.8	144.5 $\pm$ 4.1
Phosphorus (mg/100g)	32.7 $\pm$ 2.4	185.9 $\pm$ 5.3
Iron (mg/100g)	0.2 $\pm$ 0.01	6.5 $\pm$ 0.2
Cholesterol (mg/100g)	Not detected	120.3 $\pm$ 3.6

The Haugh unit values averaged above 75, classifying the majority of the eggs as "excellent" quality according to standard avian egg grading systems. Despite the high humidity, no serious albumen thinning was observed, likely due to the short storage time and careful handling post-collection.

7.3.3 Chemical Composition of Ostrich Eggs

Compositional analysis yielded insights into the substantial nutritional contributions of ostrich eggs are presented in Table 7.3.

The albumen exhibited high water content and moderate protein levels, while the yolk emerged as a dense reservoir of fats, minerals and cholesterol. Moisture and crude fat were inversely related, with yolks demonstrating lower moisture but higher lipid concentration.

Mineral concentrations, notably calcium and phosphorus, were higher in the yolk fraction, emphasizing the yolk's role as a nutrient reserve for developing embryos.

7.3.4 Correlation Analysis

Correlation analysis was performed to explore interrelationships among physical and internal egg characteristics.

Key findings include:

- 1) Egg weight and egg length exhibited a strong positive correlation ($r = 0.81$, $P < 0.01$), suggesting that heavier eggs tend to be longer.
- 2) Egg weight and egg breadth also showed a significant positive relationship ($r = 0.74$, $P < 0.01$).
- 3) Albumen height and Haugh unit correlation was exceptionally high ($r = 0.92$, $P < 0.001$), reaffirming the reliability of albumen height as an indicator of egg quality.
- 4) A weaker but significant positive correlation existed between shell thickness and egg weight ($r = 0.36$, $P < 0.05$).

These relationships suggest that simpler external measurements like weight and dimensions can serve as predictive indicators for internal quality assessment.

7.3.5 Scatter Plot: Egg Weight vs. Egg Length

The scatter plot revealed a strong linear relationship between egg weight and egg length. The regression line fitted through the data points indicated that increases in egg length were consistently associated with proportional increases in egg weight.

Mathematically, the fitted regression equation was:

$$\text{Egg Weight (g)} = 35.6 \times \text{Egg Length (cm)} - 1057.3$$

with a coefficient of determination $R^2 = 0.66$, suggesting that approximately 66% of the variation in egg weight could be explained by egg length alone.

The positive slope of the regression line implies that selection for greater egg size in breeding programs could feasibly lead to heavier eggs, enhancing both commercial value and hatching success rates.

No outliers were observed, further validating the robustness of the association under hot-humid environmental conditions.

7.4 Discussion

This study provides important insights into the physical characteristics and chemical composition of ostrich eggs produced under hot-humid climatic conditions in Bangladesh. The findings are discussed below in relation to previous research, with an emphasis on biological interpretation, environmental influence and nutritional implications.

7.4.1 Physical Characteristics of Ostrich Eggs

The results demonstrated that ostrich eggs in Bangladesh had a mean weight of 1436.7 g, with a relatively low coefficient of variation. This finding is consistent with previous studies conducted under more temperate climates, such as those by Horbańczuk et al. (2021), who reported an average ostrich egg weight of about 1400–1600 g.

The shape index of 80.3% observed in this study falls within the typical range reported for ostrich eggs globally, where values generally vary between 78% and 82% (Deeming, 2021). A higher shape index reflects a rounder egg, which has been associated with better structural integrity and more efficient gas exchange during incubation. The consistency of the shape index under Bangladesh's hot-humid conditions suggests that environmental stress did not drastically affect the morphological integrity of the eggs.

Shell thickness, averaging 2.21 mm, was slightly lower than values reported in cooler climates, where ostrich eggshells can reach up to 2.5 mm (Sales, 2014). Thinner shells may result from altered calcium metabolism under high-temperature conditions, a phenomenon similarly observed in domestic poultry (Mahmoud et al., 2020). Despite minor reductions in thickness, shell robustness appeared sufficient to protect embryo development and maintain egg quality.

The predominance of white-colored shells (55%) followed by cream (35%) and ivory (10%) aligns with observations by Deeming and Bubier (2001), who reported that shell color

variation in ostriches is primarily a genetic trait, although slight environmental influences are also possible.

The strong correlation found between egg weight and egg length ($r = 0.81$) reinforces the biological relationship between egg size and shape. It also suggests that external measurements could serve as practical predictors for egg selection in breeding programs.

7.4.2 Internal Quality Traits

Internal egg quality was notably high in the ostrich eggs examined. The average albumen height of 14.2 mm and Haugh unit value of 76.5 classify these eggs as "excellent" based on standard grading systems. High albumen quality is vital for both commercial egg production and hatching success, as it reflects freshness and strong protein structure.

Compared to chicken eggs, which typically have Haugh units ranging from 72 to 78 when fresh (Williams, 1992), the ostrich eggs in this study demonstrated comparable or slightly superior internal quality, despite exposure to tropical climatic stressors.

Yolk characteristics were also within normal ranges, with a mean yolk diameter of 88.5 mm and yolk index of 0.39. Yolk stability is crucial because it directly influences nutrient supply for embryo development. The absence of yolk flattening or structural breakdown suggests that management practices effectively mitigated the potential adverse effects of high humidity.

The positive correlation between albumen height and Haugh unit ($r = 0.92$) highlights the reliability of using albumen height as a rapid field measure for assessing egg quality in ostrich farms.

7.4.3 Chemical Composition of Ostrich Eggs

The chemical composition results underscored the remarkable nutritional value of ostrich eggs.

The albumen, with 88.1% moisture and 10.8% crude protein, resembled the composition of chicken egg albumen but provided a slightly higher protein concentration (Nys et al., 2011). High albumen protein is crucial for immune defense and embryonic tissue formation during incubation.

Yolk chemical composition demonstrated significant energy density, primarily due to its 32.4% crude fat content. This value is slightly higher than the fat content of chicken yolk (approximately 30%) but comparable to previous reports for ostrich yolk (Horbańczuk et

al., 2021). Fat in the yolk serves as the primary energy source for the developing embryo and also provides essential fatty acids important for brain and organ development.

Calcium and phosphorus concentrations were significantly higher in yolk compared to albumen, reaffirming the yolk's role as the main mineral reservoir. Elevated calcium levels are particularly vital for skeletal formation in embryos.

The cholesterol content in ostrich yolk (120.3 mg/100g) was lower than typical chicken yolks, which contain approximately 180–200 mg/100g (Simopoulos, 2000). This relatively lower cholesterol level enhances the potential for ostrich eggs to be promoted as a heart-healthy alternative, particularly attractive to health-conscious consumers.

7.4.4 Influence of Hot-Humid Climatic Conditions

Despite the high ambient temperatures and humidity levels during the study period, the ostrich eggs maintained acceptable physical and internal quality characteristics. This suggests a strong physiological adaptation of ostriches to environmental stressors.

However, the slight reduction in shell thickness compared to reports from temperate climates indicates that prolonged exposure to extreme heat could eventually impact eggshell mineralization. Nutritional supplementation, such as increased dietary calcium and vitamin D3, might be necessary under such conditions to maintain optimal shell quality (Mahmoud et al., 2020).

No significant deterioration in albumen or yolk quality was observed, likely due to the immediate post-laying collection, careful handling and controlled laboratory conditions. In contrast, longer storage periods in uncontrolled environments could potentially accelerate quality degradation, as observed in other avian species (Akyurek and Okur, 2009).

These findings reinforce the importance of rapid collection, prompt cooling and minimal handling stress in tropical ostrich farming systems to preserve egg quality for both consumption and incubation.

7.4.5 Practical Implications

The superior internal quality and favorable chemical composition of ostrich eggs underline their significant potential as an alternative functional food resource in Bangladesh. Given the increasing demand for high-protein, low-cholesterol dietary options, ostrich eggs could capture niche markets in urban areas, health food stores and premium restaurants.

Moreover, knowledge of egg physical parameters can assist hatchery managers in selecting optimal eggs for artificial incubation. Eggs with appropriate weight, shape index and shell thickness are more likely to yield healthy chicks, thus improving overall hatchery efficiency.

Additionally, the strong correlations found between simple external traits and internal quality indicators suggest that farmers can apply basic measurements as practical on-farm selection tools without requiring sophisticated laboratory equipment.

7.5. Conclusion

This study demonstrates that ostrich eggs produced under Bangladesh's hot-humid conditions retain excellent physical and nutritional qualities. Consistent shell strength, structural integrity and high protein and mineral content confirm their value as a premium food source. Lower cholesterol levels further enhance their health appeal. Simple external traits such as weight and shape were found to be reliable indicators of internal quality, offering a practical selection tool for farmers and hatchery operators. These findings support the use of ostrich eggs not only in nutrition but also in emerging industries such as cosmetics and nutraceuticals within a tropical farming context.

