# Seasonal Variations in Blood Parameters and Hormonal Levels of Avian Species

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## Abstract

The seasonal variation in blood parameters and hormonal levels in avian species enhance survival and reproductive success by synchronizing physiology with changes in environmental conditions. Hypothalamic-pituitary-gonadal (HPG) axis regulates reproductive hormones, which drive gonadal development and sex steroid production. Courtship behavior, territoriality and gametogenesis are enhanced during breeding seasons when testosterone and estradiol levels peak. During migration, molting, or egg formation, metabolic markers such as blood glucose, lipids, and vitellogenin rise to satisfy energetic demands. Prolactin mediates seasonal transitions by facilitating parental care, while thyroid hormones contribute to the cessation of breeding activity through the induction of photorefractoriness. Environmental factors align endocrine and metabolic rhythms. Climate change disrupts the synchronization of breeding timing with resource availability, resulting in reduced reproductive success in temperate species. Comprehending these dynamics is essential for forecasting avian resilience to global change. Comparative studies among species with different life-history strategies can elucidate adaptive thresholds to environmental stressors. This chapter explores the seasonal variations in hematological and hormonal profiles across different avian species, providing insights into the complex physiological strategies birds employ to adapt to their ever-changing environments.

**Keywords:** Hematology, Breeding seasonality, Hematochemistry, Sex hormones, Birds, Physiological adaptation

**Cite this Article as:** Abbas N, Umar Z, Zubair M, Rehman HSU, Ansari AR, Sajid M, Shah M, Yasin G and Rehan S, 2025. Seasonal variations in blood parameters and hormonal levels of avian species. In: Ismael SS, Nisa QU, Nisa ZU and Aziz S (eds), Diseases Across Life: From Humans to Land and Sea. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 8-14. https://doi.org/10.47278/book.HH/2025.007

A Publication of Unique Scientific Publishers

**Chapter No:** 25-002

**Received:** 12-Feb-2025
**Revised:** 25-March-2025
**Accepted:** 07-May-2025

## Introduction

Avian species show amazing physiological adaptation to fit seasonal environmental variations. Often related with reproduction, environmental pressures, and survival strategies, seasonal fluctuations in blood parameters are major markers of these physiological changes (Ghosh et al., 2013). Blood serves as a critical diagnostic tool for assessing the health of birds and animals exposed to various toxins and environmental factors (Fossi et al., 2020). Pathological, physiological, and nutritional conditions can significantly impact an animal's health, and blood analysis provides the opportunity to detect the presence of specific compounds and other elements within a bird's system. Blood composition varies according to a bird's physiological state, making these variations essential for understanding how farm animals respond to different physiological conditions (Owen-Ashley et al., 2007). Numerous factors, both genetic and environmental, contribute to these variations. Age, breed, sex, and management practices all influence the blood characteristics of farm animals, necessitating the establishment of benchmark indicators based on these parameters and how they can affect those indices.

White blood cells (WBCs) and their differentials primarily combat pathogens, defend the organism against invading particles through phagocytosis, and produce antibodies in response to immunological stimuli. Birds with low WBC counts are more susceptible to infections, while organisms with higher WBC counts may produce antibodies during phagocytosis, enhancing their disease resistance and flexibility in environments where pathogens are prevalent (Isaac et al., 2013).

In avian species, RBCs are generally elliptical and contain a central nucleus; however, immature RBCs may appear similar to medium lymphocytes because of their round shape (Gallo et al., 2015). The location of the nucleus aids in differentiating red blood cells, which possess a central nucleus, from lymphocytes, characterized by an eccentric nucleus. During the maturation of red blood cells, their shape becomes increasingly oval. Variations in the morphology of white blood cells, such as heterophils, eosinophils, monocytes, and basophils, are dependent on species and warrant careful evaluation for changes, as these modifications may indicate avian health status. This chapter seeks to present comprehensive data on blood parameters and hormones in avian species, along with their correlation to seasonal variations.

**Hematological Profile in Avian Species**

The avian blood differs from mammalian blood due to the presence of nucleated erythrocytes and thrombocytes.. Furthermore, heterophils, rather than neutrophils, are the primary granulocytes in avian species. Hematological outcomes are influenced by various physiological factors, including age, gender, diet, and environmental conditions (Ahmed et al., 2020).

