

Seasonal effects on hematological parameters of Senepol and Zebu cattle raised in Vietnam

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Abstract

Seasonal conditions are recognized as important environmental factors influencing physiological and hematological characteristics in cattle raised under tropical climates. The present study aimed to evaluate the effects of seasonal conditions on hematological parameters in Senepol and Zebu cattle raised in Vietnam. A total of 40 clinically healthy cattle, including 20 Senepol and 20 Zebu animals aged between 12 and 36 months, were used in the experiment. Blood samples were collected during both the rainy and dry seasons and analyzed using an automated hematology analyzer. The evaluated parameters included white blood cell count (WBC), red blood cell count (RBC), hemoglobin concentration (HGB), hematocrit (HCT), erythrocyte indices, and platelet-associated parameters. Statistical analysis was performed using a paired-samples t-test at a significance level of $P < 0.05$. The results showed that seasonal variation significantly influenced several hematological parameters in both cattle breeds. WBC values increased during the dry season, whereas RBC and HGB values tended to decrease. Hematocrit values showed a moderate increase during the dry season. Erythrocyte indices, including MCV, MCH, and MCHC, remained relatively stable across seasons, while RDW-CV and RDW-SD values generally increased during the dry season. Platelet counts decreased, whereas MPV and PDW values showed increasing trends in both breeds. Seasonal hematological fluctuations were observed in both breeds; however, no direct statistical comparisons between breeds were performed. The findings indicate that seasonal conditions can influence hematological characteristics in imported cattle breeds raised in Vietnam and likely reflect normal physiological responses to seasonal environmental variation. These results provide useful reference data for health monitoring, veterinary assessment, and management strategies for imported cattle raised under tropical climatic conditions.

Keywords: hematological parameters, seasonal variation, tropical climate, Senepol cattle, Zebu cattle.

Efeitos sazonais nos parâmetros hematológicos de bovinos Senepol e Zebu criados no Vietnã

Resumo

As condições sazonais são reconhecidas como importantes fatores ambientais que influenciam as características fisiológicas e hematológicas de bovinos criados em climas tropicais. O presente estudo teve como objetivo avaliar os efeitos das condições sazonais sobre os parâmetros hematológicos de bovinos Senepol e Zebu criados no Vietnã. Um total de 40 bovinos clinicamente saudáveis, incluindo 20 animais da raça Senepol e 20 da raça Zebu, com idades entre 12 e 36 meses, foi utilizado no experimento. Amostras de sangue foram coletadas durante as estações chuvosa e seca e analisadas utilizando um analisador hematológico automatizado. Os parâmetros avaliados incluíram contagem de leucócitos (WBC), contagem de eritrócitos (RBC), concentração de hemoglobina (HGB), hematócrito (HCT), índices eritrocitários e parâmetros plaquetários. A análise estatística foi realizada utilizando o teste t pareado, considerando nível de significância de $P < 0,05$. Os resultados demonstraram que a

variação sazonal influenciou significativamente diversos parâmetros hematológicos em ambas as raças bovinas. Os valores de WBC aumentaram durante a estação seca, enquanto os valores de RBC e HGB apresentaram tendência de redução. Os valores de hematócrito mostraram aumento moderado durante a estação seca. Os índices eritrocitários, incluindo MCV, MCH e MCHC, permaneceram relativamente estáveis entre as estações, enquanto os valores de RDW-CV e RDW-SD aumentaram, em geral, durante a estação seca. As contagens de plaquetas diminuíram, enquanto os valores de MPV e PDW apresentaram tendência de aumento em ambas as raças. Foram observadas flutuações hematológicas sazonais em ambas as raças; entretanto, não foram realizadas comparações estatísticas diretas entre elas. Os resultados indicam que as condições sazonais podem influenciar as características hematológicas de bovinos criados no Vietnã e provavelmente refletem respostas fisiológicas normais às variações ambientais sazonais. Esses achados fornecem dados de referência úteis para o monitoramento da saúde, avaliação veterinária e estratégias de manejo de bovinos criados sob condições climáticas tropicais.

Palavras-chave: parâmetros hematológicos; variação sazonal; clima tropical; bovinos Senepol; bovinos Zebu.

