



Putative Blood Biomarkers on Tropical Resilience in Philippine Native and Crossbred Heifers

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(Received 10-02-2026; Revised 04-05-2026; Accepted 05-05-2026)

ABSTRACT

Hematological values are essential in understanding the health of an animal. Interpretation of these values must consequently be clinically accurate. These values are also putative biomarkers for resiliency under tropical conditions. In this study, blood profiles of Panay Native (PN) and crossbred Holstein x Jersey (HxJ) heifer cattle were compared to identify biomarkers of tropical resilience. Blood samples from 58 heifers were analyzed using General Linear Models and multivariate techniques. Results demonstrated that temperate-derived Reference Intervals frequently misclassified healthy animals. The Panay cattle exhibited a superior erythropoietic phenotype (significantly higher RBC, HGB, PCV, $p < 0.001$), driven by a unique regulatory mechanism in which increased red cell counts were balanced by reduced cell volume (negative RBC-MCV correlation, $r = -0.76$, $p < 0.001$). In contrast, crossbred heifers exhibited signs of compensated hemolysis, characterized by regenerative anemia (>55% prevalence). Multivariate analysis revealed a clear divergence in physiological strategies, with crossbred cattle displaying a trade-off between erythropoiesis and immune stability, whereas the native cattle demonstrated superior homeostatic stability. Overall, this study confirms that non-localized reference intervals misinterpret the physiological realities of tropical herds, causing systemic diagnostic errors. Furthermore, the unique regulatory patterns substantiate the 'viscosity clamp' or the uncoupling of cell count and volume as putative biomarkers of innate climate resilience in indigenous cattle.

Keywords: anemia score; bovine hematology; reference intervals; tropical resilience

INTRODUCTION

The Philippine dairy sector is highly reliant on imports, producing less than 1% of the national demand (Department of Agriculture Press Office, 2024). To bridge this gap, upgrading programs have extensively utilized Holstein x Jersey (HxJ) (*Bos taurus taurus*) crosses to improve milk yields (Lagare, 2026). However, the introduction of temperate genetics into tropical environments often compromises herd health and milk performance (Polsky & Von Keyserlingk, 2017). This causes metabolic instability, exacerbated by heat stress and vector-borne diseases (Xiong *et al.*, 2025). Addressing these failures requires a critical understanding between the concepts of adaptation and resilience.

Adaptation refers to the accumulation of fixed genetic traits over evolutionary time, which allows a population to survive in a specific environment (Henry *et al.*, 2018). Less-dense coat surface is an example of an evolutionary morphological feature that facilitates rapid heat dissipation through sweating from the animal's body back to its environment (Santos *et al.*, 2022). Whereas resilience is defined as the dynamic capacity of an animal to minimize the impact of disturbance (Berghof *et al.*, 2019). This could manifest via high heat load or a quick return to homeostasis (Colditz & Hine, 2016). In other words, while adaptation is a passive state of being fit to an environment, resilience is the active response to environmental adjustments. Tropical resilience, in this context, refers to the ability to maintain functional physiological stability even with

high Temperature-Humidity indices or disease-related challenges.

Indigenous or native cattle populations, such as Panay Native (PN) (*Bos taurus indicus*) cattle are perceived to exhibit tropical resilience. Previous breeding programs in the Philippines tend to neglect the underlying mechanisms that made these cattle exceptional under the tropics (Ortega *et al.*, 2021). Recently, a study by Dominguez *et al.* (2026) confirmed that these populations have specific selection signatures associated with tropical insular adaptation and resilience. Thereby, an exploration of their physiological processes is of the essence. A robust putative biomarker for measuring qualities of resiliency is the hematological profile. Observed variations in erythrograms and leukocyte differentials provide insights into the animal's thermoregulatory capacity (Sejian *et al.*, 2021) and immunocompetence (Rashamol *et al.*, 2018). Sejian *et al.* (2018) reported indicators including erythrocyte osmotic fragility, Neutrophil:Lymphocyte (N:L) ratio, and the maintenance of Packed Cell Volume (PCV) without hemoconcentration.

To maximize the usage of these biomarkers, accurate veterinary diagnostics is paramount. At its core, is a Reference Intervals (RIs) that reflects the specific genetic, environmental, and management factors of the population (Quagliardi *et al.*, 2024). Unfortunately, the Philippines continues to rely on antiquated, foreign-derived RIs such as those founded by Oscar William Schalm in 1965. Clinical misdiagnosis may potentially emanate from the continued use of these outdated, non-contextual, and non-native intervals to tropical herds (Chantip *et al.*, 2025). This mismanagement may mask anemia in susceptible crossbreeds or misinterpret distinct adaptive physiological baselines of indigenous breeds. Currently, no published hematological standards exist for Philippine native animals and temperate breeds under Philippine conditions. This creates a strategic gap in the evidence needed to support selection for tropical-resilient traits and biomarkers.

Therefore, this study intended to assess hematological values specific to each breed in PN and HxJ heifers managed under tropical conditions. It sought to quantify differences in erythropoietic and immunological profiles to identify putative biomarkers of tropical resilience. This pioneering data will guide the establishment of local RIs, which are essential for correcting diagnostic standards. Ultimately, this provides the biological rationale for developing composite breeds combining the metabolic efficiency of native cattle with the production potential of exotic breeds.