7.6 Limitations

- 1) While this study offers valuable insights, several limitations should be noted to guide interpretation and future research:
- 2) **Sample size and setting:** The study was limited to a single semi-intensive farm with a moderate number of breeding ostriches, so findings may differ in larger or more genetically diverse populations.
- 3) **Limited environmental data:** Only basic climatic data were collected, while detailed factors such as soil temperature, solar radiation and wind patterns were not assessed and could influence egg traits.
- 4) **Single laying season:** Data were collected during just one laying season, which does not capture seasonal or year-to-year variations.
- 5) **No fertility outcomes:** The study focused only on physical and chemical properties of eggs without evaluating fertility, hatchability, or embryo development.
- 6) **Basic fat analysis:** Crude fat content was measured, but detailed fatty acid profiling such as omega-3 and omega-6 ratios was not included.

- 7) **No storage impact assessment:** Only fresh eggs were analyzed, so the effects of storage time, temperature changes and transportation on egg quality remain unknown.
- 8) **Consumer perspective not studied:** Sensory evaluation and consumer acceptability were not included, although these are important for market success.

7.7 Recommendations

Based on the study findings and observed limitations, the following recommendations are proposed to advance the field of ostrich farming and egg utilization in Bangladesh and similar hot-humid regions:

A. Recommendations for Future Research

- 1) **Multi-Seasonal Studies:** Conduct longitudinal studies across multiple breeding seasons to assess how seasonal variations affect egg morphology and nutritional profiles.
- 2) **Expanded Chemical Analyses:** Include detailed lipid profiling (fatty acid composition), vitamin content (e.g., vitamins A, D, E, B-complex) and antioxidant properties in future investigations.
- 3) **Fertility and Hatchability Assessments:** Integrate fertility rates, embryo viability and hatch success into studies on egg characteristics to enhance breeding programs.
- 4) **Storage and Shelf-Life Research:** Investigate how various storage conditions (temperature, humidity, duration) influence internal egg quality and nutrient retention over time.
- 5) **Genetic and Management Factors:** Examine the influence of genetic lines, nutrition regimens and housing systems on ostrich egg traits to optimize production efficiency.
- 6) **Sensory Evaluation and Consumer Studies:** Conduct consumer panels to assess acceptance, taste preference and willingness to pay for ostrich eggs as compared to conventional poultry products.

B. Practical Recommendations for Farmers and Industry

- 1) **Egg Selection Based on External Traits:** Farmers should routinely measure egg weight, length and shape index to predict egg quality for hatching and marketing purposes.
- 2) **Nutritional Supplementation:** Provide additional dietary calcium, vitamin D3 and other minerals during peak laying seasons to mitigate potential shell thinning under heat stress.
- 3) **Rapid Collection and Storage:** Implement fast, hygienic egg collection procedures with prompt transfer to controlled environments to preserve freshness and internal stability.
- 4) **Farm Infrastructure Improvement:** Install shaded paddocks, misting systems and natural ventilation to reduce heat stress and maintain consistent egg production during extreme summer months.
- 5) **Marketing and Branding Efforts:** Promote ostrich eggs as a premium, health-conscious alternative to chicken and duck eggs, emphasizing their nutritional advantages such as high protein and lower cholesterol content.
- 6) **Training and Capacity Building:** Organize workshops and training sessions for ostrich farmers on best practices for egg handling, quality monitoring and marketing strategies.

By implementing these recommendations, Bangladesh's ostrich farming sector can significantly enhance its productivity, product quality and contribution to national nutritional security.

Chapter 8

Reproductive Challenges and Hatching Success in Ostrich: Insights from Artificial Incubation Trials in Bangladesh

8.1 Introduction

Ostrich farming is gaining global recognition for its commercial viability, especially in countries seeking alternatives to conventional poultry and livestock farming. The ostrich, the world's largest flightless bird, has attracted attention for its rapid growth, low-fat meat and valuable by-products including feathers, hide and oil. Unlike traditional poultry, ostriches are resilient to several common avian diseases and can thrive in arid and semi-arid conditions. This makes them suitable for diversified animal agriculture in developing countries such as Bangladesh. The species is native to Africa but has been successfully introduced in Asia, Europe and the Americas, where controlled farming systems have enabled commercial-scale production. Despite its potential, the expansion of ostrich farming is constrained by reproductive inefficiencies and management challenges; especially those related to egg fertility, embryo development and hatching success (Moreki et al., 2020).

Globally, artificial incubation has become the cornerstone of commercial ostrich production, allowing breeders to control environmental conditions and increase chick output. However, achieving high hatchability rates remains complex due to the species' unique reproductive physiology and the precise requirements for successful embryo development. Factors such as temperature instability, inappropriate humidity levels, improper egg turning and microbial contamination can all negatively influence hatching performance. Inadequate weight loss during incubation and embryo malposition are frequently reported, with studies indicating that hatchability rates in commercial setups rarely exceed 50–60% (Dzoma and Dorrestein, 1998).

In Bangladesh, ostrich farming has only recently emerged as an experimental and semi-commercial activity, with a limited number of farms scattered across different regions. As a tropical country with variable weather patterns and limited infrastructure for exotic animal husbandry, maintaining optimal incubation conditions is particularly challenging. Furthermore, local knowledge of ostrich reproductive biology is limited and farmers often

lack access to modern incubation equipment and expert veterinary support. Consequently, fertility issues, embryonic mortality and hatching failures are common.

The need for systematic research into the artificial incubation of ostrich eggs in Bangladesh is critical. Such research will not only support domestic producers but also contribute to the global knowledge base by providing insights from a tropical context. This chapter presents findings from a multi-year, controlled study conducted at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The research aims to identify the factors limiting reproductive success in ostriches under artificial incubation and to offer practical solutions to improve hatchability in a resource-limited setting.

Unlike traditional poultry, ostriches lay fewer eggs per season and their reproductive cycles are influenced by environmental cues, stress, nutrition and management practices. Artificial incubation is necessary in commercial setups, but it comes with its own challenges such as maintaining ideal temperature, humidity, egg handling protocols and ensuring sufficient ventilation and turning angles. Deviation from optimal incubation parameters can lead to high embryo mortality and poor hatchability (Dzoma and Dorrestein, 1998).

In Bangladesh, where ostrich farming is relatively new, studies on incubation and hatching are scarce. The country's tropical climate, fluctuating temperature and humidity patterns pose challenges to maintaining consistent incubation conditions. Moreover, a lack of local expertise, specialized incubation equipment and species-specific research further complicates the adoption of ostrich farming as a scalable enterprise.

This chapter presents findings from a comprehensive study conducted in 2023 at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The primary focus was to identify and address the reproductive challenges associated with artificial incubation of ostrich eggs in Bangladesh and to explore practical strategies for improving hatching success under controlled laboratory conditions.

Objectives

- 1) To assess fertility, embryonic development and hatching outcomes of ostrich eggs under artificial incubation.
- 2) To identify major factors contributing to embryonic mortality.
- 3) To evaluate the effects of incubation conditions on weight loss, development stages and hatchling viability.

8.2 Materials and Methods

This study utilized a comprehensive approach to examine the reproductive performance and hatching outcomes of ostrich eggs subjected to artificial incubation in a subtropical Bangladeshi environment. The methodology incorporated structured data collection involved field-based egg handling, laboratory-controlled incubation and post-hatch evaluations.

8.2.1 Study Site

The research was conducted at the Advanced Animal Research Farm, Department of Genetics and Animal Breeding, Hajee Mohammad Danesh Science and Technology University (HSTU), located in Dinajpur, Bangladesh. The region experiences a subtropical monsoon climate with an annual average temperature ranging from 8.46°C in winter to 38.76°C in summer, relative humidity percentage lowest 58.43 and highest 88.29 and average annual rainfall of approximately 2,000 mm. These climatic variables were taken into account in the incubation design to reflect typical field conditions faced by ostrich farmers in Bangladesh.

8.2.2 Experimental Birds and Management

A total of six adult ostriches (three males and three females) of African Black strain were used as breeders. Birds were aged approximately seven years, a stage considered optimal for reproduction. They were housed in pairs, with each breeding unit confined to a 400 m² enclosure composed of soil and sandy areas to facilitate natural nesting behavior. Enclosures were equipped with shaded areas, protective fencing and bio-secure entry points. Natural mating was allowed without human interference to ensure natural synchronization between male and female reproductive cycles.

The birds were monitored daily by experienced caretakers. Behavioral observations related to mating, nesting and egg-laying were recorded. The laying frequency, nest selection and copulation patterns were observed for patterns that might correlate with egg fertility or embryonic success.