1. Introduction

Cattle production plays an increasingly important role in food security and agricultural sustainability, particularly in tropical and subtropical regions where environmental conditions strongly influence animal productivity and adaptation. In Vietnam, beef cattle farming has expanded considerably in recent years under intensive and semi-intensive production systems. The growing demand for high-quality beef has promoted the introduction and acclimatization of imported cattle breeds with favorable productive and adaptive traits.

Among imported breeds, Senepol cattle have received considerable attention because of their tolerance to high environmental temperatures, resistance to solar radiation, and ability to maintain productive performance under tropical climatic conditions. Zebu cattle are likewise recognized for their adaptability to hot environments, disease resistance, and efficient feed utilization. The incorporation of Zebu genetics into beef production systems has contributed to improved reproductive performance and environmental adaptability in many tropical countries. In Vietnam, imported and crossbred cattle have increasingly been integrated into breeding programs to improve beef productivity and production efficiency. Hoàng Thị Ngân et al. (2021) reported favorable adaptive and reproductive performance in imported Red Angus cattle raised under Vietnamese conditions, while Trần Thị Ánh Nguyệt et al. (2025) described hematological characteristics in Brahman and Wagyu crossbred cattle.

Hematological parameters are widely used as important indicators for evaluating physiological status, immune response, metabolic activity, and environmental adaptation in livestock animals. Hematological parameters provide valuable information regarding oxygen transport, inflammatory responses, and maintenance of physiological homeostasis in cattle (Onasanya et al., 2015). Platelet-associated parameters are also closely related to inflammatory and hemostatic processes (Watson et al., 2020). In cattle, hematological values may vary according to breed, nutritional status, physiological condition, environmental factors, and management systems (Onasanya et al., 2015).

Environmental stress, particularly heat stress and seasonal variation, has been reported to influence physiological and hematological characteristics in cattle. Berian et al. (2019) demonstrated that elevated environmental temperatures altered several hematological and biochemical parameters in crossbred dairy cattle. Similarly, Blond et al. (2024) reported that heat stress significantly affected inflammatory, metabolic, and physiological blood indicators in cows. Seasonal fluctuations in hematological profiles were also observed by Mekroud et al. (2021), who suggested that climatic conditions substantially influence physiological status in Holstein dairy cattle. Comparable findings were reported by Abera et al. (2021) and Velayudhan et al. (2023), who described hematological and physiological responses associated with heat stress adaptation in cattle raised under tropical and subtropical conditions.

Recent studies have further demonstrated that hematological responses to environmental stress may differ according to breed adaptability and thermal tolerance. Chen et al. (2023) observed distinct physiological and blood responses between heat-tolerant and heat-sensitive dairy cattle under thermal stress conditions. Likewise, Yang et al. (2022) identified differences in hematological and biochemical profiles between Senepol and Yunling cattle, highlighting the importance of breed-specific adaptation to environmental conditions. These findings indicate that hematological evaluation may serve as a useful approach for assessing the adaptive capacity of imported cattle breeds under tropical production systems.

Despite the increasing utilization of Senepol and Zebu cattle in Vietnam, information regarding seasonal influences on their hematological characteristics under local tropical conditions remains limited. Therefore, the

present study aimed to evaluate the effects of seasonal variation on hematological parameters in Senepol and Zebu cattle raised in Vietnam. The findings of this study may contribute to the establishment of reference hematological values for imported cattle breeds and provide useful information for veterinary diagnosis, health monitoring, and future studies on cattle adaptation under tropical environmental conditions.

2. Materials and Methods

2.1 Animals and study area

The study was conducted on Senepol and Zebu cattle raised in Vietnam under tropical climatic conditions. A total of 40 clinically healthy cattle were included in the study, comprising 20 Senepol cattle (10 males and 10 females) and 20 Zebu cattle (10 males and 10 females), aged between 12 and 36 months. Animals were randomly selected from the study herd and were clinically healthy throughout the sampling period. Male and female animals were presented separately for descriptive purposes only, whereas the statistical analyses focused on seasonal comparisons within each breed. All cattle were considered clinically healthy based on normal feeding behavior, locomotion, physical activity, and the absence of abnormal clinical signs or disease symptoms. Pregnant and diseased animals were excluded from the study.