The blood parameters were investigated in yellow legged gulls (*Larus michahellis)* who were not breeding in February and those that were breeding in May within the same community in the Cha Farinas Island in Northern Africa (Bellout et al., 2022). Adult blood samples of *Larus michahellis* revealed the complete blood count data showing that there was a substantial variance in hemoglobin concentration and that breeding animals and birds had reduced basophil counts and larger proportions of platelets and heterophils. *Larus michahellis* blood parameters changed between non-breeding and breeding animals as well as between the sexes because of this (Garcia et al., 2010).

A greater WBC count in juvenile animals may be related to their increased social interactions, stress levels, capture, and pace of development. California condors have a distinctive stress leukogram that might conceal a disease-related leukocytosis, as previously described. Elderly condors had greater hemoglobin levels than younger birds, which may be due to the increasing oxygen requirement of birds that are in flight (Villegas et al., 2002).

Orange-winged parrots were used to create reference intervals for the CBC in order to analyses sex-and age-related changes. In comparison to males, the females had considerably larger levels of WBCs and lymphocytes (Vergneau-Grosset et al., 2016). The frequent stress reaction of bird species to transit and handling may explain the increased upper limit of the total WBC count. In peregrine falcons, Harris's hawks, and hyacinth macaws, this had been explicitly recorded. More specifically, the median total WBC count was 17.0- 21.0 (x$10^3$ cells/ µL). Other Psittaciformes species have not had comparable increases in total WBC counts documented explicitly, but it was notable that the upper limits for RIs determined in this study for heterophil percentage were also quite robust, with all individuals more than 90%. The lower limitations for lymphocytes in almost the same species were also reduced because of this strong heterophilia.

The hematological parameters in birds have strong association with ever changing seasonal variations. This dynamic relationship has been discussed in the section below.

**Seasonal Variations in Hematology**

In house sparrows (*Passer domesticus*), the RBC counts and HCT levels were higher during summer, while MCV was lower in the same period (Nimra et al., 2023). Another research indicates that body condition indices, such as PCV and hemoglobin concentration, can predict reproductive success in birds. However, these indices may not be reliable predictors of survival, suggesting a complex relationship between body condition and hematological parameters (Minias, 2015). Furthermore, PCV has a complex relationship with body condition and stress responses, with elevations potentially indicating dehydration or acute stress (Buehler et al., 2010).

Blood reference ranges can help assess the health of critically endangered species, such as the Spix's macaw, whose population is limited to 73 individuals. Hematologic evaluations of captive macaws showed no significant differences in hematologic markers between males and females. However, differences were observed between adult and juvenile birds in terms of heterophil and lymphocyte counts. Seasonal variations, such as higher hematocrit levels in winter compared to fall, were also noted (Foldenauer et al., 2007).

Breeding conditions and sex have a considerable impact on hemoglobin concentration. However, there were no alterations in the MCHC, PCV, MCH, RBC, MCV or WBC levels. Breeding *Larus michahellis* in the blood smear tests had a much smaller incidence of basophils and a considerably larger percentage of platelets and heterophils than non-breeders. The average hemoglobin (Hb) levels discovered in the Cha farinas Islands for *Larus michahellis* were generally compatible with those reported for other gulls, and while some of these investigations make reference to samples which were non-centrifuged. Breeding and sex condition interacted statistically significantly, with breeding-season males exhibiting the maximum hemoglobin levels. There was an obvious association between body mass and haematological parameter since male organisms tend to be larger than females, hence higher levels are expected in males (Fair et al., 2007).

Many bird species showed seasonal variations in haematological parameters. The summer blood counts tend to fall below those of spring and winter. Hematological parameters in many bird species are known to be affected by rapid changes in ambient variables as they go through various phases of breeding (Sergent et al., 2004).

Studies on seasonal variations in bird hematological and biochemical profiles abound. For species like guinea fowls, for example, notable seasonal fluctuations in RBCs counts, hematocrit, and hemoglobin levels have been noted; greater erythrocytic indices reported during the breeding season (Nalubamba et al., 2014). Likewise, changes in plasma protein levels and other biochemical markers usually follow reproductive and metabolic needs (Froman, and Feltmann, 2020).