MATERIALS AND METHODS

Ethics Approval

All experimental designs and procedures were approved by the Institutional Animal Care and Use Committee (IACUC) of the University of the Philippines Los Baños (UPLB) under reference number UPLB-2025-025 (Protocol Review No. CAFS-2024-034).

Experimental Site and Meteorological Data

This study was conducted at the Dairy Training and Research Institute (DTRI) farm, UPLB, Laguna (14.17° N, 121.24° E; 100 m elevation). Meteorological data indicated an average ambient temperature of 27 °C, a total rainfall of 246.8 mm, and a mean relative humidity of 85% during the wet season (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2024).

The Temperature-Humidity Index (THI) was calculated using the equation developed by Thom (1959). The THI is an indicator of environmental thermal stress and is used to assess heat load in animals. Multiple recent studies validated this formula and it remains a highly utilized standard in bovine populations under tropical conditions (e.g., Yadav *et al.*, 2022; Ekine-Dzivenu *et al.*, 2020; Jeelani *et al.*, 2019):

$$THI = (0.8 * T) + [RH/100 * (T - 14.4)] + 46.4$$

where T is ambient temperature (°C) and RH is relative humidity. The THI for the sampling period was approximately 78.71.

Animals and Management

The Panay Native (PN) cattle represent locally adapted indigenous stock from Panay and Guimaras islands (Dominguez *et al.*, 2026). This research flock was obtained in 2021 and maintained at the DTRI farm, UPLB. Meanwhile, the Holstein x Jersey (HxJ) crossbreeds were acquired through the genetic improvement program of the Department of Agriculture-National Dairy Authority (DA-NDA).

Animal housing and management strictly adhered to the Philippine National Standard (PNS) Codes of Practice for Good Animal Husbandry Practices for Dairy Cattle (Bureau of Agriculture and Fisheries Standards [BAFS], 2017) and Beef Cattle (BAFS, 2023) to ensure freedom from hunger, malnutrition, and thermal discomfort. The HxJ heifers were confined in individual pens to minimize heat stress, as they are highly susceptible to the hot and humid tropical climate (Habimana *et al.*, 2023; Das *et al.*, 2016). The PN cattle were managed under a semi-extensive rotational grazing system in accordance with The Philippine Recommendations for Cattle Production (Philippine Council for Agriculture, Forestry and Natural Resources Research and Development, 2008).

Feeding regimens were specialized to ensure sufficient nutrient intake based on their management plan. According to the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (2010), heifers are recommended to consume 55%-65% Total Digestible Nutrients (TDN) and 12%-16% Crude Protein (CP). Thus, rations for both groups were formulated to achieve a target dry matter (DM) intake equivalent to 3% of their body weight (Department of Science and Technology - PCAARRD, 2010). Para grass (*Brachiaria mutica*) served as the shared basal forage, providing a high-yielding, palatable feed

with CP (8%-16.7%) and TDN (56%-60%) content on a DM basis. A 70:30 ratio cut-and-carry dietary system was fed to the HxJ heifers twice daily. This consists of forage grasses (70% Para grass and 30% commercial concentrate) that were mechanistically harvested and directly supplied to the animals. On the other hand, the PN cattle grazed exclusively on Para grass-dominated pastures without concentrate supplementation. They were rotated when approximately two-thirds of the vegetation had been consumed. Strategic pens and pasture locations were provided *ad libitum* access to clean drinking water throughout the duration of the study.

Sample Selection, Collection, and Laboratory Analysis

Initially, 113 apparently healthy cattle were sampled. However, strict exclusion criteria were employed to minimize physiological confounding factors. Cannulated, dry, lactating, or pregnant (including suspected pregnancies) animals, as well as bulls, teasers, calves, and individuals with incomplete pedigree records, were excluded in the final data analysis. Consequently, the final study cohort comprised 58 healthy, non-estrus heifers (40 PN and 18 HxJ) aged 3 years and older.

Blood collection was performed in the morning post-feeding. Five milliliters (5 mL) of blood was drawn via coccygeal venipuncture (Trantham *et al.*, 2025) into a K3-EDTA vacutainer (purple top) using a 21-gauge, 3.81 cm hypodermic needle. Blood samples were placed in an insulated chest with ice gel packs to maintain optimal temperature (4 °C). Complete blood counts (CBC) and Differentials Leukocyte Counts (DLC) were examined using an automated veterinary hematology analyzer (Orphee Mythic 18, Geneva, Switzerland) calibrated for bovine blood (Table 1). All laboratory analyses were conducted in the Animal Disease Diagnostic Laboratory at the Veterinary Teaching Hospital of the UPLB College of Veterinary Medicine.

Reference Interval and Anemia Scoring

Hematological values were compared against three non-native Reference Intervals (RIs) derived from temperate and tropical breeds to assess their diagnostic validity (Table 2). Anemia was categorized binomially (0=Non-anemic; 1=Anemic), according to the mechanistic criteria by Roland *et al.* (2014) for bovine populations (Table 3). Absolute anemia was defined as a simultaneous reduction in red blood cell count (RBC), hemoglobin (HGB), and hematocrit or packed cell volume (PCV) below the specific reference interval lower

limits. Regenerative anemia was identified by a decrease in PCV accompanied by normochromic indices (normal MCH), reflecting an active bone marrow response to hemolysis or blood loss. Non-regenerative anemia was characterized by concurrent microcytosis (low MCV) and hypochromia (low MCHC), indicative of iron deficiency, chronic disease, or bone marrow suppression.