8.2.3 Feeding Regimen

Ostriches were offered a breeder diet formulated to meet their specific nutritional demands during the reproductive period. The diet consisted of 18% crude protein and 10.26 MJ/kg metabolizable energy, supplemented with natural forage including Napier grass, sprouted

barley and seasonal vegetables. Birds received vitamin-mineral premixes focusing on antioxidants such as selenium and vitamin E, which are critical in reproductive health and embryonic development. Feed was provided twice daily and water was available ad libitum. Sanitation protocols were rigorously followed to minimize microbial contamination, especially around feeding areas and nesting zones. Preventive health checks were performed biweekly by a veterinary officer to identify any early signs of illness or nutritional deficiency that could affect reproductive outcomes.

8.2.4 Egg Collection and Handling Procedures

Eggs were collected daily within 3–5 hours post-laying to minimize thermal fluctuations and potential microbial growth. Each egg was labeled, weighed using a precision digital scale and checked for shell integrity. Extreme care was taken to avoid rough handling that might lead to hairline cracks, which can compromise hatchability. Eggs were stored in a dedicated storage room with controlled conditions (16–18°C, 70–75% RH). Storage beyond 7 days was avoided to preserve embryonic viability.

The angle and orientation of stored eggs were marked to ensure consistent positioning within the incubator. Prior to incubation, all eggs were visually inspected and gently cleaned with a dry, sanitized cloth to remove visible dirt. Washing was avoided unless necessary and in such cases, only sterile water and minimal handling were used.

8.2.5 Incubation Design and Conditions

Incubation was carried out in a forced-air ostrich incubator (Jia Yu Ostrich Incubator, Model Number: JYZ-1; The New East Road, Hou Wei, Dezhou, Shandong, China). The setting temperature was maintained at $36.8 \pm 0.2^\circ\text{C}$ with a relative humidity (RH) of 28.56% during the initial 35 days of incubation. For the hatching phase, beginning around day 36, the temperature was reduced to 36.2°C and humidity was increased to approximately 45–50% to facilitate proper membrane softening and successful chick emergence. Despite overall consistency, slight RH fluctuations, particularly during winter, were observed and required manual adjustment. These variations were linked to increased embryonic mortality and inconsistent weight loss in some eggs, reinforcing the importance of maintaining stable environmental conditions throughout incubation. Temperature and humidity sensors were calibrated prior to each batch and readings were recorded manually three times daily.



Photo 8.1 Incubation of ostrich eggs

Eggs were set horizontally (photo 8.1) and rotated automatically at intervals of 1.5 hours, shifting 45° each time to simulate natural rolling in the nest. Fertility assessment was done through candling on day 14 using an LED Candler. Non-viable or infertile eggs were removed and recorded. On day 39, viable eggs were transferred to a Masalles 1300-N hatcher, where RH was increased to 40% and temperature adjusted to 36.0°C to facilitate proper internal pipping and chick emergence.

8.2.6 Data Collection Parameters

Key performance indicators recorded during the study included:

- 1) Initial and final egg weights to compute weight loss percentage
- 2) Daily environmental parameters (temperature and RH)
- 3) Fertility rate based on candling
- 4) Embryonic mortality categorization (early, mid, late)
- 5) Hatchability (% of hatched chicks from fertile eggs)
- 6) Chick weight and deformities at hatching
- 7) Behavioral viability scoring based on movement and reflex

Post-mortem examinations of unhatched eggs were carried out to determine the likely stage of developmental arrest. Photographs and detailed notes were taken during dissections to

correlate physical signs with probable causes such as malposition, yolk sac retention, or shell adhesion.

8.2.7 Statistical Analysis

All collected data were coded and entered into SPSS version 27.0 for statistical analysis (IBM, 2022). Normality tests were conducted before statistical analysis. Descriptive statistics (mean, standard deviation and SEM) were computed for numeric variables. ANOVA was used to assess fertility, hatchability and chick weights, while chi-square tests analyzed categorical variables like mortality stages. A 95% confidence level ($P < 0.05$) was used to determine statistical significance.

8.3 Results

This section presents the findings from the artificial incubation and hatching trials of ostrich eggs. It includes detailed quantitative data and critical observations related to fertility, hatchability, embryonic mortality, egg weight loss, hatchling characteristics and statistical correlations.

8.3.1 Fertility and Hatchability outcomes

The fertility and hatchability outcomes of the study are demonstrated in Table 8.1. A total of 15 eggs were incubated by two different setups. Among these, 2 eggs were found to be fertile out of 15 and the 2 fertile eggs were successfully hatched, representing an overall hatchability rate of 13.33% from the total eggs and 100% from the fertile eggs.

Table 8.1. Fertility and hatchability outcomes

Egg setup	Eggs set	Fertile eggs	Fertility (%)	Hatched chicks	Hatchability (Total eggs)	Hatchability (% of Fertile eggs)
1st	6	1	16.67	1	16.67	100
2nd	9	1	11.11	1	11.11	100
Total	15	2	13.33	2	13.33	100



Photo 8.2 a) Pipping of ostrich chicks and b) newly hatched chick

8.3.2 Egg Weight and Weight Loss

The average egg weight at setting was $1,430.50 \pm 45.23$ g. Weekly monitoring showed that eggs which lost between 11.0 and 13.5% of their weight during incubation (Table 8.2).

Table 8.2. Egg weight changes during incubation

Parameter	Mean $\pm$ SEM
Initial egg weight (g)	1310.66 $\pm$ 22.14
Final egg weight (g)	1160.09 $\pm$ 22.84
Weight loss (%)	11.42 $\pm$ 0.57
Ideal weight loss range	11.0–13.5%

8.3.3 Embryonic Mortality

Embryonic mortality was assessed by candling at early (0–14 days), mid (15–38 days) and late (39–up to hatch) stage of incubation showed no embryonic mortality. Two fertile eggs were found from 35 eggs set and the 2 fertile eggs were successfully hatched, representing no embryonic mortality.

8.3.4 Hatchling Evaluation

Post-hatch evaluations confirmed that 2 chicks (100%) were healthy and average hatchling weight was 835.5 g, any deformities and mortality were not observed (Table 8.3).

Table 8.3. Hatchling health characteristics

Parameter	Value
Total chicks hatched	2
Average hatchling weight (g)	835.5 ± 112.5
Healthy chicks (%)	100
Minor deformities (leg/splay) (%)	0
Mortality within 72 hours	0



Photo 8.3 A newly hatched healthy ostrich chick

8.4 Discussion

The findings from this study provide critical insights into the reproductive performance and hatching success of ostriches under artificial incubation in a subtropical environment like Bangladesh. The results reinforce the complexity of ostrich reproductive biology, particularly under artificial conditions where precise environmental and management controls are essential for favorable outcomes.

One of the most notable outcomes of the study was the relatively low fertility rate of 13.33%, which is considerably lower than the global average reported in commercial ostrich operations, where fertility typically ranges from 40% to 70% (Horbańczuk and Cooper, 2020). This suggests underlying constraints in breeder management, environmental stress, or possibly inadequate behavioral synchronization during the mating season. Despite housing the ostriches in well-managed enclosures and providing a nutritionally balanced breeder diet with antioxidant support (e.g., vitamin E and selenium), reproductive performance remained limited. These findings align with earlier observations by Al-Dobaib (2007), who emphasized that reproductive success in ostriches depends not only on physical conditions but also on behavioral and physiological readiness of breeding pairs.

However, a key strength of this study was the 100% hatchability of the fertile eggs, indicating that once fertilization occurred, the artificial incubation conditions were highly conducive to embryonic development and hatching. This suggests effective calibration and control of environmental parameters within the incubators. The incubation temperature of $36.83 \pm 0.03^{\circ}\text{C}$ and relative humidity of $28.56 \pm 1.14\%$ during the setting phase, followed by reduced temperature and increased humidity during hatching (36.2°C and 45–50% RH), matched international standards for ostrich incubation (Bovera et al., 2012). These conditions facilitated optimal egg weight loss of $11.42 \pm 0.57\%$, which is within the ideal range of 11.0–13.5% required for effective gas exchange and successful embryonic development (Soleimani et al., 2022).

Remarkably, the study recorded zero embryonic mortality, a rare outcome in ostrich incubation studies where early-stage embryo deaths are frequently reported due to improper turning, microbial contamination, or suboptimal temperature and humidity (Brand et al., 2021). The absence of mortality can be attributed to several management strengths in this study, including timely egg collection (within 3–5 hours of laying), optimal storage

conditions (16–18°C and 70–75% RH) and consistent egg turning every 1.5 hours at 45° intervals in a forced-air incubator. These practices mirror best practices in commercial hatcheries and may be particularly effective in low-volume settings where individual egg handling is more feasible.

The post-hatch performance further validated the incubation protocol. All chicks were healthy, with no cases of deformities or mortality within the first 72 hours, indicating that the brooding system provided an appropriate microenvironment immediately after hatching. This contrasts with studies such as Moreki et al. (2020), which reported high incidences of leg splay and other deformities under inconsistent brooding conditions. The success in this study may be attributed to careful regulation of post-hatch temperature, humidity, lighting and ventilation, which factors often underestimated but critical in ensuring early chick survival.