The study was conducted in southern Vietnam, a region characterized by a tropical monsoon climate with two distinct seasons: a rainy season from May to November and a dry season from December to April. The annual average ambient temperature is approximately 27.96 °C, with the highest monthly average temperature recorded in April (30.5 °C) and the lowest in December (26.0 °C). Relative humidity generally ranges from 66% to 86%, depending on seasonal conditions.

To characterize the environmental conditions during blood sampling, meteorological data, including ambient temperature and relative humidity corresponding to each sampling date, were obtained from the local hydro-meteorological station. Based on these data, the Temperature–Humidity Index (THI) was calculated to assess the thermal conditions during each sampling period and was used to support the interpretation of seasonal hematological variations observed in the studied cattle. The recorded environmental conditions confirmed that the rainy and dry seasons differed in both ambient temperature and relative humidity, providing an appropriate basis for evaluating seasonal influences on hematological parameters.

2.2 Hematological parameters

The evaluated hematological parameters included white blood cell count (WBC), red blood cell count (RBC), hemoglobin concentration (HGB), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), red blood cell distribution width (RDW-CV and RDW-SD), platelet count (PLT), mean platelet volume (MPV), plateletcrit (PCT), platelet distribution width (PDW), neutrophils (NEUT), monocytes (MON), and lymphocytes (LYM). All hematological evaluations were performed under normal physiological conditions.

2.3 Blood sample collection and hematological analysis

Blood samples were collected in the morning between 07:00 and 08:00 h before feeding. Each animal was sampled three times during the rainy season and three times during the dry season. Blood was collected from the coccygeal vein using sterile syringes and transferred immediately into EDTA-containing anticoagulant tubes. After collection, samples were gently mixed to prevent hemolysis and transported under cooled conditions to the laboratory for analysis. Samples were stored at 2–8 °C and analyzed immediately after arrival at the laboratory. All hematological parameters were analyzed using a Hemascreen 18 automated hematology analyzer (Hospitex Diagnostics, Sesto Fiorentino, Florence, Italy), according to the manufacturer's instructions.

2.4 Statistical analysis

Each animal was sampled three times during the rainy season and three times during the dry season. For each hematological parameter, the three measurements obtained within each season were averaged to generate one representative seasonal mean per animal, thereby ensuring that each animal contributed a single value for each season in the statistical analysis. Data were expressed as mean $\pm$ standard deviation (Mean $\pm$ SD). Statistical analyses were performed using IBM SPSS Statistics version 20. Differences between the rainy and dry seasons

were evaluated using paired-samples t-tests based on the seasonal mean values of each animal. Statistical significance was set at $P < 0.05$.

3. Results

3.1 Hematological parameters of Senepol cattle under seasonal conditions

The hematological parameters of Senepol cattle during the rainy and dry seasons are presented in (Table 1). Several hematological indices were significantly affected by seasonal variation ($P < 0.05$).

White blood cell count (WBC) increased during the dry season in both sexes. In male Senepol cattle, WBC increased from 13.90 ± 3.58 K/ μ L during the rainy season to 15.90 ± 4.58 K/ μ L during the dry season. A similar increase was observed in females, from 13.23 ± 3.55 K/ μ L to 14.23 ± 4.55 K/ μ L.

In contrast, red blood cell count (RBC) and hemoglobin concentration (HGB) decreased during the dry season. Male cattle showed a reduction in RBC values from 9.61 ± 2.53 M/ μ L in the rainy season to 7.61 ± 2.32 M/ μ L in the dry season, whereas HGB decreased from 12.65 ± 2.91 g/dL to 10.26 ± 3.56 g/dL. Similar trends were observed in female cattle. Hematocrit (HCT) values showed a slight increase during the dry season, reaching $32.51 \pm 4.78\%$ in males and $31.62 \pm 4.65\%$ in females.

Erythrocyte indices, including MCV, MCH, and MCHC, showed relatively small seasonal variation. However, RDW-CV and RDW-SD values were higher during the dry season. In male cattle, RDW-CV increased from $25.03 \pm 2.81\%$ to $27.38 \pm 3.85\%$, while RDW-SD increased from 30.87 ± 3.28 fL to 33.83 ± 4.99 fL.