Statistical Analysis

Data were analyzed using R Statistical Software v4.5.2 (R Core Team, 2025). The individual animal served as the experimental unit and significance was set at $p < 0.05$.

Univariate analysis. Data assumptions were assessed using the Shapiro-Wilk and Kolmogorov-Smirnov normality tests. Normally distributed variables were analyzed using One-Way Analysis of Variance (ANOVA). Non-normal variables (Eosinophils, MCH, PLT) were analyzed using General Linear Models (GLM) with a Gamma distribution and log-link function to account for skewness. The model included “Breed” as a fixed effect.

Multivariate analysis. Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) were performed using the MASS package (Venables & Ripley, 2013). Data were log-transformed ($\log_{10}[x + 1]$) prior to multivariate analysis to standardized variance (Whitlock & Schluter, 2020).

Associations. Relationships between variables were assessed using Pearson’s correlation coefficients. The association between breed and anemia frequency was tested using the Chi-square test of independence.

Table 1. List of hematological variables analyzed

Variables	Units
White Blood Cell (WBC) count	$\times 10^3/\mu\text{L}$
Differential Leukocyte (DL) count	
Neutrophils (N)	%
Lymphocytes (L)	
Eosinophils (E)	
Red Blood Cell (RBC) count	$\times 10^6/\mu\text{L}$
Hemoglobin (HGB)	g/dl
Packed Cell Volume (PCV)	%
Mean Corpuscular Volume (MCV)	fl
Mean Corpuscular Hemoglobin (MCH)	pg
Mean Corpuscular Hemoglobin Concentration (MCHC)	g/dl
Platelet (PLT) count	$\times 10^3/\mu\text{L}$

Table 2. Basis for reference interval

References	Location	Breed
Schalm (1965)*	North America	Holstein cows
George <i>et al.</i> (2010)	North America	Holstein cows
González-Garduño <i>et al.</i> (2023)	South Mexico	<i>Bos taurus</i> (Charolais, Holstein, Angus, Simmental) × <i>Bos indicus</i> (Brahman, InduBrasil, Guzarat, Nelore, Gyr)

Note: *used by the ADD Laboratory, VTH - UPLB.

RESULTS

Variation in Hematological Variables

Significant breed-associated variation was detected across the majority of hematological variables (Table 4). The PN heifers exhibited a superior erythropoietic profile compared to the HxJ crossbreeds (RBC, HGB, and PCV: $p < 0.001$). The HxJ mean HGB (7.59 ± 0.34 g/dL) and PCV (21.9 ± 0.96 %) consistently fell below the lower value limits of all tested RIs.

In terms of immune-related variables, the PN heifers displayed a myeloid-biased profile (N: $p < 0.05$), whereas HxJ heifers exhibited a lymphoid-inclined profile (L: $p < 0.01$). Although both eosinophils and platelet counts were elevated in select RIs, no sufficient breed differences were detected ($p > 0.05$).

The collective discrepancies observed are a reflection of the persisting use of non-context-specific RIs, which may lead to plausible misdiagnosis when evaluating tropical cattle.

Multivariate Clustering and Physiological Divergence

Principal Component Analysis (PCA) revealed a clear disparity in hematological relationships between the breeds (Figure 1). The log-transformed variables resulted in a biplot whose principal components (PC1 and PC2) accounted for 43.45% and 21.88% of the total

variance, respectively. Vector geometry showed a trade-off between the coefficients of erythroid volume (MCV and MCH = 0.85) and immune/hemostatic capacity (L = -0.82, PLT = -0.46) in PC1, while erythroid mass (RBC = 0.96, MCHC = 0.63) dominated PC2.

Silhouette width analysis determined K=3 as the optimal number of clusters. This suggests a physiological gradient in the sample population under tropical conditions. Cluster 1 (orange hull) was dominated by the HxJ group (82%). Cluster 2 (green hull) represented a transition zone containing both PN (65%) and HxJ (35%) breeds. Cluster 3 (blue hull) had the majority of the PN population (96%) but virtually excluded the crossbred group (4%).

Discriminant Analysis on Hematological Traits

Linear Discriminant Analysis (LDA) used a single discriminant function (LD1) to reveal a clear divergence, substantially driven by erythroid variables, between the breeds. The PN heifers clustered predominantly in the positive range of the axis (Figure 2a). This axis was greatly characterized by HGB (+3.46), RBC (+3.21), and MCV (+2.28) loadings (Figure 2b). Meanwhile, MCH recorded the strongest overall loading (-4.48). Together with PCV (-1.93), they immensely influenced the HxJ group to cluster in the negative range. Other variables, such as L and PLT counts, had negligible coefficients (range -0.4 to +0.2) that contributed little to the discriminant model.