Slight fluctuations in relative humidity during winter were manually adjusted, demonstrating the limitations of non-automated systems in responding to environmental variability. In tropical regions like Bangladesh, daily and seasonal variations in temperature and humidity can significantly affect incubation outcomes, as emphasized by Soleimani et al. (2022). This points to the importance of upgrading to automated incubators with real-time environmental control and alarm systems to minimize manual errors and maintain consistent embryonic conditions.

The impact of egg storage duration was minimal in this study due to strict adherence to a maximum 7-day storage period, which likely prevented the decline in hatchability associated with prolonged storage (Horbańczuk and Cooper, 2020). Although only two fertile eggs were obtained, their successful development suggests that the incubation and handling protocols were scientifically sound and applicable in resource-limited contexts.

In summary, while fertility remains a challenge, likely due to biological or environmental constraints, the incubation and post-hatch management practices in this study demonstrated high efficiency and success. The findings advocate for more intensive research into breeder behavior, nutritional supplementation and environmental synchronization to boost fertility, while affirming the feasibility of artificial incubation as a viable strategy for ostrich chick production in subtropical climates like Bangladesh.

8.5 Conclusion

This study confirms that artificial incubation, when managed with precision, can yield excellent hatching success in ostriches under Bangladeshi conditions. The 100% hatchability of fertile eggs and absence of embryo or chick mortality highlight the effectiveness of incubation protocols, environmental control and egg handling techniques. Optimal weight loss during incubation and consistent physiological conditions supported successful embryo development. Despite low fertility rates, the outcomes demonstrate that well-managed incubation can overcome many field-level constraints. These findings offer practical guidance for farmers aiming to improve reproductive efficiency and establish viable ostrich farming systems in tropical environments.

8.6 Limitations

1. **Small Sample Size:** Only 15 eggs were set, limiting the statistical power and generalizability of results.
2. **Single Location:** The findings are specific to one geographical and climatic region and may not represent all parts of Bangladesh.
3. **Unmeasured Genetic Factors:** Breeding stock was not genetically evaluated, limiting insight into the genetic influence on fertility and hatchability.

8.7 Recommendations

1. **Improve Breeder Management:** Evaluate mating behavior and ensure optimal health and nutrition to improve fertility rates.
2. **Maintain Controlled Storage:** Limit egg storage to under 7 days at 16–18°C and 70–75% RH to maximize viability.
3. **Optimize Incubation Conditions:** Continue regulating temperature and RH strictly 36.8°C and 28–30% RH for setting; 36.2°C and 45–50% RH for hatching.
4. **Expand Flock Size:** Larger breeding populations may provide more representative data and improve overall productivity.
5. **Behavioral Monitoring:** Document and analyze mating and nesting behavior to time egg collection more effectively.

Chapter 9

General Summary and Conclusion

9.1 General Summary

The study entitled “*Productive and Reproductive Performances of Ostriches under Bangladeshi Agro-Climatic Conditions*” constitutes a landmark investigation in the field of non-traditional livestock farming in South Asia. It addresses a pressing national need for livestock diversification in Bangladesh is a country facing a critical intersection of land scarcity, nutritional insecurity, rising demand for animal protein and the need for environmentally sustainable farming practices. Ostrich farming, though globally established in countries such as South Africa, Israel, Australia and China, remains in its infancy in Bangladesh, where both scientific data and technical expertise are limited. This research is therefore timely, innovative and of high relevance to policy planners, researchers and entrepreneurs.

The overarching goal of the study was to assess the growth, feed efficiency, reproductive parameters and early-stage chick viability of ostriches raised under Bangladeshi subtropical conditions. A major thrust of the investigation was placed on artificial incubation and hatchability performance, as natural hatching is often inconsistent and inefficient in captive breeding systems. The study was conducted over a multi-year period at a controlled research facility in Dinajpur, incorporating seasonal variability and applying rigorous management and analytical methodologies.

Scientific Contributions and Key Insights

1. Growth and Adaptability of Ostriches

The study confirmed that ostriches can adapt well to the agro-climatic zones of Bangladesh, particularly when raised under structured and biosecure systems. Growth performance indicators such as body weight and feed conversion ratio (FCR) were comparable to international values, validating the biological suitability of ostriches for this region. However, it was observed that climatic factors especially excessive humidity during monsoon months posed challenges to feed intake and metabolic efficiency. These findings suggest that environmental modifications, such as provision of shade, ventilation and seasonal diet adjustments, are essential for maximizing production efficiency.

2. Feed Efficiency and Nutritional Management

Feeding trials revealed that ostriches fed scientifically balanced rations, enriched with crude protein and essential vitamins such as E and selenium, exhibited enhanced feed utilization and better overall health. However, given Bangladesh's reliance on imported feed ingredients, cost-effective and locally available alternatives such as agro-industrial by-products and green forages must be further explored and standardized to make ostrich farming economically feasible on a larger scale.

3. Reproductive Performance and Artificial Incubation

Perhaps the most critical insight of the study lies in the analysis of reproductive parameters. The fertility rate was relatively low (13.33%) compared to benchmarks from established ostrich industries, raising questions about breeder management, sexual synchronization, genetic diversity and stress mitigation. Nonetheless, the 100% hatchability of fertile eggs, coupled with zero embryonic and post-hatch mortality, stands as a remarkable success. This outcome underscores the effectiveness of the incubation protocol applied that meticulously calibrated temperature and humidity levels, egg turning every 1.5 hours and tight control of egg storage and hygiene. These results offer a replicable model for small-scale producers and set a foundation for broader application in commercial settings.

4. Egg Physiology and Weight Loss

The average egg weight loss of 11.42% during incubation fell precisely within the scientifically recommended range of 11–13.5%, which is necessary to ensure adequate gas exchange and prevent both dehydration and developmental failure. This not only validates the humidity control system used in the study but also affirms that even in a subtropical setting with variable environmental conditions, it is possible to simulate optimal incubation environments through low-cost but well-monitored systems.

5. Hatchling Health and Brooding Success

All chicks hatched were healthy and exhibited normal behavior, with no deformities or early mortality that stand in contrast to numerous global reports citing high incidences of splay leg, yolk sac infections and dehydration within the first 72 hours post-hatching. This suggests that immediate post-hatch care, including proper brooder temperature, sanitation and early access to water and feed, was highly effective in this trial. This highlights the

importance of post-incubation management, which is often underestimated in ostrich production systems.

6. Environmental and Technological Challenges

While the success of incubation demonstrates technical feasibility, the manual adjustment of environmental parameters (especially relative humidity during winter) indicates the need for more **automated, sensor-driven incubation systems**, particularly if ostrich farming is to scale beyond pilot projects. This becomes even more crucial in regions with wide daily and seasonal climatic fluctuations.

Strategic Relevance for Bangladesh

The implications of this study transcend biological outcomes and extend into the socio-economic and environmental domains:

- a) **Nutritional Security:** Ostrich meat is lean, low in cholesterol and rich in iron and omega-3 fatty acids, offering a viable alternative to red meat and aligning with the dietary needs of a health-conscious population.
- b) **Rural Development:** Ostrich farming can stimulate job creation and entrepreneurship, especially among rural youth and smallholders, who can benefit from meat, hide, feather and oil production.
- c) **Climate Resilience:** Compared to ruminants, ostriches emit fewer greenhouse gases and consume less water per kilogram of meat produced, positioning them as an environmentally responsible livestock option.
- d) **Export Potential:** With proper investment in cold chain logistics and veterinary protocols, Bangladesh could tap into international markets for ostrich meat and by-products.

Contribution to Academic and Developmental Discourse

This research fills a major void in the literature on ostrich production under tropical conditions, particularly in South Asia. It contributes:

- a) **Empirical data** on ostrich physiology and productivity in a novel setting.
- b) **Operational protocols** for artificial incubation and brooder management in resource-limited contexts.

- c) **Policy-relevant insights** into the opportunities and challenges of non-traditional livestock in emerging economies.

Moreover, this study is aligned with several Sustainable Development Goals (SDGs), including:

- i) **SDG-1: No Poverty** – by creating new income opportunities through diversified livestock farming.
- ii) **SDG-2: Zero Hunger** – by promoting high-quality protein sources.
- iii) **SDG-8: Decent Work and Economic Growth** – by stimulating rural enterprise.
- iv) **SDG-12: Responsible Consumption and Production** – by promoting efficient and low-footprint meat production.

In summary, this study is not merely an academic exercise but a strategic contribution toward transforming livestock agriculture in Bangladesh. It provides a robust scientific foundation for future interdisciplinary work and offers a clear roadmap for policymakers, researchers and farmers seeking to harness the full potential of ostrich farming under subtropical conditions.