Blood parameter changes in species from many different climatic zones have also been connected to seasonal variations in metabolic parameters like BMR and summit metabolism. Research on the southern red bishop (*Euplectes orix*) for example highlights the adaptive relevance of metabolic flexibility by revealing notable seasonal increases in BMR and hematological indices during winter. Important mediators of seasonal blood changes are habitat and food. For instance, birds living in colder inland areas show more seasonal changes in metabolic and hematological characteristics than those in milder coastal areas. As shown in omnivore and granivorous bird species, dietary changes also influence seasonal fluctuations in digestive enzyme activity and blood biochemistry (Van de Ven et al., 2012).

Furthermore, the breeding seasonality has been linked with immunity parameters and hormonal level fluctuations in birds and have been discussed in the following section.

**Association of Reproductive States, Immune Function**

Birds often experience immunosuppression during reproduction due to competing demands for resources: Egg-laying females allocate resources to yolk formation (e.g., proteins, lipids, antioxidants), reducing availability for immune responses. For example, female European starlings (Sturnus vulgaris) with higher egg production show weaker antibody responses (Hasselquist et al., 2001). Birds investing heavily in feeding chicks may downregulate inflammatory responses to conserve energy (Martin et al., 2008).

Seasonal changes in immunological responses have been documented; sex and reproductive state have been found to often influence these variations. Males showed more immunological parameter fluctuations, including macrophage concentrations, during the breeding season than in non-breeding seasons, according to a meta-analysis of wild birds (Valdebenito et al., 2020). These variations imply a complex link between seasonal environmental stresses, immune system, and reproductive hormones.

Stress hormones like corticosterone rise during breeding, indirectly suppressing immunity. For example, female tree sparrows (*Passer montanus*) show reduced lymphocyte proliferation during egg-laying (Ardia, 2005). Male house sparrows (*Passer domesticus*) with experimentally increased testosterone exhibit reduced antibody production (Owen-Ashley et al., 2004). Migratory birds (e.g., barn swallows, *Hirundo rustica*) prioritize immune function during migration but suppress it during breeding (Møller & Saino, 2004). Long-lived birds (e.g., albatrosses) invest more in immune maintenance, while short-lived species (e.g., passerines) prioritize reproduction (Tieleman et al., 2005). Furthermore, breeding-associated alterations in gonadotropin-releasing hormone (GnRH) and related physiological indicators have been recorded in tropical species such as the rufous-collared sparrow (*Zonotrichia capensis*) (Stevenson et al., 2012).

**Hormonal Profile and Breeding Seasonality**

Hormonal regulation plays a pivotal role in orchestrating reproductive cycles in birds, involving a complex interplay between neuroendocrine signals and environmental cues. Recent research has shed light on the intricate mechanisms underlying this regulation, enhancing our understanding of avian reproductive physiology. The avian reproductive system is primarily governed by the hypothalamic-pituitary-gonadal (HPG) axis, where the hypothalamus secretes gonadotropin-releasing hormone (GnRH), stimulating the anterior pituitary to release luteinizing hormone (LH) and follicle-stimulating hormone (FSH). These hormones act on the gonads, promoting gametogenesis and steroidogenesis. Recent studies have also highlighted the significance of thyroid hormones in modulating this axis, with local activation of thyroid hormones within the hypothalamus influencing seasonal reproduction. Enzymes like type 2 iodothyronine deiodinase (DIO2) play a crucial role in this process, regulating photoperiodic responses that impact reproductive timing (Nakao et al., 2008). Fluctuations in the estradiol, luteinizing hormone, prolactin and tri-iodothyronine hormones of birds occur during breeding, nesting and non- breeding seasons, as shown in the Fig. 1.