Correlation among Hematological Variables

Pearson correlation coefficients revealed explicit associations among the eleven hematological traits. In both breeds, MCV and MCH displayed a near-perfect positive correlation (HxJ: $r = 0.98$; PN: $r = 0.99$; $p < 0.001$). This pertains to the reductions in cell size accompanied by lower cellular hemoglobin content. Particularly in the HxJ group (Figure 3, left), a strong positive correlation cluster among the oxygen-carrying capacity variables was observed. Namely, RBC exhibited very highly

Table 3. Anemia scoring for bovine populations (Roland *et al.*, 2014)

Anemia type	Characteristics
Absolute	↓ RBC, ↓ HGB, and/or ↓ PCV
Regenerative (Hemolysis)	↓ PCV and ↔ or ↓ MCH
Non-regenerative (Microcytic, Hypochromic)	↓ MCV and ↓ MCHC

Note: ↓ below the lower limit of RI, ↔ within the normal limit of RI. RI – Reference Interval; RBC – Red Blood Cell; HGB – Hemoglobin; PCV – Packed Cell Volume; MCV – Mean Corpuscular Volume; MCH – Mean Corpuscular Hemoglobin; MCHC – Mean Corpuscular Hemoglobin Concentration.

Table 4. Hematological indices of Holstein x Jersey and Panay Native heifers compared with different reference intervals

Variables	LS Mean±SE		Reference interval		
	HxJ (n = 18)	PN (n = 40)	Schalm (1965) ¹	George <i>et al.</i> (2010) ²	González-Garduño <i>et al.</i> (2023) ³
<u>WBC</u> *	7.08±0.52 ³	8.35±0.35 ³	4.0-12.0	4.9-12.0	11.0-15.7
<u>N</u> *	21.55±2.06	27.95±1.38	15-33	16-55	15.6-29.9
<u>L</u> **	73.89±2.57 ^{2,3}	64.33±1.73 ^{2,3}	45-75	14-49	41.4-57.2
<u>E</u>	4.45±1.01	7.64±1.16	0-20	0-9	0-20
<u>RBC</u> **	6.62±0.30	7.68±0.20 ²	5.0-10.0	5.1-7.6	5.8-10.7
<u>HGB</u> ***	7.59±0.34 ^{1,2,3}	10.09 ±0.23	8-15	8.5-12.2	8.2-13.4
<u>PCV</u> ***	21.9 ± 0.96 ^{1,2,3}	28.55±0.65	24-46	22-33	24-42.3
<u>MCV</u> *	33.47±1.45 ^{1,2}	37.95±0.97 ^{1,2}	40-60	38-50	31.8-49.6
<u>MCH</u> **	11.57±0.43 ²	13.40±0.34 ²	11-17	14-18	10.3-16.2
<u>MCHC</u> *	34.6±0.21 ²	35.38±0.14 ²	30-36	36-39	29.9-35.7
<u>PLT</u>	562.05±81.61 ³	457.95±44.60 ³	100-800	193-637	79-194

Note: Underlined variables used Gamma GLM; Significant differences between breed are indicated by *($p < 0.05$), **($p < 0.01$), ***($p < 0.001$), and NS(not significant); 1,2,3 outside normal values on the indicated Reference Intervals; n – sample size per breed group; HxJ – Holstein x Jersey, PN – Panay Native, WBC – White Blood Cell, N – Neutrophils, L – Lymphocytes, E – Eosinophils, RBC – Red Blood Cell, HGB – Hemoglobin, PCV – Packed Cell Volume, MCV – Mean Corpuscular Volume, MCH – Mean Corpuscular Hemoglobin, MCHC – Mean Corpuscular Hemoglobin Concentration, PLT – Platelet.

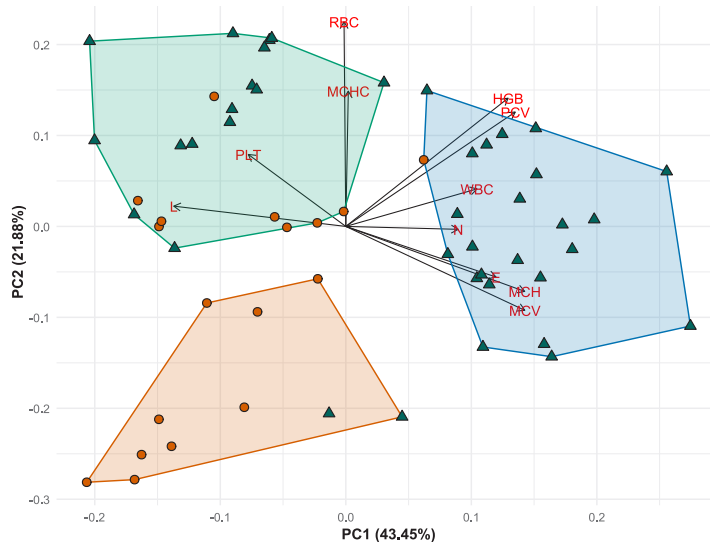


Figure 1. Principal component analysis of hematological variables by breed (PC1 – first principal component, PC2 – second principal component, points – individual heifer per breed). Cluster : Cluster 1; Cluster 2; Cluster 3. Breed : Holstein x Jersey; Panay Native