9.2 Conclusions

Based on the empirical results and critical evaluations, the following conclusions can be drawn:

- 1) **Biological Feasibility Confirmed:** Ostriches can be viably reared in Bangladesh, demonstrating satisfactory growth, adaptability and reproductive potential when managed under structured systems.
- 2) **Fertility Limitation Identified:** Fertility rates were significantly lower than global averages, indicating that improved breeder selection, mating behavior monitoring and possibly genetic evaluation are necessary.
- 3) **Incubation Success Validated:** Artificial incubation protocols applied in this study particularly regarding temperature, humidity, egg turning and storage were validated by the exceptional outcome of 100% hatchability from fertile eggs and zero embryonic or post-hatch mortality.

- 4) **Importance of Management Precision:** Proper handling, egg hygiene, rotation frequency and brooder design played key roles in determining success. These factors are often overlooked but proved critical in ensuring embryo viability and chick health.
- 5) **Scalability Requires Systemic Support:** Despite biological success, scaling up ostrich farming in Bangladesh will require investments in breeder management, feed formulation, farmer training, veterinary infrastructure and market development.
- 6) **Policy and Research Gaps Must Be Bridged:** A coherent policy framework supporting exotic livestock farming is urgently needed. In parallel, continued research, particularly in breeder fertility, genetic improvement and disease resistance which is essential for long-term success.

This study demonstrates that ostrich farming, while still in its early stages in Bangladesh, holds significant promise. With focused attention on reproductive efficiency, standardized incubation practices and integrated management systems, ostrich production can evolve into a viable, sustainable and economically rewarding sector within the country's diversified livestock portfolio.

9.3 Limitations

While this study offers an important foundation for advancing ostrich farming in Bangladesh, several limitations should be noted to better understand the scope and generalizability of the findings:

1. **Small scale:** The research was conducted on a limited breeding flock and evaluated only 15 eggs in controlled trials, which reduces statistical strength and makes it harder to generalize results across different regions or larger operations.
2. **Short duration:** The study focused mainly on early reproductive output and chick survival during the first weeks, without capturing data on lifetime productivity, reproductive longevity, or multi-year trends.
3. **Manual monitoring:** Temperature and humidity inside incubation units were recorded manually, leading to minor fluctuations that could affect hatchability and chick health.

4. **No genetic or behavioral profiling:** The study did not include genetic screening or behavioral observations of breeding birds, which could have helped explain observed fertility challenges.
5. **Economic aspects not assessed:** While biological performance was measured, the research did not analyze cost-benefit, market potential, consumer acceptance, or economic viability under local farming conditions.
6. **Policy gaps:** The lack of formal national guidelines and coordinated institutional support limited opportunities for farm licensing, veterinary services and wider industry collaboration.

These limitations point to the need for larger, longer-term and more interdisciplinary studies that combine biological, economic and policy perspectives to sustainably develop ostrich farming in Bangladesh.

9.4 Recommendations

To operationalize the findings of this study and foster a viable ostrich farming industry in Bangladesh, targeted actions are required across multiple stakeholder levels:

9.4.1 Recommendations for Farmers and Farm Managers

1. **Specialized Training Programs:** Farmers should undergo formal training in ostrich behavior, nutrition, artificial incubation and brooding to build capacity and reduce early-stage losses.
2. **Adoption of Scientific Brooding Systems:** Temperature- and humidity-controlled hatchers and brooders are essential for reducing chick deformities and mortality.
3. **Standardized Record-Keeping:** Comprehensive documentation of breeding activity, egg quality, weight loss and chick health must be maintained to support farm-level analysis and decision-making.

9.4.2 Recommendations for Government and Policymakers

1. **Formulation of a National Ostrich Farming Policy:** A regulatory framework should address licensing, breeding standards, biosecurity, animal welfare and market incentives.

2. **Financial Incentives and Risk Protection:** Low-interest loans, startup grants and livestock insurance schemes should be introduced to lower the high entry barriers for smallholders and entrepreneurs.
3. **Veterinary Capacity Building:** Investment in ostrich-specific veterinary training, diagnostic tools and health protocols is essential for maintaining flock productivity and biosecurity.

9.4.3 Recommendations for Research Institutions

1. **Long-Term and Multi-Regional Studies:** Future research should include lifetime productivity tracking, seasonal fertility variations, disease prevalence and genetic trait selection across regions.
2. **Development of Localized Feeds:** Efforts must focus on formulating nutritionally balanced, cost-effective rations using agricultural by-products, reducing reliance on expensive imports.
3. **Value Addition Research:** Studies into ostrich meat preservation, leather processing, feather commercialization and oil extraction are needed to diversify income streams and enhance product value.

9.4.4 Recommendations for the Private Sector and Investors

1. **Development of Integrated Value Chains:** From breeding to processing and marketing, coordinated supply chains can improve efficiency, traceability and profitability.
2. **Consumer Engagement and Branding:** Public awareness campaigns highlighting ostrich meat's nutritional benefits and low-fat profile can foster demand and support market expansion.

9.5 Future Research Directions

The promising outcomes of this study point to several critical pathways for future research and strategic development:

9.5.1 Genetic and Breeding Program Development

Selective breeding programs should aim to enhance fertility, growth rate, disease resistance and environmental adaptability through genetic characterization and trait-based selection.

9.5.2 Climate-Resilient Farming Technologies

Research into climate-smart housing, misting systems, seasonal feed adjustments and breeding synchronization tools is vital for coping with Bangladesh's variable tropical climate.

9.5.3 Incubation and Brooding System Innovation

Design and dissemination of energy-efficient, region-specific incubation and brooding systems are essential for improving hatch rates and chick survivability in rural areas.

9.5.4 Health Protocol and Biosecurity Frameworks

Development of ostrich-specific vaccines, disease monitoring tools, feed additives (e.g., probiotics, immune enhancers) and emergency response plans can significantly reduce morbidity and mortality.

9.5.5 Market Research and Product Commercialization

Studies on consumer behavior, willingness to pay, market segmentation, export potential and product branding are needed to support commercialization and build investor confidence.

9.5.6 Institutional Collaboration and PPP Models

Effective public-private partnerships (PPPs) involving government agencies, universities, NGOs and the private sector are crucial for capacity building, technology transfer and enterprise development.

9.5.7 Environmental and Socioeconomic Impact Assessment

Quantitative research should evaluate the carbon footprint, water use, employment generation, gender participation and income diversification potential of ostrich farming relative to conventional livestock.

References

- Abou El-Azm, M. S., Mohamed, R. A., Salem, I. F. and Al-Nedawi, A. A. (2023). Hatchery hygiene and chick survival in commercial ostrich farming. *Veterinary Poultry Research*, 15(1), 33–42.
- Adanza, E. G. (2006). *Research methods: Principles and applications*. Rex Book Store.
- Aganga, A. A., Mosalagae, D. and Monyatsiwa, K. (2021). Nutritional strategies and feed efficiency in ostrich production: A comparative review. *Tropical Animal Health Research*, 13(4), 215–228.
- Ahmed, M. F., Alam, M. M. and Hossain, M. E. (2021). Ostrich farming as a means of sustainable livelihood in Bangladesh. *Bangladesh Journal of Animal Science*, 50(2), 27–34.
- Ahmed, M. S. and Hossain, M. T. (2023). Managing heat stress in large avian species: Housing adaptations for tropical zones. *Asian Journal of Avian Science*, 7(2), 101–110.
- Ahmed, R., Hossain, M. S. and Kamal, M. A. (2022). Consumer perception and market potential of ostrich meat in Bangladesh. *Bangladesh Journal of Animal Science*, 51(1), 45–52.
- Akter, R. and Islam, M. S. (2023). Risk factors for respiratory disorders in exotic avian species under tropical humid conditions. *Bangladesh Journal of Veterinary Medicine*, 21(1), 1–9.
- Akyurek, H. and Okur, A. A. (2009). Effects of storage conditions on egg quality. *Journal of Poultry Science*, 46(2), 122–128.
- Al-Dobaib, S.N. (2007). Effect of dietary vitamin E supplementation on reproductive and productive performance of ostriches (*Struthio camelus*). *International Journal of Poultry Science*, 6(2), 154–157.
- Alagawany, M., Elnesr, S. S., Farag, M. R., & Tufarelli, V. (2020). Nutritional significance of amino acids, vitamins and minerals as nutraceuticals in poultry production and health – A comprehensive review. *Veterinary Quarterly*, 40(1), 1–21.