Platelet-related parameters also differed between seasons. Platelet count (PLT) decreased from 725.36 ± 59.25 K/ μ L during the rainy season to 640.87 ± 77.62 K/ μ L during the dry season in male cattle. In contrast, mean platelet volume (MPV) and platelet distribution width (PDW) increased during the dry season in both sexes.

Table 1. Hematological parameters of Senepol cattle during the rainy and dry seasons (Mean $\pm$ SD).

Parameters	Rainy season		Dry season	
	Male	Female	Male	Female
	(n = 10)	(n = 10)	(n = 10)	(n = 10)
WBC (K/ μ L)	$13.90^a \pm 3.58$	$13.23^a \pm 3.55$	$15.90^c \pm 4.58$	$14.23^b \pm 4.55$
RBC (M/ μ L)	$9.61^a \pm 2.53$	$9.62^a \pm 1.09$	$7.61^b \pm 2.32$	$7.76^b \pm 1.09$
HGB (g/dL)	$12.65^a \pm 2.91$	$12.32^a \pm 2.09$	$10.26^b \pm 3.56$	$10.32^b \pm 2.94$
HCT (%)	$30.35^a \pm 5.73$	$30.68^a \pm 4.83$	$32.51^c \pm 4.78$	$31.62^b \pm 4.65$
MCV (fL)	$43.66^a \pm 7.78$	$42.68^a \pm 5.57$	$44.56^b \pm 6.47$	$46.62^c \pm 4.73$
MCH (pg)	$14.76^a \pm 3.27$	$15.14^b \pm 1.72$	$15.07^b \pm 2.70$	$15.14^b \pm 1.72$
MCHC (g/dL)	$35.61^a \pm 3.48$	$34.42^a \pm 3.54$	$36.96^a \pm 3.40$	$35.47^a \pm 3.50$
RDW-CV (%)	$25.03^a \pm 2.81$	$24.65^a \pm 3.16$	$27.38^c \pm 3.85$	$26.52^b \pm 4.67$
RDW-SD (fL)	$30.87^a \pm 3.28$	$30.16^a \pm 2.82$	$33.83^c \pm 4.99$	$32.96^b \pm 3.42$
PLT (K/ μ L)	$725.36^a \pm 59.25$	$646.95^b \pm 66.81$	$640.87^b \pm 77.62$	$546.95^c \pm 76.68$
MPV (fL)	$4.86^a \pm 0.92$	$4.63^a \pm 0.88$	$5.22^b \pm 1.12$	$5.76^b \pm 0.81$
PCT (%)	$0.16^a \pm 0.07$	$0.17^b \pm 0.04$	$0.15^a \pm 0.04$	$0.16^b \pm 0.03$
PDW (fL)	$6.85^a \pm 1.14$	$6.28^a \pm 1.27$	$7.14^b \pm 0.54$	$7.22^b \pm 0.87$

Note: Mean $\pm$ SD values followed by different letters within the same row indicate significant differences at $P < 0.05$. Source: Authors, 2026.

3.2. Hematological parameters of Zebu cattle under seasonal conditions

The hematological profile of Zebu cattle across the rainy and dry seasons is summarized in (Table 2). Seasonal fluctuations were observed in several blood parameters, although the magnitude of variation differed among hematological indices and between sexes.

Leukocyte values tended to be higher during the dry season. In male Zebu cattle, WBC values increased from 14.73 ± 1.45 K/ μ L in the rainy season to 15.73 ± 2.34 K/ μ L during the dry season. Female animals showed a comparable trend, with WBC values rising from 14.84 ± 1.87 K/ μ L to 15.84 ± 2.71 K/ μ L.

A reduction in erythrocyte-related parameters was also observed during the dry season. In males, RBC values declined from 8.27 ± 3.39 M/ μ L to 7.73 ± 2.95 M/ μ L, while HGB decreased from 12.46 ± 2.51 g/dL to 11.34 ± 2.55 g/dL. Female cattle exhibited a similar pattern, with HGB values decreasing from 13.83 ± 3.62 g/dL in the rainy season to 11.26 ± 2.46 g/dL in the dry season. In contrast, HCT values showed a moderate increase under dry-season conditions, reaching $33.10 \pm 3.70\%$ in males and $34.00 \pm 4.55\%$ in females.