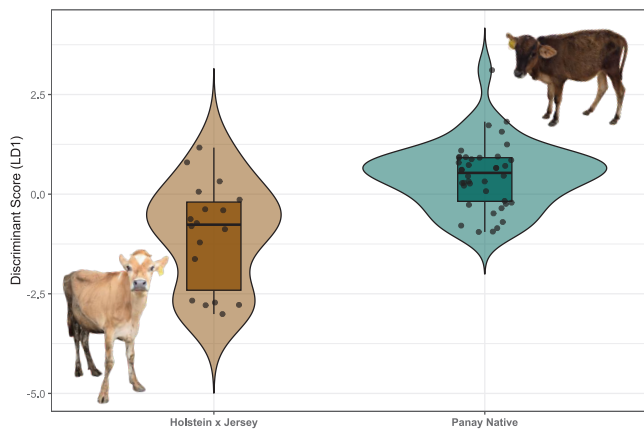


Figure 2a. Linear discriminant analysis of the breed effect on hematological profiles in heifer cattle

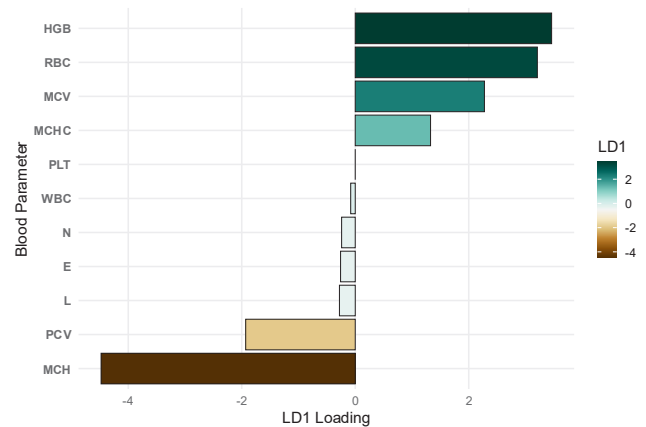


Figure 2b. LDA loadings on blood variable contribution to LD1 scores in heifer cattle (WBC – White Blood Cell, N – Neutrophils, L – Lymphocytes, E – Eosinophils, RBC – Red Blood Cell, HGB – Hemoglobin, PCV – Packed Cell Volume, MCV – Mean Corpuscular Volume, MCH – Mean Corpuscular Hemoglobin, MCHC – Mean Corpuscular Hemoglobin Concentration, PLT – Platelet)

significant positive correlations between PCV and HGB ($r = 0.83, p < 0.001$). However, the correlation between RBC and MCV was non-significant ($r = -0.41, p > 0.05$).

In contrast, a peculiar regulatory pattern was projected by the PN group (Figure 3, right). Unlike in the HxJ, the PN RBC showed no significant correlations with PCV ($r = 0.12, p > 0.05$) or HGB ($r = 0.18, p > 0.05$). It alternatively showed a strong, very highly significant negative correlation with MCV ($r = -0.76, p < 0.001$).

With regards to leukocyte variables, N and L demonstrated a very strong negative correlation in both breeds ($r = -0.82, p < 0.001$). For cross-cluster relationships, only the PN group exhibited highly significant positive correlations between RBC and L ($r = 0.37, p = 0.018$) and between RBC and PLT ($r = 0.55, p < 0.001$). These synergies were absent in the HxJ group ($p > 0.05$).

Breed Differences in Anemic Prevalences

As described by Roland *et al.* (2014), the mechanistic anemia scoring differed significantly

between breeds across all RIs (Figure 4). Beginning with Absolute anemia (simultaneously low RBC, HGB, and/or PCV values), the HxJ group had significantly higher prevalence rates (61.11%-66.67%) than the PN group (12.50%-15.00%) ($p < 0.001$). This resulted in the proportion of non-anemic animals to be expectably higher in PN groups (85.00%-87.50%).

Regenerative anemia (low PCV with low or normal MCH) resembles this pattern. The HxJ heifers bared a significantly higher prevalence (55.56%-61.11%) compared to PN heifers (5.00%-15.00%) across the RIs ($p < 0.001$).

In Non-regenerative anemia (low MCV and MCHC), results varied depending on the RI used. For instance, the HxJ cattle showed a significantly higher prevalence (88.89%) than PN (37.50%) ($p < 0.001$) when scored using the George *et al.* (2010) standard. However,