- Alam, M. J., Hossain, M. T. and Hasan, M. N. (2023). Employment generation through non-traditional livestock: A case of ostrich production. *Bangladesh Journal of Rural Development*, 39(2), 78–85.
- Alam, M. J., Rahman, M. M. and Kabir, M. H. (2022). Ostrich farming in Bangladesh: Challenges faced by commercial farms. *Livestock and Agricultural Review*, 11(1), 23–31.
- Alam, M. S., Hossain, M. A. and Rahman, M. M. (2023). Commercial ostrich farming in Bangladesh: Current status, prospects and challenges. *Asian Journal of Poultry Science and Technology*, 11(2), 88–96.
- Ali, N., Parvin, R. and Sultana, S. (2023). Empowering women through exotic livestock farming in rural Bangladesh. *Journal of Agricultural Economics and Development*, 15(2), 54–62.
- Alshamy, M. A., Abdelrahman, M. M., and El-Sayed, M. E. (2023). Comparative performance of ostriches under extensive, semi-intensive, and intensive farming systems in arid regions. *Journal of Avian Production Systems*, 12(1), 25–33.
- AOAC International. (2019). *Official Methods of Analysis* (21st ed.). AOAC Int., USA.
- Babiker, S. A., & Mohamed, H. E. (1988). The effects of dietary protein and energy levels on the performance of broiler chickens in Sudan. *Tropical Animal Health and Production*, 20(2), 107–113.
- Balog, J. M. and Almeida Paz, I. C. L. (2007). Nutrient formulation standards for poultry.
- Baltić, B., Ivanović, J., Karabasil, N. and Dimitrijević, M. (2021). Functional meat and ostrich production trends. *Meat Technology*, 62(1), 27–35.
- Begum, R., Hasan, M. N. and Sultana, S. (2022). Assessing climate-resilient ostrich farming systems in Bangladesh. *Journal of Agricultural Innovation and Sustainability*, 10(3), 211–219.
- Begum, R., Karim, M. J. and Sultana, N. (2022). Training and awareness development for exotic animal farming in Bangladesh: A policy review. *Livestock Extension Journal*, 9(1), 12–19.
- Berendsen, L. (1995). Behavioral study on captive ostriches.

- Bertram, B. C. R. (1992). *The Ostrich Communal Nesting System*. Princeton University Press.
- Bertram, B.C.R. and Burger, A.E. (1981). Are ostrich eggs the wrong size for their parents? *Nature*, 293, 58–59.
- Birkett, M. A., Olotu, O. and Hassim, H. (2019). Biosecurity and waste management in ostrich production systems. *African Journal of Agricultural Research*, 14(10), 512–520.
- BLRI. (2023). Ostrich farming feasibility and baseline study. Bangladesh Livestock Research Institute (BLRI) Technical Bulletin No. 17.
- Bovera, F., Tudisco, R., Nizza, S., Piccolo, G., D’Angelo, D., Cutrignelli, M.I. and Nizza, A. (2012). Reproductive performance and blood metabolites of ostriches (*Struthio camelus*) fed diets with different protein levels. *Poultry Science*, 91(2), 500–507.
- Brand, Z., Cloete, S.W.P. and Malecki, I.A. (2021). Incubation and hatching in ostriches. In: *Advances in Poultry Welfare* (pp. 125–144). Woodhead Publishing.
- Bunchasak, C. (2009). Role of dietary methionine in poultry production. *The Journal of Poultry Science*, 46(3), 169–179. <https://doi.org/10.2141/jpsa.46.169>
- Carbajo, M. (2006). On international ostrich production.
- Chigavazira, K., Chimonyo, M. and Manyevere, A. (2021). Growth performance of ostriches under intensive and semi-intensive systems. *Tropical Animal Health and Production*, 53(2), 209–217.
- Chowdhury, M. S. I., Khatun, M. R. and Islam, M. N. (2023). Preliminary study on ostrich behavior and feeding in controlled environments. *Journal of Livestock and Environment*, 14(1), 101–108.
- Chowdhury, M. S., Hossain, M. T. and Karim, R. (2024). Housing and ventilation design for exotic birds in tropical environments. *Tropical Livestock Engineering Journal*, 9(1), 15–23.
- Cooper, R. G., Horbańczuk, J. O. and Saccà, E. (2009). Ostrich farming: Feed conversion and sustainability. *World’s Poultry Science Journal*, 65(3), 389–395.
- Corzo, A., Kidd, M. T., Dozier, W. A., & Tillman, P. B. (2007). Valine: Beyond the building blocks. *Journal of Applied Poultry Research*, 16(4), 561–568.

- Creswell, J. W. and Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (3rd ed.). Sage Publications.
- Deeming, D. C. (2013). *The ostrich: Biology, production and health*. CAB International, Wallingford, UK.
- Deeming, D. C. (2021). Commercial ostrich farming: Innovations and sustainability. *Ostrich Science Review*, 18(2), 77–91.
- Deeming, D. C. and Bubier, N. E. (2001). Behavioral and welfare aspects of captive ostriches. *Animal Welfare*, 10(4), 363–376.
- Deeming, D. C. and Bubier, N. E. (2020). Managing reproductive cycles in ostrich farming under controlled environments. *International Journal of Avian Management*, 11(1), 51–66.
- Department of Agriculture, Forestry and Fisheries (DAFF). (2022). *Annual report on ostrich production and trade*. Government of South Africa.
- Department of Livestock Services (DLS). (2023). *Livestock Economy and Future Strategies Report 2022-2023*. Ministry of Fisheries and Livestock, Bangladesh.
- Dzoma, B.M. and Dorrestein, G.M. (1998). Anatomical and physiological causes of mortality in ostrich chicks aged 0 to 90 days. *Onderstepoort Journal of Veterinary Research*, 65(4), 297–301.
- Faitarone, A. B. G. et al. (2019). Use of amino acids in poultry feed: implications for growth and gut health. *Brazilian Journal of Poultry Science*, 21(3), 1–10.
- Fakoya, E. O., Agbonlahor, M. U. and Dipeolu, A. O. (2015). Farmers' perception of animal welfare and biosecurity in livestock enterprises. *Livestock Research for Rural Development*, 27(3), Article #65.
- Fernández-López, J. et al. (2006). Nutritional properties and culinary uses of ostrich meat. *Meat Science*, 73(3), 451–457.
- Food and Agriculture Organization (FAO). (2023). *World livestock: Transforming the livestock sector through innovation*. Rome: FAO.
- Ghebremariam, M. K., Hussen, A. H. and Mohamed, A. E. (2021). Role of mineral nutrition on ostrich reproductive development. *Avian Biological Research*, 14(2), 103–109.

- Girolami, A., Napolitano, F., Faraone, D., Braghieri, A. and Grittani, A. (2003). Ostrich meat: Nutritional value and consumer acceptability. *Meat Science*, 64(3), 309–316.
- Grobler, M. M., Malan, J. A. and Cloete, S. W. P. (2020). Biosecurity practices on commercial ostrich farms in South Africa. *South African Journal of Animal Science*, 50(1), 12–20.
- Hasan, M. N., Kabir, M. H. and Chowdhury, M. S. (2023). Policy and practice: Inclusion of ostrich farming in Bangladesh's livestock development plan. *Journal of Livestock Policy and Planning*, 8(1), 1–10.
- Hassan, M. A., Islam, R. M. and Parvin, R. (2022b). Challenges of consumer awareness and meat acceptance in exotic poultry in Bangladesh. *Journal of Agricultural Marketing and Consumer Research*, 9(2), 41–49.
- Hassan, M. N., Sultana, Z. and Rahim, M. A. (2022a). Environmental benefits of ostrich farming in comparison with traditional livestock. *Environmental Livestock Studies*, 7(3), 56–64.
- Hernandez, M., Ariza-Nieto, C., & Afanador-Tellez, G. (2018). Dietary amino acid supplementation and poultry immune responses. *Revista MVZ Córdoba*, 23(3), 6815–6825.
- Herrero, M., Thornton, P. K. and Power, B. (2021). Innovation pathways towards sustainable livestock systems in the developing world. *Nature Sustainability*, 4(2), 89–98.
- Hoffman, L. C., Engelbrecht, A. and Muller, M. (2020). The nutritional composition of ostrich meat: Implications for human health. *Meat Science*, 168, 108179.
- Hoffman, L. C., Mostert, A. C., Kidd, M. and Laubscher, L. L. (2008). Meat quality of ostrich compared to beef and chicken. *Meat Science*, 79(2), 228–234.
- Horbańczuk, J. O. and Sales, J. (2019). Nutrient composition and utilization of ostrich meat and by-products. *World Poultry Science Journal*, 75(4), 723–733.
- Horbańczuk, J. O., Deeming, D. C. and Sales, J. (2021). Biosecurity and fertility management in commercial ostrich farming. *Ostrich Production Science*, 10(1), 45–58.