The erythrocyte indices MCV, MCH, and MCHC remained relatively stable throughout the experimental period. Among these variables, MCV values ranged from 36.98 ± 4.34 fL to 38.62 ± 4.18 fL across seasons and sexes. Meanwhile, RDW-CV values were generally higher during the dry season, increasing to $27.84 \pm 3.45\%$ in males and $27.96 \pm 3.38\%$ in females.

Clear seasonal differences were additionally recorded for platelet-associated parameters. Platelet counts declined during the dry season in both sexes, decreasing from 436.83 ± 71.42 K/ μ L to 365.82 ± 59.46 K/ μ L in males and from 467.56 ± 61.19 K/ μ L to 367.55 ± 61.77 K/ μ L in females. Conversely, MPV and PDW values showed an upward trend during the same period.

Table 2. Hematological parameters of Zebu cattle during the rainy and dry seasons (Mean $\pm$ SD).

Parameters	Rainy season		Dry season	
	Male (n = 10)	Female (n = 10)	Male (n = 10)	Female (n = 10)
WBC (K/ μ L)	$14.73^a \pm 1.45$	$14.84^a \pm 1.87$	$15.73^b \pm 2.34$	$15.84^b \pm 2.71$
RBC (M/ μ L)	$8.27^a \pm 3.39$	$8.38^a \pm 2.81$	$7.73^b \pm 2.95$	$7.56^b \pm 3.53$
HGB (g/dL)	$12.46^a \pm 2.51$	$13.83^b \pm 3.62$	$11.34^c \pm 2.55$	$11.26^c \pm 2.46$
HCT (%)	$29.10^a \pm 4.07$	$30.16^a \pm 3.15$	$33.10^b \pm 3.70$	$34.00^b \pm 4.55$
MCV (fL)	$37.21^a \pm 3.46$	$38.62^b \pm 4.18$	$36.98^a \pm 4.34$	$37.36^b \pm 4.64$
MCH (pg)	$14.59^a \pm 2.26$	$15.13^a \pm 3.73$	$14.55^a \pm 3.12$	$15.77^a \pm 4.36$
MCHC (g/dL)	$36.36^a \pm 4.38$	$35.12^a \pm 3.76$	$35.67^a \pm 3.64$	$35.19^a \pm 2.96$
RDW-CV (%)	$26.54^a \pm 2.21$	$26.93^a \pm 2.93$	$27.84^b \pm 3.45$	$27.96^b \pm 3.38$
RDW-SD (fL)	$31.68^a \pm 3.53$	$31.34^a \pm 4.58$	$32.76^a \pm 5.35$	$31.88^a \pm 4.94$
PLT (K/ μ L)	$436.83^a \pm 71.42$	$467.56^a \pm 61.19$	$365.52^b \pm 59.46$	$367.55^b \pm 61.77$
MPV (fL)	$7.26^a \pm 1.02$	$7.31^b \pm 0.83$	$8.52^a \pm 0.95$	$8.23^b \pm 1.31$
PCT (%)	$0.26^a \pm 0.08$	$0.25^a \pm 0.06$	$0.24^a \pm 0.10$	$0.24^a \pm 0.09$
PDW (fL)	$7.75^a \pm 1.82$	$7.92^a \pm 1.46$	$8.97^b \pm 2.08$	$9.12^b \pm 1.94$

Note: Mean $\pm$ SD values followed by different letters within the same row indicate significant differences at $P < 0.05$. Source: Authors, 2026.

4. Discussion

The present study demonstrated that seasonal conditions influenced several hematological parameters in both Senepol and Zebu cattle raised under tropical conditions in Vietnam. Variations were mainly observed in leukocyte counts, erythrocyte-associated parameters, and platelet indices, suggesting that seasonal environmental conditions affect physiological homeostasis in imported cattle breeds. Comparison with the bovine hematological reference intervals reported in the Merck Veterinary Manual (Fielder, 2024) indicated that most hematological parameters remained within the normal physiological ranges for clinically healthy cattle despite the observed seasonal variations. These findings suggest that the seasonal changes observed in the present study likely represent normal physiological variation rather than clinically significant hematological abnormalities.