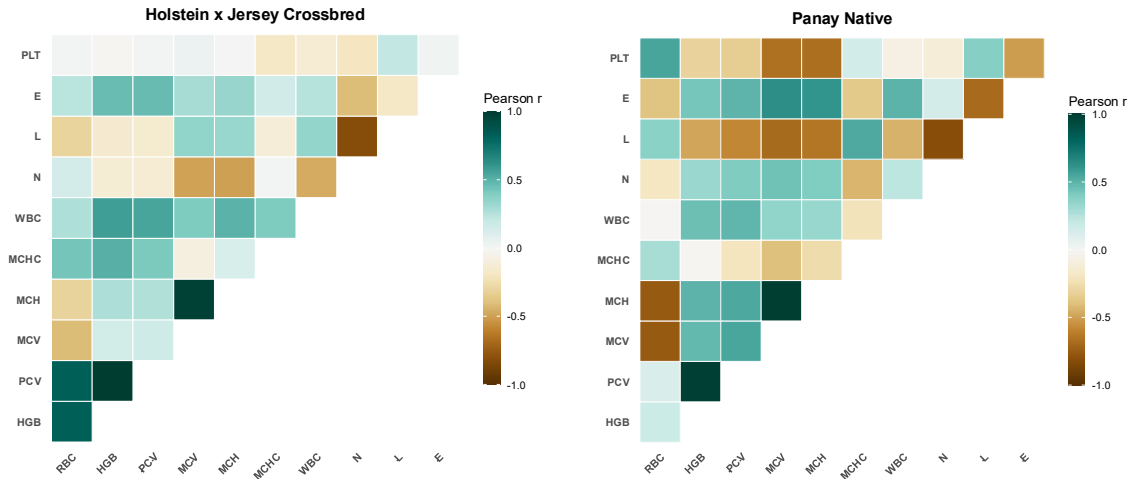


Figure 3. Correlation of hematological variables (Left: Holstein x Jersey, Right: Panay Native; WBC – White Blood Cell, N – Neutrophils, L – Lymphocytes, E – Eosinophils, RBC – Red Blood Cell, HGB – Hemoglobin, PCV – Packed Cell Volume, MCV – Mean Corpuscular Volume, MCH – Mean Corpuscular Hemoglobin, MCHC – Mean Corpuscular Hemoglobin Concentration, PLT – Platelet)

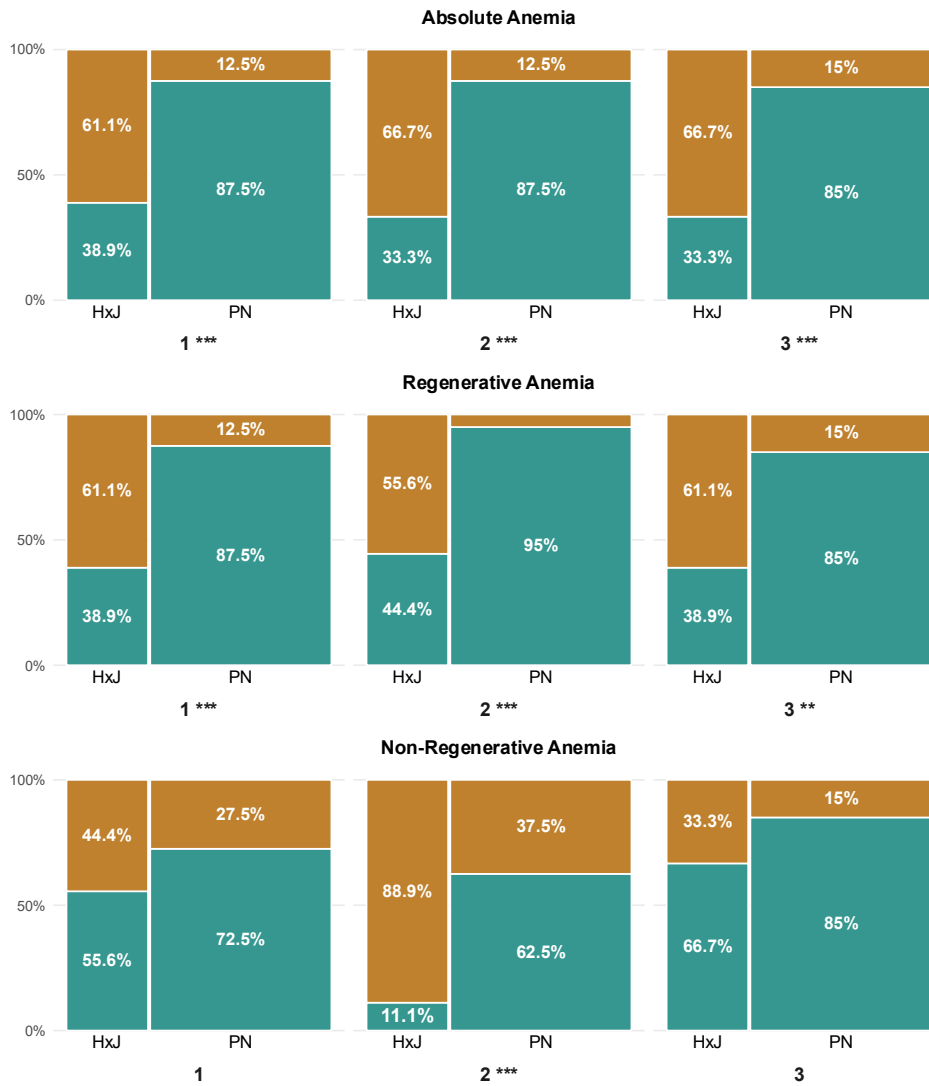


Figure 4. Mosaic plot of percent of cattle with and without anemia based on various categories and Reference Intervals (Significant Chi-square χ^2 association between breed indicated by *(p<0.05), **(p<0.01), and ***(p<0.001); HxJ – Holsteins x Jersey, PN – Panay Native; Reference Intervals: 1 – Schalm (1965), 2 – George *et al.* (2010), 3 – González-Garduño *et al.* (2023)) Anemia categories were based on Roland *et al.* (2014). Anemia status: ■ With anemia; ■ Without anemia

no significant breed differences were detected when applying either the Schalm (1965) or the González-Garduño *et al.* (2023) intervals ($p > 0.05$).