- Horbańczuk, J. O., Li, X. and Malebana, P. (2023). Advances in ostrich reproductive biotechnology. *World Journal of Avian Reproduction*, 2(1), 1–11.
- Horbańczuk, J. O., Sales, J. and Cooper, R. G. (2020). Meat quality and sustainability of ostrich production. *Journal of the Science of Food and Agriculture*, 100(2), 428–434.
- Hossain, M. T. and Mia, M. M. (2022). Waste and water management for large exotic birds under monsoon conditions. *South Asian Livestock Management Journal*, 6(2), 75–82.
- Hossain, M. Z., Rahman, S. M. E. and Alam, M. R. (2021). Evaluation of current ostrich farming practices in Bangladesh. *Journal of Livestock and Poultry Production*, 9(2), 44–52.
- Hussein, A. A., Al-Dobaib, S. N. and Mahrous, U. E. (2020). Prevalence and risk factors of ostrich diseases in commercial farms. *Veterinary World*, 13(11), 2345–2352.
- IBM Corp. (2022). *IBM SPSS Statistics for Windows, Version 27.0*. Armonk, NY: IBM Corp.
- International Meat Secretariat. (2023). *Global trends in exotic meat markets: 2022–2023 outlook*. Paris: IMS.
- Iowa State University. (1997). *Nutrition guidelines for meat-type poultry*. Department of Animal Science, Iowa State University.
- Islam, M. A., Rahman, M. S. and Khatun, M. (2020). Health and biosecurity management in commercial ostrich farms in Bangladesh. *Bangladesh Veterinary Journal*, 54(1), 21–28.
- Islam, M. S., Alam, M. A. and Rahman, M. M. (2022). Emerging challenges in Bangladesh's livestock sector: A policy perspective. *Bangladesh Veterinary Journal*, 39(2), 72–81.
- Islam, R. M., Miah, M. I. and Kabir, M. H. (2023). Effect of amino acid supplementation on growth and carcass yield of ostrich chicks in Bangladesh. *Bangladesh Journal of Animal Science*, 52(1), 33–42.

- Kabir, M. H., Karim, M. R. and Hasan, M. A. (2023). A review of ostrich farming in Bangladesh: Opportunities and limitations. *South Asian Journal of Agriculture and Livestock*, 10(1), 23–31.
- Karunaratne, K. D. K. R., Samarakoon, S. M. A. R. and Pathirana, K. K. (2021). Consumer perception of exotic meats in Asia: Challenges and future prospects. *Asian Food Research Journal*, 20(3), 98–105.
- Kemp, C., Scholtz, M. M. and Van Ryssen, J. B. J. (2016). Amino acid requirements of ostriches. *South African Journal of Animal Science*, 46(5), 517–528.
- Lambrechts, H. (2017). Nutritional management of ostriches in commercial production systems [Doctoral dissertation, Stellenbosch University]. SUNScholar Research Repository.
- Li, X., Malebana, P. and Horbańczuk, J. O. (2022). Genetic potential and fertility enhancement in ostrich breeding systems. *Journal of Genetic Avian Science*, 3(2), 89–98.
- Louw, G. N., Theron, H. E. and van der Westhuizen, E. J. (2021). Optimizing ostrich production under intensive conditions. *African Journal of Animal Science*, 51(4), 217–224.
- Magwedere, K., Muchadeyi, F. C. and Nyoni, T. (2020). Public health perspectives on emerging ostrich production systems. *Journal of Veterinary Public Health*, 18(1), 1–9.
- Mahala, A. G. et al. (2019). Role of methionine in health and production of poultry. *Sudan Journal of Animal Production*, 34(1), 17–24.
- Mahmoud, H. et al. (2020). Effect of heat stress on calcium metabolism and eggshell quality in poultry. *Poultry Science Journal*, 58(2), 115–125.
- Malebana, P., Li, X. and Horbańczuk, J. O. (2022). Fertility management strategies in semi-intensive ostrich farming systems. *International Avian Breeding Research*, 9(2), 122–129.
- McCrindle, C. M. E. and Verwoerd, D. W. (2019). Biosecurity and management practices in the ostrich industry. *Veterinary Research Communications*, 43(1), 9–17.

- Mehmood, S., Nawaz, M. A. and Imran, M. (2021). The role of biosecurity in reducing ostrich mortality and improving farm income. *Pakistan Journal of Agricultural Sciences*, 58(1), 99–105.
- Menon, R., Krishnan, G. and Padmanabhan, A. (2014). Captive ostrich ethology and welfare in tropical farms. *Tropical Animal Health and Production*, 46(1), 125–132.
- Miah, A. G., Abdulle, K. M. Rahman, M. and Salma, U. (2020). Growth performance and survivability of ostrich chicks reared under Bangladesh conditions. *Journal of Veterinary Research Advances*, 02(02), 32–40.
- More, S. J. (1996). A longitudinal study of enteric disease in young ostriches in Ireland. *Veterinary Record*, 139(21), 532–537.
- Moreki, J. C. and Seabo, B. (2019). Constraints and opportunities in ostrich farming in developing countries: A review. *African Journal of Poultry Science*, 6(1), 20–30.
- Moreki, J. C. and Seabo, D. (2012). Ostrich production and its contribution to food security in Botswana. *Journal of Animal Science Advances*, 2(10), 825–831.
- Moreki, J. C. and Tshireletso, K. (2013). Biosecurity practices in poultry production in Botswana. *Research Journal of Agriculture and Environmental Management*, 2(7), 192–200.
- Moreki, J. C., Seabo, B. and Letsapo, P. (2020). Factors influencing fertility rates in commercial ostrich production. *Journal of Agricultural and Veterinary Research*, 5(4), 301–307.
- Mushi, D. E., Abubakar, H. I. and Said, A. M. (2022). Ostrich farming in Africa and Asia: Trends, performance and future directions. *Global Avian Science Review*, 4(1), 1–19.
- Mushi, D. E., Safari, J., Mtenga, L. A. and Kifaro, G. C. (2021). Amino acid balance in alternative meat production. *African Journal of Animal Science*, 51(3), 153–161.
- Mutibvu, T., Nengovhela, B. and Mushunje, A. (2022). The economics of ostrich leather in luxury goods supply chains. *Journal of Fashion and Leather Studies*, 9(2), 80–92.
- NRC (National Research Council). (1994). *Nutrient Requirements of Poultry* (9th ed.). National Academies Press.

- Nys, Y., Bain, M. and Van Immerseel, F. (2011). Improving the Safety and Quality of Eggs and Egg Products. Woodhead Publishing.
- Oosting, S. J., Udo, H. M. J. and Vellinga, T. V. (2021). Environmental aspects of livestock protein production. *Animal Frontiers*, 11(3), 43–50.
- Pogorzelska-Przybyłek, P., Wierzbicka, A. and Ptak, A. (2023). Exotic meat market dynamics in Europe: A comparative analysis. *European Journal of Food and Animal Research*, 12(2), 56–68.
- Polawska, E., Cooper, R. G. and Horbańczuk, J. O. (2011). Ostrich meat quality and utilization: An updated review. *Animal Science Papers and Reports*, 29(1), 5–18.
- Preez, J. J. du. (1991). Ostrich production. In *Livestock Production Science*, 29(1), 101–115.
- Rahman, M. M. and Sultana, S. (2023). Constraints to commercialization of ostrich meat in Bangladesh. *Journal of Agricultural Business and Marketing*, 5(1), 28–36.
- Rahman, M. M., Hasan, M. A. and Islam, M. A. (2021). Ostrich farming in Bangladesh: Early experiences and prospects. *Bangladesh Journal of Livestock Research*, 41(1), 61–70.
- Rahman, M. M., Kabir, M. H. and Chowdhury, M. I. (2024). Towards a sustainable ostrich industry in Bangladesh: Policy, production and profitability. *Journal of Agricultural Policy and Practice*, 11(1), 14–27.
- Rajendran, R., Islam, R. and Das, A. (2022). Knowledge and attitude towards biosafety and hygiene in ostrich farms. *Asian Journal of Agricultural Extension, Economics and Sociology*, 40(5), 50–59.
- Rehman, M. U., Waseem, M., Ahmad, A., & Saeed, M. (2019). Role of amino acids in poultry health and production: A review. *International Journal of Agriculture and Biology*, 21(5), 1079–1085.
- Ross, T. and Deeming, D. C. (1998). Behavioral constraints in captive ostriches. *Ratite Journal*, 14(1), 11–19.
- Sales, J. (2014). Growth performance and carcass traits of ostriches under intensive feeding systems. *International Journal of Exotic Livestock*, 8(2), 134–142.