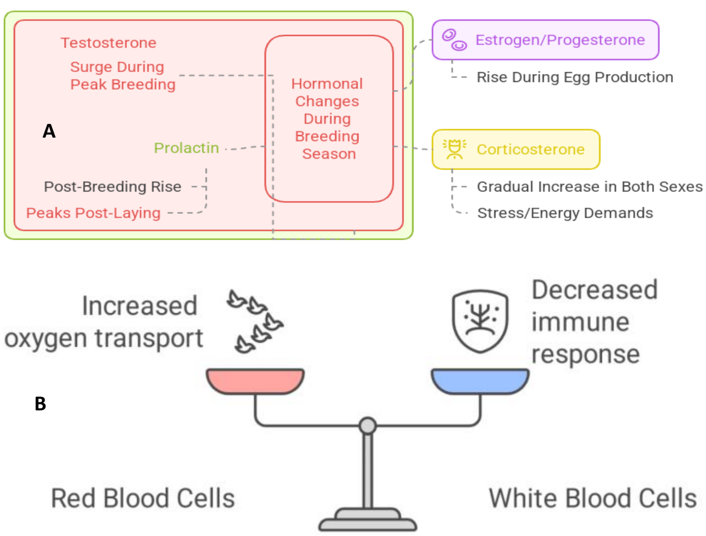


**Fig. 1:** A; Summarized view of the hormonal changes during breeding season in birds.
B; An illustration of tradeoff between elevated RBCs and oxygen level to immune response during breeding season.

The hypothalamic-pituitary-gonadal (HPG) axis remains central to avian reproduction. Gonadotropin-releasing hormone (GnRH) secretion stimulates pituitary release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), which regulate gonadal steroidogenesis and gametogenesis (Stevenson & Ball, 2020). Recent work highlights the role of kisspeptin, a neuropeptide upstream of GnRH, in mediating photoperiodic responses in Japanese quail (*Coturnix japonica*) (Ubuka et al., 2022). Seasonal plasticity in the avian brain, such as changes in GnRH neuron density and synaptic connectivity, is modulated by photoperiod and thyroid hormones (Stevenson et al., 2020). For example, in Arctic-breeding Lapland longspurs (*Calcarius lapponicus*), rapid gonadal recrudescence under continuous daylight involves thyroid hormone interactions with the HPG axis (Hahn et al., 2021).

In addition to gonadotropins, sex steroid hormones such as androgens and estrogens are central to avian reproductive behavior and physiology. Testosterone, a key androgen, influences brain development and behavior, with recent research emphasizing the role of androgen receptor signaling in avian species, particularly in galliform birds and songbirds (Nature Communications, 2024). Another important androgen, dehydroepiandrosterone (DHEA), has been implicated in regulating territorial aggression in species like the song sparrow (*Melospiza melodia*), especially during non-breeding seasons when gonadal testosterone levels are low. This suggests that adrenal androgen production provides an alternative mechanism for maintaining aggressive behaviors even in the absence of high gonadal testosterone levels (Soma et al., 2008). Testosterone and estradiol regulate both physiological and behavioral traits. In males, testosterone surges correlate with territorial aggression and courtship displays, though trade-offs with immune function are evident (Goymann et al., 2019). Female reproduction relies on estradiol-mediated yolk precursor synthesis (vitellogenin) in the liver (Williams, 2020). Experimental elevation of corticosterone in female house sparrows (*Passer domesticus*) suppresses estradiol, delaying clutch initiation (Lattin et al., 2021). Progesterone, critical for ovulation, is now linked to nest-building behavior in zebra finches (Prior et al., 2023). This interplay of hormones during breeding season of birds has been summarized in Fig. 1.

Chronic stress elevates corticosterone, which inhibits LH and testosterone via hypothalamic suppression (Lattin & Romero, 2020). A meta-analysis of 85 species confirmed that prolonged corticosterone elevation reduces clutch size and nest success (Schoenle et al., 2022). However, some urban-adapted species, like the dark-eyed junco (*Junco hyemalis*), show attenuated corticosterone responses, suggesting hormonal acclimatization to anthropogenic stressors (Atwell et al., 2023).

While much research has focused on male reproductive endocrinology, female reproductive physiology has historically been underexplored. Recent perspectives advocate for a more balanced approach, emphasizing that the hormonal regulation of reproductive behaviors in female birds is equally crucial. Studies underscore the need to examine how hormonal control influences reproductive decision-making, investment in offspring, and overall reproductive success (Williams et al., 2022).

Environmental factors, especially photoperiod, significantly influence reproductive cycles in birds. Increased exposure to daylight hours initiates hormonal cascades that facilitate gonadal development and activate reproductive processes. Molecular analyses indicate that light exposure during particular phases triggers the expression of genes in the mediobasal hypothalamus, enabling the conversion of thyroxine ($T_4$) to triiodothyronine ($T_3$), thereby enhancing reproductive activities. The findings underscore the complex interplay between environmental stimuli and endocrine responses in avian species (Yoshimura et al., 2003).