DISCUSSION

The fundamental hematological divergence realized in this study is a direct reflection of the genetic potential between the breeds Panay Native (PN) and Holstein x Jersey (HxJ) crossbreeds and their environment. With a mean THI of 78.71 in the DTRI farm, experimental animals experienced continuous thermal pressure. This accounted for mild-to-moderate heat stress, especially to the temperate-derived breeds (Yan *et al.*, 2021). The thermoneutral zone (TNZ) is also an indispensable aspect of the functional health of the heifers. Yadav *et al.* (2025) reported that tropical breeds, much like the PN, can easily tolerate a thermal load within the 18-30 °C range. Given that farm conditions reached an average ambient temperature of 27 °C, this jeopardized our HxJ temperate crosses, as it exceeded their 16-25 °C optimum TNZ (Dimov *et al.*, 2020). As a result, significant physiological shifts in the erythropoietic and leukocytic pathways in the HxJ group occurred, altering their blood profiles. Recent comprehensive studies published by Habimana *et al.* (2023) and Velayudhan *et al.* (2022) corroborate these findings. They noted that the high heat load of tropical microclimates is deleterious to sustaining homeostasis in temperate-derived crossbreeds.

The clusters identified on the PCA biplot (Figure 1) are proof that these hematological variations are not random. The clusters represent precise physiological strategies illustrating a biological gradient. The HxJ profile is heavily pulled by indices of cellular turnover (MCV, MCH), which predominantly marked Cluster 1. This reflects chronic physiological response to environmental thermal pressure (Koch *et al.*, 2025). In contrast, the PN breed dominated the physiological space of Cluster 3. This cluster is compelled by superior oxygen-carrying capacity (RBC, HGB, PCV), which preserves homeostatic stability amidst tropical conditions (Slayi & Jaja, 2025a). The presence of Cluster 2 implies a transition zone. This presumes that even if a small percentage of crossbreeds may achieve a basal coping level, they still fail to reach the superior physiological durability of the adapted native breed. Moreover, these results provide valid phenotypic evidence for the recent genomic findings of Dominguez *et al.* in 2026. Their study identified various selection signatures linked to tropical insular adaptation and resilience in Philippine Visayan native cattle. The hematological baselines of PN cattle are therefore a functional manifestation of these fixed evolutionary traits.

The limitations of using temperate-derived, non-contextual RIs emerged as a vital gap in evaluating the diagnostic health of tropical cattle. Results showed key blood components having significant variations between breeds. The HxJ group had HGB and PCV values constantly below the lower limits of all tested RIs (Schalm, 1965; George *et al.*, 2010; González-Garduño *et*

al., 2023). As a consequence, at least 60% of HxJ heifers were scored as having Absolute anemia despite being apparently healthy. This is in stark comparison to only ~12% of the PN group. The PN breed exhibited a superior erythroid profile, even exceeding the upper limits of temperate standards. This tendency should not be misinterpreted as pathological dehydration. Supposably, it reflects the evolutionary upregulation of erythropoiesis adhered to by the native cattle (Constable *et al.*, 2016). This relates to the specific adaptation of maintaining tissue oxygenation under high thermal load in tropical environments.

Nonetheless, these hematological variations monitored between the breeds must be construed in the context of their respective production systems (Rubio Lozano *et al.*, 2021). In this study, the two genetic groups were managed in accordance with the practical realities of tropical dairy production in the Philippines. Each system was optimized to satisfy its physiological requirements. The HxJ crossbred, being a high-yielding exotic composite, naturally requires nutrient-dense supplementation and confinement (Cooke *et al.*, 2020) to support metabolic demands and mitigate exposure to environmental stressors (Brito *et al.*, 2021). On the contrary, the evolution of the indigenous breed made them accustomed to forage-based grazing systems (Slayi & Jaja, 2025b). In the Philippine setting, the PN cattle are traditionally managed in this scheme. Hartwiger *et al.* (2019) framed that transitioning cattle between indoor and pasture-based systems may influence their immunological and hematological baselines. So, while evaluating these breeds within their production settings provides grounded validity for local farmers, it introduces management as a baseline factor (Jongbo *et al.*, 2026).

This study is limited to presenting profiles under the cohorts' typical field conditions. Albeit the results signified that blood inconstancies are rooted in breed divergence, the impact of management vs. genetics cannot be overstated. Case in point, the elevated HGB and PCV observed in PN heifers possibly reflect a combination of genetic resilience and the effects of active foraging. Additionally, the HxJ heifers exhibited a higher prevalence of regenerative anemia when the thermal load challenged their intensive housing system. To thoroughly isolate the genetic effect, it is advised to use a controlled, uniform protocol across breeds. Nevertheless, the results undeniably demonstrated that PN cattle maintain different physiological processes compared with HxJ crosses following standard Philippine dairy practices.