- Sales, J. and Horbańczuk, J. O. (2018). The production, quality and utilization of ostrich products. *World Poultry Science Journal*, 74(4), 783–802.
- Sales, J., Horbańczuk, J. O. and Cooper, R. G. (2019). Nutritional sustainability of ostrich meat. *Sustainability*, 11(15), 4183.
- Samraus, H. H. (1994). *Verhaltensstörungen bei Nutztieren [Behavioral Disorders in Livestock]*. Eugen Ulmer Verlag.
- Sarker, S. M., Parvin, R. and Ahmed, M. S. (2023). Consumer awareness and future market prospects of ostrich meat in Bangladesh. *South Asian Journal of Food and Nutrition*, 5(2), 90–97.
- Sauer, E. G. F. and Sauer, E. M. (1966). Social behavior and courtship displays in ostriches. *The Living Bird*, 5, 45–75.
- Selle, P. H., & Liu, S. Y. (2019). The relevance of starch and protein digestive dynamics in poultry. *World's Poultry Science Journal*, 75(1), 47–56.
- Shafey, T. M., Al-Batshan, H. A. and Al-Sobayel, A. A. (2020). Economic importance of growth traits in ostriches. *Emirates Journal of Food and Agriculture*, 32(6), 431–439.
- Shini, S., Shini, A., & Huff, G. R. (2015). Oxidative stress in poultry: Functions of vitamins and phytochemicals in poultry health. *Poultry Science*, 94(6), 1205–1216.
- Simopoulos, A. P. (2000). Cholesterol and fat quality in human health. *Nutrition and Metabolism*, 27(1), 1–12.
- Smit, B., Lategan, L. A. and Scholtz, M. M. (2022). Evaluating environmental footprints of ostrich and cattle production systems. *Sustainable Agriculture Reviews*, 44, 95–110.
- Soleimani, A.F., Hajati, H. and Sharifi, S.D. (2022). Effect of storage duration on hatchability and chick quality of ostrich eggs in a hot climate. *Journal of Applied Animal Research*, 50(1), 183–188.
- Thornton, P. K., Herrero, M. and Notenbaert, A. (2022). Climate-smart livestock production: Challenges and strategies. *Global Food Security*, 32, 100621.
- Tshabalala, P. A., Muchenje, V. and Maphosa, V. (2018). Effects of vitamin and mineral supplementation on ostrich productivity and health. *Journal of Nutritional Avian Biology*, 11(1), 39–48.

- Tully, T. N., & Shane, S. M. (1996). Diseases of ratites. In B. W. Calnek (Ed.), *Diseases of poultry* (10th ed., pp. 1205–1216). Iowa State University Press.
- Ullrey, D. E., & Allen, M. E. (1996). Nutrition and dietary husbandry. In D. G. Kleiman, M. E. Allen, K. V. Thompson, & S. Lumpkin (Eds.), *Wild mammals in captivity: Principles and techniques* (pp. 469–482). University of Chicago Press.
- USDA (United States Department of Agriculture). (2010). National Nutrient Database for Standard Reference, Release 23.
- Van Schalkwyk, S. J., Cloete, S. W. P. and Grobler, M. M. (2005). Reproductive performance and welfare of ostriches under different production systems. *South African Journal of Animal Science*, 35(4), 235–242.
- Venter, C. S., Jerling, J. C. and Schutte, A. E. (2020). MUFA-rich diets and cardiovascular outcomes. *Nutrition Reviews*, 78(10), 843–857.
- Walter, D. et al. (2000). Marketing strategies for ostrich products. *Journal of Food Products Marketing*, 6(4), 45–58.
- Williams, K. C. (1992). Some factors affecting albumen quality in eggs. *World's Poultry Science Journal*, 48(1), 5–12.
- Wilson, R. T., Cumming, R. B. and Hall, E. J. (2018). A review of production parameters in ostrich farming systems. *World's Poultry Science Journal*, 74(3), 409–420.
- World Health Organization. (2020). Healthy diet: Fact sheet No. 394.
- World Organization for Animal Health (WOAH). (2022). Ostrich health monitoring and disease control protocols. Paris: WOAH.
- Zhang, Y., Chen, Y. and Liu, S. (2018). Extraction and application of ostrich oil in dermal health: A review. *International Journal of Cosmetic Dermatology*, 17(3), 207–215.
- Zhao, X., Zhang, T., & Li, J. (2021). Effects of dietary amino acid supplementation on meat quality and carcass characteristics in poultry. *Poultry Science*, 100(9), 101256.
- Zhou, X., Liu, Y. and Zhang, M. (2023). Biosecurity enhancement in exotic bird farming: Lessons from global practices. *Journal of Veterinary Science and Biosecurity*, 8(1), 39–48.

Questionnaire/Interview schedule on
Problems and Prospects of Ostrich Production in Bangladesh

Name of the Farm : Location :

A. Personal Information

- 1) Name of the farmer:
- 2) Father's/Husband's name:
- 3) Age: years
- 4) Educational qualification:
- 5) Mobile number:
- 6) Email (if any):
- 7) NID/Birth registration number:
- 8) Address: Village/Mohalla: Union/Ward:.....
Upazila:.....District:
- 9) Date of farm establishment:
- 10) Name of the farm (if any):
- 11) GPS location of the farm (if available):

B. Farm-related Information

- 12) Present number of ostriches on the farm: Male: Female:
..... Chick (0–3 months): Grower:

- 13) Source of ostriches: a) Hatchery: b)
Other farm: c) Import:
.....
- 14) Purpose of ostrich farming (you may tick more than one): ☐ Meat production
☐ Egg production ☐ Chick production/sale ☐ Tourism/Business ☐
Others (specify):
- 15) Type of housing system: ☐ Open shed ☐ Semi-intensive ☐ Intensive
☐ Free-range
- 16) Farm area (in decimals): Shed: Open/pasture space:
- 17) Shed construction materials (tick applicable): ☐ Bamboo ☐ Corrugated iron
sheet ☐ Concrete ☐ Netting ☐ Wire fencing ☐ Others (specify):
.....
- 18) Do you follow any biosecurity measures? ☐ Yes ☐ No If yes, specify:
.....
- 19) Monthly farm expenditure (in Taka): Feed: Labor:
Treatment: Electricity/Utilities: Miscellaneous:
.....
- 20) Number of workers on the farm: Permanent: Temporary:
.....
- 21) Have you received any training on ostrich farming? ☐ Yes ☐ No If yes,
source of training:
- 22) What challenges do you face in ostrich farming? (tick applicable): ☐ Lack of
technical knowledge ☐ Unavailability of quality feed ☐ High chick mortality
☐ Lack of veterinary services ☐ Marketing problems ☐ Financial
constraints ☐ Others (specify):
- 23) What kind of support do you expect from the government or other organizations?
.....
.....

- 24) Are you a member of any ostrich farmer's association or cooperative? ☐ Yes
☐ No If yes, name of the association/group:

C. Feeding Management

- 25) What type of feed do you provide to ostriches?
.....
- 26) Do you use commercial feed or prepare your own? ☐ Commercial ☐ Own
formulation If own formulation, specify ingredients:
- 27) What is the daily feed amount per bird (approx.)? Chick:
Grower: Adult:
- 28) Do you provide any supplements or vitamins? ☐ Yes ☐ No If yes,
specify:
- 29) What is the source of drinking water? ☐ Tube well ☐ Pond ☐ Supply
line ☐ Others:
- 30) Do you maintain cleanliness of feeders and drinkers? ☐ Yes ☐ No If yes,
how often?

D. Reproductive Management

- 31) At what age do ostriches start laying eggs? months
- 32) How many eggs are produced per female per year (approx.)?
- 33) What method of incubation do you use? ☐ Natural ☐ Artificial If
artificial, brand/model of incubator:
- 34) Hatchability rate (approx.):%
- 35) Average fertility rate:%
- 36) Major problems in incubation:
.....
- 37) Source of chicks: ☐ Own hatchery ☐ Purchase from others ☐ Imported

E. Health Management

- 38) Do you vaccinate ostriches? ☐ Yes ☐ No If yes, name of vaccines:
.....
- 39) Do you deworm the birds? ☐ Yes ☐ No If yes, frequency:
Drug name:
- 40) Do you face any disease outbreaks? ☐ Yes ☐ No If yes, which ones?
.....
- 41) Do you consult a veterinarian? ☐ Regularly ☐ Occasionally ☐ Never
- 42) Distance to the nearest veterinary service center: km

F. Marketing and Economics

- 43) Where do you sell ostrich products? ☐ Local market ☐ Wholesale ☐
Online ☐ Export ☐ Middlemen ☐ Others:
- 44) What products do you sell? ☐ Meat ☐ Eggs ☐ Chicks ☐ Feathers
☐ Skin ☐ Oil
- 45) Price per unit (approx.): Meat (per kg): Egg (per piece):
..... Chick (per piece): Leather (per skin):
- 46) Monthly income from ostrich farm: Taka
- 47) Is the farming profitable? ☐ Yes ☐ No ☐ Uncertain
- 48) If not profitable, what are the reasons?
.....

G. Social and Environmental Aspects

- 49) Has ostrich farming created employment in your area? ☐ Yes ☐ No If
yes, how many people?

- 50) Are women involved in ostrich farming activities? ☐ Yes ☐ No If yes, in which areas?
- 51) Do you face any objections from the community? ☐ Yes ☐ No If yes, reasons:
- 52) Is the surrounding environment (temperature, humidity) suitable for ostrich farming? ☐ Yes ☐ No ☐ Seasonal variation exists
- 53) What environmental challenges do you face? ☐ Excessive heat ☐ Flood ☐ Cold wave ☐ Others:

H. Suggestions and Opinions

- 54) In your opinion, what are the prospects of ostrich farming in Bangladesh?
.....
- 55) What steps should be taken to promote ostrich farming?
.....
- 56) Would you recommend ostrich farming to others? ☐ Yes ☐ No Why?
.....
- 57) Any other comments or suggestions:
.....
.....

Name of data collector: _____

Signature of data collector : _____

Date : _____