The interplay between hormones and behavior is further evident in studies exploring courtship displays and mating behaviors. Research on the golden-collared manakin (*Manacus vitellinus*) has revealed that sex differences in courtship behaviors are significantly influenced by androgen levels, with higher testosterone concentrations leading to increased frequency and intensity of display behaviors. These findings illustrate how endocrine mechanisms shape reproductive strategies in birds, ensuring reproductive success and species survival (Schlinger et al., 2021).

In quails and helmeted guinea fowls, a physiological trade-off is vital between reproductive and immune systems for reproductive performance and optimum survivability. This is indicated by elevated reproductive hormones and decreased WBC count during breeding season and vice versa during non-breeding season. Variation in morphometry of primary lymphoid organs (thymus and bursa of Fabricius) was much more pronounced. (Hayat et al., 2022; Ali et al., 2015). The seasonal variations significantly influence the physiological parameters of avian species, particularly blood parameters and hormonal levels (Table 1).

**Table 1:** Seasonal Variations in Avian hormonal and Blood Parameters in Hot and Cold Weather Regions:

| Aspect | Findings | Species/Study Subjects | References |
|---|---|---|---|
| Metabolic Adaptations | - Higher BMR in cold-acclimated birds compared to warm-acclimated ones.<br>- Winter birds showed a decrease in metabolic rates over time, while summer birds showed an increase. | House sparrows (*Passer domesticus*) | Swanson et al. (2021) |
| Hematological Changes | - Hematocrit values change during migration to enhance fitness. | Migratory bird species | Krause et al. (2016); Butler (2016) |
| Body Condition and Weather Patterns | - Body condition influenced by maximum and minimum temperatures, and precipitation with non-linear threshold effects. | General avian populations | Gardner et al. (2023) |
| Hematological Parameters | - Higher WBC counts during breeding season due to increased energy demands and pathogen exposure.<br>- Lower WBC counts in winter due to reduced metabolic activity.<br>- Higher hemoglobin concentrations in males during summer linked to testosterone-induced erythropoiesis.<br>- Increased MCV and MCH during breeding seasons to meet oxygen demands (Figure 1). | House sparrows (*Passer domesticus*) | Nimra et al. (2023); Razia et al., 2025 |
| Glucose Metabolism | - Elevated baseline glucose levels during the dry season due to increased energy requirements for thermoregulation.<br>- Elevated glucose levels due to stress during the dry season indicate an increased metabolic response to stress.<br>- Seasonal diet composition influences blood glucose levels as an adaptive strategy to resource availability. | Village weaver (*Ploceus cucullatus*) and Black-crowned waxbill (*Estrilda nonnula*) | Pouadjeu et al. (2023); Gutiérrez et al. (2014) |
| Hormonal Fluctuations | - Plasma testosterone levels significantly higher during the breeding season, promoting aggressive behaviors for territorial defense and mating success.<br>- Males consistently showed higher testosterone levels than females throughout the year.<br>- Testosterone levels declined post-egg-laying, correlating with a shift from mating efforts to parental care. | Campo miner (*Geositta poeciloptera*) | Lopes et al. (2021) |
| | - Higher serum thyroid hormone, T3 concentrations in winter, enhancing metabolic rate for cold adaptation. | General Avian species | Saarela & Heldmaier (1987) |
| | - Melatonin increases body temperature and cold resistance. | Chickens, Japanese quail | Saarela & Reiter (1994) |

**Conclusion**

Seasonal variations in blood parameters and hormones are absolutely essential for physiological adaptation of bird species to their dynamic environment. These fluctuations measure define energy balance, immune system, thermoregulation, and reproductive cycles. Increased red blood cell counts, hemoglobin concentrations, and hematocrit levels help to maximize oxygen delivery during physically demanding times; metabolic variations optimize energy utilization over seasons. Hormonal changes, especially those in corticosterone, testosterone, and GnRH ensure birds respond suitably to environmental challenges and reproductive demands. Photoperiod-induced hormonal changes also alter gonadal development and time of reproduction, therefore ensuring synchronization with optimal conditions. Interacting closely, hemostatic and endocrine systems reveal the tradeoffs between immunity, reproduction, and survival. Emphasizing the need of greater research in this field, a complete knowledge of these seasonal physiological changes provides insightful study of avian ecology, conservation, and the possible consequences of climate change on bird populations.

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