Clinical diagnostics made on differing breeds must align with their respective production systems. In the Philippines, a one-size-fits-all approach is scientifically flawed. According to Abramowicz *et al.* (2019), accurate clinical diagnosis in bovine medicine accounts for the specificity of animal nutrition, genetics, and herd management. These requisite actions for localized, system-specific data are further magnified by recent revelations in neighboring Southeast Asian tropical production systems. Nguyen & Bui in 2026 confirmed that the establishment of age-specific hematological

baselines for Holstein-Friesian cattle proved essential for effective diagnosis and health assessment. The PN cattle require a threshold to validate their adaptive polycythemia-leaning traits. Temperate and crossbred stocks equivalently warrant RIs that mirror their specific physiological realities. Therefore, designing environment-specific RIs for native and crossbred cattle is not merely an academic exercise but a clinical obligation to prevent the misdiagnosis of healthy native stock from vulnerable crossbreds.

Beyond the diagnostics, this study also unraveled hemodynamic mechanisms notably promoting tropical resilience. Correlation analysis revealed that the PN group possesses an active viscosity clamp. This is supported by a highly significant negative correlation between RBC and MCV. The uncoupling averts cardiac strain in the animals during heat stress (Morshedi *et al.*, 2022) by increasing the oxygen-carrying capacity while maintaining blood viscosity. It appears that indigenous cattle vigorously reduce cell size in response to erythrocytosis to uphold homeostasis.

In contrast, the HxJ group lacks this homeostatic control. The crossbred showed a strong positive coupling between RBC and PCV variables without appropriate regulation of cell size reduction. The HxJ group has a high prevalence of regenerative anemia with microcytosis, as indicated by anemia scores. Results suggest that HxJ cattle are suffering from compensated hemolysis. Rajashekaraiah *et al.* (2023) narrated that the process begins when the chronic thermal load seemingly accelerates the accumulation of reactive oxygen species (ROS) within the cell's membrane. This consequently shortens the lifespan of circulating red blood cells. The cascade triggers a compensatory erythropoietic response from the bone marrow. At the same time, chronic thermal load and oxidative stress impair cell maturation. This limits the cell volume resulting in the observed microcytosis. Compensated hemolysis thereby diverts energy away from growth and lactation (Brooks *et al.*, 2022) and becomes a significant production constraint. The dichotomy between stable (PN) and high-turnover (HxJ) biological strategies affirms the utility of selected erythroid indices as putative biomarkers of tropical resilience.

The interaction of immunological parameters underscored the cost of this metabolic strain. While both groups supported an N:L inverse relationship, the PN breed remarkably demonstrated pan-myeloid coherence. This is achieved by a significant positive correlation between RBC, N, and PLT levels (Bagath *et al.*, 2019). This conformity suggests that adapted cattle can synchronize oxygen transport and immune surveillance without resource trade-offs (Chauhan *et al.*, 2021). The proposed biological balance aligns with current genomic evidence from Dominguez *et al.* (2026) on immune-regulating genes (i.e., MHC complex) in native Visayan cattle. Their study asserted that the breed's versatile immune function is a genetically inherent trait rather than just temporary environmental acclimation.

The HxJ group plainly missed this synergy. The significantly higher L counts, paired with a lack of PLT correlation in HxJ heifers, exposed an immune baseline alarming from that of the native breed. This system corresponds with Gupta *et al.*'s (2022) theory on resource allocation, implying that unadapted animals under chronic stress prioritize immediate robustness.

Finally, these hematological insights serve as a rationale for developing composite breeds that can withstand the Philippine climate. While valued for their superior milk production, the data in this present study indicated that HxJ animals are hematologically fragile under a tropical environment. This group is surviving at a physiological deficit induced by compensated hemolysis (Brooks *et al.*, 2022). Conversely, the PN breed possesses specific physiological strengths, such as efficient erythropoiesis, immune stability, and a viscosity-clamp regulatory mechanism, that the HxJ lacks. These findings suggest that future breeding programs should not focus solely on yield but systematically introgress these PN-specific putative resilience traits into dairy lines. Selecting for the identified putative biomarkers, such as high erythroid indices and hemodynamic stability, could effectively reduce the productivity gap caused by environmental stress.

CONCLUSION

This study confirms that Panay Native and Holstein x Jersey heifers exhibit fundamentally distinct hematological profiles when managed under tropical conditions. The Panay Native cattle display a highly adapted erythropoietic profile, whereas the crossbreds show evidence of physiological strain. Consequently, current temperature-derived reference intervals are diagnostically inaccurate for these populations. Establishing local, environment-specific baselines is essential, and the unique erythropoietic traits of Panay Native stock should be considered as valuable putative biomarkers for breeding climate-resilient tropical dairy composites.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

ACKNOWLEDGEMENT

The authors are grateful to the Department of Science and Technology – Science Education Institute (DOST-SEI) for funding this research and scholarly support in 2023. This collaborative work was also supported by the project “Capacity-building for Higher Education and the Establishment of Genome Agricultural Research Center at the University of the Philippines Los Baños” funded by the Korea International Cooperation Agency between 2021

and 2027, grant number 2021-00072. The authors acknowledge Dr. Emman Hernandez and the staff of the Dairy Training and Research Institute (DTRI), particularly Mr. Philip Abrigo and Mr. Ahries Reyes, for their supervision and assistance during sample collection.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used Gemini Pro (Google) to generate R scripts and troubleshoot code for statistical analysis. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

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