One of the most noticeable findings in the present study was the increase in WBC values during the dry season in both breeds. Elevated leukocyte counts may reflect responses associated with seasonal environmental conditions

and possibly increased thermal load. However, because physiological indicators of heat stress were not measured, these findings should be interpreted as associations rather than direct evidence of heat stress. Similar observations were reported by Berian et al. (2019), who found that heat stress significantly altered hematological and biochemical profiles in crossbred dairy cattle. Blond et al. (2024) likewise demonstrated that elevated ambient temperature affected inflammatory and metabolic blood parameters in cows.

Previous studies have suggested that increased thermal load may influence endocrine and inflammatory responses, thereby affecting leukocyte dynamics and immune regulation in cattle. Nevertheless, the present study did not directly evaluate physiological indicators of heat stress. The relatively moderate increase in WBC values observed in Zebu cattle is consistent with previous reports describing the thermotolerance of *Bos indicus*-derived breeds, although the present study was not designed to directly compare breed-specific adaptive capacity. Habimana et al. (2023) emphasized that tropical cattle breeds generally possess superior mechanisms for coping with heat stress compared with more heat-sensitive breeds, contributing to the maintenance of physiological stability during periods of environmental challenge.

In contrast, Senepol cattle exhibited slightly greater fluctuations in several hematological variables, although the observed values remained within physiological ranges reported for adapted beef cattle breeds. Red blood cell count and hemoglobin concentration decreased during the dry season in both breeds. Similar trends have been reported in cattle exposed to elevated environmental temperatures and seasonal challenges. Chen et al. (2023) reported that heat-sensitive cattle exhibited reductions in erythrocyte-related parameters under thermal stress, suggesting impaired oxygen transport efficiency and altered physiological regulation.

Comparable findings were also reported by Abera et al. (2021), who observed significant seasonal changes in physiological and biochemical indicators in cattle raised under tropical conditions. Reductions in RBC and HGB values may reflect adjustments to seasonal climatic conditions, although direct evidence of heat stress was not assessed in the present study. Importantly, the observed RBC and HGB values remained within the established bovine hematological reference intervals reported in the Merck Veterinary Manual (Fielder, 2024), indicating that these seasonal variations were more likely to represent normal physiological fluctuations than clinically significant hematological abnormalities.

Interestingly, despite reductions in RBC and HGB values, hematocrit values showed a slight increase during the dry season. This pattern suggests that hematological responses to seasonal stress are complex and may involve changes in plasma volume, erythrocyte morphology, and hydration status. The slight increase in hematocrit despite reductions in RBC and HGB may be associated with seasonal changes in plasma volume and hydration status, which have previously been described in cattle exposed to different environmental conditions (Abera et al., 2021; Mekroud et al., 2021). Variations in hematocrit may therefore reflect compensatory physiological mechanisms related to seasonal environmental changes.

In both breeds, MCV, MCH, and MCHC values remained relatively stable across seasons. These findings indicate that although environmental conditions influenced erythrocyte quantity, the structural characteristics and hemoglobin content of individual erythrocytes were less affected. Similar stability in erythrocyte indices was reported by Mekroud et al. (2021), who found relatively limited seasonal variation in several hematological indices of Holstein cattle. Yang et al. (2022) also reported that Senepol cattle maintained relatively stable hematological profiles under different environmental conditions, supporting the resilience of this breed under tropical climates.

The increase in RDW-CV and RDW-SD values during the dry season, particularly in Senepol cattle, may indicate greater variation in erythrocyte size distribution under environmental stress conditions. Elevated RDW values are often associated with intensified erythropoietic activity and altered erythrocyte turnover. Velayudhan et al. (2023) suggested that heat stress may induce physiological and hematological adjustments associated with oxidative and metabolic stress responses in cattle. Increased RDW values observed in the present study may therefore reflect compensatory hematopoietic responses during periods of elevated environmental temperature.

Platelet-associated parameters also showed clear seasonal variation. Platelet counts decreased during the dry season, whereas MPV and PDW values generally increased in both breeds. Platelets are increasingly recognized as important components of inflammatory and physiological stress responses. Watson et al. (2020) emphasized the role of platelets in inflammation, tissue repair, and hemostatic regulation. Similarly, Blond et al. (2024) observed that heat stress significantly affected several blood indicators associated with inflammatory and metabolic activity in cows. Increased MPV and PDW values may indicate enhanced platelet activation or compensatory circulatory responses under seasonal environmental conditions.

Although both breeds exhibited seasonal hematological fluctuations, descriptive comparisons suggested that the magnitude of seasonal changes differed between Senepol and Zebu cattle. However, because direct statistical

comparisons between breeds were not performed, these observations should be interpreted with caution. Previous studies have demonstrated that breed-related differences play an important role in physiological responses to heat stress (Chen et al., 2023; Habimana et al., 2023).

Therefore, the apparent differences observed between Senepol and Zebu cattle in the present study may warrant further investigation using appropriate statistical models to evaluate breed-specific responses under tropical environmental conditions. Nevertheless, most hematological values observed in the present study remained within the normal physiological ranges reported for tropical and adapted cattle breeds (Yang et al., 2022; Mladenović et al., 2024).

The present findings indicate that seasonal variation can significantly influence hematological characteristics in imported cattle breeds raised under tropical environmental conditions in Vietnam. The observed hematological changes may reflect seasonal influences on immune regulation and metabolic homeostasis. Because physiological indicators of heat stress were not directly measured, these findings should be interpreted as associations rather than evidence of a causal relationship between heat stress and hematological alterations. These results provide additional reference data for evaluating cattle health and may contribute to future studies on imported beef cattle production under tropical climatic conditions.

5. Conclusions

Seasonal variation significantly influenced several hematological parameters in both Senepol and Zebu cattle raised under tropical environmental conditions in Vietnam. Variations were primarily observed in leukocyte counts, erythrocyte-related indices, and platelet-associated parameters, suggesting physiological responses associated with seasonal environmental conditions. Descriptive comparisons indicated that the magnitude of seasonal hematological changes differed between the two breeds; however, direct statistical comparisons between breeds were not performed. Therefore, breed-specific differences should be interpreted with caution. The findings provide useful reference data for health monitoring, veterinary assessment, and management strategies for imported cattle raised under tropical climatic conditions.

6. Acknowledgments

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7. Authors' Contributions

Nguyen Thi Thu Hien contributed to the study conception and design, data collection, laboratory analysis, statistical analysis, interpretation of results, and manuscript preparation. *Tran Thi Anh Nguyet* contributed to sample collection and assisted with data collection during the study.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

This study was conducted under the institutional research project entitled "Assessment of Hematological Parameters in Zebu, Brahman, and Senepol Cattle", approved by Thu Dau Mot University (Decision No. 465/QĐ-ĐHTDM, dated April 9, 2024). Blood samples were collected from clinically healthy cattle by experienced veterinarians using routine veterinary procedures. No experimental treatment or invasive procedure beyond standard blood collection was performed specifically for research purposes. At the time the study was conducted, no separate Institutional Animal Ethics Committee approval was available for this type of routine veterinary blood sampling. All procedures complied with institutional guidelines for animal care and

internationally accepted principles of animal welfare, and every effort was made to minimize animal stress and discomfort during animal handling and blood collection.

10. Artificial Intelligence Statement: Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that generative AI and AI-assisted tools were used exclusively to generate the Graphical Abstract and to perform grammar corrections in the manuscript. The Graphical Abstract was created entirely by AI based on the authors' instructions and did not incorporate any images provided by the authors. No AI tools were used for the scientific writing, study design, data collection, data analysis, interpretation of results, or preparation of the scientific content of the manuscript. The AI-generated Graphical Abstract and grammar corrections were carefully reviewed, verified, and approved by the authors, who assume full responsibility for the accuracy, integrity, and originality of the work. The use of AI is disclosed in the Graphical Abstract caption. AI tools are not authors and assume no responsibility for the content of the manuscript.

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Informed Consent Statement

Not applicable.

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